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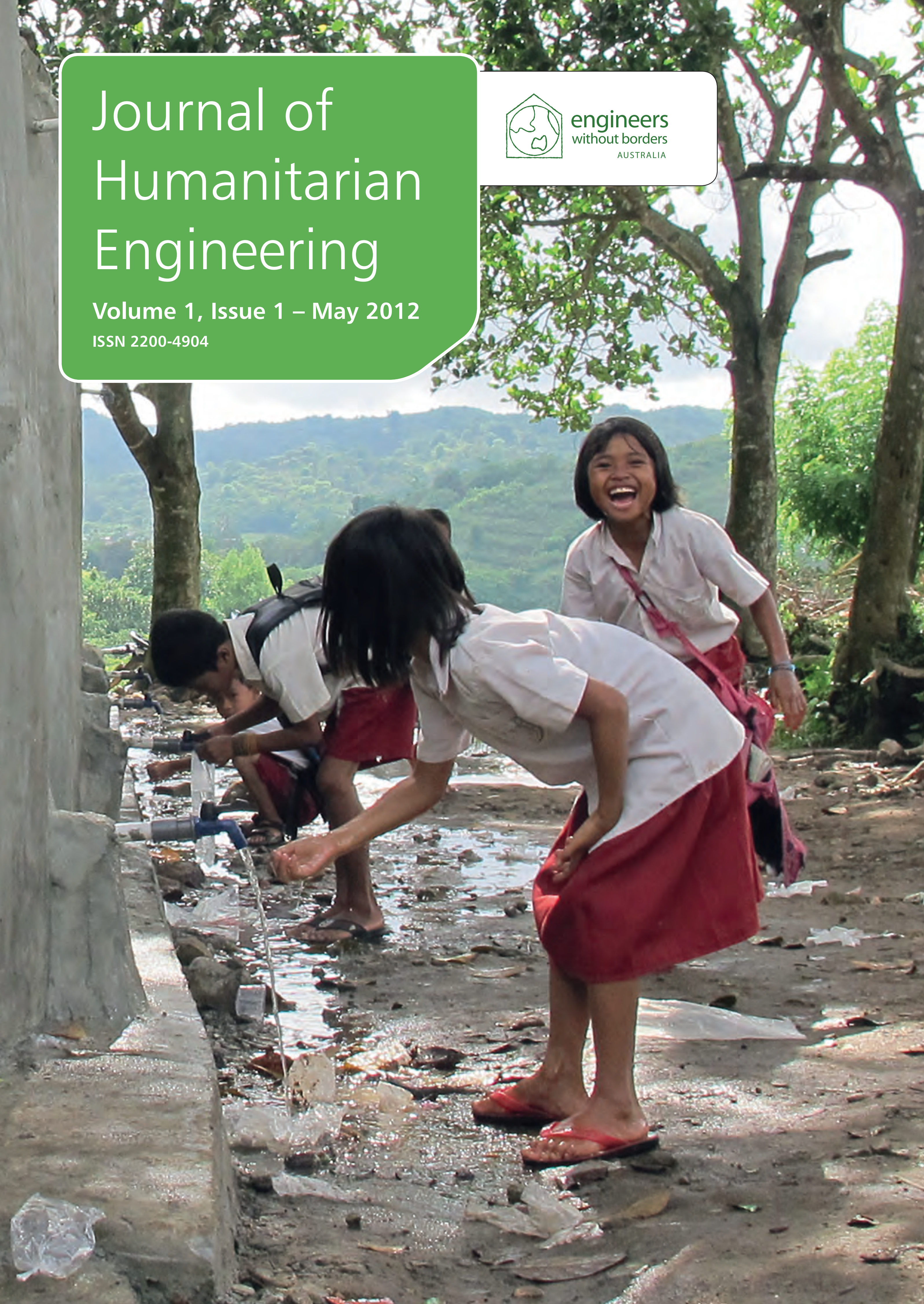

Journal of Humanitarian Engineering (JHE)

The Journal of Humanitarian Engineering publishes outcomes of research and field experiences at the intersection of technology and community development. The field of 'humanitarian engineering' describes the application of engineering and technology for the benefit of disadvantaged communities. This field spans thematic areas from water to energy to infrastructure; and applications from disability access to poverty alleviation. The JHE aims to highlight the importance of humanitarian engineering projects and to inspire engineering solutions to solve the world's most pertinent challenges.

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SUBSCRIPTION

The Journal of Humanitarian Engineering team encourages collaboration and the dissemination of ideas. JHE is an open access publication and electronic copies are freely available from the website: www.ewb.org.au/journal

FEEDBACK AND CONTACT

The editorial team welcome your feedback, comments and suggestions for the future direction of the journal. We also welcome people who are interested in becoming involved in supporting this initiative.

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EDITORIAL

It is my pleasure to launch the first edition of the Journal of Humanitarian Engineering (JHE). This new publication showcases the innovative work of researchers and practitioners working at the intersection of technology and community development.

Humanitarian engineering is about applying and developing technology – not to meet a market or financial opportunity – but to address a real human need. These projects are each designed to serve a disadvantaged community or group, often overlooked by traditional engineering and technology projects. From poverty alleviation to disability access, these projects highlight a new approach to developing and implementing technologies.

Research that collects dust on shelves or is stored away in the depths of an electronic archive is research that fails to make an impact. Dissemination is key, and the JHE aims to help facilitate this, as a destination for research outcomes. We expect the audience of this Journal will be engineers, researchers, students, NGO workers and community development practitioners. Promoting collaboration is just as important an aim for the Journal as publishing new knowledge.

Engineers Without Borders Australia (EWB) is a leader in the field of humanitarian engineering and is proud to be the publisher of this Journal. With almost a decade of experience working in partnership with communities in Australia and across Asia, EWB is also well placed to share the lessons learned from its experience in the field.

This first issue highlights research that addresses some major global issues: energy access, water quality and occupational safety, all within the context of developing countries. The articles come from researchers and practitioners with an interest in creating change as much as they are interested in creating knowledge.

Good humanitarian engineering research starts at the local level and addresses a real challenge, one that the local community have identified for themselves. It is rigorous while remaining accessible; technically innovative without losing its connection to the community. We hope that this Journal will be the home of research that embodies this approach.

As this is the first issue we are actively seeking involvement from the community to help us chart the direction, and be involved in the future of this publication. We are open to contributors from all over the world, particularly engineers, scientists, designers and innovators that are addressing challenges in their own community. The publication frequency, use of theme issues and editorial guidelines will be led by the interest and needs of the readers. Please make your thoughts heard and get in contact if you are interested in being involved in this publication or have ideas on how to make it great.

Once again, welcome to the JHE and to being part of a community committed to making an impact, and committed to doing it well.

Julian O'Shea
Editor, Journal of Humanitarian Engineering

Cover: Students using water from their new rainwater tanks installed at a primary school in Kedaro village, Indonesia. Photo: Michelle Quach

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Water and sanitation human rights for stone quarry communities at Wagholi, India

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ABSTRACT: *SANTULAN is an Indian Non-Government Organisation working to provide advocacy, education and health facilitation access to basic human rights for stone quarry worker communities in India. Engineers Without Borders (EWB) volunteers were employed to work alongside SANTULAN's existing programs and to conduct research into the water and sanitation issues faced by the stone quarry communities. This case study was developed based on five communities located near the Wagholi Township. It consisted of the assessment of the existing water sources and sanitation conditions and evaluating their subsequent health risks, in order to determine whether they are a violation of human rights and whether recommendations for improvement can be developed. Information was gathered based on observation, interviews/surveys with community members and SANTULAN staff, meetings with the Gram Panchayat (Local Self-Government) and water quality testing. Overall, it was found that the stone quarry communities do not have adequate access to clean, safe and reliable drinking water provisions, nor do they have adequate sanitation. Consequently, this poses significant health, financial, environmental and social consequences for the communities. India strongly supports the right to water and sanitation and has a duty to respect, protect and fulfil these commitments. However, in the case of the stone quarry communities, these obligations are not being met. This research will provide valuable support for SANTULAN in the form of documentational evidence to feed into an advocacy based approach for improving access to safe water and sanitation for stone quarry communities.*

KEYWORDS: Water and sanitation, human rights, stone quarrying, EWB and SANTULAN.

INTRODUCTION

SANTULAN is an Indian Non-Government Organisation working in advocacy, education and health facilitation access to basic human rights for the stone quarry worker communities. Stone quarry communities migrate frequently from their villages due to low income and lack of land. The daily wages provided by quarry mining work often dissuades the workers from returning to their villages. The quarry workers tend not to stay at work-site for more than 2 to 3 years as the work can be too sporadic, the present quarry closes or they are in search of a better wage.

This lack of permanency means they do not have any kind of government personal documentation and therefore are not eligible for government benefits, they are not enrolled to vote and they do not have access to ration cards from the state Government or the local councils. Additionally, the mine industry is highly unregulated and exploitation of workers is common practice including hazardous occupational health and safety risks, low wages and no job security (figure 1).

The community housing is generally located in slum settlements next to the stone quarry/crushing sites in huts covered with temporary iron or plastic sheets and walls made of loose stones. They have no basic amenities such as a reliable clean water or sanitation (figure 2).

SANTULAN has developed various initiatives for the education, organisation and empowerment of stone quarry communities including: provision of schools, education, shelter and nutrition for children, fostering women empowerment groups and developing informal stone quarry workers' organisations to advocate for workers' rights.

As part of the Engineers Without Borders volunteer placement scheme, volunteers were assigned work in parallel with SANTULAN's existing programs for approximately 12 months. This work focused on identifying the water and sanitation issues faced by the stone quarry communities. A case study was developed to assess the existing water sources and sanitation conditions and their subsequent health risks in order to determine

Figure 1: Working conditions on the stone quarry sites located near Wagholi Township.

whether they are a violation of human rights and where recommendations for improvement could be made. This research will provide valuable support for SANTULAN in the form of documentational evidence to feed into an advocacy based approach for improving access to safe water and sanitation for stone quarry communities.

2 METHODOLOGY

To fully understand the nature and extent of the water and sanitation issues, background research was undertaken which included a review of international laws and treaties, national and state policies, local plans of water infrastructure from the Gram Panchayat (local self-government) and reports on previous work undertaken by SANTULAN.

This research was based on five communities located on the quarry sites near the Wagholi Township which included: Dabhade Khanwasti (160 people), Wageshsvarnagar Khanwasti (700 people), Gorewasti (200 people), Shindewasti (200 people) and Suyog Nagar (1500 people). The communities were visited several times over the period of September 2010 until April 2011 and the current conditions of their water sources and sanitation practices were assessed based on observation, interviews/surveys with community members, meetings with the Gram Panchayat (Local Self-Government) and water quality testing undertaken in conjunction with Pune Engineering College in March 2011.

2.1 Findings

A particularly interesting finding for this research was that a water supply scheme was built in 2006 to service all of the communities listed above due to a successful appeal won by SANTULAN. Unfortunately, there are several issues with the water supply scheme as investigated in 2010/11. The water is supplied by the Municipal Corporation (local government body) in Pune City to the Gram Panchayat (local self-government) in Wagholi, who is responsible for distributing the water. The pumping station at Wagholi is the furthest town from Pune City being supplied and there are many illegal connections and transmission losses (Rode, 2003) in between. Therefore, the Gram Panchayat is not receiving their full entitlement to manage the distribution of the water and only possesses a significantly diminished water volume to supply the stone quarry communities.

Another issue with the existing scheme is the quality of the piping in the water distribution scheme. The piping is damaged in several locations potentially due to poor quality materials, poor construction techniques combined with the excessive loads from the stone carrying dumper trucks. Additionally, there are rumours that the pipes have been intentionally blocked due to caste differences and power politics. The Gram Panchayat has taken on the responsibility for operation and maintenance costs of the water supply scheme and does not charge the mining communities a user fee. Despite this, the issues of the defunct infrastructure have not been resolved. Not requesting a user fee charge may also be compounding the issue, as it is easy to discriminate against non-paying users.

The main source of drinking water for most communities is generally from wells located on neighbouring agricultural properties with access agreed upon with the local farmers. These are unprotected water sources and have varying degrees of water quality issues and require treatment to be suitable for drinking. Some people use disinfectant or boil the water but the majority of people filter the water using cloth or do not treat the water at all. Sources of pollution may include: human faeces, animal faeces, household waste, dust, sediment from erosion, fuel/oil from heavy vehicles/machines, chemicals from explosives, mineralisation, fertilisers, nitrates, phosphates from agricultural practices and pathogenic waterborne microbiological organisms.

The community of Dhabhade Khanwasti sources their water from the stone quarry pit as there are no alternative sources nearby. Community members commented that the water is not very good and has an odour. Water quality tests show high pH, high faecal contamination and large amount of nitrates that deems the water not suitable for drinking based on the World Health Organisation drinking water guidelines. The people surveyed in this community generally do not apply any treatment methods to this water.

Aside from water supply, sanitation is also a major issue faced by the community, issues include:

- Open defecation away from the community housing is common practice and the few toilets that exist are commonly defunct. Additionally, the limited access to water means that people do not wash their hands after going to the toilet. When hand washing occurs, soap is not commonly used.
- Household waste is discarded beyond the household boundary in open fields. There is a rubbish dump at the entrance of the Wageshvarnagar community which is located on a drainage line (figure 4). This putrefying waste is provides a breeding ground for flies and rats and attracts foraging animals such as cows and pigs making it a high risk zone for infection and disease. The drainage line suffers from a significant mosquito problem as it contains muddy and stagnant water. Additionally, the waste from the Wageshvarnagar community rubbish dump is able to seep into the drainage line.
- There is a lack of stormwater drainage in all the communities. Apart from flooding during the monsoon the lack of drainage allows water to accumulate at low points in the roads creating pools of water and mud. This creates difficult access for vehicles and also a potential breeding ground for mosquitoes. Anecdotal evidence shows that there have been cases of malaria communities with such problems. The community attempts to remove the waste by burning it but the odour is foul and impacts public health as well as the environment.
- Hygiene practices are currently part of the school

Figure 2: Typical Housing at stone quarry communities located at Shindewasti near Wagholi Township.

Figure 3: A woman and a school girl collecting water from a nearby well at Shindewasti.

curriculum and are followed by some of the children including: nail cutting, hand washing, bathing, combing, and wearing clean clothes. However, these practices vary between children (and also adults) and some are not so well kept.

Within each of the schools there are no drinking water or sanitation provisions. Additionally, the mine owners do not provide drinking water or sanitation facilities for employees during their shift.

There are also a number of issues are impact on the health, environment, social and financial situation of the stone quarry communities, these include:

Health Issues: Anecdotal evidence reveals that intestinal worms and diarrhoea are common health issues in the community. This can be directly attributed to poor hygienic practices, poor quality drinking water or a combination of both. Additionally, skin and eye infections are also common due to inadequate quantities of clean water for personal hygiene. There have also been cases of malaria reported within the communities indicating that the pools of stagnant water on-site encourage breeding of mosquitoes that transmit disease.

Social Issues: Women and girls are traditionally responsible for domestic water supply and sanitation and maintaining a hygienic home environment. They bear the burden of fetching water and as a result compromise their education, productive activity and leisure time.

Women also pay a heavy price for poor sanitation. The only time available for women or girls to defecate, if they do not have a latrine, is after dark. Apart from the discomfort caused by the long wait, this can cause serious illness (UNICEF, 2008). There is also a risk of harassment and assault during the night-time walk to and from the communal defecation fields.

The lack of safe, separate and private sanitation and washing facilities in schools is a factor preventing girls from attending school, particularly while menstruating.

Financial Issues: Diseases from poor water and sanitation practices mean there is a high rate of sick days from work impacting pay and also a high rate of sick days from schools impacting the children’s education.

Additionally, the community members spend their already scarce amount of money on medicine. Some families also spend money on water carting.

Environmental Issues: Lack of sanitation is polluting the environment including ground water, surface water and air quality. Drinking water sources are under increasing threat of contamination, with far reaching consequences for the health of children and for the economic and social development of the communities.

3 EVALUATION

What do these findings mean in terms of human rights violations and whose responsibility is it to do something about it?

The right to water is defined as follows (UN, 2010a): *“The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses.”* The right to sanitation is *“access to, and use of, excreta and wastewater facilities and services that ensure privacy and dignity, ensuring a clean and healthy living environment for all”* (The Rights to Water and Sanitation Portal, 2010).

India has repeatedly acknowledged these rights at an international level and is a State party to several documents which explicitly recognise water and sanitation as a human right, these include: the International Covenant on Economic, Social and Cultural Rights (ICESCR); Convention on the Elimination of all Forms of Discrimination Against Women (CEDAW); and Convention on the Rights of the Child (CRC).

Consequently, India has an obligation at both the national and state levels to respect, protect and fulfil these commitments. A part of these commitments includes recognising the right to water and sanitation within national legislation. Although India does not have an explicit reference to these rights in the national legislation, the Supreme Court has ruled that both water and sanitation are part of the right to life (Article 21 of the Indian Constitution).

Based on the findings of this case study, the following obligations are not being met:

- The Municipal Corporation has failed to provide adequate water supply to Wagholi pumping station presumably due to low revenues and low levels of investment in urban infrastructure. Given that there are sufficient financial resources to address lack of access to water (not necessarily in the municipality, but at higher ranks of State), the failure to meet the State's obligation to fulfil this duty is a violation of people's right to water. As India is a State party to the (ICESCR), the Government should ensure investments in water facility access for all members of society and prioritise investment in water and sanitation services and facilities to areas that currently have low or limited access. The State is duty bound to ensure the right of access to water and water services and facilities on a non-discriminatory basis, especially for marginalised or disadvantaged groups.
- In order to manage the reduced allocation of water, the Wagholi Gram Panchayat has significantly reduced if not ceased to provide water to the stone quarry communities. Additionally, part of the water supply system is defunct and has not been maintained by the Gram Panchayat. The quarry communities tend to be the first to miss out as they cannot afford to pay for water and they do not have any representation in the political sphere. The Gram Panchayat has plans to construct a new water supply scheme in 2011 but this does not guarantee that issues regarding discrimination will be resolved. The State has a duty to prevent the service delivery from compromising equal, affordable and physical access to sufficient, safe and acceptable water and the failure to meet the State's obligation to fulfil this duty is a violation of people's right to water.
- There is a high rate of disease attributed to poor quality drinking water from unprotected sources. The Government is duty bound to ensure drinking water meets quality standards, and provide information to all groups regarding safe water storage, hygienic sanitation and water quality to combat disease. Failure to do this is a violation of the right to water and a violation of the right to health.
- Women pay the heaviest price for poor water and sanitation. Governments should take measures to alleviate the disproportionate burden women bear in the collection of water, and ensure that children are not prevented from enjoying their human rights (such as right to education) due to time collecting water. Additionally, The State has a duty to ensure that no person is discriminated against in regard to her right to sanitation. Failure to do so is a violation of the right to water and sanitation and is discrimination against women.
- The failure to provide sanitation services such as waste collection and latrines to the stone quarry communities is a violation of the right to sanitation, a violation of the right to health and a violation of the right to a clean and

Figure 4: Uncontrolled dumping of rubbish located at the entrance of Wageshvarnagar Khanwasti.

wholesome environment. According to the Indian Constitution the State has duty to ensure amongst others, a decent standard of life and to improve public health and sanitation. It declares a national commitment to protect and improve the environment.

- Mine owners are also duty bound to meet their obligations based on the Mines Act (1952) and the Mines Rules (1955). This includes provision of drinking water and latrines for all employees during their shift at conveniently accessible locations. Mine owners failing to meet their responsibilities are committing a violation of rights to water and sanitation.

4 CONCLUSIONS AND RECOMMENDATIONS

Through this case study, it is clear that the stone quarry communities settled near Wagholi do not have adequate access to clean, safe and reliable drinking water provisions nor do they have adequate sanitation. The information collected throughout this research is useful evidence for SANTULAN to adopt an advocacy approach directed towards the key actors causing the water and sanitation problems including the: Gram Panchayat, Municipal Corporation and the mine owners.

Demands for the Gram Panchayat should include: on-going maintenance of the entire water supply scheme to ensure continual operation, provision of a minimum of 20-50 L/person/day of water suitable for drinking, provision of water carting if there is a water shortage, representation of the stone quarry community at the next Wagholi Water and Sanitation Committee meeting, construction of at least 1 toilet per 20 people as per minimum standards for each community and implementation and maintenance of storm-water drainage systems.

Demands for the Municipal Corporation should include weekly waste collection from the Wagholi quarry site.

Demands for the mine owners should include provision of at least 2 L per person per shift and the provision of at least 1 toilet per person at conveniently accessible places on the mine site, in accordance with ‘The Mines Rules (1955)’.

Additionally, an advocacy campaign should be complemented by work with the community to raise awareness of their rights and promote water, sanitation and hygiene practices. Each school should also include toilets, washbasins and drinking water provisions as per requirements of ‘The Right to Free and Compulsory Education Act, 2010’. With funding support, SANTULAN has the capacity to undertake these activities.

ACKNOWLEDGEMENTS

I would like to thank the professors and students from Pune Engineering College who enthusiastically assisted with collecting and testing water samples. Thanks also to the team of support at EWB and most importantly thanks to SANTULAN for the selfless dedication to such a noble cause that is making a difference in the world.

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Developing a manual to guide project evaluation for RainWater Cambodia

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ABSTRACT: *The Project Evaluation Manual has been developed to guide the Non-Government Organisation (NGO) RainWater Cambodia through the steps of project evaluation. Ultimately, those conducting the evaluation will make decisions as to what is important in the evaluation but the manual provides a guide. The manual has been written with only post-project evaluation in mind, but it may also be used as a guide for project development and mid-project evaluation. It may also be used to be adapted for use in other organisations or NGOs. The design of this manual was conducted with consideration as to the fact that RainWater Cambodia has limited funding to steer towards project evaluation and limited time scheduled for conducting project evaluations.*

KEYWORDS: Project evaluation manual, guidelines, RainWater Cambodia, impact assessment.

1 INTRODUCTION

This manual has been written for RainWater Cambodia (RWC) with the support of Engineers Without Borders (EWB) Australia. RWC is a not-for-profit organisation founded in 2003, based in Phnom Penh that aims to address the lack of access to clean drinking water in rural Cambodia. While many projects have been implemented over the past eight years, very little project evaluation has taken place. The main reasons for this are a lack of funding, resources and time. This manual aims to ease project evaluation and make it more accessible to RWC.

Research conducted over three months and a consequent field trip to Cambodia highlighted the need for a simple project evaluation guide suitable for RWC that was more tangible available online guidelines. This manual was developed based on research conducted on project evaluation, a field trip to Cambodia, interviews with EWB in-country volunteer James Oakley and RWC director Kea Pheng, along with three existing evaluation guides: *Evaluation of the Development of the Biosecurity Strategy for Victoria (Bennetts 2009); Program Evaluation Training (McGeary 2008),* and *Water Quality Project Evaluation : A Handbook for Objectives-Based Evaluation of Water Quality Projects (Ohio State University, n.d)* At the heart of this manual's design is a logical step-by-step process by which RainWater Cambodia can evaluate its projects.

The following is a highly condensed version of the complete manual. The full edition can be obtained by contacting Engineers Without Borders Australia (contact details at conclusion of paper), or by contacting the author directly.

2 METHODOLOGY

This manual has drawn extensively on work conducted by Clare Bennetts, Julie McGeary and The Ohio State University in their documents *Evaluation of the Development of the Biosecurity Strategy for Victoria; Program Evaluation Training and Water Quality Project Evaluation: A Handbook for Objectives-Based Evaluation of Water Quality Projects* respectively. This manual is also the product of an investigative report that was conducted to survey literature on project evaluation. The investigative report can be obtained by contacting the author of this manual

3 EVALUATION

Step 1 – Getting started

The first step of the manual details the commencement of evaluation, this involves the gathering of an evaluation team. This section guides the reader through what to consider when gathering a team.

One of the main considerations is who to involve in the evaluation team. The team should consist of as many relevant project stakeholders as possible – for RWC these project stakeholders include RWC staff, project participants, village health volunteers, commune council members, local entrepreneurs and WASH committees.

Project stakeholders are both the target of and the drive for project evaluation, so interacting effectively with project stakeholders holds the key to a successful evaluation. Actively involving the stakeholders in the evaluation process requires informing them of the benefits of taking part in the process both for the stakeholders themselves and RWC.

Project evaluation provides great opportunity for learning, and for strengthening relationships between stakeholders. Some reasons for conducting Project Evaluation include:

- assessment of project sustainability/suitability
- identification of areas for improvement
- assessment of the social, economic and enviromental impact of the project impact
- to fulfil project accountability requirements
- to understand budget spending
- to report back to donors
- or all of the above

Step 2 – Understanding the project

Step two guides the reader through understanding the reason for the evaluation, for example, RWC may wish to assess the level of competency of trained local entrepreneurs in supplying demand, to determine whether they are fully equipped to expand and maintain the projects initiated by RWC.

One key questions is 'For whom is the evaluation being conducted?' The answer to this question will help determine the kind of information that will be collected during the evaluation. The possible evaluation audiences include RWC (to improve on their projects), donors (to give them a 'return' on their investment), commune councils (to develop a better understanding of their community's needs), local entrepreneurs (to address any business weaknesses), WASH committees (to assess project impact) and the Cambodian Government (for compliance reasons), or a mixture of any of the above.

Step two recommends **'creating a picture of what success would look like'** and to brainstorm ideas of what that encompasses, e.g. increasing access to clean drinking water; improving the health and well-being of women and children; increasing attendance at school. Step two recommends using **'Program Logic'** as a way of documenting this picture.

Step 3 – Evaluation barriers/challenges/ limitations

Step three highlights the importance of addressing potential barriers to the success of the evaluation. This ensures that provisions can be made to overcome those barriers to result in smoother evaluation. Alternatively, it may be decided that barriers for the particular project deem the evaluation unsuitable at that point in time.

The decision not to undertake an evaluation may expenditure costs but project evaluation has great potential to improve projects and subsequently the efficiency at which they run. It is necessary at this point in time to decide whether or not the evaluation should go-ahead. This should be a group decision involving all participants.

Step 4 – Developing key evaluation questions

Step four guides the reader through developing key evaluation questions (KEQs). KEQs guide the evaluation and are about learning.

Examples of KEQs include the following:

- How can the project be improved?
- What worked for which people and why?
- Are trained entrepreneurs able to supply project demand?
- Is there demand for the project?
- What difference has the project made?
- Have there been any unexpected outcomes as a result of the project?

Including 'Performance Indicators' (PI) in the data collection framework is an excellent way to assess the project on a statistical basis. An example of a PI for RWC would be the number of rain-water harvesting (RWH) systems built and installed by newly trained local entrepreneurs. This gives a quantitative value to success, and can be very useful for assessing projects at a glance.

Performance Indicators are about proving and focus on measurement and are therefore relatively easy to analyse and aggregate. KEQs are about learning and focus on questioning in an effort to provide a qualitative analysis of the PIs. It is crucial to incorporate KEOs and IPs in tandem as measuring only PIs is not recommended, their singular use can be misleading (McGeary, 2008).

Step 5 – Data collection

Once the KEQs been determined, the data collection method must be chosen. The most suitable data collection method is chosen based upon how appropriately it can answer the KEQs and how suitable it is to the resources available to RWC.

There are many well-known methods for collecting project evaluation data. Taking into account RWC's resources and level of experience with evaluation, the following methods are considered suitable options:

i **Asking people individually**
   - Structured interviews

- Semi-structure interviews
- Questionnaires: face-to-face, telephone, mail

ii **Asking people as a group**

- Focus discussion group

iii **Physical methods**

- Observation

The full edition of this manual describes each method, including advantages and disadvantages, as well as a list of considerations to be aware of when choosing a method.

4 VALIDITY

Questions in data collection frameworks can always be misinterpreted. One way of testing if questions are being understood properly is to conduct the same pilot test, several times, with the same group of people over a period of weeks. In this way questions which are not understood become apparent from the answers given, and can be adjusted accordingly in an attempt to streamline the framework.

Step 6 – Analysing and reporting results

Step six guides the reader through the process of reporting and analysing results. It is very important when analysing results to acknowledge and list all known limitations and possible influences. This helps the evaluator see possible explanations for why results appear to be the way they are. Pilot testing is one way of assessing and then justifying the reliability of evaluation results.

Carter McNamara in his *Basic Guide to Program Evaluation* argues 'there is a strong chance that data about the strengths and weaknesses of a program will not be interpreted fairly if the data [is] analysed by the people responsible for ensuring the program is a good one' (McNamara, n.d).

It may be worthwhile to have someone from outside the organisation analyse the evaluation results to ensure credibility, especially if the evaluation is being conducted for project donors.

Step 7 – Putting Evaluation findings to use

The final step in this manual is perhaps the most simple to instruct but the most important to implement.

The next step after the compilation of a report is communicating the results to the audience of the evaluation, so that decisions can be made based on those results and action taken in decided areas. A verbal presentation or workshop is the recommended method for communicating results to all project participants, including staff and beneficiaries, as it reaches a wide group of people and is easily absorbed when compared to report reading (McGeary, 2008).

Following a broadcast of the results, workshops should be conducted to find solutions to the problems uncovered in the evaluation, and a plan of action put in place. It is essential that evaluation results be fully utilised, and translated into necessary action.

5 CONCLUSIONS

Conducting project evaluation adheres to the age old adage: 'it is better to teach a man how to fish than to give him a fish'. The main aim of evaluation is learning and this manual provides RWC with an avenue for learning and conducting evaluation. Guidelines presented in this manual are based on research of other authors on the subject and the understanding of how RainWater Cambodia operates.

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Arsenic removal for ceramic water filters

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ABSTRACT: *Arsenic in drinking water is a hazard to human health and is a known carcinogen (Mass 1992). Resource Development International – Cambodia (RDIC) has researched, developed, and manufactured simple ceramic water filters (CWF) which have proved to be extremely effective in removing pathogens from water. These filters however, do not remove arsenic from water, which exists in the source water at levels above the World Health Organisation (WHO) guideline of 10µg/L. The aims of this literature based study were to investigate conventional and non-conventional arsenic removal processes, and to discuss the options for applying an arsenic removal technology to the CWFs produced by RDIC. It was found that conventional arsenic removal technologies are difficult to implement in the context of household water treatment in a developing country. This study suggested that non-conventional arsenic removal technologies shall be more effective and that field studies must be undertaken to verify the success of such methods.*

KEYWORDS: Ceramic, filter, arsenic, removal, household.

1 INTRODUCTION

Over 137 million people suffer from arsenic related problems each year (WHO, 2001). Arsenic is a metalloid, which is a known carcinogen to humans if consumed in small doses, over a long period. The water which is consumed by CWF users exceeds the WHO international guideline of 10 µg/L.

The WHO has identified that the best method for obtaining safe drinking water and reducing the affliction of waterborne diseases in developing countries is household water treatment. Of the various household water treatment technologies, CWFs have proven to be extremely effective in removing disease causing pathogens. Resource Development International – Cambodia (RDIC) has developed and manufactured CWFs which are able to remove 99.99% of pathogens which cause disease. However, this filter is not capable of removing arsenic, and thus options are considered and evaluated to extend the capabilities of these filters.

An independent study (Van Halem, 2006) which evaluated the effectiveness of CWF reported that the filters leached arsenic into water in the first 2-4 weeks of use. It is in the scope of this study to research and provide recommendations to reduce the possibility of excess arsenic being consumed by the water filter user.

Undoubtedly, there is no single solution of removing arsenic from water which is appropriate for all areas affected. There are many variables such as the concentration of arsenic in source water and the socio-economic status of the area which has a direct relation to the most effective and efficient solution. Thus, further research needs to be undertaken, focusing on individual areas which include data gathering, methodology proposal, experimental procedures, results testing and analysis before the implementation of any solution can occur. This study aims to accelerate this process by assessing various arsenic removal technologies and identifying which methods would be more applicable to CWFs.

2 ARSENIC REMOVAL TECHNOLOGIES

2.1 Conventional

Membrane technologies are a method of arsenic removal which use microscopic pores which allows certain constituents through while rejecting others. Due to the dense nature of the material used, a force is required to assist the movement of molecules through the membrane. An effective method of providing this force is to have a potential difference on either side of the membrane.

The greatest difficulty with applying membrane technologies to CWFs is to provide the pressure required to pass the source water through the dense membrane. Traditionally, this requires power, which is not readily available in rural areas of developing countries. Another disadvantage of membrane technology is the small amount of raw water (10-15%), which passes through the membrane as permeate. This means that more than one membrane needs to be connected in series to ensure higher recovery rates (80-90%) are achieved (Nguyen et al, 2009). This also constitutes to a higher source water requirement, which is not readily available in rural contexts throughout the year.

Although membrane technologies are capable of treating arsenic to excellent standards, conventional methods have a high water and energy cost, as well as a high sensitivity to other contaminants, which endow it unsuitable for the context of CWFs in developing countries.

Adsorption/ion exchange technologies utilises the natural charge of arsenic causing the attraction of arsenic to an added material, which is added to the water. The added material can be of various forms and needs to be regenerated, and, or replaced regularly.

It is the nature of this method to remove only charged ions, which means arsenite, which has a neutral charge, is not removed. Since the source water in developing countries has a high variability, it is difficult to know the charge of the arsenic, and hence whether or not it has been removed. This technology requires the regular regeneration and replacement of the material in order to continue absorbing arsenic. It has also been found that sulfate, which is also present in the source water, is more attracted to the added material than arsenic, making it difficult to monitor at a household level the efficiency of arsenic removal.

The major variance in source water, namely the amount of arsenic and sulfate, combined with the responsibility of regeneration and replacement, which is transferred to the end user, makes these technologies apidly. The coagulant can add a positive force, which reduces the overall negative charge of the arsenic incldifficult to implement with CWFs.

Coagulation/filtration technologies consist of destabilising the contaminant by introducing a coagulant and mixing ruded in water. This allows particles to collide, forming larger particles (Choong et al, 2007). This process is followed by flocculation, where larger particles clump together.

Coagulation and filtration technologies for arsenic removal have been used effectively around the world in both laboratories and in the field. Currently, they operate as stand alone systems, in which chemicals are added to water and stirred, followed by sedimentation and filtration. Further research and experimentation is required to investigate the best coagulant that can be used with CWFs. The application of this method can be adapted into CWFs by adding chemicals to the pot and manually mixing as required. This can be left for natural sedimentation before using the current water filter for microbial filtration. The disadvantage with such technologies is the level of effort required to operate such a system at a household level. This includes the addition of coagulants, mixing as required, and removal of flocs regularly to ensure the arsenic removal mechanisms can work effectively. Field studies were evaluated in a study in Bangladesh (Karim, 2000), which found that the amount of operational effort required was one of the key reasons for rejections of a technolog.

2.2 Non-conventional

Based on the different context in which developing countries operate, it is necessary to consider non-conventional methods of arsenic removal. These are new innovative ways which arsenic can be removed with a focus on specific objectives such as reduced cost, sustainable, low energy requirements and using materials that are locally available. The following technologies have been identified to have great potential to remove arsenic from water, and can be combined with the current actions of CWFs:

- 'Plastic bottle' solution (Tongesayi, 2011): this technology involves using pieces of plastic bottles coated with a commonly available amino acid to remove arsenic. At a laboratory scale, this method has proven to effectively reduce the amount of arsenic in drinking water from concentrations of 20 µg/L to 2 µg/L. This technology can easily be implemented with CWFs by adding the amino acid coated plastic into the filter pot. The major benefits of this method are the use of locally available waste products and the simple to use technologies of coating the plastic.
- Idaho National Laboratory scientists have engineered a new Nano-Composite Arsenic Sorbent (N-CAS), which is specifically designed to remove arsenic from water. "N-CAS is a compound that can remove arsenic contamination from drinking water over eight times as effective than any other method to date, for a fraction of the cost" (Mower, 2011). This breakthrough technology uses a special polymer, which is highly porous with an iron oxide to trap arsenic. Due to its small particle like shape, a small amount of the sorbent has a large surface area, making it extremely practical and requiring much less effort that conventional adsorption methods.
- A study (Malik et al, 2009) was conducted to investigate the potential of low cost adsorbents to remove arsenic from water. This technology uses local waste products from agricultural and industrial processes such as rice husks, slag, fly ash and red mud as adsorbents. This modification of the conventional adsorption method reduces the initial and ongoing operational cost and can potentially be implemented with CWF.

These non-conventional methods were found to be much more appropriate than conventional methods for developing countries. The key differences were in the cost and simplicity of the technologies, which would help the acceptance of such methods by communities. Of the non-conventional technologies identified, most were in laboratory testing phase and require further research and development to create a product with which the arsenic removal technology can be developed. The CWF developed by RDIC can be used to deliver the arsenic removal capabilities of these upcoming technologies.

3 INITIAL RINSING TO REDUCE ARSENIC

A recent study (Archer et al, 2011) was conducted to address the issue of the significant arsenic leaching from CWFs in the first 2-3 weeks of use. The study investigated the effects of initial rinsing on 50 water filters which were tested between January 2010 and March 2011. This study provided conclusive data on the effectiveness of current practices adopted at a CWF production facility in Guatemala. The following process describes the method which was used to ensure the significant spike in arsenic isn't exposed to the CWF user:

1. A new, unused, and dry CWF that had not been wetted since firing was placed in a bucket that had been rinsed with tap water and dried.
2. The CWF was filled with tap water and allowed to filter for approximately 2 hours.
3. The volume of filtered water was measured, and a sample was collected for arsenic analysis.
4. The CWF was periodically refilled over a 24 hour period, and the volume of filtered water was measured.
5. At the end of the 24 hour period, the CWF was emptied, refilled, and allowed to filter water for approximately 1 hour. The filtered water volume was recorded, and a sample was analysed for arsenic.
6. Step number 5 was repeated 3 more times, so that the total number of samples collected for arsenic analysis was 5 for each CWF evaluated in January, and 10 for the March CWFs. Step 5 was repeated 4 times, so that a total of six arsenic analyses were performed for ten of the CWFs evaluated in March.

The results of this study clearly indicated that initial rinsing using approximately 15 L of water reduced the arsenic concentration from levels of up to 240 µg/L to less than 20 µg/L. It is therefore recommended that RDIC follow a similar process before the distribution of their ceramic water filters.

4 CONCLUSIONS

To improve the capacity of CWFs to provide clean and safe water to its users, this research investigated arsenic, its contamination and options which could be explored for suitable arsenic removal from drinking water. This literature based research was aimed at identifying which technologies would be most appropriate to research and develop, so that arsenic removal could also be a function of the CWF. The key findings of this research have been summarised below:

- Harmful amounts of arsenic (up to 240 µg/L) leached from the CWF into the effluent in the first 2-3 weeks of use. This reduces to a significantly lower concentration (approximately 17 µg/L), which is still greater than the WHO guideline of 10 µg/L (Van Halem, 2006).
- The long term effects of consuming water with an arsenic concentration of 17 µg/L has shown to have significant detrimental health effects.
- Rinsing the filters following the method provided is an effective way to ensure the initial spike of arsenic is not exposed to the users of the CWF (Archer et al, 2011).
- It is not appropriate to implement the same conventional technologies that are used in developed countries in developing countries. This is due to large differences in water, economic and social contexts.
- Non-conventional arsenic removal processes have great potential to combine with CWF and increase its ability to remove arsenic.
- Further research and development is required in a particular technology to specifically collaborate with the CWF.

These key findings are important to the development of a specific technology, which can be implemented for the CWFs that have been developed by RDIC. To accelerate the development of a method to remove arsenic from water for CWFs, it is recommended to:

- Identify the key factors and priorities for the design of the arsenic removal technology. This will help focus research and engineering on the most important objectives.
- Explore non-conventional arsenic removal technologies and provide specific data where required to scientists, researches and engineers to assist the development of their technologies.
- Collaborate with laboratory researchers to conduct in-field testing to verify results of laboratory tests and upscale technologies.

The reduction of arsenic from drinking water has numerous benefits and will have significant improvements in the lives of all users.

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Dust masks for Indian quarry workers: A comparative analysis of the filtering efficiency of fabrics

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ABSTRACT: *The filtration properties of Indian fabrics were measured using modified respiratory protective device (RPD) tests, to match conditions in Indian quarries. Results were compared to those of dust masks meeting Australian and International standards. Four layers of loose weave fabrics were found to perform best, but would still be insufficient for use at sites with highly hazardous dusts.*

1 INTRODUCTION

Through the industrial revolution and into the past decade, a greater awareness and understanding has been gained regarding the health effects of breathing fine dust particles. In Australia, the long-term effects of asbestos in the respiratory system have been widely publicised in recent years and exposure standards are now in place to protect Australian workers from dust-related respiratory illnesses (National Occupational Health and Safety Commission, 1995).

1.1 Standards and legislation

While strict and effective standards are in place to protect workers in Australia, the situation in India is very different. The few standards and little legislation which do exist are rarely enforced or regulated, resulting in dangerous working conditions for those exposed to high levels of fine dust (K Wood 2011, pers. comm., 11 March). Workers in mines and stone quarries are particularly at risk, with many dying of silicosis or other respiratory illnesses each year (Madhaven, 2009).

In India, National Ambient Air Quality Standards have been in effect for some time, defining the maximum allowable levels of particulate matter in the air in both industrial and 'ecologically sensitive areas' (Central Pollution Control Board, 2009). However, reports from the Indian Government have shown that these levels are not usually met (Central Pollution Control Board, 2006). The *Environment (Protection) Act 1986* with its subsequent rules and amendments include standards for implementing dust control measures, such as dust suppression, wind breaking and water spraying (Bhawan, 2009).

The *Factories Act 1948* applies to stone crushing processes and similarly stipulates that effective measures must be taken to prevent inhalation of excessive concentrations of dust. Amendments to this legislation also specifically set the Permissible Exposure Limit of respirable silica at 0.1 mg/m^3, in line with exposure limits for Australia (Commonwealth of Australia 2010), the United States (U.S. Department of Labor, 2011) and many European countries (IMA Europe, 2007).

1.2 Health risks

The health issues related to breathing respirable dust vary widely depending on the type of dust involved and the concentration inhaled. Pneumoconiosis, the general term given to a range of lung diseases caused by breathing dusts, typically causes chest tightness, shortness of breath and coughing (Encyclopædia Britannica, 2011). Under continued exposure it may develop into chronic bronchitis (inflammation of the bronchi) or emphysema (destruction of lungs over time) (National Center for Biotechnology Information 2010, 2011a).

Silicosis is the most likely form of pneumoconiosis to be dangerous to mine and quarry workers. Silica, or silicon dioxide (SiO_2), is extremely common in rocks and ores, particularly as quartz or sand. Silicosis is contracted by breathing respirable silica dust in one of its pure crystalline forms. As a result, crushing or blasting rocks with crystalline silica present is likely leave nearby workers at high risk of contracting the disease.

There are three types of silicosis, depending on the level and duration of exposure. These are (National Center for Biotechnology Information, 2011b):

- Simple chronic silicosis – from small concentrations over long periods (20+ years)
- Accelerated silicosis – from higher concentrations over mid-range periods (5-15 years)
- Acute silicosis – from extremely high exposure over very short periods.

Progressive fibrosis (scarring of lung tissue) is most common in accelerated silicosis, but is also likely from the simple chronic form. Once fibrosis has been established, it is irreversible (Murray et al, 2010). Treatment can only slow the progression, so exposure should be prevented wherever possible. Silicosis has also been linked to a range of other lung disorders (American Thoracic Society, 1997; Patel, 2009). Tuberculosis, a contagious lung infection, has been strongly linked to silica exposure, with reports of tuberculosis being from 2 to 30 times more common in silica exposed workers (Cowie, 1994; Sherson & Lander, 1990). The International Agency for Research in Cancer has listed silica as carcinogenic to humans, but some authors claim high smoking rates amongst workers would have affected previous findings (International Agency for Research in Cancer, 1996; Wong, 2002; Pelucchi et al. 2006). Some non-lung diseases, such as rheumatoid arthritis and renal disease have also been associated with silicosis (American Thoracic Society, 1997). It has been suggested that clay dust can also cause fibrosis, but usually requires long-term exposure to have serious effects (Encyclopædia Britannica 2011). Kaolin, or china clay, has been the subject of numerous studies on the issue, with links identified as early as 1948 (United Nations Environment Programme, 2005; Sheers, 1989).

Altekruse et al (1984) studied the level of kaolin dust exposure with the prevalence of fibrosis, and took the effect of smoking into account. They found that pneumoconiosis only occurred amongst workers who were exposed to the highest levels of kaolin dust, and that the effects of kaolin pneumoconiosis were minimal.

A survey of 70% of china clay workers in the United Kingdom by Rundle et al (1993) concluded that only under long-term exposure (~42 years) at the most dusty of common exposure levels would kaolin cause severe fibrosis.

1.3 The situation in India

Despite defined standards in India, the lack of enforcement and education about the dangers of respirable dust means that many people work and live in highly dangerous conditions. Sivacoumar et al (2006) found that the total suspended particulate concentration on these sites can be as high as 1.706 mg/m^3. The families of workers often live on or near the worksite, so women and children are also exposed to high levels of potentially dangerous airborne dust.

It has been shown (Bhawan, 2009; Lahiri et al, 2005) that the most cost effective way to address dust exposure is by implementing engineering controls which trap and collect dust at its source. To prevent the dust which does become airborne from harming workers' lungs, Australian and International standards state that respiratory protective devices (RPDs) should be used as an important last resort against airborne contaminants (Joint Australia/New Zealand Standards Committee, 2009; International Organization for Standardization, 2010). Most workers in India do not usually wear any form of face mask, while others drape silk or cotton scarves around their faces in an attempt to reduce irritation. Any benefit these scarves may provide is often counteracted by a poor facial seal – air flowing around the scarf will carry dust with it.

The prevalence of silicosis in India has not been accurately measured, and the consolidated number of diagnosed cases is simply not available (Srivastava & Fareed, 2009). However, various estimates have been made as to silicosis prevalence in particular industries or regions. Saini et al (1984) reported 20% prevalence amongst stone cutters in Kashmir, while Sethi & Kapoor (1982), and Gupta et al (1972) claimed higher nation-wide estimates within the stone-cutting industry: 25% and 30% respectively. The Indian National Institute of Occupational Health (NIOH) (1987) reported 22% prevalence of silicosis in stone quarry workers in 1987, and since 2002 have completed studies showing that the levels of silica in stone crushing workplaces were so high that only six months of work was sufficient to cause silicosis (Patel, 2009).

While accurate statistics are not readily available about overall prevalence of silicosis in India, there are many reports of deaths and illness from silicosis from across the country (Patel, 2009; Choudhury, 2010). According to Patel (2009), every state in India has reported cases of silicosis. He also claimed that in one village, every second quarry worker was reported to have symptoms of silicosis or tuberculosis, and 60% of beds in a hospital in Guntur, an industrial stone-crushing city, were occupied by silicosis affected patients.

Compounding the problem in India is that silicosis is often misdiagnosed as tuberculosis (Choudhury, 2010). Doctors prescribe antibiotics and send people home, where their condition deteriorates and may lead to death.

It is clear that dust suppression and filtering technologies are desperately needed to improve the health of workers in India and protect them from this potentially fatal lung disease.

This work was conducted in conjunction with Kristen

Wood, a volunteer with Engineers Without Borders, working with Santulan, an NGO based in the Indian state of Maharashtra. The work was designed to improve the occupational health and safety of workers in quarry sites. This work aims to address the lack of RPDs at these sites by investigating the filtration properties of fabrics readily and affordably available in the region. The parameters for the experiment were chosen with respect to a case study site in Pune, Maharashtra.

Results were limited by the precision of measurement equipment, leading to potentially high percentage error in returned values. Multiple measurements were taken to minimise this error where possible.

2 METHODOLOGY

Modified versions of standard RPD tests were run which closely matched the typical conditions in Indian quarries. A vacuum pump was used to pull air from a dusty environment through the test fabrics. This dusty environment was contained within a box with a circulation fan to keep the dust suspended, and samples were mounted inside the box, over a port to the vacuum equipment. Various pieces of measuring equipment were connected between the vacuum pump and the sample to measure its performance and control the rate of flow. These included a valve, vacuum gauge, flow meter and a secondary filter. The secondary filter consisted of 20 g of glass beads, housed within tubing adapters.

Dusty air was passed through each of the eight test fabrics at 100 L/min for two minutes. Three commercial-grade respirators were also tested for comparison. The mass of the samples and secondary filter before and after the test was measured, as was the change in flow as dust accumulated on the samples. The ratio of penetrating dust to total dust captured was calculated to evaluate the efficiency of the samples.

Initially, two layers of fabric were used in each of the tests, oriented so that the fibres were orientated at 45° to each other. Based on the results of these tests, samples with four layers of a loose weave fabric were also tested, as well as a sandwich structure of two loose weave layers enclosed between two medium weave layers. One gram of dust was used in each test, placed within the dust box with inner dimensions of 306 x 276 x 306 mm.

Both the dust and test fabrics were taken from the quarry Wood was working at, according to what was readily available in the region. In addition to the fabric testing, the dust sample was analysed by X-ray diffraction (Siemens 6000 X-ray Diffractometer) and scanning electron microscopy (Zeiss UltraPlus FE-SEM).

3 EVALUATION

The filtration efficiency tests showed that some fabrics would be certainly unsuitable for use as RPDs, but further tests may be required to determine if others may provide adequate substitutes for commercial-quality masks. As shown in figure 2, the penetration varied with the weave tightness, while the material and weave type did not seem to affect the filtration properties. While the tight weave fabrics filtered the dust reasonably effectively, their flow drop was very high. This indicated that they were quick to clog with dust, and if used as a mask would rapidly become very difficult to breathe through.

Based on its low flow drop value, the loose twill weave fabric was tested again, with four layers in each test. This had a much lower penetration value, whilst maintaining reasonable flow over the duration of the tests. The commercial-grade masks were typically made of a thick, loose weave material between two thin, tighter weave layers to hold this in place. The 'sandwich' design of two loose weave layers between two moderate weave layers was also

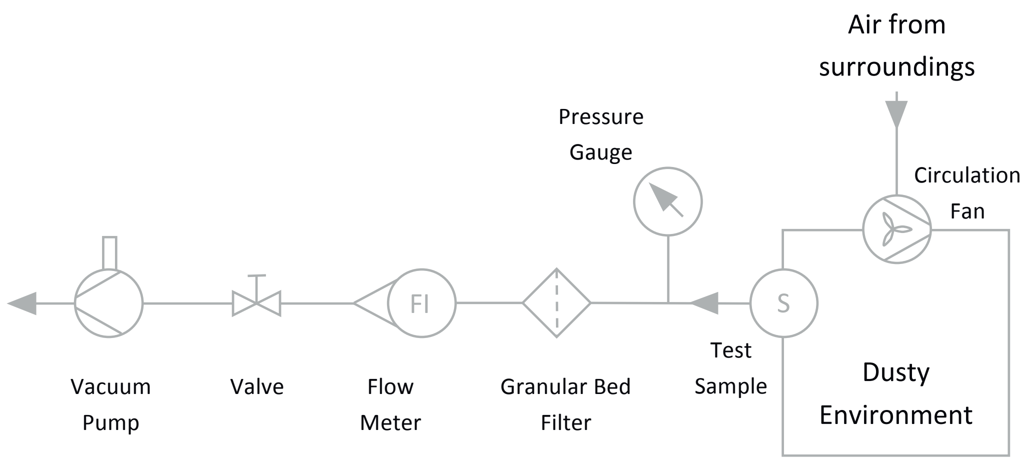

Figure 1: Piping and Instrumentation Diagram (P&ID) of setup.

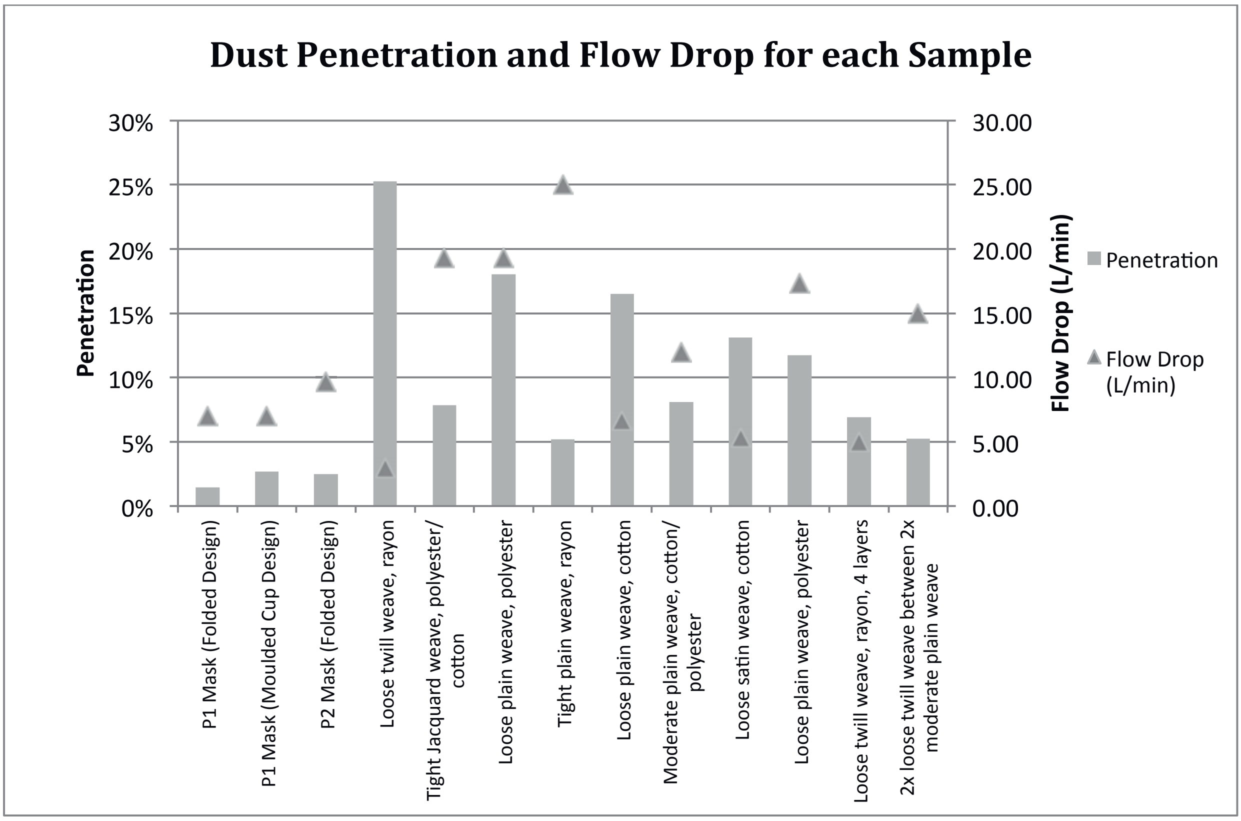

Figure 2: Penetration and flow drop of each sample.

tested in the hope of obtaining similar results. While the penetration value for this combination was quite good, the drop in flow was too high to be practicable.

Analysis of the dust sample indicated that there was no crystalline silica present, and that the material was likely to be a form of clay. This is likely to be relatively harmless to the human body at reasonable concentrations.

4 CONCLUSIONS

This work has shown that some fabrics would not be suitable for use in designing simple dust masks, while others may be found to be appropriate after additional testing.

Fabrics with tight weaves provided far too much breathing resistance when dirty, as dust filled small spaces between the fibres and obstructed air flow. Many layers of loose weave fabrics may provide similar efficiencies with less resistance, as alternative paths through the material will be available as others fill with dust. Loose fibres will also help bridge the gap between threads and improve the efficiency of the filter.

Similarly, cotton and other natural fibres may make better filters: the random curl of natural fibres may contribute to threads which are less dense, and also bridge gaps between each other, providing good filtration efficiency with minimal obstruction of air flow.

Simple water spraying or dust extraction systems may be sufficient for use at the case study site, with masks using the four-layer loose weave fabrics as a secondary measure. For use at sites with crystalline silica present in the dust, better performing masks would need to be identified.

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Development and commercialisation of rechargeable wooden LED lamps

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ABSTRACT: *The focus of this project was to work with local staff at Kathmandu Alternative Power and Energy Group to commercialise a product which would generate recurring income for the organisation, to enable staff to learn the process of commercialisation and to provide employment and skills in the local community. Rechargeable Light Emitting Diode (LED) lamps were deemed suitable for these aims, as they are a simple product, yet one that is urgently required in Nepal due to the prevalence of 'load-shedding' – scheduled electrical blackouts. After reviewing the market, it was found that it would be impossible to compete with the price of cheap imported Chinese rechargeable LED lamps, so an alternative approach was taken. This involved sourcing wooden off-cuts from a local furniture factory and transforming them into attractive desk lamps, with the target market being affluent Nepalis, ex-pats living in Nepal and tourists. Successful initial sales were achieved through a Kathmandu-based ex-pat email group, hotel-markets and souvenir stores. KAPEG staff have continued the project, producing variations on the initial design including Himalayan rock salt lamps, employing local people to manufacture lamps and selling them at markets in Kathmandu. Staffing and marketing challenges remain to ensure the lamp manufacture and sales continue.*

KEYWORDS: LED, lighting, lamp, commercialisation, Nepal.

1 INTRODUCTION

Kathmandu Alternative Power and Energy Group (KAPEG) is a small organisation located in a village near Dhulikhel, Nepal, which is striving to develop and commercialise alternative energy products which will help people in Nepal improve their access to electricity (Freere et al, 2008). KAPEG aims to keep the financial benefits from their work within Nepal by building products locally and developing a world-class professional Engineering team. KAPEG is set up as a company, owned by its staff, with a charter that states that any profits will be invested in the community.

KAPEG staff are all university educated with Engineering degrees, however there is a lack of commercialisation experience in the team – a skill which is vital if products such as wind turbines and micro-hydropower are to be a success. Additionally, KAPEG currently relies on funding from research grants – which typically are once off injections of funding, making it difficult to run the business long term. It was desired that alternative forms of recurring income be found. As part of EWB Australia's volunteer placement scheme, the author, who has over 8 years of product commercialisation experience, worked with the team at KAPEG for 5 months with the aim of imparting commercialisation skills and beginning the process of creating recurring revenue through commercialisation of a product. It was suggested that an LED lighting product warranted further investigation as a suitable candidate.

2 METHODOLOGY

Initially, research into the requirements for lighting in Nepal was performed. Along with access to safe drinking water and sanitation, access to lighting is one of the major development challenges facing Nepal (Sharma et al, 2005). Currently, villages with no electricity use kerosene lamps for lighting, which are expensive to run and cause respiratory and eye health problems (Sharma et al, 2005). There are currently several NGO-run projects to address these issues such as the Solar Tuki ("Lamp") project which aims to train local entrepreneurs to build and sell lamps (Sharma et al, 2005). Other projects include Light Up The World (LUTW) (Irvine-Halliday, 2000), which is now international but originally started in Nepal, and various individual NGO projects.

Figure 1: KAPEG head office (left) and prototype wind turbine (right).

In addition to requirements for villages with no access to electricity, there is the requirement for every household in Nepal to have battery powered lighting, as Nepal suffers from 'load-shedding' blackouts due to a shortage of electricity, which is predominantly provided by hydropower. Load-shedding means that the electricity is shared amongst different districts, meaning most households in Nepal have between 2 and 16 hours per day without electricity, depending on the time of year.

The above NGO-run projects made significant headway into the diffusion of solar lighting into villages in Nepal, however the cost of commercially available lighting products has now decreased markedly, meaning more people can access lighting without the need for NGO projects. Research into these other lamps consisted of visits to shops and markets in Kathmandu and Dhulikhel as well as visits to NGOs who have been working with LED lighting projects. LED is the lighting technology of choice due to its low power consumption and long bulb-life. It was found that a wide variety of rechargeable LED lamps were available, in varying qualities. It was readily apparent that it would be impossible to compete with most of these lamps on a price basis, as the cost of the components as purchased off-the shelf from electronic component stores in Kathmandu would be more than most of the cheap Chinese and Indian import lamps cost in total.

Example lamp costs included NRs 750 (A$8.84) for a good quality mains rechargeable LED lamp with 44 LEDs and a 6 V 4.2 Ah sealed lead acid battery (the same battery later used in the wooden desk lamps) running for 4 to 24 hours depending on mode. For NRs 150 (A$1.70), a smaller lamp was available that included a 4 V 0.6 Ah battery and charged directly from a normal 240 VAC light bulb socket, running for several hours. This was a very low quality lamp, but the price point was low.

Investigations were also conducted into electronic components available in Kathmandu in order to compare prices of components to the cost of lamps. Once again, the quality of components available

Figure 2 : Variety of lamps available in a store in Kathmandu (left) and a rechargeable lamp with 6 V 4.2 Ah SLA battery, 44 LEDs and integrated charger for NRs 750 (A$8.60).

Figure 3: Pile of wood off-cuts at Shaan Furniture (left) and the off-cut type ultimately chosen for the LED desk lamp.

varied widely, but on the whole components were of low quality. During this time, the beginnings of a database of electronic component shops and the good quality components they sold was collated. This database is now available on the KAPEG website (www.kapeg.com.np) and anyone is able to submit new information to it via email.

In light of the above research, it was decided that it would be too difficult to compete directly with low cost commercial LED lighting products, meaning an alternative approach was required. One of Nepal's largest furniture factories, Shaan Furniture, is located in Banepa, close to the KAPEG office. KAPEG has an ongoing engineering consulting arrangement with Shaan Furniture and has worked with the owner in various ways including solar wood drying and repair of electrical equipment.

Investigations were undertaken into the wood off-cuts available at the furniture factory. It was found that there were numerous amounts of off-cuts, currently chipped and burned as part of the wood treatment process. It was thought that a some of the off-cuts which were of a particular shape, were large enough and suitably shaped to be shaped into LED lamps. A wooden LED lamp would be a unique product, could potentially be significantly more attractive than plastic equivalents and could potentially fetch a higher price.

Design of the lamps was then conducted, focussing on making the lamps look attractive. Large amounts of time spent on shaping would were needed to achieve this. Electronic design was kept very simple. Volt, 4.2 Ah batteries were used and were charged using simple resistor charging circuits. LEDs were driven with simple resistor current limiting as opposed to more complex constant current designs. An LED was included to confirm that the lamp was charging.

Figure 4: Lamp design mocked up in Google Sketchup (left) and a sanding wheel fashioned out of bolt, sandpaper and a piece of wood (right).

Figure 5: Finished prototype lamp. These photos were emailed out to market the lamps initially.

Several prototype lamps were constructed. Challenges at this point included difficulties shaping the wood with very limited tools and also coping with load-shedding, meaning electricity for power tools was only available for a few hours per day. Obtaining high quality tools and components is difficult in Nepal meaning that tools often and easily break, causing delays and extra costs.

The final lamp runs for around 20 hours, providing enough light to read by and ambient light to light an entire average room. The selling price was set at NRs 2500 (A$28.64) – a high price compared to other plastic lamps available, but comparable to wooden souvenirs available in souvenir stores in Kathmandu.

3 HIMALAYAN ROCK SALT LAMPS

Additionally, lamps were developed that used wood off-cuts as the base, with 1 to 2 LEDs shining up into a piece of Himalayan rock salt. This salt is available in various colours at many Nepali markets in Kathmandu, and the result is a very attractive lamp which provides some ambiance in a dark room. Small batteries were included inside the lamps and standard Nokia-brand mobile phone chargers used to charge the lamps.

4 MARKETING

The target market for the LED desk lamp was affluent Nepalese, ex-pats living in Nepal and tourists. Initial test marketing of the lamps was performed via email to a Kathmandu email list which is commonly used by many ex-pats to share information about events and general advice on living in Kathmandu. Additionally, an online order form was set up on the KAPEG website using Google Forms / Google Documents.

Initial response was extremely positive, with orders for around 12 desk lamps and 6 salt lamps being taken – an ideal amount for an initial small batch. These initial orders were manufactured mainly by the author's counterpart at KAPEG, a recent engineering graduate. Once manufactured and tested, they were hand-delivered to the customers, with most customers being happy with the lamps according to initial feedback. There was some negative feedback based around the plaque on the back of the desk lamps, which presents a difficult challenge as the plaque is actually placed to cover electronics in the lamps. In later versions, a plain plaque with no branding was used on some lamps to minimise unsightliness.

It was around this stage that the author finished his volunteer placement in Nepal and returned to Australia, however communications continued via email and it was necessary to conduct some remote project management to ensure timely delivery of lamps. This was made possible with the use of Google Documents as a tool for managing orders. This approach however has not since been continued by KAPEG staff.

Figure 6 : Initial prototype Himalayan Rock Salt lamps.

Several souvenir shops in Kathmandu were visited, and most expressed interest in stocking the lamps on consignment. There are several markets in Kathmandu which Western ex-pat frequent. One of these is the weekly markets at Summit Hotel at which a stall was set up to sell the lamps.

5 CONCLUSION AND EVALUATION

Since the author's departure from Nepal, work on the LED lamps has continued, although at a reduced pace. This is due to various issues, including turnover of staff at KAPEG and the ongoing problem of KAPEG being committed to many projects.

It remains to be seen whether the LED lamps become a profitable product for KAPEG, due to the issues listed above. However, several local high school students have been employed part time shaping the wood for the lamps and KAPEG staff have continued to occasionally sell lamps at markets in Kathmandu. Several souvenir stores in Kathmandu have sample stock on their shelves. In order for the lamps to be profitable, it would be necessary for them to be completely manufactured by local people rather than KAPEG Engineers due to different pay rates.

Over the past 12 months, KAPEG staff have developed several variations on the lamp design based on different wood off-cuts and feedback from customers. Enquiries have been received from overseas as to the possibility of exporting the lamps, but this is probably too difficult to achieve at this stage. Based on the positive feedback gained in Australia on the lamps that the author brought back with him, an export market may be viable at some point.

While it is true that these LED lamps are not contributing directly to remote villages in Nepal, they have the potential to achieve the original aims of the project, which were to build commercialisation experience within the KAPEG team and to provide a recurring income to the organisation. Additional benefits include the re-use of wood that would otherwise be discarded, the provision of jobs and training to villagers who live near the KAPEG office and the beginnings of a new industry in Dhulikhel.

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Figure 7 : KAPEG staff selling LED lamps at the Summit Hotel markets in Kathmandu markets (left) and a variation on the desk lamps, developed recently (right).

Limits of grid extension in the Lao PDR: A financial perspective

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ABSTRACT: *This paper articulates a financial model for estimating the limits of grid extension in the Lao PDR versus three decentralised renewable energy (DRE) options: micro-hydropower, pico-hydropower and solar photovoltaic. The model is based on a like-for-like comparison of the different DRE options against grid extension, such that each option supplies the same amount of electricity (in kWh) over the project timeframe. The amount of electricity supplied is estimated based on the forecast electricity demand of a typical rural Lao household. Therefore, if a household consumes 7 kWh per day, then the micro-hydro, pico-hydro, solar PV and grid extension systems are all sized in the model to supply 7 kWh per day. This is in contrast to more conventional approaches, where grid extension is compared to DRE systems of typically lower capacities (e.g. grid extension compared against 50 W solar home systems). The limits of grid extension are expressed in terms of a breakeven distance, which is the maximum distance from a village at which grid extension is the more cost-effective option. Beyond this breakeven distance, DRE technologies can be installed at a lower cost, while providing the same amount of electricity to the end-use*

KEYWORDS: Rural electrification, grid extension, distributed renewable energy, Lao PDR.

1 INTRODUCTION

The Lao PDR is a small landlocked country in Southeast Asia that is considered by the United Nations to be among the least developed countries. As part of a bid to graduate to developing country status, the Lao government has set an ambitious target to provide 90% of households with electricity by 2020. Starting from a low base of around 15% in 1995, the electrification rate has improved considerably, rising to a rate of 73% in 2010 (EdL, 2011).

Throughout this period, the majority of new electricity connections were made via extension of the existing grid. This was reasonably cost-effective for connecting denser population centres, but this may not continue to be the most efficient option given that a large proportion of the remaining unelectrified households are located in the remote, less dense parts of the country. Depending on the remoteness of an unelectrified village, the costs of grid extension may be prohibitive and off-grid distributed renewable energy (DRE) sources may be a more economical option.

This paper presents a financial framework for analysing grid and off-grid electricity options for unelectrified villages in the Lao PDR, with the aim of investigating the limits to grid extension. A financial model is constructed, firstly taking into account electricity demand and then the costs of grid extension and three DRE technologies – micro-hydro, pico-hydro and solar photovoltaic systems. The limits of grid extension are then derived by calculating the "breakeven distance", defined here as the maximum distance from an unelectrified village at which grid extension is the more cost-effective option. The results of the analysis for the three DRE technologies are then presented, followed by a discussion of the model limitations and then finally some concluding remarks.

2 BASELINE ELECTRICITY DEMAND

The major difficulty with comparing grid and off-grid electricity options is the fact that a grid supply has the potential capacity to deliver a significantly higher power output to end-users (notwithstanding the technical issues associated with voltage support at the end of long lines). Therefore, in order for the comparisons to be valid, the same electricity demand data will be used for the analysis of both grid and off-grid options.

The electricity demand is based on estimates of average household electricity demand in the Lao PDR. The total electricity demand for a village is then calculated by multiplying the household estimate by the number of households in the village. Three baseline electricity demand scenarios will be analysed – low, medium and high scenarios – to cover a range of possibilities in electricity demand.

2.1 Household electricity demand estimates

For this study, three baseline electricity demand scenarios are constructed based on the estimated average household demand for grid electricity in 2008 as per the Renewable Energy Master Plan (REMP) Vol 1 Part A Section 9.3.2 (Nippon Koei, 2010), and an additional estimate for very remote villages.

Note that the electricity demands shown in table 1 include an allowance of 30% for non-household demand.

Table 1: Average household electricity demand estimates for the north, south and remote regions of the Lao PDR.

Scenario	Demand (kWh/ month/hh)	Remarks
North	39	Average of rural northern provinces
South	78	Average of rural southern provinces
Remote	13	Estimate for remote villages

2.2 Growth rates in electricity demand

Household electricity demand has risen steadily in the Lao PDR over the last 20 years and it is expected that demand will continue to grow into the future. The financial model will make allowances for the growth rates in electricity demand as shown in table 2.

The sizing of equipment will be based on the prospective demand at the end of the project lifetime (e.g. 2030 for the 20 year timeframe).

Table 2: Demand growth rates.

Time Period	Growth Rate	Remarks
Present – 2020	5%	Based on EdL estimates in the PDP (EdL, 2010)
2020 onward	4%	Based on REMP Vol 1 Part A Table 9.3.1

2.3 Load Profiles

The literature on the load profiles of rural villages (Fall et al, 2007; Cross & Gaunt, 2003; Ketjoy, 2005), particularly in sub-tropical Asian regions, suggest an average daily load profile with two major peaks – the first in the morning between 5 and 9 am and the second in the evening between 6 and 9 pm. The approximate daily load profile model (figure 1) is used in this study (note that the load profile is expressed in per unit quantities where 1.0 pu is the peak load).

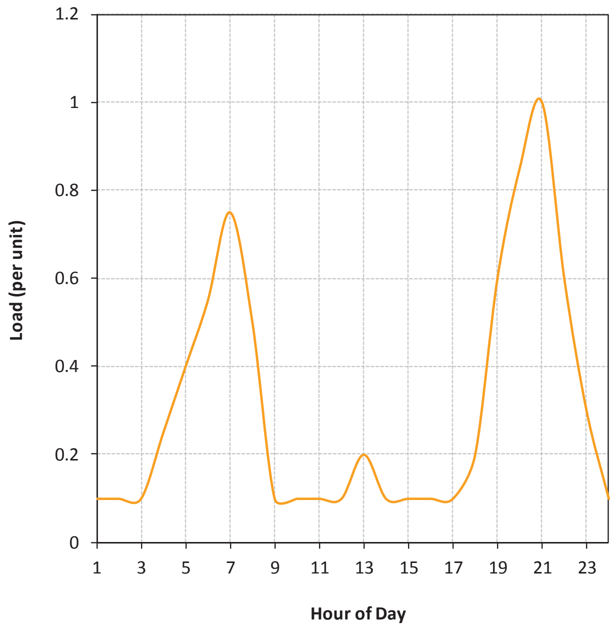

Figure 1: Approximate daily load profile model.

The approximate load profile above is intended to estimate the peak loading (in kW) for a typical household, which will be used later for the sizing of micro- and pico- hydro systems.

To calculate the peak loading (in kW) given a daily electricity demand (in kWh/day), the daily demand is fitted to the approximate load profile, such that the area under the curve is equal to the daily demand. The peak loading is the load of the fitted curve at approximately 9 pm.

3 COSTS OF GRID EXTENSION

The Levelised Cost of Electricity (LCOE) for grid extension is estimated by the following formula (LIRE, 2011):

$$LCOE = LRMC + \frac{CAPEX + O\&M}{E} \quad (1)$$

Where *LCOE* is the levelised cost of electricity (USD/kWh)

LRMC is the long run marginal cost of electricity (USD/kWh)

CAPEX is the capital cost for the grid extension, which includes the costs for MV transmission lines, distribution transformers and the LV distribution system (USD)

O&M is the operations and maintenance cost over the lifetime of the project, expressed as a net present value (USD)

E is the useful energy output of the grid extension over the lifetime of the project (kWh), based on the baseline electricity demand estimates developed earlier.

3.1 Long run marginal cost

The long run marginal cost (LRMC) of electricity is the incremental cost of generating an additional 1 kWh. The LRMC is typically composed of two constituent parts – 1) the marginal cost of additional generation capacity, and 2) the marginal cost of fuel / energy. Note that the LRMC reflects the cost borne by the producer to generate an additional 1kWh, not the cost imposed on the end-user.

Table 3: Weighted average cost of past projects.

Facility Name	Capacity (MW)	Capital Cost (millions USD)	Cost per kW (USD)
Se Xet I	45	42	933
Nam Ko	1.5	9.8	6,533
Nam Leuk	60	112.6	1,877
Nam Mang III	40	63	1,575
WEIGHTED AVERAGE			1,552

In this study, the LRMC is based on the cost of additional generation capacity through large hydropower (by far the most common source of electricity in the Lao PDR), which has a negligible marginal cost of fuel. Because a significant number of large hydropower projects are intended for export, only the facilities that are for domestic use are considered in this study.

As a proxy for the capital cost per kW for new hydropower capacity in the Lao PDR, the weighted average cost of past projects (intended for domestic supply) is used. Ideally, the LRMC would be based only on the capital costs of the newest projects, but doing so would result in too few data points.

The estimate of the LRMC is calculated as shown in table 4 below.

The annual O&M costs are estimated based on values suggested by Goldsmith (1993) and the utilisation factor and T&D losses are based on the EdL 2010 statistical yearbook (EdL, 2011).

It should be noted that for any sensitivity analysis, the maximum LRMC shall be capped at around US$ 0.0496/kW, which is the average price of electricity imports from neighbouring countries (EdL, 2011). The cost of producing electricity domestically cannot be higher than the import price, otherwise it would be more cost-effective to import electricity rather than generate it domestically at higher cost.

3.2 Grid extension capitalcost

In this paper, the capital costs of grid extension to an unelectrified village are based on a 12.7 kV Single Wire Earth Return (SWER) line, one of the most common and cheapest types of grid extension to remote, low density areas. The costs are based on the figures in the REMP Study Table 9.2.1 (Nippon Koei, 2010) and summarised as shown in table 5.

Table 4: Estimate of long run marginal cost (LRMC) of electricity.

Assumptions		
Capital Cost	$1,552	USD/kW
Lifetime	20	Years
Annual Operations and Maintenance (O&M) Costs	1.5%	of capital cost
Utilisation Factor	0.7	Pu
Transmission and Distribution (T&D) Losses	15%	
Calculation		
Annual Production	6,132	kWh per kW
Annual O&M Costs	$113.70	USD/kW
NPV of O&M Costs (over power plant lifetime)	$1,116.32	USD/kW
NPV of Total Cost	$1,874.32	USD/kW
Estimated LRMC (without losses)	$0.01452	USD/kWh
Estimated LRMC (with losses)	$0.01670	USD/kWh

Table 5: Summary of single wire earth return (SWER) costs.

Component	Cost (USD)	Unit
12.7 kV SWER	18,544	Per km
12.7/0.4 kV single phase distribution transformer	113	Per household
0.4 kV distribution costs	369	Per household

The overall capital costs for grid extension can be expressed as a linear equation depending on the length of the grid extension (*L*) and the number of households (*H*):

$$CAPEX = 18{,}544\times L + 482\times H \tag{2}$$

3.3 Operations and maintenance costs

The annual operations and maintenance (O&M) costs are estimated to be 2% of the capital costs, as suggested by the REMP study (Nippon Koei, 2010). Over the lifetime of the project, the NPV of the O&M costs is calculated as follows:

$$O\&M_{NPV} = \frac{0.02\times CAPEX}{r}\left[1-(1+r)^{-n}\right] \tag{3}$$

3.4 Total cost of grid extension

Putting the CAPEX and O&M costs together, the total cost of the grid extension (CAPEX + O&M) can be expressed as a linear equation of the form:

$$Cost_{grid} = a_1 L + a_2 H \tag{4}$$

Where L is the distance of the grid extension (km)

H is the number of households in the village

a_1 is the coefficient of the grid extension corresponding to the distance (= US$ 22,185/km)

a_2 is the coefficient of the grid extension corresponding to number of households (= US$577/hh).

4 COSTS OF MICRO-HYDROPOWER

The Levelised Cost of Electricity (LCOE) for micro-hydro is estimated by the following formula:

$$LCOE = \frac{CAPEX + O\&M + R}{E} \tag{5}$$

Where *LCOE* is the levelised cost of electricity (USD/kWh)

CAPEX is the capital cost (installed) of the micro-hydro facility (USD)

O&M is the operations and maintenance cost over the lifetime of the project, expressed as an NPV (USD)

R is the replacement cost, expressed as an NPV (USD)

E is the useful energy output of the grid extension over the lifetime of the project (kWh), based on the baseline electricity demand estimates developed earlier.

4.1 Micro-hydro system sizing

The sizing of a village micro-hydro system is based on the peak load demand of the village, and is computed as follows:

1. *Calculate peak household load demand*

   The household electricity demand at the end of life (in kWh) is used in conjunction with the typical household load profile in order to estimate the peak household load demand (in kW).

2. *Calculate peak load demand of village*

   The peak load demand of the village can be estimated by multiplying the peak household load demand with the number of households in the village. In addition, a design allowance (typically 25%) is added to obtain the final micro-hydro system size (in kW). The design allowance captures inaccuracies in estimating the loads and a higher allowance can be used for more conservative estimates.

For example, suppose there is a village with 65 households and each household consumes 39 kWh per month. The daily household consumption is

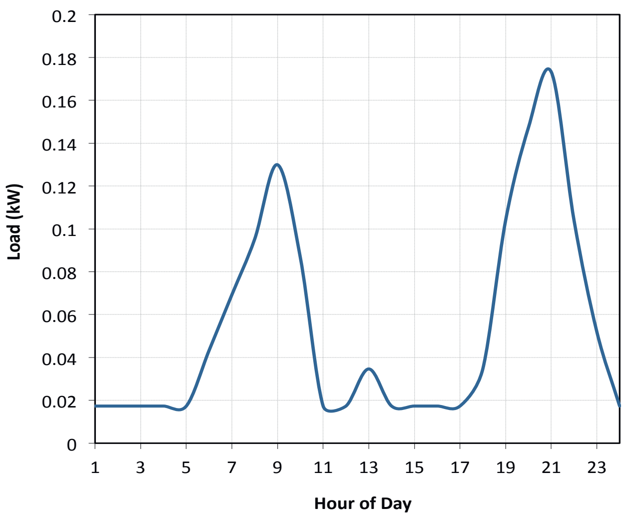

Figure 2: Daily household electricity consumption load profile.

1.282 kWh. Fitting this daily consumption onto the typical load profile, we get the load profile for each household as shown in figure 2.

From the load profile, we can see that the peak household load demand is 0.173 kW at 9 pm. Multiplying by the total number of households, we get a peak village load demand of 65 x 0.173 = 11.245 kW.

Applying the design allowance of 25%, we get a final design size of 11.245 x 125% = 14.06 kW. This is the size of the system that will be used in the subsequent cost calculations.

4.2 Micro-hydro capital costs

The capital costs of micro-hydro facilities are site specific and can be highly variable. However, a number of sources in the literature (Greacen, 2004; World Bank, 2006; IEA, 2005; Dhungel, 2009; Vaidya, 2002) estimate that the capital costs typically fall in the range of US$1,500 to US$4,500 per installed kW (adjusted to 2011 US Dollars), with a mean cost of US$2,500/kW.

For this study, capital cost estimates are applied as shown in table 6.

The capital cost estimates above are total installed costs which include the micro-hydro system itself, civil works, transmission lines, transformers, low voltage distribution grid in the village and household connections and wiring.

Table 6: Micro-hydro capital cost estimates.

Estimate Type	Capital Cost (USD/kW)
Probable	2,500
Low	1,500
High	4,500

The capital cost estimates above are total installed costs which include the micro-hydro system itself, civil works, transmission lines, transformers, low voltage distribution grid in the village and household connections and wiring.

4.3 Micro-hydro operations and maintenance costs

From the literature (Greacen, 2004; World Bank, 2006; IEA, 2005; Dhungel, 2009; Vaidya, 2002), annual operations and maintenance costs are estimated to be in the range of 10 to 15% of the CAPEX. For the base financial model, 15% is used. Over the lifetime of the project, the NPV of the O&M costs is calculated as follows:

$$O\&M_{NPV} = \frac{0.15 \times CAPEX}{r}[1-(1+r)^{-n}] \quad (6)$$

4.4 Micro-hydro replacement costs

It is assumed that over the 20 year lifetime of the project, no major equipment replacements are required and that the O&M costs cover the costs of any replacement parts required.

4.5 Total cost of micro-hydro

Putting the CAPEX and O&M costs together, the total cost of micro-hydro (CAPEX + O&M) can be expressed as a linear equation of the form:

$$Cost_{micro} = b_1 H \quad (7)$$

where *H* is the number of households in the village

b_1 is the cost coefficient of the micro-hydro system (USD).

5 COSTS OF PICO-HYDROPOWER

The Levelised Cost of Electricity (LCOE) for pico-hydro is estimated by the following formula:

$$LCOE = \frac{CAPEX + O\&M + R}{E} \quad (8)$$

where *LCOE* is the levelised cost of electricity (USD/kWh)

CAPEX is the capital cost (installed) of the pico-hydro system (USD)

O&M is the operations and maintenance cost over the lifetime of the project, expressed as an NPV (USD)

R is the replacement cost, expressed as an NPV (USD)

E is the useful energy output of the grid extension over the lifetime of the project (kWh), based on the baseline electricity demand estimates developed earlier.

5.1 Pico-hydro system sizing

Pico-hydro systems are sized in the same manner as micro-hydro systems (see the previous section for more details on the sizing methodology).

5.2 Pico-hydro capital costs

The capital costs of a pico-hydro system is based on a 1kW turbine with an electronic load controller, draft tube and draft channel. The low cost estimates are based on generic equipment (e.g. brandless Chinese

Table 7: Pico-hydro capital cost estimates based on a 1kW turbine of various builds.

Equipment Item	Probable (USD/kW)	Low (USD/kW)	High (USD/kW)
Pico-hydro turbine	400	150	750
Draft tube and channel	200	0	300
Electronic load controller	150	50	200
TOTAL	750	200	1250

Table 8: Low voltage cable cost estimates.

Equipment Item	Probable (USD/hh)	Low (USD/hh)	High (USD/hh)
LV distribution cables	120	70	150
Household wiring	80	30	150
TOTAL	200	100	300

or Vietnamese made turbines), while the high cost estimates are based on quotes from Hydrotec Vietnam received in March 2010.

No labour costs have been allowed for since it is assumed that the pico-hydro system is self-constructed by the village.

In addition to the cost of the pico-hydro turbine system, the costs for low voltage cables from the installation site to the end-users and household wiring (per household) are estimated as shown in table 8.

5.3 Pico-hydro operations and maintenance costs

O&M costs associated with pico-hydro systems include turbine bearing and winding replacements, oiling of the bearings and basic electrical maintenance associated with the distribution equipment.

For the base financial model, it is assumed that the annual O&M costs for pico-hydro are 10% of the capital costs. Over the lifetime of the project, the NPV of the O&M costs is calculated as follows:

$$O\&M_{NPV} = \frac{0.10 \times CAPEX}{r}\left[1-(1+r)^{-n}\right] \tag{9}$$

5.4 Pico-hydro replacement costs

It is assumed that 75% of the capital cost needs to be replaced every 5 years, and this cost is spread over the period, i.e. the annual replacement cost is 15% of the capital cost. Over the lifetime of the project, the NPV of the replacement costs is calculated as follows:

$$R_{NPV} = \frac{0.15 \times CAPEX}{r}\left[1-(1+r)^{-n}\right] \tag{10}$$

5.5 Total cost of pico-hydro

Putting the CAPEX, O&M and replacement costs together, the total cost of pico-hydro (CAPEX + O&M + R) can be expressed as a linear equation of the form:

$$Cost_{pico} = b_1 H \tag{11}$$

Where H is the number of households in the village

b_1 is the cost coefficient of the pico-hydro system (USD).

6 COSTS OF SOLAR PHOTOVOLTAIC SYSTEMS

The Levelised Cost of Electricity (LCOE) for solar PV systems is estimated by the following formula:

$$LCOE = \frac{CAPEX + O\&M + R}{E} \tag{12}$$

where *LCOE* is the levelised cost of electricity (USD/kWh)

CAPEX is the capital cost (installed) of the solar PV system (USD)

O&M is the operations and maintenance cost over the lifetime of the project, expressed as an NPV (USD)

R is the replacement cost, expressed as an NPV (USD)

E is the useful energy output of the grid extension over the lifetime of the project (kWh), based on the baseline electricity demand estimates developed earlier.

6.1 Solar PV system sizing

Based on the approximate load profile developed earlier and modelling in HOMER software, a system capable of producing 1kWh per day in the Lao PDR has the following components:

- 3 x 120 W solar PV array
- 12 V 630 Ah battery
- Solar charge controller.

To simplify the calculations, it is assumed that this system above can be scaled linearly to supply arbitrary electricity demands. For example, to supply 7 kWh per day, 7 of the 1 kWh systems above are required.

6.2 Solar PV capital costs

The capital costs for a 1 kWh /day system described above are estimated based on standard trade prices for solar PV hardware (as at November 2011) as shown in table 9.

In addition to the solar PV generation equipment, the cost for low voltage distribution equipment (per household) is estimated as shown in table 10.

6.3 Solar PV operations and maintenance costs

O&M costs associated with solar PV systems include cleaning the PV arrays, refilling the batteries with distilled water and regularly performing a battery equalisation charge.

For the base financial model, it is assumed that the annual O&M costs for solar PV are 2% of the capital costs. Over the lifetime of the project, the NPV of the O&M costs is calculated as follows:

$$O\&M_{NPV} = \frac{0.02 \times CAPEX}{r}\left[1-(1+r)^{-n}\right] \tag{13}$$

6.4 Solar PV replacement costs

The solar PV arrays and controllers are typically designed to last for the project lifetime of 20 years. Batteries can last between 4 to 10 years and will need to be replaced periodically.

It is assumed that 50% of the capital cost needs to be replaced every 10 years, and this cost is spread over the period, i.e. the annual replacement cost is 5% of the capital cost. Over the lifetime of the project, the NPV of the replacement costs is calculated as follows:

$$O\&M_{NPV} = \frac{0.02 \times CAPEX}{r}\left[1-(1+r)^{-n}\right] \tag{14}$$

6.5 Total cost of solar PV

Putting the CAPEX, O&M and replacement costs together, the total cost of solar PV (CAPEX + O&M + R) can be expressed as a linear equation of the form:

$$Cost_{solar} = b_1 H \tag{15}$$

where H is the number of households in the village

b_1 is the cost coefficient of the pico-hydro system (USD).

7 BREAKEVEN DISTANCE ANALYSIS

The breakeven distance is the distance (in km) away from a village at which the cost of grid extension equals the cost of a DRE system (i.e. there would be different breakeven distances for micro-hydro, pico-hydro and solar PV).

Using the financial model articulated in this report, the breakeven distance can be calculated as a simple linear equation in terms of the number of households

Table 9: Solar PV capital cost estimates.

Equipment Item	Probable (USD/System)	Low (USD/System)	High (USD/System)
3 x 120 W solar PV array	1,050	900	1,500
12 V 630 Ah battery	1,800	1,350	2,340
Solar charge controller	50	30	90
TOTAL	2,900	2,280	3,930

Table 10: Low voltage distribution cost estimates.

Equipment Item	Probable (USD/hh)	Low (USD/hh)	High (USD/hh)
1500 W Inverter	150	60	250
Household wiring	80	30	150
TOTAL	230	90	400

in a village. In this section, the expression for the breakeven distance is derived, and then the results of the breakeven analysis are presented.

7.1 Derivation of breakeven distance

The cost models developed for grid extension and DRE technologies (micro-hydro, pico-hydro and solar PV) are linear and can be expressed as follows:

For Grid Extension:

$$LCOE_{grid} = LRMC + \frac{a_1 L + a_2 H}{E} \tag{16}$$

For DRE technologies:

$$LCOE_{DRE} = \frac{b_1 H}{E} \tag{17}$$

where L is the distance of grid extension (km)

H is the number of households in the village

E is the forecast household electricity demand at the end of the study period (kWh)

a_1 is the coefficient of the grid extension corresponding to the distance (USD)

a_2 is the coefficient of the grid extension corresponding to number of households (USD)

$LRMC$ is the long run marginal cost of generation capacity (USD)

b_1 is the coefficient of the distributed renewable energy source (USD).

From the equations above, the breakeven distance between grid extension and a DRE system can be solved analytically as follows:

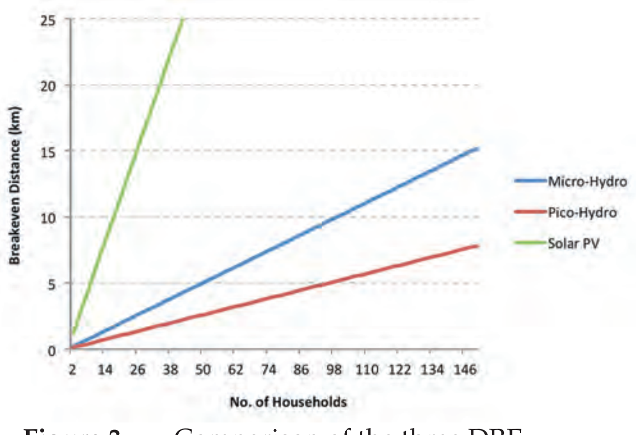

Figure 3: Comparison of the three DRE technologies compared with a 12.7 kV SWER line grid extension for a village in the northern provinces.

$$L_{breakeven} = \frac{(b_1 - a_2 - LRMC \times E)}{a_1} H \tag{18}$$

At this distance, the total cost of grid extension is equal to the total cost of the DRE system. Therefore, the following two inferences can be made, if:

- Distance of grid extension > breakeven distance, then the DRE system is the cheaper option
- Distance of grid extension < breakeven distance, then the grid extension is the cheaper option

7.2 Analysis of breakeven distances

Using the base parameters developed earlier in this paper, the breakeven distances for the DRE technologies (compared with grid extension) are computed for a range of household sizes. A project timescale of 20 years and a discount rate of 8% were used for the calculations.

Figure 3 shows a comparison of the three DRE technologies compared with a 12.7 kV SWER line grid extension for a village with 0 to 150 households in the northern province. The breakeven distances on the graph are calculated for the electricity demand expected in the northern provinces and the most probable cost estimate (which is neither optimistic or pessimistic).

Similarly, the breakeven distances for a village in the southern provinces is shown in figure 4.

As a general rule for comparison, a breakeven distance of 20 km is the threshold for the majority of grid extensions, i.e. with the exception of several of the more remote districts, most of the presently unelectrified villages are within 20 km of a grid supply.

It is evident that solar PV is not cost-competitive against grid extension (except for tiny villages of < 15 households in the south and < 30 households in the north). Even taking into account more optimistic electricity demand and capital cost scenarios, solar PV is still not an attractive alternative to grid extension. However, it must be remembered that these are judgements based on like-for-like comparisons and lower capacity solar PV systems (like solar home systems) could represent a more attractive option. After all, one would likely opt for a lower capacity system given the choice between it and no electricity at all.

Pico-hydro is the most compelling option from a cost perspective, showing low breakeven distances (< 20 km) for the entire range of village sizes. The disadvantages of pico-hydro are more or less technical, particularly the availability of water resources and pico-hydro sites suitable to supply entire villages. Given a suitable water resource however, pico-hydro should be considered as a very cost-effective option in lieu of grid extension.

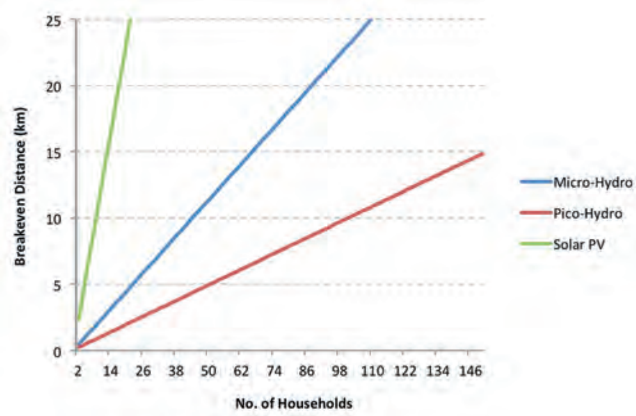

Figure 4: Breakeven distances for a village in the southern provinces.

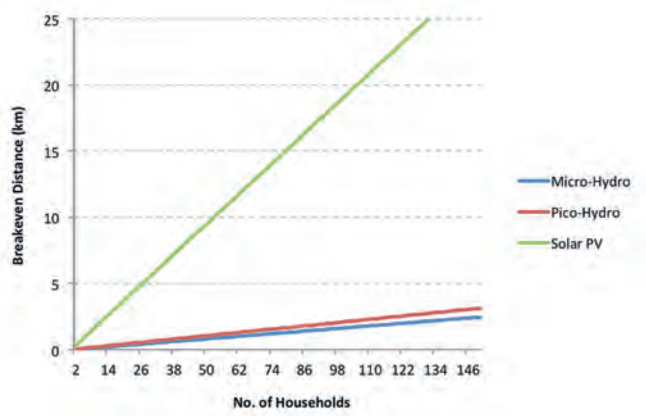

Figure 5: Breakeven distances for remote villages.

Micro-hydro also presents itself as a reasonable alternative to grid extension, especially for smaller villages of < 60 households. Provided that the right topography and water resource exists for a village scale system, micro-hydro can be cost-competitive against grid extensions and can typically be sized for a relatively high capacity.

The model was also run for a special demand scenario – very remote villages that are expected to use only minimal amounts of electricity (assumed to be 13 kWh/month per household). The breakeven distances for these remote villages are shown in figure 5.

Under these assumptions, all of the DRE technologies are cost-effective compared to grid extension.

7.3 Mapping breakeven distances

The use of GIS maps can provide a visual representation of breakeven distances. The following three maps show the breakeven distances for villages in Xiangkhuang province (in the centre-north of the Lao PDR) for the three DRE technologies – micro-hydro, pico-hydro and solar PV.

On the maps, the red dots and pink lines represent electrified villages and existing transmission lines respectively. The yellow crosses represent unelectrified villages and the yellow circles around them indicate the breakeven distances of the DRE technology against grid extension. Inside the yellow circle, grid extension is cheaper and outside the circle, the DRE technology is cheaper. Therefore, if a red dot (electrified village) or pink line (existing transmission line) falls within a yellow circle, then grid extension is the cheaper option for the village at the centre of the circle (yellow cross).

8 LIMITATIONS OF THE MODEL

The financial model proposed in this paper was conceived to compare grid extension and DRE technologies purely from a cost perspective. Therefore, there are aspects of the model that are not particularly realistic. The following inherent limitations need to be borne in mind when interpreting the outputs of the model.

Firstly, the model takes a simplified approach to system sizing that does not consider the technical limits of the DRE technologies. For example, it would be inconceivable to see a 60 household village with 65 kW of pico-hydro turbines installed, but that is precisely what the model would imply for the average electricity demand scenario. Furthermore, it is almost impossible to know a priori (without a pre-feasibility survey) if a village has the natural resources available for a particular DRE technology. The model simply assumes that they do.

Secondly, the costs of grid extension in the model is independent of electricity demand. This is a simplifying assumption, but a reasonable one given that network planners would typically size the grid extension for a far higher rating than would be consumed by end-users.

Thirdly, the costing models for the DRE technologies (micro-hydro, pico-hydro and solar PV) are all linear. That is, the price per kW (or kWh) is constant for all system sizes. In reality, one would probably expect a diminishing price per kW (or kWh) as the size of the system increases, i.e. exploiting economies of scale.

Furthermore, the linear costing model implicitly assumes that systems can be purchased for an exact power demand. For example, if a village has a power demand of 52 kW, the model assumes that a 52 kW DRE system can be purchased. However in reality, this is not always the case, particularly for systems with fixed unit sizes. In future, non-linear cost curves could potentially be added to account for these limitations.

Fourth, the annual growth rates in electricity demand are assumed to be static across the range of villages (i.e. 5% per year to 2020 and 4% thereafter). However, there is an asymmetrical link between the demand for electricity (and energy in general) and economic activity.

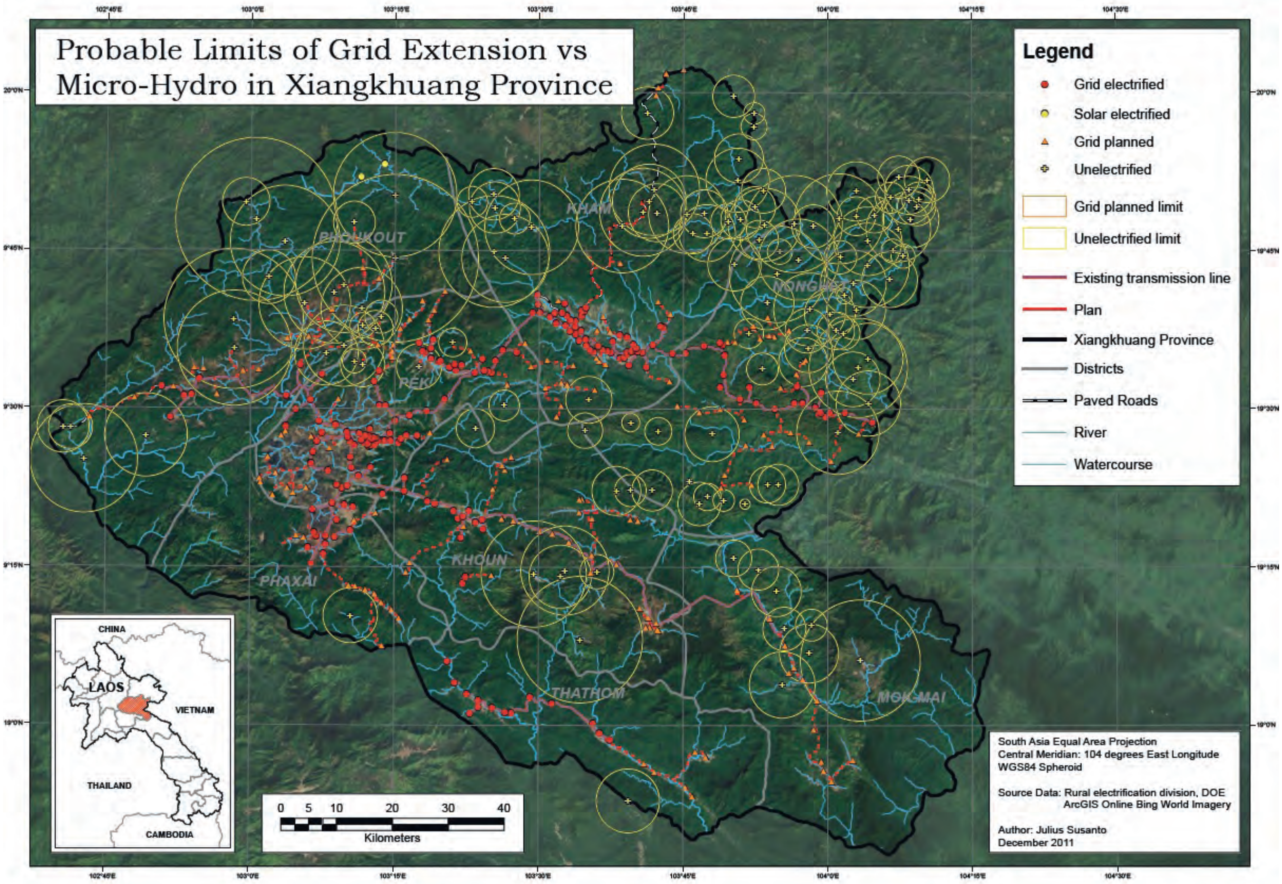

Figure 6: GIS visual representation – micro-hydro.

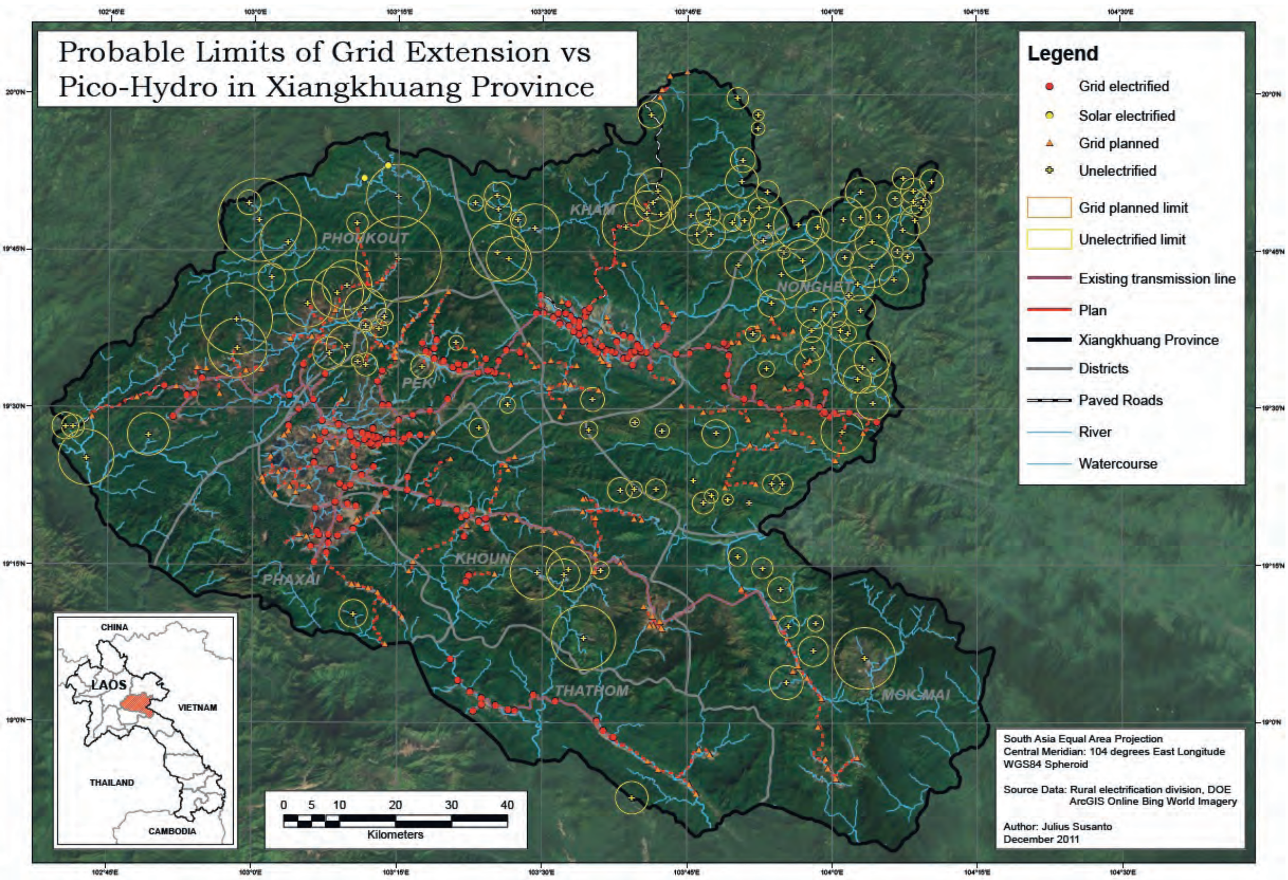

Figure 7: GIS visual representation – pico-hydro.

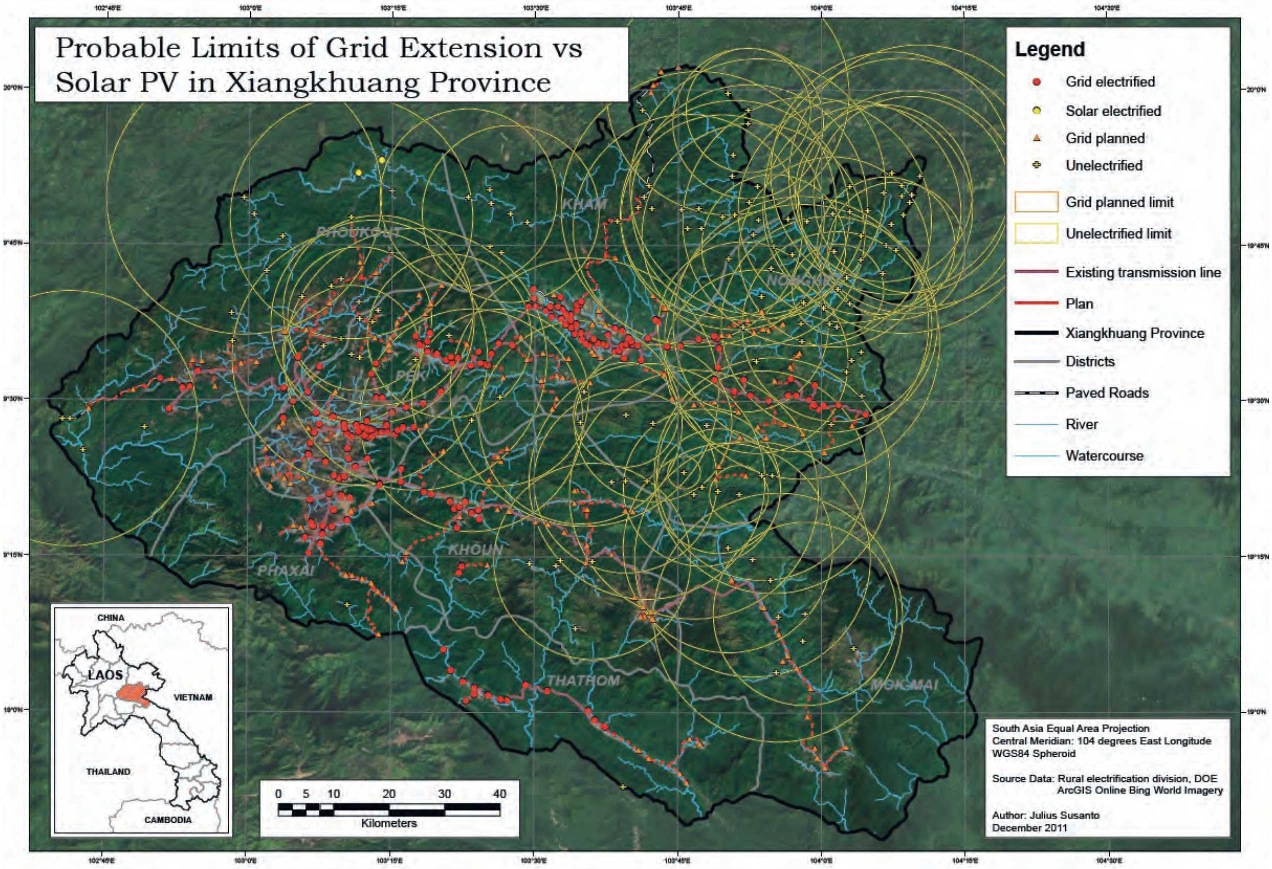

Figure 8: GIS visual representation – solar PV.

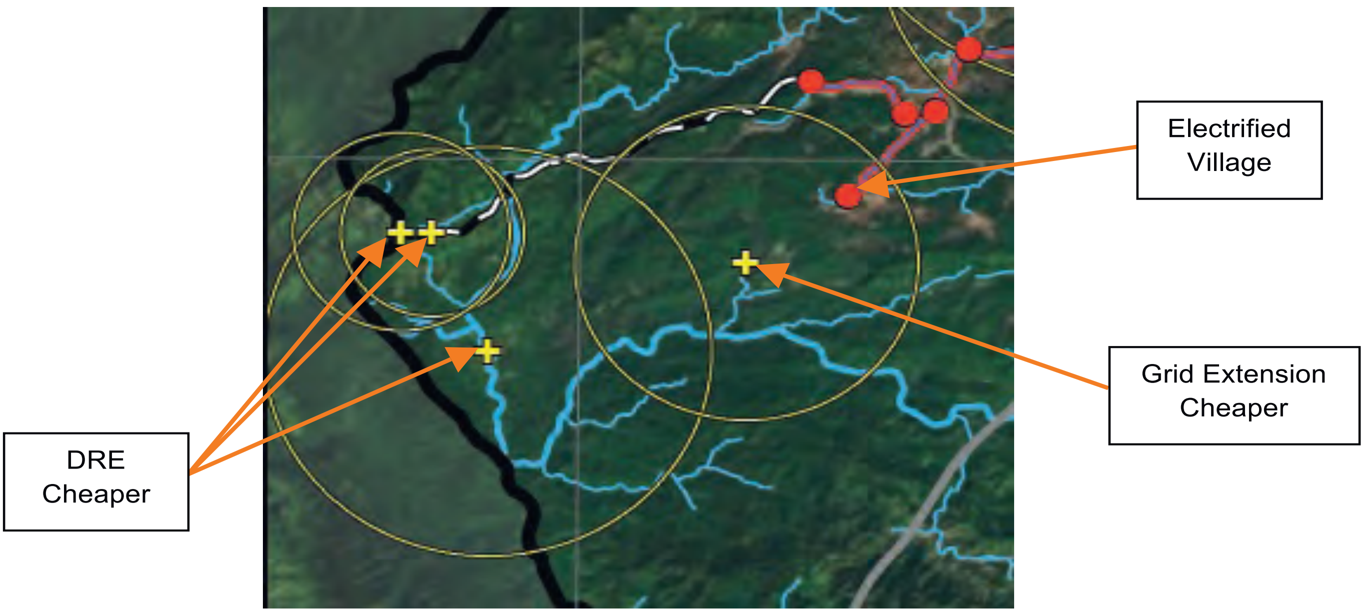

Figure 9: GIS visual representation enlargement.

Access to electricity may not necessarily stimulate economic activity, but economic growth will almost certainly increase electricity demand. The model does not take into account the economic development prospects of the villages and the implications that growth (or lack thereof) will have on future electricity demand.

Lastly, the model has nothing to say about the quality of electricity supplied to the end-users. This applies to both grid extension and DRE technologies – both are subject to power supply interruptions and power quality problems (e.g. poor steady-state voltage regulation).

9 CONCLUSIONS

In this paper, a financial model was developed to compare grid extension versus three decentralised renewable energy options (micro-hydro, pico-hydro and solar PV). The results show that given available natural resources, micro-hydro and pico-hydro are viable alternatives to grid extension. Solar PV, however, is too costly on a like-for-like basis and any comparison with grid extension can only be made at reduced power outputs.

While the proposed model has limitations, it could potentially be used for screening purposes; to assist in the selection of villages to be electrified with DRE technologies instead of by grid extension. By calculating the breakeven distance of a DRE technology vs grid extension, one can use decision thresholds to determine whether a village could be a candidate for grid extension or a DRE technology.

However given the limitations described above, the model should be used as a complementary tool, in conjunction with natural resource assessments and village surveys.

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Proposed reduction of preventable deaths in rural Indonesia through stormwater harvesting and wastewater treatment

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ABSTRACT: *Worldwide, what is responsible for killing the most children each year? Acute Respiratory Infection (2 million children). What is second? Diarrhoea (1.8 million children). This statistic does not include the additional 300,000 adults who also die from this preventable condition. Diarrhoea kills more children that malaria, HIV and measles combined (UNDP, 2006). "In most of the developing world, unclean water is a greater threat to human lives than violent conflict. Right now almost half the population of the developing world suffer from diseases because of dirty water and inadequate sanitation" (Peace Child International, 2006). While the Millennial Development Goals (MDG) and the United Nations provide an overarching view of the existing situations by country, the initial goal of this project is to investigating the specific existing conditions in rural Indonesia, especially Southern Kalimantan, and how they relate to the MDG (UNDP, 2003). This will in turn allow site specific proposals in partnership with the local communities that are culturally and financially feasible. They will then be designed and constructed in conjunction with community education. The preliminary proposal is to use stormwater harvesting to provide a clean water source in replacement of their current sources; seasonal wells, contaminated rivers and swamps. In conjunction is the proposal to eliminate their exposure to open sewage through simple septic systems. Through these processes, the goal is to decrease the preventable cases of sickness through increased access to clean up and decreased exposure to open sewage. This in turn will reduce the associated deaths due to diarrhoea (WHO/UNICEF, 2009). The project is still in the initial research and development stages as of March 2012 with the first project hoping to be undertaken by the end of 2012.*

KEYWORDS: Water, wastewater, rainwater, health.

Figure 1: Typical housing in rural Southern Kalimantan.

1 INTRODUCTION

1.1 Background

Of the 5 billion cases of diarrhoea in the world each year, 1.8 million children perish (UNDP 2006). Every year, at least 300 out of 1,000 Indonesians suffer from water-borne diseases, including cholera, dysentery, and typhoid fever, according to the Ministry of Health (Asian Development Bank, March 2006). Indonesia is only second in the world to India, relative to the number of people, consistently exposed to open sewer (66 million) (WHO/UNICEF, 2009). The percentage of Indonesia's population without sustainable access to an improved water source is 23% (UNDP, 2006). Note that an improved water source still may not be an acceptable water source. While this reality in Indonesia leads to many different consequences, one that is alarming is that within the economically poorest 20% of the population in Indonesia (in 2005), the mortality rate for children under 5 was over 10%. The average across the country was approx. 7% (UNDP, 2006). These statistics and outcomes are not unrelated. Diarrhoea usually originates from contaminated water and/or food. Open sewers is a common source for the contamination and spread of much disease and sickness. Access to clean water and sanitation can reduce the risk of a child dying by as much as 50% (UNDP, 2006).

1.2 Existing conditions

While the residents living in Banjarmasin and Banjarbaru, the larger cities of Southern Kalimantan, have greater access to clean water than most areas of Indonesia (35%), there has been no specific information from the rural areas.

The initial survey already undertaken in conjunction with the local authorities has identified 29 villages of greatest need in the area. The following information has been collected on these particular villages:

- The sources of drinking water vary depending on geographical location. These sources range from the river, wells, ponds/swamps, and a supply truck from the city water supplier. Typically each village has only one of these sources with some having multiple sources.
- The source for bathing is typically from the river with some villages using supply from wells and ponds/swamps.
- The source for washing clothes, etc is typically from the river with some villages using supply from wells and ponds/swamps.
- All human wastewater usually goes into the river untreated. There are some 'septic' tanks in the ponds/swamp directly adjacent to the houses although their functionality is minimal at best. They may actually be creating more of a long term problem though we have yet to investigate them in finer detail.

The typical treatment for any of this water (except from the truck) in each household is the application of an aluminium flocculent readily available (Tawas) and boiling for up to 10 minutes. The local authorities do not see this local treatment as a long term sustainable solution. Further onsite research consisting of interviews with community leaders and locals in the villages will be conducted to help determine solutions that will be culturally appropriate and constructed using local resources as much as possible. As this work is development focused as opposed to relief or rehabilitation, one goal is to construct these projects with a minimal investment from outside of their communities and government.

1.3 Limitations

The geographical dimensions to consider in this project are that villages are usually either on the river flood plains (certainly below the Q100 flood line and often below the Q5 flood line), in swamp areas or inland with limited access to groundwater. Access to these villages is usually by motorbike or boat with only a few accessible by a car or truck. This can make basic construction challenging and requires that we anticipate both local and river flooding scenarios to limit the possibility of further contamination from flood waters. Because of the remote locations, materials for construction will need to be utilised that are familiar to and easily available to the local people. This will help reduce the overall financial costs and allow infrastructure to be built that is feasible and ultimately sustainable and reproducible for the long term.

Understanding the culture will be critical to enabling 'buy in' from the entire community and not just the government leaders. Initial studies already show an underlying apprehension from the people about using rainwater although their reasoning changes from village to village. They believe that the river water is cleaner and better for them. We need to be careful not to make the assumption that the local people want clean water and their wastewater treated.

The community will need to be involved in the project from the beginning otherwise the infrastructure will rarely be used and quickly fall into disrepair. This has already been witnessed in one of the villages already surveyed.

A comprehensive public education program (based on anthropological studies and tailored to their culture) along with community commitment (contribution of finances, time, resources, etc.) will hopefully lay a strong foundation for the longevity and propagation of this project.

Figure 2: The close proximity of the bathing/washing area and the toilet.

Figure 3: Example of 'septic' tank – uncontained system with fish.

1.4 Assumptions

We are assuming or at least working towards these projects being cost neutral. This is a large assumption and something that is being assessed in the initial research and planning. The assumption has also been made that the rain water in Southern Kalimantan is acceptable for human consumption without further treatment. Initial research indicates a pH of the rain water to be 5.2 but this needs to be verified through further research. If this is in fact the case, an additive will need to be used to neutralise the pH value. The assumption is also being made that using rainwater, if not currently culturally acceptable, will be after anthropological studies and contextual education. While there are real obstacles and challenges to overcome, the primary focus of the project should not be lost.

1.5 Thesis

The purpose of this project is to reduce the number of preventable deaths, particularly of children, from diarrhoea and other waterborne diseases. This will be done through eliminating exposure to untreated wastewater and increasing the availability to an uncontaminated water source.

2 METHODOLOGY

2.1 Materials and equipment used

The two major components being considered for success in the project are as follows:

2.1.1 Uncontaminated water source

Currently, locals use river water, local wells, swamps or trucked in water for consumption and domestic use. Because of contamination, financial costs and the long dry seasons, these options are not sustainable for the development of the wider community.

Most water sources, except for the larger rivers, are dry for at least some part, if not most of the dry season thus leaving the village with no water supply at all.

Figure 4: Access is difficult: transportation of construction materials is a challenge.

Figure 5: Typical housing in rural Southern Kalimantan, typically surround by swamp.

Through the utilisation of rain water harvesting, this project intends to overcome the current barriers to a consistent uncontaminated water source. The first step is to identify an impervious area that is acceptable from which to retrieve rainwater. An assessment of the roofs in the local villages will be conducted to see if they are feasible. If so, simple roof guttering can be attached to the roofs to collect the rainwater and direct it to a storage tank.

If the roofs are not adequate, an alternative solution will be designed such as constructing rainwater tanks with impervious roofs that will enable a suitable catchment area. These will all be designed to take into account the hydrology, costs and local resources, sustainability, reproducibility and functional practicalities.

Depending on the density of the housing within the villages, it is envisaged to have one tank service anywhere from 1 to 4 houses. Everything will be gravity fed and each house and will collect the rainwater directly from the tank. In very limited situations, the tanks may be connected into a household plumbing system (typically houses do not have plumbing systems). It is envisaged that the tanks will be above ground and large enough to store drinking water (at a minimum) over the dry season for each family it services. The specific design of this will evolve over time to take all aspects into consideration.

Figure 6: Previous project infrastructure sitting unused (reticulated river water).

2.1.2 Wastewater treatment

Currently, human sewage is not treated and most of it is deposited directly into the closest water course, river, surrounding pond or swamp. For villages not located close to a river or swamp, the sewage usually goes straight into a hole in the ground that is typically not protected and quite often subject to flooding. As stated earlier, there are also some 'septic' tanks in numerous places that are basically ineffective from the initial research. Ideally, this project aims to treat the wastewater and remove the exposure to the village population. The initial thought is to utilise conventional single or two stage septic tank systems.

The local government is familiar with these contained systems and has encouraged the project to implement them as a long term sustainable solution in this area. Topography, local and river flooding along with the swamps and ponds in immediate proximity to the houses will be critical factors in the design solutions along with the other challenges such as maintenance.

3 CONCLUSIONS

While the project is still in the early stages, the initial research results along with the co-operation with the regional government lay a solid foundation. By utilising the technical engineering and anthropological experience of those committed to the project, along with the partnership from local knowledgeable and influential professionals, the challenges before the project are manageable. Our

Figure 7: Example of a storage tank.

goal to reduce the number of preventable deaths, particularly of children, from diarrhoea and other waterborne diseases through eliminating exposure to untreated wastewater and increasing the availability to an uncontaminated water source is certainly possible and unquestionably necessary for the sake of the people living in rural Southern Kalimantan.

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Figure 8: Example of roofing – village housing.

Figure 9: Example of roofing – village office.

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The Journal of Humanitarian Engineering welcomes submissions from students, researchers, community workers, academics and NGO professionals. The editors welcome diversity and particularly encourage papers describing local solutions to local challenges.

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Submission style and templates: Please download the electronic template from the JHE website: www.ewb.org.au/journal or contact the editor to receive the template via e-mail. The template consists of the full formatting instruction required for submission. For ease of editing it is asked that the paper be submitted as a Microsoft Office Word text document (or equivalent with .doc or .docx extension) and that the length of the submission paper does not exceed 8 pages.

Photographs: We strongly encourage the use of photographs to complement your paper submission. Any accompanying photographs need to be attached separately to submission e-mail and in high-resolution format where possible. All images need to be saved as a JPEG file with an appropriate title to ease identification. The placement of the photo within the submission must be indicated by the author in the body of the submission in square parentheses, accompanied by an appropriate caption, with a corresponding title for the image file.

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