Hand pump Failure – Investigating the socio-technical failure modes of hand pumps in post conflict Sierra Leone using case-based reasoning

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Abstract

The United Nations (UN) set as a target to halve the proportion of the populations without sustainable access to safe drinking water by 2015. While the world is on track to meet the drinking target in urban areas, accelerated and targeted efforts are needed to secure access to drinking water in rural areas. The considerable lack of research methodology and data on the reasons behind the decline in access to improved water sources raises critical questions on project sustainability and organisational accountability and ultimately, how should the Millennium Development Goal for access to safe drinking water be measured. Sierra Leone is one example of this challenge. It is one of the most underdeveloped countries in the world and is still recovering from a brutal civil war (1991-2002). Only 1% of the population has access to piped water and access to improved water sources has been declining in the rural areas for the past decade, even though there has been a sustained effort to combat the decline through the widespread installation of community level hand pumps and wells. A large community level survey was carried out in Northern Sierra Leone on hand pumps and wells installed after 2004. This study develops an innovative non-biased methodology for quantitatively assessing the socio-technical trends in the failure rates of rural community water projects through the use of case-based reasoning and discusses the results with respect to project sustainability and continual monitoring. The study has the potential to impact not only how organisations define the failure of a project, but also how projects are continually monitored and evaluated.

Keywords: Sustainability; Case-based Reasoning; International Development.

Introduction

Overview of global water problem

Currently 884 million people do not have access to safe water supplies (WHO and UNICEF, 2008). The former United Nations (UN) Secretary General Kofi Annan stated that '*access to safe drinking water and sanitation is both a development target in its own right and integrally linked to achieving all the Millennium Development Goals (MDGs)*' (United Nations, 2006). It is also well understood that access to adequate drinking water is essential for reducing disease (Carter *et al.*, 1999). Pruss-usten (2008) demonstrated that access to safe water and adequate sanitation can potentially reduce the number of global deaths by 6.3% and significantly reduce the number of child deaths. This problem is exacerbated when considering the term '*improved water source*' infers that the source is only likely to provide safe water. The majority of the population without access to safe water live in rural areas where little infrastructure and low population density makes using large scale piped systems unfeasible (WHO and UNICEF, 2006).

Project Sustainability and Organisational Accountability: Is it happening?

In 2010 the UN stated that the world was on track to meet or even exceed the drinking water target by 2015 if current trends continued. Therefore, by 2015 an estimated 86% of the population in developing regions will have gained access to improved sources of drinking water, up from 71% in 1990 (UN, 2011). However, the issues of poor project sustainability records and lack of long term accountability of water provision organisations is casting a shadow over the success hailed by the UN (Jha, 2010). Some have argued that success should not be measured by the percentage of the population who have gained access to an improved source, but the percentage of the population who have retained access to improved sources for a certain length of time (WaterAid, 2011, Haysom, 2006). This is being recognised by organisations such as the projects developed by Water For People and Triple–S (IRC), which are developing the Field Level Operations Watch (FLOW) monitoring system, whereby beneficiaries easily evaluate and report on local Water, Sanitation and Health (WASH) projects remotely via their mobile phone (Water For People, 2011). Unfortunately, little research has been undertaken to clearly demonstrate the problem of unsustainability due to the difficulty in obtaining conclusive data (WaterAid, 2011). Consequently it is difficult to know which socio-technical factors are the most significant to the success or failure of a WASH project and hence which factors should be included in a monitoring system. Figure 1 presents one of the only published time-series of rural water supply functionality demonstrating the issue of poor sustainability (WaterAid, 2011). Although heavily cited, these results were determined from a small randomised trial and were determined through basic observational data, whereby the significance of each socio-technical factor that influenced the failure of each well was determined from the comparison of only two individual factors at any one time. One example in the study was the relationship between the age of the pump and its functionality (Haysom, 2006).

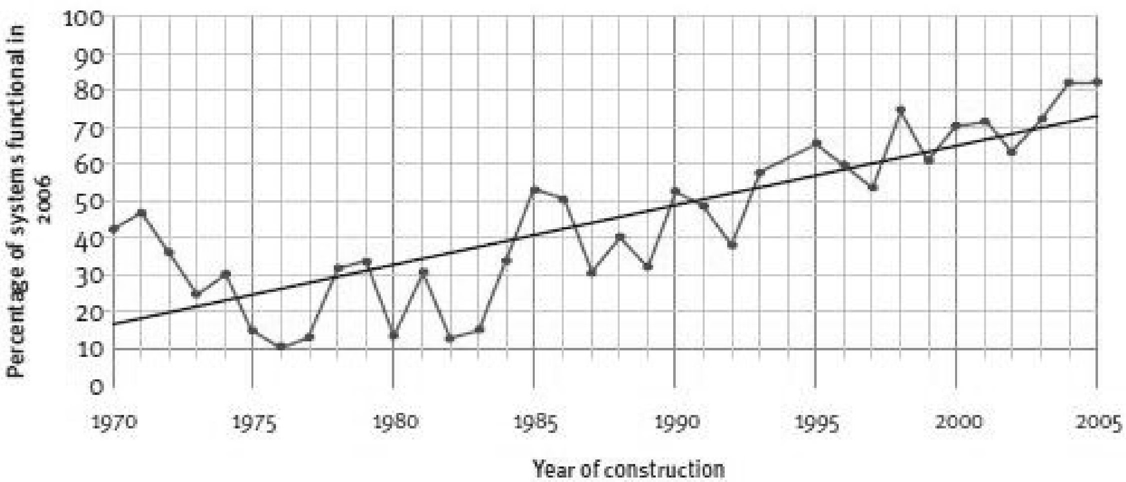

Figure 1 Percentage of water systems functional in 2006 from year of construction, Tanzania (Haysom, 2006)

Lack of methodology for recognising failure mechanisms of hand pumps

As mentioned above, very little detailed research exists on the reasons for high levels of hand pump failure in rural Sub-Saharan Africa as many organisations are seen to have their *'hands tied'* as they are required to meet the requirements of the donor over the beneficiary and therefore cannot commit to setting aside sufficient resources to continually monitor past projects over a long term period.

Currently the main method used in the field is by analysing household level knowledge, attitude and practice (KAP) surveys, whereby data are collected orally by an interviewer using a structured, standardized questionnaire. These data can then be analysed quantitatively or qualitatively depending on the objectives and design of the study. Commonly, basic statistical analysis is carried out and hypotheses are based on expert opinion and individual case studies. This method also applies to identifying the significance of a particular factor influencing the failure of a hand pump, such as the distance to a water source. It also encompasses the study of the influence of one factor on another, also known and interdependencies. An example of interdependencies could be the volume of drinking water collected per day with respect to the distance to the nearest water source. Interdependencies between various factors are incredibly difficult to evaluate. Generally only the interdependencies between two or three factors can be determined at any one time with relative accuracy, which reduces the effectiveness of the argument. It is widely known that there are many social, health, technological, economic, financial, institutional and environmental factors which can affect water treatment projects (WaterAid, 2011). Therefore any conclusion on interdependencies is weakened further when considering that the long term success of any singular hand pump depends on a plethora of interlinked factors, where each factor may affect the outcome of the other.

Access to improved drinking water supplies in Sierra Leone

Currently ranked 180th out of 187 countries in the Human development Index, Sierra Leone is one of the least developed countries in the world. It is still recovering from a brutal civil war (1991-2002) that caused severe political instability, large-scale population re-distribution and over 50,000 dead. Presently only 1% of the population has access to piped water and access to improved water sources is declining in the rural areas, even though there has been sustained efforts to combat the decline through the widespread installation of community level hand pumps (Fig. 2).

This trend is highly visible when analysing the 2011 MDG progress report by WHO/UNICEF (2008). Figure 2 demonstrates that although access to water in urban areas is increasing, it is rapidly decreasing in rural areas and has now dropped to only 26% coverage (WHO and UNICEF, 2008). The decline in access to improved water sources raises critical questions on project sustainability and organisational accountability and furthermore, how should the MDG for access to water be measured. This study investigates the widespread failure of hand pumps installed in Sierra Leone after 2004 and uses case-based reasoning to identify key socio-technical trends. It addresses the issue of sustainability and accountability within the water provision sector.

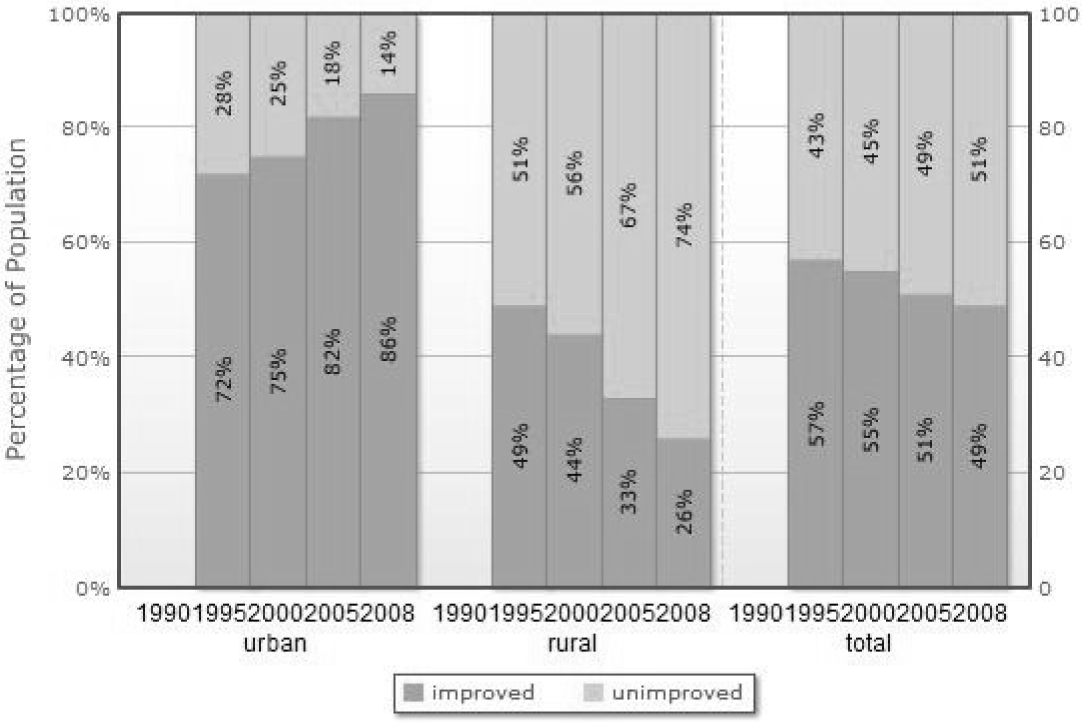

Figure 2 Decline in improved rural water sources from 1990-2008 Sierra Leone (WHO and UNICEF, 2008)

Case-based Reasoning

Case-based reasoning (CBR) is a form of artificial intelligence which attempts to replicate human learning by using past experience to solve complex problems. It has been successfully applied to solve complex problems in a wide range of holistic fields including medicine, law and engineering (Fenner *et al.,* 2007; Aleven, 2003; Holt, 2006). Aamodt and Plaza's (1994) research determined that there are four main components to CBR: (i) retrieve similar cases, (ii) reuse the cases to solve a new problem, (iii) revise the solution, and (iv) retain experience. A case may contain dozens of factors such as; the type of hand pump, number or years since installation, hand pump productivity, water quality and number of users (Fig. 3) (Barrie *et al.,* 2010). Each case contains one evaluation indicator that identifies if the case in question has failed; this study uses the quantity of water from an improved source per household. A new case, for which a solution is sought, is tested by comparing its similarity with other 'known' cases from the systems case base to determine the possible outcome of the case (Lopez de Mantras *et al*., 2006).

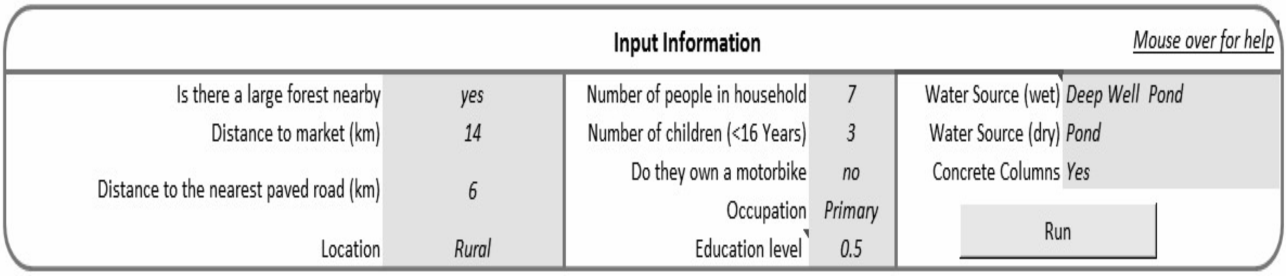

Figure 3 Example of an individual case in the CBR model (Barrie *et al.*, 2010)

Case-based reasoning uses the process of genetic algorithms (GA) to quantitatively determine the significance and level of interdependencies of factors (or sustainability indicators) affecting the outcome of a process by processing hundreds of thousands of case evaluations, and therefore replicating the experience of the expert. There are many different methods with which to implement GA, however all methods follow the same general steps used in this research to determine the significance of each factor.

1. An initial population of random sets of weightings are created and applied to each case variable, where the weights can be either 0,1, 2 or 4.
2. Each set of weights is tested to determine the case base error with respect to predicting the value of the evaluation indicator of the case in question.
3. The more successful sets of weights are combined randomly to create a new population of weightings, the two most successful set of weights are retained unchanged.
4. Steps 2 and 3 are repeated one hundred times.
5. The most successful set of weights is then selected.

Therefore if the user selects 100 generations for a case size of 20 factors, the model will analyse 2000 possible weighting scenarios per case. Hence, a case base of 151 cases will amount to the equivalent of 302,000 individual case evaluations.

The effectiveness of the GA's ability to ascertain the significance of each factor is determined by the size of the case base, or '*experience*'. Therefore, as the number of cases in the case base increases, the accuracy of the GA increases. The advantage of GA is its ability to gain a much larger '*experience*' than any single expert and the influence of bias is much reduced as the outcome is based purely on qualitative data. Furthermore it can assess all interdependencies between all factors included in the case-base.

Research Aim and Objectives

As of yet, no substantial evidence exists for the high failure rates of hand pumps installed in post conflict Sierra Leone. Furthermore the methodology that currently exists for determining the socio-technical failure modes for hand pumps in the developing world is basic and relies heavily on practitioner experience, which is regularly influenced by bias on the part of the practitioner. Therefore the aim of this study was to carry out an extensive hand pump survey in Sierra Leone and investigate the viability of using CBR as an unbiased method to suggest the key socio-technical factors that influence the failure of hand pumps and their respective interdependencies. In order to test the viability of CBR for this problem, the main objectives of the research were: (i) identify a range of variables that influence the uptake of water treatment technologies in Sierra Leone through a detailed KAP survey; (ii) develop a user friendly CBR model that can identify the significance of a range of socio-technical failure modes for hand pumps; (iii) to evaluate the results of the CBR model; and (iv) to discuss the applicability of CBR, for instance to help determine more efficient sustainability indicators for the FLOW continual monitoring program.

Methodology

Barrie *et al.* (2010) developed a decision support CBR model which demonstrated the capacity to predict the success of future water supply projects in rural Cambodia. Firstly the significance of each variable in the database was determined by evaluating previous projects using genetic algorithms. The user then entered the value of a range of variables linked to the community project in question. The model would then compare the characteristics of the community with regards to past community projects and their respective project outcomes and suggest the likely success. This model included social, technical, political and economic factors when evaluating. Furthermore, it included a module to determine the accuracy of the models prediction by testing the prediction of the outcome of an existing case.

The model developed by Barrie *et al.* (2010) aimed to determine the success of a project, whereas the model developed in this study aims to identify the reasons behind past projects failing. Therefore the CBR model developed by Barrie *et al.* (2010) will be altered so that each case includes a wide range of socio-technical factors determined through the Sierra Leone KAP survey. See Table 1 for a list of the factors that will make up each individual case.

Table 1 List of the factors included for each case

1. Number of males / females in each age group	2. Overall feeling of the well (sum of five factors: strong flow of water, well had plenty of water, ease of effort to get to water, short queues, good tasting water)
3. Combined total monthly household income	4. Did you *(or do you)* expect the system to fail?
5. Age of the head of the household	6. Do you know where spares can be bought for the well?
7. Maximum level of schooling completed by the head of household	8. Total water collected in the household in one month (person with the most tokens)
9. Water sources	10. How often is the source cleaned?
11. How long does it take to reach main source?	12. Has the household ever used a water treatment system?
13. How long does it take to queue at this source?	14. Did the household participate in the building of the water supply system?
15. How long does it take to return from this source?	16. Would the household have liked to contribute more in the well projects?
17. Number of times a day water is collected from the source	18. Do you think that the village could provide a well system without outside help?
19. Number of months of the year family is most likely to have water shortages	20. Does the household own a phone?
21. Person who makes the decision for source of water , volume to be collected and buy new household items	22. Scientific and technical capacity
23. Who controls the well? Whose property is the well? Whose responsibility is it to make decisions about the well? Whose responsibility is it to fix the well? Who has the capacity to provide new wells?	24. Distance to medical treatment

Results and Discussion

Upon completion of the Sierra Leone KAP survey the data will be input into the CBR model and the following results will be analysed and discussed:

1. Basic statistical analysis of survey data to determine clear trends.
2. Determine model error and learning ability of CBR model.
3. Weightings for each case variable will be determined using the CBR genetic algorithms and ranked by significance. Discussion on trends identified by model, comparison of trends to specific cases. Results compared to basic survey analysis whereby any similarities or disparities are identified.

4. Discussion on sustainability, accountability, predicting potential future failure and the potential for applying CBR to continual monitoring processes currently being developed.

Summary

Historically there has been little emphasis and resources dedicated to continual monitoring of water supply projects in rural developing countries. This has led to widespread long term project failure and misrepresented data with regards to MDG progress. There has, however been a gradual shift towards promoting continual project monitoring and organisational accountability. Currently there is little work carried out to determine, in an unbiased manner, the significance of a wide range of socio-technical factors affecting rural community level water supply project. Therefore, the process of continual monitoring is restricted both by bias and relevance. This project proposes a novel method for determining the significance of the socio-technical factors. Furthermore the results produced by the model could be used to further improve the continual monitoring processes currently being developed.

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