Decision Analysis Tool for Appropriate Water Treatment Technologies in Impoverished Villages

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Abstract

To meet the dire need for clean water in the developing world, many water treatment technologies have been developed. For years, volunteers have been sent into the field to implement and train users to manage these technologies. However, these well intentioned volunteers do not usually have a water treatment background, which can lead to the improper technology being used. There have been multiple decision analysis tools created to aid in the appropriate water treatment technology selection process, but they all are insufficient for one reason or another. This project found that the most successful decision analysis technique for water treatment is the use of an expert system because expert systems make the knowledge of the few available to the many. The expert system for this application was created on Microsoft Excel and utilizes factors such as resource availability to discern which technology would be best for any particular set of circumstances based off of data collected in the field. The decision analysis tool was found to efficiently produce appropriate results with a large amount of data. Even with this success, this application of expert systems is suggested to be used as a foundation for further research to create an even more powerful tool.

Problem Statement

There is an overwhelming need for clean and accessible water in the third world. To answer this need, there has been an abundant amount of technologies developed to filter, disinfect, or by some other means, create potable drinking water. The difficulty lies in distinguishing the appropriate technology for differing social, climatic, and economic situations. The necessity then arises for a tool to aid in the technology-selection processes for certain impoverished communities that can ensure a sustainable process to provide clean water for years to come.

Introduction

More than 1 billion people lack access to freshwater, nearly 17% of the world's total population (Herron & Dabelko, 2006). Every year, 1.8 million children die due to diarrhea (Heierli, 2008). One writer put it as being equivalent to 20 large airliners crashing every day with the loss of almost 250 lives each. The need for clean accessible water in the developing world is un-debatable and overwhelming.

The causes for this atrocity are many, but so is the amount of people looking for solutions. Some focus on the overall lack of governmental structure and support in these countries, trying to help governments create sustainable infrastructures. Even more, however, focus on the micro, village level water problems.

One organization looking for a solution to the water problem is Lifewater International. Lifewater, working through in-country organizations, regularly approaches the water crisis with the creation wells. With training local communities on how to maintain those wells, Lifewater has been successful in creating a sustainable source of potable water for many people living in developing villages. In addition to wells, Lifewater also supplies biosand filters (described later) when appropriate. However, there are many situations in which wells and biosand filters would not create the most efficient solution.

Due to an urgent search for practical results, many novel systems and mechanisms have been invented to aid in the production of potable water. Lifewater is aware of the vast array of filters, methods, and chemical treatments developed with the intention to solve the water crisis. However, not one treatment technique can be used in every situation. Social, economic, climatic, resource, and political factors create a wide array of situations that must be taken into account when deciding what treatment technology should be used for a certain community. Lifewater has noticed that the ability to do this effectively in the field is difficult; especially when the decision maker does not have a water treatment background. This project focuses on making that decision process, based off of the factors mentioned previously, easier and more efficient to help create an appropriate and sustainable source of water.

What is intended to be created by this project is an easy to understand tool that can assess each major treatment technology's appropriateness to a diverse set of situations. This tool will utilize not only quantitative data, but qualitative analysis to ensure a high probability of success. For this project, success will be defined by these 5 objectives:

1) Incorporates all major classifications of water treatment technologies.
2) Incorporates all major aspects involved in the decision making process including issues such as social, environmental, resource, economic, and political.
3) Provides an accurate projected cost for all treatment techniques down to the $/liter.

4) Helps create a sense of accountability within the community.

5) Helps create clean water for those most in need.

To meet all of these objectives, a vast amount of research is needed. This research first and foremost includes an extensive review of some of the major treatment technologies. This involves a breakdown of: how the process works, what is removed, the rate of water flow, how much it will cost at the $/liter level, and the strengths as well as weaknesses of each technology.

Research into decision analysis techniques is also crucial to the success of this project. Once every aspect of the major water treatment technologies has been examined, it is critical that a scientific and largely quantitative process is developed. This must utilize these aspects in ensuring the appropriate treatment is consistently being utilized for the differing situations that exist in the developing world.

Next, this report will describe the background of water treatment in impoverished villages. The factors that matter most in the decision process will be amassed and organized so that the differences between technologies are evident. Also, different decision analysis techniques will be reviewed and the most appropriate will be utilized. Finally, a tool will be created and described that will meet all previously mentioned objectives.

Background

Creating a successful tool involves knowledge of what make a stechnology successful. To create a basis for further discussion, a brief summary of the main water treatment technologies will now be described.

Available Technology Summation

The goal of this section is to identify and summarize the installation, operation, and maintenance requirements for a variety of water treatment technologies. It is important to note that two steps are critical for all processes. The first step is that if at all possible, strain the water first, which can be done through any tightly woven cloth. This step drastically reduces turbidity and can even strain out some biological material, increasing the likelihood of success for any water treatment process. The next important step takes place after the water is cleaned and that is to store the water in a disinfected container with a tight lid to protect against re-contamination. This is a crucial step often overlooked for its simplicity. However, storing cleaned water in disinfected containers with lids helps protect against recontamination, which would make any previous treatment effort worthless.

Boiling

Process

Boiling is one of the simplest and most ancient forms of water treatment. It is carried out by heating water to a rolling boil for periods up to ten minutes (sometimes 20 minutes is recommended to ensure safety). This constant heat will destroy most waterborne pathogens of concern (Skinner & Shaw, 1998). It is highly recommended that the water is then stored in the container that it was boiled in, then sealed to protect from recontamination.

Contaminants Removed

Boiling is effective in removing most pathogens. Table 1 below is taken from "Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures" by Anthony T. Spinks, R.H. Dunstan, T. Harrison, P. Coombes, and G. Kuczera:

Table 1 - Thermal Destruction of Microorganisms for 100% by Time and Temperature (°C)

Microorganism	1 min	6 min	60 min
Enteroviruses			62°
Rotaviruses			63° (30 min)
Salmonellae		62°	58°
Shigella		61°	54°
Vibrio Cholera			45°
Entamoeba Histolytica cysts	57°	54°	50°
Giardia Cysts	57°	54°	50°
Hookworm eggs and larvae		62°	51°
Ascaris eggs	68°	62°	57°
Schistosomas eggs	60°	55°	50°

Taenia eggs	65°	57°	51°

Economics

The cost is heavily dependent on local resources i.e can the fuel be collected or must it be purchased? Cost can vary from .01$/liter to .04$/liter. In addition, there is no initial investment in the boiling system.

Rate

The rate is completely dependent on the consumer's fire source and water collection ability. Because of this, it is not practical for large quantities.

Strengths

This technology is appealing as most communities have access to a combustion source such as wood or brush. Also, in countries where tea drinking is a custom, this process is already popular and the benefits are understood.

Weaknesses

It is estimated that one kilogram (2.2lbs) of firewood is needed to boil one liter of water (Heierli, 2008). This can then become either labor intensive, involving the collection of the energy source, or financially intensive, needing to continually buy the energy source. Also, it is necessary that there is a local source of abundant combustible energy. Finally, some societies find is socially unacceptable for to boil water. In one study done in the mountains of Peru, they explain one women's reasons for not boiling water: "Mrs . C ' s allegiance to traditional village norms is at odds with the boiling of water. A firm believer in the hot-cold superstition, she feels that only the sick should drink boiled water" (Heirli, 2008).

Biosand Filtration

Process

Biosand filtration (BSF) is a derivation of simple sand filtration in which particulates are filtered out through the increasing fineness of sand grains. The difference of biosand filtration is the use of a biological layer that can form at the top of the water before being processed through the sand. This layer, called the Schmutzdecke, attacks 'bad' pathogens while allowing larger contaminants to be filtered out by the sand below. A typical biosand filter is shown to the right in Figure 1.

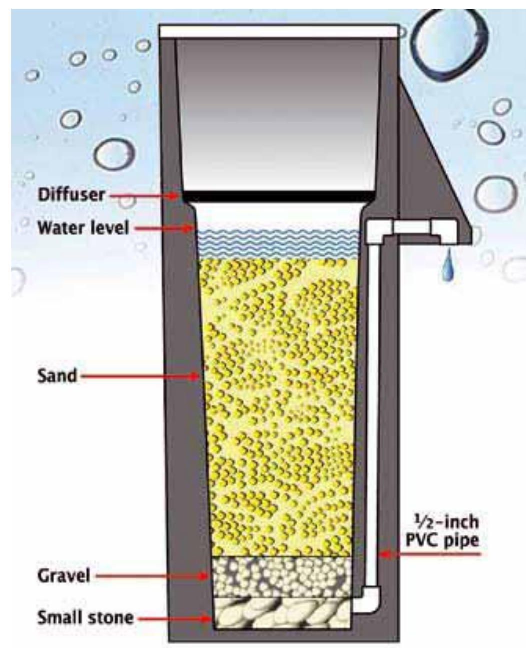


Figure 1 - Biosand Filter (Heierli, 2006)

Contaminants Removed

BSFs have been consistently shown to reduce bacteria by 81-100% and protozoa by 99.98-100% (Lantagne, Quick, & Mintz, 2006). Though successful in the reduction of biological material, it isn't sufficient in reducing non-organic material such as heavy metals.

Economics

The initial cost of a BSF is relatively high, costing between $15 and $70. However, water afterwards is essentially free. Assuming a 2 year life, with a flow rate of 20-60liters/hr, and 4hrs of operation a day, this technology could have a cost of only between $.000086/liter and $.0012/liter.

Rate

BSFs have a variable output rate of between 20 and 60liters of water per hour (Heierlie, 2008).

Strengths

As mentioned above, it has an efficient pathogen removal rate. In addition, it can be made from local materials, reducing costs. BSFs also tend to have long lives and low maintenance needs/costs after initial investment. Finally, they have a high possible production of 20-60liters per hour (Heierli, 2008). With the need of 2 liters per day, per person, one BSF could provide enough water for multiple families.

Weaknesses

As previously mentioned, the initial investment can be between $15 and $70; a high price for the very poor of developing countries earning at or below $1/day. Also, biosand filters have a low rate of virus inactivation (Lantagne, Quick, & Mintz, 2006).

Ceramic Filter

Process

Ceramic filters are made very similar to normal clay pots. However, in this clay there is a combustible material (called burnout) mixed in, such as sawdust. Once the clay is fired, the additive is burned off leaving small holes and making the clay porous. This then allows water to be filtered through the tiny holes created by the absence of the additive. To increase the filter's effectiveness, it is recommended that colloidal silver be added to the filter.

Contaminants Removed

The process of the filter can remove up to 99.99% of bacteria, and with the silver, nearly 100% of protozoa are eliminated (Lantagne, Quick, & Mintz, 2006) (Heierlie, 2008).

Rate

Depending on the size of the filter, the rate can range from either 8-10 liters a day up to 20 liters a day (or 1-2liters/hour) (Lantagne, Quick, & Mintz, 2006) (Heierlie, 2008).

Economics

Models of the ceramic filter can be sold for between 8$ and 35$. Assuming the flow rate discussed above and an estimated average life of one year, ceramic filters can have a cost as low as .0022$/liter and as high as .0048$/liter.

Strengths

The main strength of ceramic filters is that the infrastructure for their creation is already present in most developing countries, as pottery is a global industry. Potters for Peace, a non-profit organization focused on the dissemination of ceramic filters, manufactured and sold 23,000 ceramic filters in Nicaragua and set up factories in twelve other countries (Lantagne, Quick, & Mintz, 2006). Another organization, Resource Development International, has disseminated over 200,000 of their 'Frog' brand ceramic filters in Cambodia (Heierlie, 2008). This is due in large part to the acceptance and ease of production for these filters.

Weaknesses

Because the filter is essentially a clay pot, it is fragile and susceptible to breaking, rendering the filter useless. The filter also has to be cleaned a regular basis, sometimes weekly. This is then dependent on effective training of the end user. Finally, ceramic filters also have a relatively high initial investment, and the flow rates are impractical for a large family.

Chlorination

Process

There are several ways chlorine can be introduced into a system. The first way is done by directly putting commercially made chlorine tablets, liquid, or gas into a water supply. The second way is by creating chlorine through an electrical process with salt. Both processes removed the same contaminants, but everything else is slightly different.

Contaminants Removed

Chlorine is very affective in killing pathogens in a water supply. As described in Surface Water Treatment for Communities in Developing Countries, chlorine's "ability to kill pathogenic organisms and to maintain a residual in the distribution system…make them well-suited for disinfection" (Shulz & Okun, 1984).

Direct Chlorine

Rate

The rate of direct chlorination is completely dependent on the user ability to collect water and how much chlorine they have access to. It is recommended that in order to make water biologically safe, .3mg of chlorine is needed for every liter of water. Also, that water should be contacted with the chlorine for a half hour (Mann & Williamson, 1983).

Economics

There are a lot of different producers of chlorine. One of the most popular is a product created by Procter & Gamble called PUR. PUR is chlorine sold in a small packet for about $.08/each that can disinfect 10liters. A US-based NGO called Population Services International sells chlorine tables under the name ‘Waterguard’ that can filter 20liters for only $.005. Either way, direct chlorine disinfection is relatively inexpensive ranging from $.00025/liter to about $.008/liter.

Strengths

As seen above, it is very inexpensive. Also, it is highly effective in killing biological pathogens initially, and there is some residual chlorine that stays behind to effectively keep the water clean (Skinner & Shaw, 1998).

Weaknesses

In order to acquire chlorine, there must be an easily accessible distribution for the tablets or sachets. Also, it can leave a bad taste, which results in some people preferring contaminated water. In addition, it must be measured relatively accurate to avoid over chlorination that can create the possibility that consistent drinkers of chlorinate water can lose their natural immunity to some diseases (Skinner & Shaw, 1998).

Site Produced Chlorine

A well developed on-site producer of chlorine is a system called the ‘WATA’ created by the Geneva-based NGO Antenna Technologies. The WATA utilizes a car battery to create hypochlorite with a salt solution. There are other methods of creating a chlorine solution, but they all use the same variation of electrolysis.

Rate

The WATA system can produce 1 liter of chlorine per hour, which can treat up to 4,000 liters of water (Heierlie, 2008). With that much chlorine being produced, the rate is then up to the user and how much water is available for treatment.

Economics

The WATA system has a high up front cost of nearly $220. However, at the rate of 1liter of chlorine/hour, enough to clean 4,000liters of water, within the first hour the cost is brought down to $.055/liter. With a conservative estimate of 1 year of life, running 3hrs a day, the cost is down to $.00005/liter.

Strengths

As with the distributed chlorine, this method is very inexpensive in the long run. In addition, it doesn't rely on an outside distribution network for a continual supply of chlorine, which can create a sustainable local market.

Weaknesses

The main weakness is that it has a huge up front cost, too much for most developing villages equaling about the yearly salary of most third world citizens. Also, it involves a lot of training in order to operate.

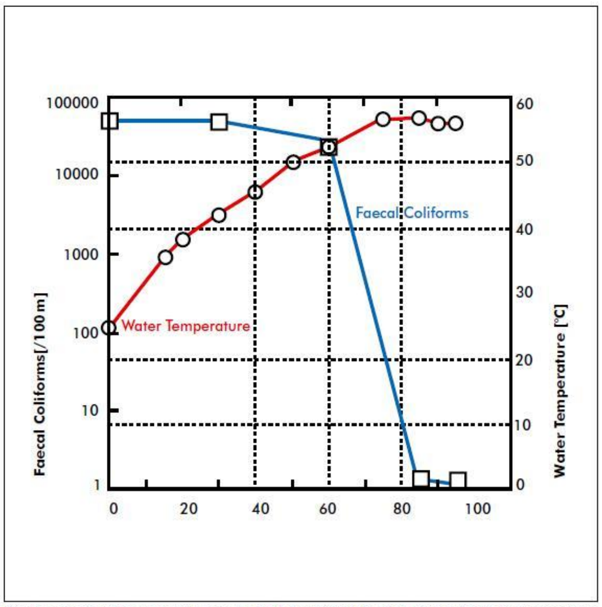
SODIS

Process

SODIS, or Solar Disinfection System, is a relatively new but very simple concept. The process of SODIS involves filling a bottle, preferably a 2liter PET bottle. Once the bottle is filled, it is should be shaken or a little and then placed in direct sunlight. This process relies on solar radiation and heat from the sun to inactivate organic material. It is recommended to leave the bottle

Figure 2 - SODIS Instructions (Heierlie, 2008)

in direct sunlight for 6 hours centered around noon if sunny conditions exist, or two days if the weather or the water is cloudy (Lantagne, Quick, & Mintz, 2006). Though it isn't necessary, if the water reaches 50°C (122°F), the time can be reduced to 3hrs. This heat can be reached more easily by painting the back black and placing the bottle on corrugated steel.



This graph shows how UV treatment and heat work together in a catalytic way to reduce the number of germs in contaminated water

Contaminants Removed

If the exposure is long enough, SODIS has been shown to effectively inactivate bacteria and viruses (Lantagne, Quick, & Mintz, 2006). The figure on the right depicts the relationship between time and heat on effectiveness of a SODIS system.

Rate

Comparatively, the rate is much slower for SODIS then the other treatment options. This is because the rate is dependent upon how many bottles the user has, as well as having to wait at least 6 hrs to have sufficiently cleaned water. A reasonable assumption would be only 10 bottles daily, producing at most 20liters/day.

Economics

In theory, SODIS can be completely free due to the regular availability of PET bottles throughout the world. At most, a bottle could be obtained for $.10, bringing the cost of SODIS from free to at most $.0005/liter (assuming a 100 uses before the bottle becomes unusable).

Strengths

SODIS is incredibly cheap (most of the time free) because the user is able to use a bottle of any kind, though PET is recommended. Also, its low technology requirements allow training to be quick, and access to be widespread.

Weaknesses

The main weakness is the rate and the type of water. To produce a sufficient amount of water daily for a family of 5, there would need to be at least 5-10 SODIS bottles prepared the day before. This cane become logistically difficult and forgetfulness can lead to an unsustainable source of water. Also, SODIS does not work well with highly turbid water, relying on a readily available clear water source to be effective.

Aeration

Process

Aeration is the process of allowing more oxygen to reach the water. This is done either through simply shaking the water, or allowing the water to flow over a mechanism that exposes the water to air. These mechanisms are often comprised of gravel or brick particles that allow water to flow through the system while creating as much turbulence as possible. However, the process can be as simple as flowing the water over corrugated steel.

Contaminants Removed

Aeration reduces the concentration of volatile substances, such as hydrogen sulphide, and oxidizes iron and manganese (Skinner & Shaw, 1998). This mostly improves the taste of the water, which deters a large amount of users from drinking perfectly clean water, but it doesn't successful filter or disinfect any other contaminants.

Rate

The rate of Aeration is dependent on the mechanism used. In most cases, it is filtered at the same rate the water is available. One gravel and stone aeration filter was found to filter up to 1,600 liters per hour (Mann & Williamson, 1982), more than enough for a sizeable community.

Economics

Most aeration filters are made from local sources, as no special chemicals are involved. Because of this, aeration is free, only requiring manpower for collection of material and construction of the filter.

Strengths

The main strength is that it is a free and simple filtration technique. Also, it is made from local resources and can improve the taste of water, increasing the likelihood of consumption.

Weaknesses

The main weakness of aeration is that it doesn't filter out any actual harmful contaminants, merely neutralizing impurities that affect taste. Because of this, it can be seen as a waste of time.

Storage and Settlement

Process

Storage and Settlement is one of the easiest means of treating water. The concept is carried out in a three-pot system of transferring water. Initially, water taken from the source is poured into the first pot. It is recommended that this source water is also strained to aid in contaminant removal. The water in the first pot then must sit for an entire day to allow particulates to settle. After a day, water from the first pot can be slowly poured into the second pot. Pot one can then be cleaned and filled with newly strained source water. After another day, water from the second pot can then be carefully poured in the final third pot. After another day of waiting, the water in the third pot is now drinkable and one must always remember to drink only from the final pot. To aid in the process, pots should be regularly disinfected with boiling water and if possible, water transfer should be done by siphoning through a flexible tube. Finally, it is crucial to cover each pot tightly to protect against recontamination.

Contaminants Removed

This process is best for suspended solids, or when the water is highly turbid. Also, even though this procedure doesn't disinfect the water, it is successful with pathogens. Storing water for just one day can kill up to 50% of most bacteria (Skinner & Shaw, 1998). The longer the water takes to go through the system, the more pathogens that either settle to the bottom or die due to the lack of a host.

Rate

The rate is completely dependent upon the size of the pots available to the user. Also, because of the need for the final pot to settle an entire day, only one pot of potable water is available on a daily basis. For one three pot system, it is then reasonable to infer a rate anywhere from 1-15 liters/day.

Economics

Most villages, no matter how rural, usually already have some form of water containment. Because of this, storage and settlement can be assumed to be free. If necessary, three 10liter clay pots can be purchased for around $10 and assuming at least a year of life, the cost for this process would be at most $.0027/liter.

Strengths

Because of the availability of water vessels, this treatment technique is very cheap, free for most. Also, the technique is very simple and doesn't involve any special equipment so training is simple.

Weaknesses

This treatment cannot be guaranteed to kill all bacteria or other harmful pathogens. Also, there is a high risk of recontamination due to the extensive settling time and multiple transfers of water.

Rapid Sand Filter

Process

Rapid sand filtration refers to a group of filters in which water moves through the system under pressure. This pressure can be either created by the natural flow of the water source, a hydraulic system, or merely through gravity. There are also many ways in which the water can flow through the system. Regardless of the means, it is recommended that the sand used be between 1mm and .5mm. In addition, it is necessary to have 1.5 to 2m of water always above the layer of sand in order to maintain an adequate flow (Mann & Williamson, 1983). An example of a gravity up-flow rapid sand filter is shown below.

Contaminants Removed

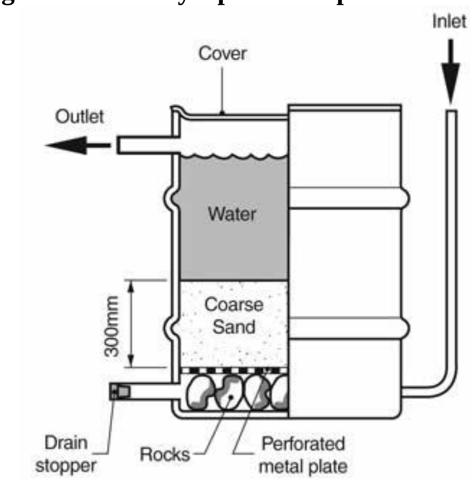


Figure 3 - Gravity Up-Flow Rapid Sand Filter

Rapid sand filtration is usually used in coordination with coagulation and sedimentation. Utilizing these simple techniques along with rapid sand filtration will remove color, turbidity, tastes/odors, and bacteria (Reid, 1982). However, the level of contaminants removed is dependent on the cleanliness of the source water, specific filter construction, and other techniques used in parallel to the rapid sand filter.

Rate

Rapid sand filters enjoy a much higher rate of filtration then most methods. Depending on the specific configuration, water throughput can reach rates between 2,400 and 7,200 liters per hour.

Economics

Most rapid sand filters are built with local materials by a local workforce. Because of this, costs can vary widely. However, most of the cost is for the initial investment as the filter only needs occasional cleaning after construction. In quantitative terms, a safe estimate would be a $100 initial investment in materials. With the low estimate of 2,400 liters an hour and an assumption of 75% utilization over a 1year life, rapid sand filters could cost only $ .0000007/liter.

Strengths

The main strength of rapid sand filters is the rate at which water can be filtered. This technology is actually used widely at the city level to filter mass amounts of water. Because of the high rate of filtration, any initial investment is easily justified through the massive output, making this treatment technique also very affordable.

Weaknesses

Rapid sand filters involve training and knowledge in order to be constructed and maintained properly. In addition, it is only truly effective removing bacteria when used with other treatment methods such as coagulation/flocculation and sedimentation.

Literature Review

For further understanding of water treatment and decision analysis, books were reviewed and are summarized below. This a condensed list of books reviewed and used for this paper; a more complete list of literature is seen in the bibliography near the end of this paper.

Reid, George. (1982). ***Appropriate methods of treating water and wastewater in developing countries*****. Ann Arbor Science Publishers.**

Though written nearly 30yrs ago, this book is very appropriate for research into water treatment decisions. Prof. Reid begins by describing the problems facing most developing villages. He then reaches the conclusion that "to encourage the use of lower levels of technology an effective approach seems to be the training of local engineers who in turn would train other local people." (Reid, 1982) This then sets up his creation of a "prediction methodology for suitable water and wastewater processes."

He writes in detail the factors that should go into technology consideration such as indigenous resources, education level, population forecasting and more. Though the methodology is very sound, there are still a number of critiques that can be made of Reid's approach. In addition, the technology that is suggested is outdated for more modern terms.

United Nations, World Water Assessment Programme. (2009). ***Water in a changing world*****. United Nations Educational**.

This report, compiled by a branch of the United Nations, focuses on macro issues effecting water. Its major theme is that “important decisions affecting water management are made outside the water sector and are driven by external, largely unpredictable forces…”(United Nations, 2009) They focus on the political, financial, legal, and social aspects of water management throughout the globe.

They also have a chapter on technological innovation. However, their inspection of technology is on a macro level, examining mankind’s impact on the environment, how that affects water supplies, and the technology that can fix these problems. They conclude that “some of these impacts result from ignoring the environmental consequences of human development actions. Others result from ignorance of the many, often subtle, interactions between the natural environment and the human activities that fundamentally affect it.” (United Nations, 2009).

Though they do not focus on specific technologies, they do look at important macro issues that may need to be considered in decision analysis. However, its uses are to understand the overall issues facing the world in terms of water supply and not how to help individual communities in obtaining potable water.

United States Department of the Interior, Bureau of Reclamation, (2001), *Water Treatment Primer for Communities in Need*, Water Treatment Engineering and Research Group

This is a report created by the US Dept. of the Interior to aid small or low economic communities that can not afford their own water treatment specialists. In it, they describe how to remove 25 different contaminants. They do this by detailing the data on the contaminant, a summary of the appropriate removal techniques, and the best available technology process description and related cost data. The report then goes into detail how to perform each removal technique for the specific contaminant and how much that technique's equipment and annual costs would be based of the needed flow rate of the community.

This report is a great resource to better understand the technologies that are available. However, it's written more for creating and then adapting water treatment techniques. Also, it doesn't adapt the contaminant information for each individual technique, but merely states that it can be used to remove the contaminant. This shortfall doesn't allow for a precise or accurate implementation of the available water treatment techniques for the differing situations that exist.

Gleick, Peter H, (1993), *Water In Crisis: A guide to the World's Fresh Water Resources*, Oxford University Press

Mr. Gleick focuses on "background information on critical water issues and extensive, carefully chosen water data." (Gleick, 1993) The data is quite extensive, with tables showing everything from highest waterfalls and world fish production, to worldwide access to safe drinking water. The last table is probably the most useful table in the book for actual water treatment. However, it is also a macro issue that is difficult to apply to singular village application.

Schulz, Christopher, & Okun, Daniel, (1984). *Surface water treatment for communities in developing countries*. Wiley-Interscience.

Schulz and Okun begin by using examples of inappropriate technology to highlight some of the fallacies that can be made in deciding a water treatment technology. In one example, they conclude: “here is a situation where local conditions should help dictate the most appropriate design.” They then describe in great length the different types of treatment options available, including chemicals, hydraulic rapid mixing/flocculation, and sedimentation.

The strength of this book is the detail in which they describe each technology, and the appropriate settings of those technologies. The problem is that his book is nearly 30 years old, so some of the technologies are out dated. However, the general principles of most of these techniques are still used today. In addition, most developing villages cannot afford modern equipment, so older and cheaper technologies may be more beneficial.

Mann, H. T., & Williamson, D (1982), *Water treatment and sanitation: a handbook of simple methods for rural areas in developing countries*, Imprint London: Intermediate Technology Publications, Edition 3rd. rev. ed

Mann and Williamson provide a very good description of the water treatment process. This includes selecting the water source/supply, explanations of most of the applicable water treatment techniques, wastewater treatment, and also temporary/emergency treatment. The extensive review is very useful for treatment analysis, but it is also very brief. They only spend 13pgs on the actual description of the water treatment technologies, not enough to do an in depth analysis. However, they do supplement the writing with very apt pictures which aid in the description.

Kirkpatrick, Colin, & Weiss, John. (1996). ***Cost-benefit analysis and project appraisal in developing countries*****. Edward Elgar Pub.**

For this book, Kirkpatrick and Weiss compile and edit 18 articles related to financial project analysis in the third world. These articles cover everything from discounting and project appraisal to using project finance to minimize state budget funding in emerging market economies. Specifically for water treatment projects, the article by John D. MacArthur on estimating acceptable ERRs with minimal data is incredibly useful. However, this entire book may be overkill for small, household water treatment technologies. If one is looking at municipal sized water treatment facilities, this book would be an invaluable asset for economic analysis.

Edwards, Ward, Miles, Ralph, & Winterfeldt, Detlof. (2007). ***Advances in decision analysis*****. Cambridge Univ Pr.**

In this current book, the authors explore every aspect of decision analysis. They spend a couple of chapters describing how decision analysis was founded and what decision analysis actually entails. What is very useful is the step by step manner in which they approach the explanation of decision analysis. They spend entire chapters discussing how to define a decision analytic structure, developing objectives and attributes, as well as how to elicit probabilities from experts.

Another strong aspect of this book is the use of examples. There are five whole chapters devoted to explaining different applications of decision analysis. This is an incredibly useful technique as successful decision analysis relies on qualitative as well as quantitative analysis. The examples highlight some of these successful approaches.

Rivett, Patrick, (1972), *Principles of Model Building,* John Wiley & Sons

Mr. Rivett delves heavily into the theory of model building. Because of this, the text is a little heavy and for the most part impractical for water treatment decision analysis. In addition, the book is written for use in the finance world, having all of the examples related to the market and other economic analysis. However, there is a chapter on decision trees which can be very useful for a lot of applications.

Marshall, Kneale T, & Oliver, Robert M., (1995), *Decision Making and Forecasting,* McGraw-Hill, Inc.

This book is a complete dissection of all major decision analysis techniques; from the most simple to the advanced. Not only do they cover every major topic, but examples follow every subsection of those topics. This book most certainly can help in the decision for appropriate water treatment techniques. Not only does it describe the ever useful decision tree in great detail, but also how to assess trade-offs through preferences. This is exactly what needs to be done when comparing and contrasting treatments. They also give the example of comparing cars based off of price, performance, and fuel economy. These attributes could easily be changed to price, flow rate, and removal effectiveness; three attributes crucial in water treatment.

Heierli, Urs, (2008), *Marketing Safe Water Systems,* Swiss Agency for Development and Cooperation

This booklet is essential for anyone with a need to understand water treatment techniques and their application in the developing world. Heierli's main focus in writing this is to increase the successful dissemination of affordable water treatment in the third world. He examines the problems some NGOs face when implementing certain techniques, from economic to social acceptance, as well as extensive backgrounds of a handful of the most successful technologies. This in depth analysis provides not only useful information into how each technology works, but how they become sustainable within a community. Even further, he provides numerous examples of commercial successes for each treatment method.

International Federation of Red Cross and Red Crescent Societies, (2008), *Household Water Treatment and Sage Storage in Emergencies,* International Federation of Red Cross and Red Crescent Societies.

This is a field manual produced by the Red Cross for volunteers in the field. They begin with how to analyze the water source to understand what is exactly contaminating the water. There are also good descriptions of eight main water treatment methods. A strength of their descriptions is the heavy reliance on pictures, allowing users with poor English to still understand the processes. However, this does reduce their analysis to be very brief descriptions. To supplement, they include a good summary of the positive and negatives of each technique. The manual then concludes with fact sheets of popular commercial treatment methods such as PUR, if such resources are available.

An interesting addition to this manual is an actual decision tree to help in deciding how to treat water. It is a great start of a successful decision analysis tool; however, it is very basic. They ask only four levels of questions and group multiple technologies into single answers. Also, it only takes into account factors of successful water treatment, not sustainable use, such as cost.

Groendijk, L. , & de Vries, H. (2009). Development of a mobile water maker, a sustainable way to produce safe drinking water in developing countries. *Desalination*, *248*(1-3), 106-113.

This article details one particular apparatus that is portable, doesn't use external electricity, and can produce up to 500L/day. The diagram to the right depicts the mechanism, which utilizes both solar energy and human-power to operate. This mechanism is good as a reference, but not much else.

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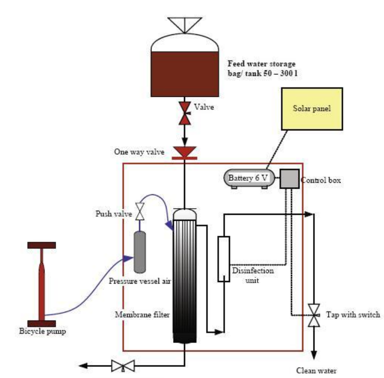

Fig. 1. Experimental laboratory test set up.

Hunter, P. (2009). Household water treatment in developing countries: Comparing different intervention types using meta-regression. *Environmental Science and Technology*, *43*(23), 8991-8997

Mr. Hunter analyzed studies of Home Water Treatment techniques, using Meta Regression analysis, to determine if the results were valid. Though the results are useful, as he examines most useful technologies, Meta Regression analysis may be unnecessary.

Batac, Gail, (1997), ***Water treatment options : a feasibility study for developing countries,*** **California Polytechnic State University, Senior Project**

Ms. Batac examined the actual bacteria that cause such ailments as diarrhea and cholera. She then discussed the social issues involved in different treatment options, such as the readily available cloth of a Sari, worn by women in Bangladesh. Filtering water through this material led to the "percent reduction in plankton associated V. cholerae ranged from 95.12% to 99.84%."

The purpose of this report was to highlight the different factors that need to be considered depending on the region of the world the technique will be utilized. This is then useful for developing techniques in those regions, but not in depth enough to perform a thorough analysis.

Ramming, Daniel, (1981), ***Biosand - U.V. light disinfection*****, California Polytechnic State University, Senior Project**

This report merely describes certain aspects of biosand and UV Light Disinfection. As these are two well known treatment technologies, it is relatively useful information, but it isn't in depth. In addition, UV Light Disinfection is impractical for communities that do not have electricity.

Daw, Brian, (1994), ***Application of ozonation disinfection process at the Patterson Pass Water Treatment Plant,*** **California Polytechnic State University, Senior Project**

This senior project focused on the application of ozonation in a treatment plant. It is useful knowledge on the process, but most of the information isn't practical for decision analysis. Also, Ozone is an expensive process in this application, which is impractical for most communities within developing countries.

Design

As seen in the summation of water treatment technologies section of this report, there is a lot of information for each technology, and that is only a partial list of the many viable water treatment techniques. Even further, new techniques are being devised all the time. All of these factors pose a problem for volunteers working in the field. First, most volunteers either (1) do not have an extensive background in water treatment technologies, or (2) have created a water treatment tool and are only looking to apply that tool without regard for any other treatment technology.

Both scenarios posses a variation of the same problem: lack of expertise for all of the options available. There are many people that are experts in the realm of water treatment for impoverished communities. The problem is that sometimes their skills aren't best served by actually working in the field. This is why a decision analysis tool is so important to help non-experts discern which treatment is most appropriate for the specific situation they are helping improve.

There have been attempts in the past to assimilate the different technologies and create a uniform procedure for choosing an appropriate water treatment technique. The most in-depth and notable example of this is found in "Appropriate Methods of Treating Water and Wastewater in Developing Countries", by George W. Reid. In it, Reid describes a prediction methodology for suitable water and wastewater processes. This methodology is impressive in that it covers everything from social technological factors (such as labor force, income and level of education), to cost (including construction, operation, and maintenance). This approach is a great starting point for this project.

However, there are a couple problems with this tool. The first difficulty is that it is too arduous to be effectively used quickly and by someone with little training. Examining factors such as the education of the eventual water user is highly qualitative and needs an expert to assess. In addition, the technologies used in this book are outdated as the book was written in 1982. It is the goal of this project to be able to recommend technologies that are cutting-edge.

Another decision tool researched was created through a joint venture between the Red Cross and Red Crescent. This tool is also a great start, but it mostly focuses on the condition of the water, and then clumps technologies together after a couple brief questions. The Red Cross decision tree is included in the appendix as reference (A1). Finally, both The Red Cross/Red Crescent and the George Reid approach have in common the inability to include newly developed technologies.

After much research, a method was found that can incorporate the positives of the aforementioned decision tools, while being able to address their downfalls as well. This method is the concept of Expert Systems and can be applied to the realm of water treatment technology decision making. The background, as well as the applicability and application of an expert system will now be discussed.

Brief Expert System Introduction

Expert systems are a branch of Artificial Intelligence and are used in operations research. In brief, they can be described as making knowledge of a few available to the many (Gallacher, 1989). This is done with a computer program that utilizes a three-part system comprised of the knowledge base, an inference engine, and finally a user interface.

The knowledge base is where all of the information obtained from an expert is pooled, then accessed when needed. This is seen as one of the most time intensive aspects in expert systems as it involves eliciting useful information from an expert. Some reasons given for this difficulty are (1) that the experts usually have their own jargon; (2) facts are sometimes unable to be described in precise mathematical terms; (3) experts use judgment to discern what information is reliable and relevant to the task at hand; and finally (4) a lot of experts utilize a good deal of commonsense in their decision making which pulls from an enormous set of information created from day to day experiences (Jackson, 1999).

The inference engine is the process in which the program applies a given set of rules to retrieve or manipulate the appropriate information from the knowledge base. The means in which the engine can perform this process are generally broken down into two ways: forward chaining and backward chaining (Gallacher, 1989). Forward chaining involves taking input from the user and applying rules to reach a conclusion. Backward chaining involves having a conclusion and using the user to confirm criteria to match that conclusion.

Finally, the user interface is the means in which the non-expert works with the expert systems to reach an expert conclusion. A good user interface is crucial to the entire system's effectiveness and perceived benefit. It must not only be able to allow for proper input by the user but also allow the user to understand the conclusions reached. It is recommended that user interfaces utilize a menu driven approach so that the inputs are controlled and can easily be manipulated throughout the inference engine.

Applicability

There are numerous reasons an expert system would be beneficial in the field of water treatment. A good place to start, however, is by answering four questions to decide if an expert system is an appropriate tool, which were proposed by Joe Gallacher in his article “Practical introduction to expert systems”. The questions are:

1) Is the present solution inadequate?
2) Is the problem domain well defined?
3) Is the expert knowledge available?
4) Is there some clearly identifiable benefit?

The short answer to all of these questions is yes. Currently, there aren’t any adequate solutions for the problem of appropriate technology in water treatment for the reasons stated earlier. The problem is very well defined: which of the available techniques are most appropriate given different factors. The expert knowledge is available in the form of the client, Lifewater International, who possesses a wealth of experience in this exact field in addition to the many non-profit organizations working to help solve the water crisis. Finally, there is a clear benefit in discerning the most appropriate technology. When the most appropriate technology is selected, it will create the most sustainable solution and therefore the most clean and available water source for those in need.

There are more reasons for why an expert system would be beneficial in this instance. Expert systems are best used on problems that involve a certain level of uncertainty as well as when the conclusions reached cannot be guaranteed (Gallacher, 1989). This is the case in water treatment; you can’t be completely sure all factors will interact in the same manner for every situation, and you don’t know if the treatment will have the same success within different cultures. It is this inherent qualitative nature that will be best served with an expert system.

Finally, a key aspect of expert systems is the ability for the system to evolve. This means the knowledge base can increase, and the inference engine can adjust, after new information is made available. This feature is critical to water treatment because of the continual improvement and invention of new water treatment technologies. For this decision analysis tool to be completely successful, it has to be able to incorporate new ideas and methods when they arise.

Application

The knowledge base of the expert system will utilize data and other pertinent information concerning each treatment technology. The pertinent information used will be comprised of the rate of water filtered, resources needed, technical ability needed, and waste produced. Cost is a large factor in technology selection and will be calculated by the inference engine using a number of calculations based off of data taken from the field.

The inference engine of the water treatment expert system will be created using Microsoft Excel. It is a desire for the decision analysis tool to be able to be used in the field and most impoverished villages do not have electricity. However, a computer program must be utilized in order to run the calculations necessary to produce a correct conclusion. Excel is possessed by a lot of people and even if it cannot be used in the field, data can be taken in the field and relayed to another individual that will have access to a computer. That person can then run the expert system with the necessary information reporting back to the field volunteer what conclusions were reached.

The user interface will be completed by designing different questions to elicit all necessary information about the particular situation the field volunteer could encounter. These questions are based around seven main decision nodes that will decide the appropriate method. These nodes are:

rate/amount of water needed, resources available, technical ability, current treatment availability, water condition, available waste services, and cultural norms. Using data collected on site, the volunteer will then be able to either enter the information into the expert system concerning the decision nodes or they can relay that information as mentioned above.

Method

The first step in creating the actual expert system is to create the structure. The structure will be based on the seven nodes mentioned earlier and have branches depicting the different options that can come from each node. In order for node calculations to be completed, all possible outcomes must be created. To do this, possible questions from each node must be identified.

Node Questions

Rate/Amount of Water Needed

1) How many people must this system provide water for on a daily basis?

Resources Available

1) What resources are available; or if not available, how much would it cost (to purchase or labor needed) to obtain one unit of the resource?
    1. Combustible material (wood, brush, coal etc.)
    2. Sand
    3. Chlorine in any form
    4. Rocks
    5. Containers
        a. How much water can it hold (liters)?

6. Pottery quality clay.
7. Plastic bottles
    a. What size (liters)?
8. Electricity
9. Batteries
10. Salt
11. Hay or large grass

Technical Ability

1) How technologically advanced is the setting?
2) Are there any water treatment techniques currently being used?

Current Treatment Availability

1) Is there any locally available water treatment techniques already manufactured?

Water Condition

1) Is the source water stagnant or flowing?
2) Is the water source turbid?
3) Is the water source contaminated with non-organics?
4) How far is the water source from the users?

Available Waste Services

1) Is there any means to dispose of removed contaminants?

Cultural Norms

1) Are there any prevailing cultural norms that would inhibit any of the technologies assimilation into the culture?
2) How important is taste?

The questions then become the backbone of the expert system. User information is solicited through these questions, and the inference engine performs the calculations based off of the responses to these questions. Once all of the answers are answered by the user, the appropriate calculations can be made.

The inference engine calculations are based off of a comparison of the technologies data and the users input. The technology will be given a 1 if it meets the requirements in that particular category i.e. it can produce the flow needed, the situation has the necessary resources etc. If it does not meet the requirement, it will receive a 0. Receiving a zero in any one category does not remove the technology from consideration, but reduces its score and therefore its chances of being the recommended technology.

The technology's score is then calculated by multiplying its category score (0 or 1) with the weight of that particular category. Category's weights are determined by its importance. For instance, cultural norm is weighted as the maximum 100 because if there is a cultural norm against a certain technology, the chances of success are very low for that particular technology. That treatment will then receive a 0 while the other technologies will receive a score of 100 for that category (as the default category value is 1), putting it far behind. Even though it will lose a large portion of its points, it will still be considered in case other technologies score worse in a lot more of the categories.

This weighted score is then used to rank the technologies from highest to lowest, with the highest being the most recommended or most likely to succeed given the various situational data. In addition, cost also must be taken in account. For each resource, it is ask of the user to enter in the cost it would take to procure one unit of the particular resource. The amount needed of that resource for each technology is then multiplied by the cost to obtain that resource. Costs are then separated into two categories depending on if it is a onetime initial cost or an operational cost that will be accrued on a per liter basis. This information is finally displayed with the score of each technology. Cost is not the deciding factor in ranking but is used as reference to understand the associated costs of any technology selected.

Results and Discussion

At the time this paper was written, the expert system had yet to be tested in the field. However, results can be derived from the system by inputting various simulated examples. A number of these test situations were run with the expected results known and all of these tests yielded appropriate results. To show how the expert system is designed and used, the entire expert system is shown in the appendix (B1-B4) for one of the test situations that was run. In addition, a link to download the actual expert system is included in the appendix so that readers can see how the actual system works.

In addition to correct results, the system allows for easy additions of new technologies. Initially created, the expert system only compares the nine technologies this project reviewed. However, adding a new technology only entails adding in a new column of data. Once the data from the new technology is added, the expert system absorbs that information and then compares it the others as if it had always been there. There is no new programming needed and thus, the expert system is much more adaptive then the other decision analysis techniques reviewed.

Even though appropriate results are given by the expert system, shortfalls still exist. Most of these shortfalls are derived from assumptions made. The biggest of these assumptions is that all of the technologies within each major category act the same. In order for the expert system to be as precise as possible, all individual technologies within a broad category should be analyzed for their individual strengths and weaknesses.

In addition, weights for each category relied heavily on qualitative beliefs. If research into how each category truly affects the sustainability of a water treatment technique is assimilated into the expert system, it will become much more powerful.

Conclusions

Even with the shortfalls previously mentioned, the expert system created meets the overall objectives of the project:

Objectives

- Incorporates all major classifications of water treatment technologies

The nine major water treatment technologies are examined by the expert system with the possibility of adding other techniques to the expert system's knowledge base.

- Incorporates all major aspects involved in the decision making process including issues such as social, environmental, resource, economic, and political.

All but one of the above factors was taken into consideration with the design of the decision tool. The one neglected factor is the political influence on water treatment decisions. However, this aspect is too large to accurately discern without a large quantity of research, which was outside the scope of this project.

- Provides an accurate projected cost for all treatment techniques down to the $/liter.

The cost analysis performed by the decision tool is based off of real data taken from the field, which is the most accurate as it is dependent on the actual situation. In addition, this cost is broken down in to initial cost as well as the running cost which is on a $/liter basis.

- Helps create a sense of accountability within the community.

This objective is hard to measure until the tool is implemented in the field. The hope, however, is that the expert system will allow the end users to help collect the data that will serve as the input and therefore create a feeling of responsibility for the technology selected.

- **Helps clean water reach those most in need.**

Only time will tell if this expert system helps those in dire need for clean water. However, a comparison to what is currently available can be made. Due to this decision analysis tool's ability to adapt to new technologies, as well as being able to reach conclusions based off of quantitative and qualitative data, it is better than what is currently available. With better tools available, better decisions can be made and more clean water can be created.

The problem this project was solving is the need for a decision analysis tool that can quickly and accurately identify the appropriate water treatment technology for a user with non-expert experience in the field. Based off those needs, an expert system was discovered to be the most suitable approach. However, expert systems are a large field of study with lots of possibilities. This project showed one basic application of expert systems to water treatment decisions, which can be improved upon.

These improvements include the enhancement of the knowledge engineering aspect. For most expert systems, knowledge engineering is the most time consuming as it involves eliciting the necessary information that becomes the knowledge base. The approach taken for this project was to obtain basic knowledge of *some* of the main means to clean water and then apply that knowledge to an expert system. Though the client, who is an expert in the field, was consulted on the conclusions and foundations of the knowledge, it may not have been the most complete method of knowledge attainment.

It is then finally recommended that the use of expert systems for water treatment decision analysis be researched more in depth. As stated earlier, this project shows a new application of an expansive area of decision analysis. With more accurate data and research the produced solution can become a more powerful tool, better able to serve the dire need for water in the developing world.

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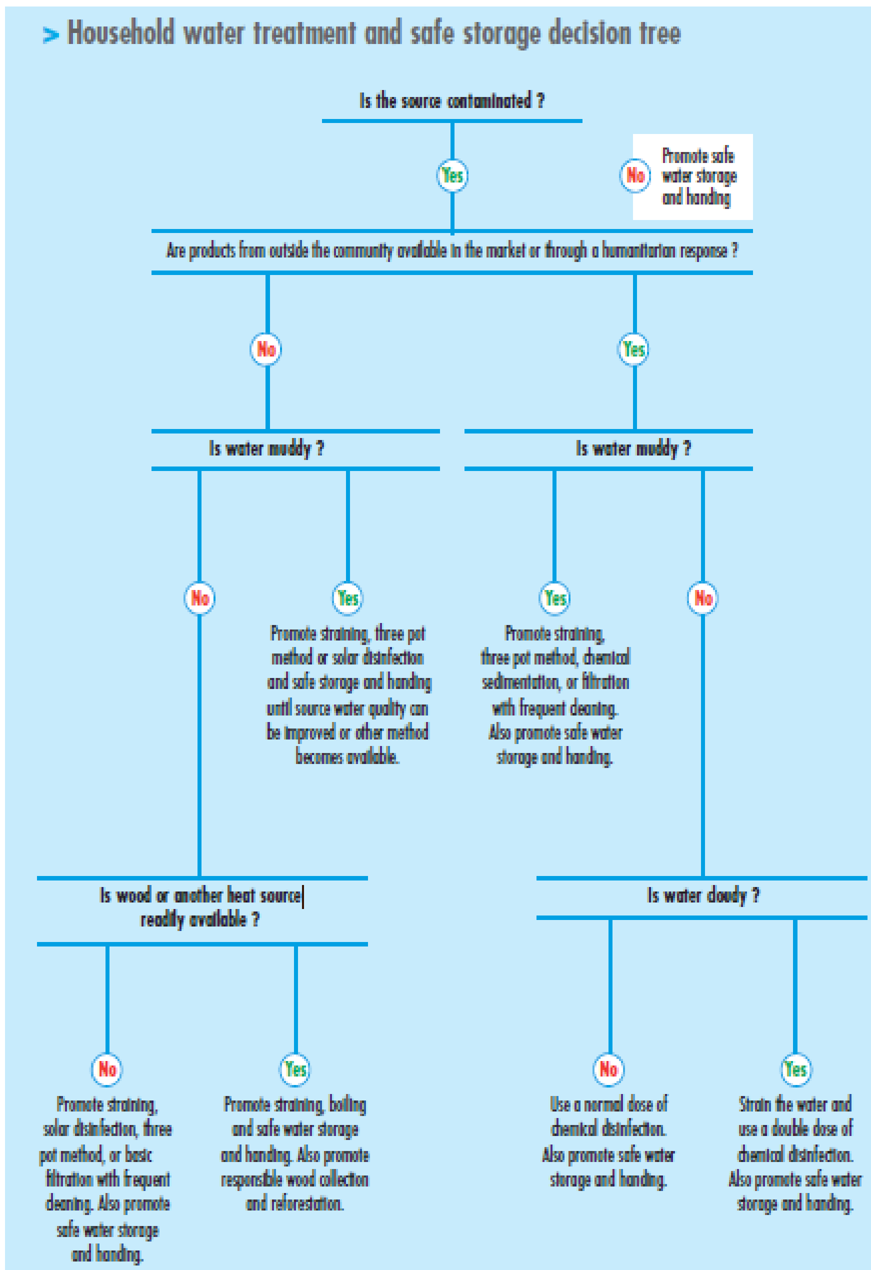
Appendix

A1) Red Cross/Red Crescent Water Treatment Decision Tree



Actual expert system can be downloaded at this address:
http://dl.dropbox.com/u/868040/Water%20Treatment%20Expert%20System.xlsm

B1) Developing World Water Treatment Expert System User Interface

Developing World Water Treatment Expert System

Water Needed

How many people will this system need to provide for on a daily basis? 5
How much water can be collected on a daily basis (liters)? 10

Available Resources

Resource - How many units of these resources are available? — Cost ($USD) to obtain 1 unit

Combustibles - coal/wood/brush (kg)	3	kg	$	1
Sand - any grain (kg)	3	kg	$	5
Rocks (kg)	5	kg	$	5
Chlorine - tablets or liquid (mg)	10	mg	$	0.1
Salt (grams)	100	grams	$	0.05
Pottery quality clay (kg)	10	kg	$	10
Hay or large grass (grams)	10	grams	$	1
Electricity?	No		$(kw/day	
Batteries	12	Volts	$	1

Containers:

If there are large containers available, enter their size or enter 0 for none	10	liter	$	5

PET Bottles:

If there are PET bottles available, enter their size or enter 0 for none	2	liter	$	0.25

Technical Understanding

How technologically advanced is the area? (0-10, 0 = Only human powered processes exist, 10 = Very advance electronics based processes exist)
4 (0-10)

Are any techniques are used locally? (If more than three, use the 3 most predominant)
SODIS | Direct Chlorination | None

Current Treatment Availability

Are any techniques sold locally? (If more than 3, select the 3 easiest to get)
None | None | None

Water Condition

The Water Is: Stagnant

Turbidity of The Water (0-10, 0 = Clear, 10 = Extremely Turbid) 3 (0-10)

Does the water contain non-organic material? No

Is the water source nearby or must it be carried in over long distances? Long Distance

Waste

What kind of waste can be handled? (0-10, 0 = no waste services, 10 = extremely harmful waste can be handled) 3 (0-10)

Cultural Norms

Do any cultural norms restrict an of these technologies?
None | None | None

How important is the taste of water? (0-10, 0 = not at all important, 10 = extremely important) 5 (0-10)

View Results

B2) Developing World Water Treatment Expert System Knowledge Base

Technology Data										
Nodes/Sub Nodes	Criteria	Boiling	Bio Sand Filtration	Ceramic Filtration	Direct Chlorination	Site Produced Chlorination	SODIS	Aeration	Storage & Settlement	Rapid Sand Filter
Water Needed										
	Water Produced (liters/day)	Dependent	40	10	Dependent	Dependent	Dependent	1000	Dependent	1000
Resources										
	Combustibles	1	0	0	0	0	0	0	0	0
	Sand	0	5	0	0	0	0	0	0	10
	Rocks	0	8	0	0	0	0	10	0	9
	Chlorine	0	0	0	0.3	0	0	0	0	0
	Salt	0	0	0	0	25	0	0	0	0
	Clean containers	1	1	1	1	1	1	1	3	1
	Pottery quality clay	0	0	1	0	0	0	0	0	0
	Hay or large grass	0	0	10	0	0	0	0	0	0
Bottles	Plastic Bottles	0	0	0	0	0	1	0	0	0
Electricity	Electricity	0	0	0	0	2	0	0	0	0
	Batteries	0	0	0	0	12	0	0	0	0
Technical Ability										
	Technical Skill Required	1	5	3	6	7	4	4	3	7
Water Condition										
	Stagnant	1	1	1	1	1	1	1	1	0
	Flowing	1	1	1	1	1	1	1	1	1
	Turbidity	0	2	0	2	2	0	8	6	8
	Non-Organics	0	0	0	0	0	0	1	1	1
	Water Distance from User	1	1	1	1	1	1	1	1	0
Waste										
	Produces Harmful Waste	2	0	0	2	2	0	2	0	2
Cultural Norms										
	Restricting Cultural Norms									
	Taste	0	2	2	8	8	4	8	3	2
Overall Filtering Effectiveness		7	7	7	8	8	6	4	4	5

B3) Developing World Water Treatment Expert System Inference Engine

Nodes/Sub Nodes	Criteria	Situational Constraints/Requirements		Category Weight	Boiling	Bio Sand Filtration	Ceramic Filtration	Direct Chlorination	Site Produced Chlorination	SODIS	Aeration	Storage & Settlement	Rapid Sand Filter
			Number needed to meet demand		0	2.5	10	0	0	50	0.1	10	0.1
Water Needed			Daily Amount Produced		0	40	10	0	0	2	1000	10	1000
	Water Needed (liters/day)	100		50	0	0	0	0	0	0	1	0	1
	Water collected (liters/day)	0											
Resources		Amount of Resource Obtainable (0 = No)	Cost to Obtain 1 unit										
	Combustibles (kg)	3	$1.00	50	1	1	1	1	1	1	1	1	1
	Sand (kg)	3	$5.00	50	1	0	1	1	1	1	1	1	0
	Rocks (kg)	5	$5.00	50	1	0	1	1	1	1	0	1	0
	Chlorine (mg)	10	$0.10	50	1	1	1	1	1	1	1	1	1
	Salt (grams)	100	$0.05	50	1	1	1	1	1	1	1	1	1
	Containers	10	$5.00	50	1	1	1	1	1	1	1	1	1
	Pottery quality clay (kg)	10	$10.00	50	1	1	1	1	1	1	1	1	1
	Hay or large grass (grams)	10	$1.00	50	1	1	1	1	1	1	1	1	1
Bottles	Plastic Bottles	2	$0.25	50	1	1	1	1	1	1	1	1	1
Electricity	Electricity (kw/day)	0	$0.00	50	1	1	1	1	0	1	1	1	1
	Batteries (volts)	12	$1.00	50	1	1	1	1	1	1	1	1	1
Technical Ability		Skill Required											
	Technical Skill Present	4		25	1	0	1	0	0	1	1	1	0
	Local Knowledge	1		25	0	0	0	1	0	1	0	0	0
Current Treatment Availability													
	Locally Available Techniques			75	0	0	0	0	0	0	0	0	0
Water Condition													
	Stagnant	1		25	1	1	1	1	1	1	1	1	0
	Flowing	0		25	0	0	0	0	0	0	0	0	0
	Turbidity	3		25	0	0	0	0	0	0	1	1	1
	Non-Organics	0		75	1	1	1	1	1	1	0	0	0
	Water Distance from User	1		25	1	1	1	1	1	1	1	1	0
Waste													
	Can Handle Harmful Waste	3		25	1	1	1	1	1	1	1	1	1
Cultural Norms													
	Restricting Cultural Norms	3		100	1	1	1	1	1	1	1	1	1
	Taste	5		25	0	0	0	1	1	0	1	0	0
Overall Filtering Effectiveness													
Initial Investment													

Results

	Boiling	Bio Sand Filtration	Ceramic Filtration	Direct Chlorination	Site Produced Chlorination	SODIS	Aeration	Storage & Settlement	Rapid Sand Filter
Initial Investment	$5.00	$90.00	$5.00	$17.00	$5.25	$5.00	$65.00	$5.00	$95.00
Per/liter cost:	$0.00	$0.00	$0.00	$0.03	$1.25	$0.00	$0.00	$0.00	$0.00
Score	825	700	825	850	775	850	800	775	650

B4) Developing World Water Treatment Expert System Example Results

Return to User Interface

Technology	Score	Est. Initial Cost	Cost/liter after
SODIS	850	$5.00	$0.00
Direct Chlorination	850	$17.00	$0.03
Boiling	825	$5.00	$0.00
Ceramic Filtration	825	$5.00	$0.00
Aeration	800	$65.00	$0.00
Storage & Settlement	775	$5.00	$0.00
Site Produced Chlorination	775	$5.25	$1.25
Bio Sand Filtration	700	$90.00	$0.00
Rapid Sand Filter	650	$95.00	$0.00

← #1 Recommended