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Remotely designed appropriate technology for emergency disaster response in Nepal

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Abstract

This paper reports on the application of a remotely designed appropriate technology (AT) to emergency needs in a natural disaster. Significantly, the present strategy was compared and contrasted with that of a traditional sustainable community development (SCD) strategy. In response to a large earthquake in Nepal, engineering students at Metropolitan State University of Denver (MSU Denver) examined technological interventions for the emergency needs of affected communities in the disaster's immediate aftermath. Using community information acquired through interviews and secondary data, they developed a simple biosand filter that is inexpensive, easy to build and made from materials that are available, accessible and affordable to beneficiaries. Students chose a design, built it, tested it and wrote instruction manuals in both Nepali and pictogram formats. These manuals were then distributed through NGO partners doing relief work in Nepal. Finally, this study explores how the use of an AT assessment tool—originally designed for decision support in the project design phase—might instead be used for monitoring and evaluation of AT effectiveness in an emergency response scenario.

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1. Introduction

In April 2015, a 7.8 magnitude earthquake struck the Lamjung District of north-central Nepal, killing over 8,000 people and injuring at least 21,000 more. Known as the Gorkha earthquake, it was the worst natural disaster to strike Nepal in 80 years [1]. As a result, thousands of people are still homeless, and many lack access to clean water in an area where water quality is already compromised [2]. With faculty guidance, students in the Humanitarian Engineering Club at Metropolitan State University of Denver (MSU Denver) designed technology that may temporarily improve emergency drinking water security while more permanent recovery resources are acquired. This project offered a unique approach to humanitarian technology in that the proposed intervention was designed and tested remotely in Denver, not locally where the aid was needed. Primary and secondary data were collected to provide a theoretical point of departure for the design, and to ensure that any solution would suit the emergency needs, based on local conditions.

To this cause, students collaborated with a disaster relief NGO in Nepal, gathering relevant community data during the community appraisal and problem identification phases. Buttressing the appropriateness of the design, one of the involved students is native to the region and provided valuable primary data (e.g. which materials might be readily available and accessible in affected areas). During the problem identification phase, students utilized these to determine that emergency post-disaster water safety was suitable for alleviation using AT intervention. Next, during the design phase, students recognized that they needed to act quickly to have the greatest impact; second only to functionality (per WHO drinking water standards), the design team prioritized the following conditions: 1) construction materials were available, accessible and affordable locally to the affected community; 2) product could be built quickly and easily as a stopgap measure until more sophisticated, permanent (or semi-permanent) water filters become available, accessible and affordable. Various solutions were designed and tested at the MSU Denver labs. The best performing design was a basic biosand filter, modified for quick emergency construction. The biosand filter is an established technology that is effective at removing pathogens and decreasing turbidity in household drinking water [3].

In the implementation phase, the chosen design was then transferred to the affected communities through an instruction manual that beneficiaries could use to build the filters locally; these were printed both verbally (in Nepali) and non-verbally using pictograms, and avoided overly technical jargon. Finally, the manuals were sent to areas identified as being in greatest need through the partner NGO.

Nomenclature

AT	Appropriate Technology
SCD	Sustainable Community Development
MCDA	Multi-Criteria Decision Analysis
MSU	Metropolitan State University of Denver

1.1. Problem Identification

Following a large-scale natural disaster like the Gorkha earthquake, the emergency needs are food, water and shelter. Disaster relief organizations like UNOCHA have provided many necessities to those impacted by the Gorkha earthquake [4], but accessibility to clean water in the quake area will likely grow as relief efforts wane and until more permanent water filters can be constructed.

After the earthquake, students in the Humanitarian Engineering Club at MSU Denver completed primary and secondary research to identify highest relief priorities. Through a systematic process, they chose drinking water accessibility as a problem with an engineering-based solution. Specifically, they focused on a design that adheres to principles of AT [5] [6].

1.2. Background

“Appropriate technology” (AT) refers to development interventions that fit both a community’s needs and capacity. Originally termed “intermediate technology” by the economist Dr. E.F. Schumacher [5] the terms “appropriate technology”, “appropriate and sustainable technology” and “culturally appropriate technology” are more commonly used today. AT refers to “small-scale, decentralized, labor-intensive, energy-efficient, environmentally sound, and locally controlled” technology [7] [8]. Especially after World War II, beneficiaries of modern development efforts became aware that exogenous technology interventions were not typically compatible with local capacities [9]. In 1955, Schumacher was serving as U.N. Economic Advisor to Burma when his perspective on this industrial model of development began to shift [5]. In a paper for the UNESCO Conference on the Application of Science and Technology to the Development of Latin America, Dr. Schumacher deemed a technology “appropriate” for that time and place if it met the following criteria:

- Created jobs where people live
- Affordable enough for common use
- Required simple tools and techniques
- Used local materials
- Made things for local use [5]

1.2.1. Applying AT to an Emergency vs. Traditional SCD

In a typical SCD scenario, an AT is chosen by stakeholders participating in the decision-making process. Specifically, stakeholders choose intervention alternatives during the design phase. To ensure project success, SCD relies on a robust community appraisal. Conversely, during the emergency period following a disaster, the scope of AT skews slightly from that of traditional SCD projects. In an emergency context, the immediate needs of people in the recovery area supersede the standard SCD objectives of long-term sustainability, job creation etc. Because of this, the community assessment is truncated to accommodate pressing needs and an accelerated timeline [10]. Ideally, any chosen intervention will not just aid in the emergency, but will also contribute to the community’s resilience by augmenting its capacities [11].

2. Engineering Design

2.1. Engineering Design Process

Students employed a fairly standard engineering design process for their solution. First, through detailed research efforts, they deemed that access to clean water was germane to the emergency situation in Lamjung. Building upon prior water filter research, students collected community data and examined various designs that employ indigenous materials: from kiln-fired pressed earth to multi-stage medium filtration. During the refinement and analysis phase, the highest priority for this solution was that it produced water to WHO standards [12]. Second only to that were construction materials’ availability, accessibility and affordability. Along with these objectives were considerations for construction simplicity and speed, in order to get clean water to affected communities. Upon completion of design refinement and analysis, students chose the concept that most adequately met all priority conditions.

Next, the team built and tested their prototype, using engineering analyses to properly modify the design for maximum functionality given the aforementioned objectives, conditions and limitations. Water samples were first inoculated with bacteria, and the effectiveness of the filter was then tested for presence of contaminants (see section 2.3.2). Results indicated that the filters would be useful and effective. Finally, students wrote an instruction manual to be printed in the Nepali language and using non-verbal pictograms. These manuals were then distributed into the most affected communities most affected through the NGO partner.

2.2. Problem Identification

2.2.1. Problem Statement

The present research question is as follows: what water filtration technology is appropriate in the interim from the moment a disaster strikes to advanced recovery when resources may be more available?

2.2.2. Customer Identification

The customer is anyone in a remote, rural settlement where a disaster has diminished or depleted water quality and/or security.

2.2.3. Design Objectives and Conditions

The present design was driven by one primary objective and two priority design conditions.

Primary Design Objective:

1. *Functionality.* The filter must produce water to WHO standards [12].

Priority Design Conditions:

1. *Materials availability/accessibility/affordability.* The basic filtration unit is essentially a bio-sand filter design. The biosand filter is a well-established technology that is effective at removing pathogens and turbidity from water [3]. Certainly, more efficient, robust designs than the present one—like those found at Water For All [13] and BiosandFilter.Org [14]—will eventually be required in such a scenario. However, larger, more permanent water filters take time to build, frequently require exogenous materials, may be unaffordable in the emergency aftermath of a disaster, and require technical knowledge to construct.
2. *Product Constructability.* The filter must be able to be built quickly and easily by people in the affected area; it is not intended as a long-term solution, but a stopgap measure until more sophisticated, permanent filters become available, accessible and affordable.

The overall design objective was to construct an adequate, functioning water filter under these conditions. The primary limitation of this design is its low flow-rate, which requires extra time and labor to collect an adequate volume of water. Another limitation is that the unit is not extremely resilient, with a useful life of between one-half and one growing season.

2.3. Compromise Solution

The product's general design is a modular bio-sand water filter with the following conditions and limitations:

- Produce drinking water to WHO standards [12]
- Materials availability
- Materials accessibility
- Materials affordability
- Transferability
- Usability
- Ease of construction and maintenance

Plastic bottles are relatively available, and if they are reusable from other purposes, then affordability is enhanced. Usability of the filter itself is generally high, and the system becomes more usable still if the support frame and catchment materials are also available, affordable and reliable. The Nepalese student stated that construction and maintenance standards are quite reasonable for local people to attend to. The presence of bacteria in test samples was the primary indicator of filtration performance. Figure 1 shows the virtual prototype of the biosand filtration unit.



Fig 1. Biosand filtration unit.

Crucially, biosand filters like those in Figure 1 rely on an active layer of beneficial bacteria that develops in the sand with approximately two weeks of use by a single person consuming an average volume of water (varies with conditions) [15]. Lab studies of bio-sand filters with mature populations of beneficial bacteria have shown reduction rates of up to 99.98% for protozoa, 90-99% for bacteria, and variable rates for viruses [16]. Field studies have documented *E. coli* removal rates of 80-98% [16]. Two health impact studies report 44-47% reduction of diarrheal disease incidence in users of bio-sand filters [17] [18].

Finally, proper filter maintenance is required for optimal performance. To achieve this, adequate training, follow-up, monitoring and evaluation are critical. Since the filter is typically used without subsequent chlorination, training beneficiaries to properly care for and maintain safe water storage containers is imperative.

2.3.1. Materials

Materials required for constructing the product are as follows:

- Plastic soda/beverage bottles (4, two-liter)
- Gravel, large
- Gravel, small
- Sand, coarse
- Sand, fine
- Cloth (cotton preferred)
- Wood or wire support frame
- Five-gallon buckets (2)
- Pan/kettle and fire for sterilization (first month of use only)

2.3.2. Prototype testing, refinement and analysis

2.3.2.1. Multiple tube method

Non-chlorinated water was diluted in multiple test tubes. These tubes were inoculated with bacterial colonies, then incubated. After incubation, the water was run through the filter and tested according to the WHO guidelines [12] given in Figure 2, below.

Table 7.7 Guideline values for verification of microbial quality^a (see also Table 5.2)

Organisms	Guideline value
All water directly intended for drinking	
<i>E. coli</i> or thermotolerant coliform bacteria ^{b,c}	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
<i>E. coli</i> or thermotolerant coliform bacteria ^b	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
<i>E. coli</i> or thermotolerant coliform bacteria ^b	Must not be detectable in any 100-ml sample

^a Immediate investigative action must be taken if *E. coli* are detected.

^b Although *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests must be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies.

^c It is recognized that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Especially under these conditions, medium-term targets for the progressive improvement of water supplies should be set.

Figure 2. WHO guidelines on Drinking Water, 3rd Ed.

2.3.2.2. Flow Rate Test Results

Flow rate was tested using the following procedure over four recorded sessions:

1. Two-liter bottles were filled with water until the level dropped to the height of the given media;
2. Four cups (236 ml) of water were then added and time was started;
3. Time stopped after four cups (236 ml) of water were collected;

Results indicated the filter produces between 20 and 60 liters of water per hour.

2.3.2.3. Water Quality Test results

Initial tests showed this bio-sand filter to be ineffective for adequate removal of pathogenic bacteria. However, subsequent testing showed gradually increasing bacteria removal rates: from approximately 20% to approximately 85% after 10 days. As expected, there is a direct relationship between contaminate removal rates and population levels of beneficial bacteria in the sand medium.

3. Monitoring and Evaluation

3.1. The Appropriate Technology Assessment Tool (ATAT)

Accurate assessment of AT performance is an important factor in the project's implementation phase, and in later monitoring & evaluation phases. Having a useful, practical tool that can be used by non-technical aid workers or beneficiaries can be helpful in achieving this. In this paper, we explore whether the performance (i.e., the local appropriateness) of the chosen water filter design can be adequately monitored using a custom tool developed by Michael Bauer called the Appropriate Technology Assessment Tool (ATAT) [6]. Significantly, the ATAT tool was designed for decision-support and risk management in SCD projects. The differences between SCD and disaster-

relief scenarios are manifold, but they overlap significantly in the area of AT. In the present analysis, the ATAT will be used for monitoring and evaluation, rather than decision support.

After the first month of use, beneficiaries/users will be sent a short questionnaire to rate how well the filter performs its intended functions within parameters that they choose. They will rank these performance parameters for weighting (Rank Order Centroid). They will then score how the filters perform, ranging from 1 (low) to 5 (high), in the areas they chose. Upon receipt of the data, students will translate local input into monitoring data using ATAT.

3.2. Multi-Criteria Decision Analysis as a Monitoring and Evaluation Tool

The ATAT will evaluate the water filter design via the Appropriateness Index (*AI*), a score given by local users. The Appropriateness Index is a weighted-sum composite index that is calculated using Multi-Criteria Decision Analysis (MCDA) techniques. Inputs from local users will be collected as social survey data using the simple questionnaire described above (Sec. 3.1). The *AI* score will reflect how well the filter performs its intended functions within the users’ chosen parameters. An example is given in Table 1, below.

Table 1. Example MCDA weighted-sum matrix

Criteria	1	2	3	<i>I_{a,b,c}</i>
<i>AT alternative</i>				
<i>a</i>	2	3	2	2.8
<i>b</i>	3	4	4	3.4
<i>c</i>	5	2	2	3.8
<i>w_{1,2,3}</i>	0.61	0.28	0.11	

As seen in Table 1, the appropriateness of each AT alternative is quantified, providing a means for monitoring and evaluating performance in the affected area during disaster recovery. The weighting of parameters *w_j* is given by the Rank Order Centroid method (Equation 2). A full description of MCDA methods and their equations in this pedagogy are given in Appendix A.

3.3. Data Analysis

Statistical analysis of data will help improve the survey tool and the *AI* metric. Any future improvements to the water filter will be accomplished through an iterative design process, using the analyzed monitoring and evaluation data.

3.3.1. Inter-Rater Reliability

Inter-rater Reliability (IRR) illustrates the degree to which “...the relation of one rated object of the other rated objects is the same across judges, even though the absolute numbers used to express this relation may differ from judge to judge” [19] (p. 98). Kendall’s coefficient of correlation (Kendall’s *W*) is the most common descriptive statistic used to evaluate IRR: if *W*=0 then no IRR, and if *W*=1 then full IRR. For this research, measuring a robust data set with IRR can reveal the degree to which the indicator rankings of different participants are proportional [20]. If Kendall’s *W* falls below a certain threshold (Equation 2), then the survey or process needs to be reexamined and refined. Equation 1 gives Kendall’s *W* as:

$$W = \frac{12(\sum R_i^2) - 3k^2N(N+1)^2}{k^2N(N^2 - 1)} \tag{1}$$

where *k* = the number of judges (surveys collected), *N* = the number of objects being ranked, and $\sum R_i^2$ is the sum of the squared rank totals. Kendall’s *W* is related to the Chi-Squared statistic and is used in hypothesis testing. If the Chi-Squared statistic of the empirical Kendall’s *W* falls to below critical values for the related Chi-Squared statistic,

we cannot reject the null hypothesis. In the present analysis, the null hypothesis is that the parameter rankings are unrelated between judges. Chi-Squared is given in Equation 2 as:

$$\chi^2 = k(N - 1)W \quad (2)$$

For very low numbers of judges ($k < 7$) the Chi-Squared statistic is not adequate for evaluating AT indicator rank correlations between the biosand filter judges [20].

4. Discussion

Continued use of this filter design will promote a bio-layer of beneficial bacteria that remove most harmful bacteria from the treated water [12] [15] [16] [17]. However, since results will vary with the user, the manual includes instructions for boiling the water for at least 1 minute after filtration during the first month of use. With this combined approach, the filter offers the benefit of removing non-biological contaminants, while the boiling ensures the remaining pathogens are killed. After one month of use, the active bio-layer will be developed to the point of effective filtration, negating the prior need for post-filtration boiling.

Given the simple, accessible and available materials for this system, local beneficiaries should be able to construct, use and service the filters with little to no training and few skills. They can employ these filters as a stopgap measure in the immediate aftermath of a disaster, but should not rely on them for long-term use due to their lack of resilience. Nonetheless, their ease of application and high degree of effectiveness will give local stakeholders potable water during the time required to marshal resources for larger, more permanent water filtration units in disaster-affected areas.

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