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A methodology for the sustainability assessment of arsenic mitigation technology for drinking water

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HIGHLIGHTS

- A method to assess technology for producing arsenic-free drinking water is described.
- Fieldwork showed cost, trust, convenience and health-awareness as key user-priorities.
- Technology that enjoys high trust and confidence is more likely to be utilised.
- Design and deployment features that promote trust and confidence are identified.
- Protocols for safe disposal of arsenical waste are often inadequate or not followed.

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ABSTRACT

In this paper we show how the process analysis method (PAM) can be applied to assess the sustainability of options to mitigate arsenic in drinking water in rural India. Stakeholder perspectives, gathered from a fieldwork survey of 933 households in West Bengal in 2012 played a significant role in this assessment. This research found that the 'most important' issues as specified by the technology users are cost, trust, distance from their home to the clean water source (an indicator of convenience), and understanding the health effects of arsenic. We show that utilisation of a technology is related to levels of trust and confidence in a community, making use of a composite trust–confidence indicator. Measures to improve trust between community and organisers of mitigation projects, and to raise confidence in technology and also in fair costing, would help to promote successful deployment of appropriate technology. Attitudes to cost revealed in the surveys are related to the low value placed on arsenic-free water, as also found by other investigators, consistent with a lack of public awareness about the arsenic problem. It is suggested that increased awareness might change attitudes to arsenic-rich waste and its disposal protocols. This waste is often currently discarded in an uncontrolled manner in the local environment, giving rise to the possibility of point-source recontamination.

1. Introduction

Naturally occurring arsenic (a well-known poison), is present in the well-water of over 100 million rural residents in the Bengal basin (India and Bangladesh) (Chowdhury et al., 2000). It is important for the people affected that the most appropriate and sustainable clean-water solutions are implemented to ensure safe drinking water. However the majority of arsenic removal technology currently fails within the first year (Hossain et al., 2005), either for technical reasons, or through inappropriate deployment in the community.

One way to improve this situation is to create a standardised and transparent evaluation for arsenic mitigation options which will help to identify the most appropriate long-term solutions for the affected communities. Many reports and papers compare mitigation options technically (Bhavan, 2007; Jain and Singh, 2012). These are useful in highlighting the ability of the technology to remove arsenic, however they do not identify the issues causing failure in the community context. The purpose of this project is to use the process analysis method (PAM) (Chee Tahir and Darton, 2010) to create triple-bottom line sustainability assessments, including economic, environmental and social factors. The resulting set of metrics, supported by field surveys in user communities, enables a standardised comparison to be made between different arsenic mitigation technologies. Our aim is to help technology developers, implementers and policy-makers promote more sustainable technology for the provision of arsenic-free water.

2. Assessment methodology

Designing an eco-friendly technology does not automatically lead to sustainable user behaviour (Derijcke and Uitzinger, 2006), especially if the sociocultural context of the user has not been considered. Several

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authors have discussed how product design can positively influence users. For instance, Jelsma and Knot (2002) applied the idea of 'scripting' to sustainable product design, by which they mean to design the product so as to guide the behaviour of the user to comply with values and intentions defined by the designer. According to this idea, features that promote sustainability are built into the design to promote a change in behaviour. Thus the design of the product takes account of ways in which people use it, in order to reach a more sustainable result (Rodríguez and Boks, 2005). Smit et al. (2002) described 'user-centred eco-design', which can reduce environmental impact of products. This design method recognises that issues of behaviour, acceptance and desirability are rarely addressed in traditional eco-design. 'User-centred' design puts the user at the heart of the design process. Instead of focusing on technological possibilities and quality measurements in terms of components, it takes solutions that fit the user as a starting point and measures product quality from a user point of view (Vredenburg et al., 2002). The user-centred design approach aims to improve the quality of the interaction between the user and the product so as to induce sustainable behaviour. Such design approaches underline the importance of understanding how the product will be used in practice.

2.1. Process analysis method

The assessment of existing arsenic mitigation technologies thus requires a method that considers the degree to which they are designed to facilitate sustainable use in the community. The process analysis method (PAM) was chosen in this study because the activities and perspectives of stakeholders are central to the method. In this case, the user of the arsenic mitigation technology is identified as the primary stakeholder (a user-centred view). Issues which arise from using a particular technology are recognised and characterised with indicators. Product designers can then look to these issues and indicators when considering scripting or user-oriented modification. The steps in the application of the methodology are illustrated in Fig. 1.

The PAM is rooted in engineering systems theory. An overview of the system being considered (in this case, a technology application) is made in which it is described as a set of *processes*, as shown in Fig. 2. The *impact* of a process causes a change in one or more *stores of value* (capital), belonging to the domains — economic, environmental and sociocultural. This is the essence of "triple bottom line" accounting (Elkington, 1998), in which a sustainable outcome is seen as one which is most beneficial for all the domains taken together. At the heart of the PAM is the framework, in which the activities or policies (termed *impact generators*) within the system that cause an impact on sustainability are identified. Each *impact* may be beneficial or detrimental; these impacts give rise to *issues* — the consequences that are important for one or more stakeholders (termed *impact receivers*). The issues are characterised by *indicators* within the economic, environmental and sociocultural domains. Overall then, the set of indicators describes the effect of the system on sustainability. Indicators are given a numerical value with one or more *metrics*, which quantify the effect (good, or bad) on sustainability. PAM requires a clear definition of sustainability and what should be regarded as a sustainable outcome, in order to guide the choice of relevant indicators. Previously PAM has been used to select indicators to quantify the sustainability performance of business operations related to the palm oil industry (Chee Tahir and Darton, 2010) and of the UK transport system (Smith et al., 2013). This paper demonstrates how PAM can be used to assess arsenic mitigation technology.

Various other assessment tools are available, like Life Cycle Assessment, Ecological Foot-printing and various Impact and Risk assessments. Ness et al. (2007) categorised such tools by area, showing that none include a triple-bottom-line approach to product assessment. The Global Reporting Initiative (GRI) is a network-based organisation that creates sustainability reporting guidelines for companies and institutions, but its indicator sets are naturally appropriate for monitoring company-wide operations rather than assessing particular products

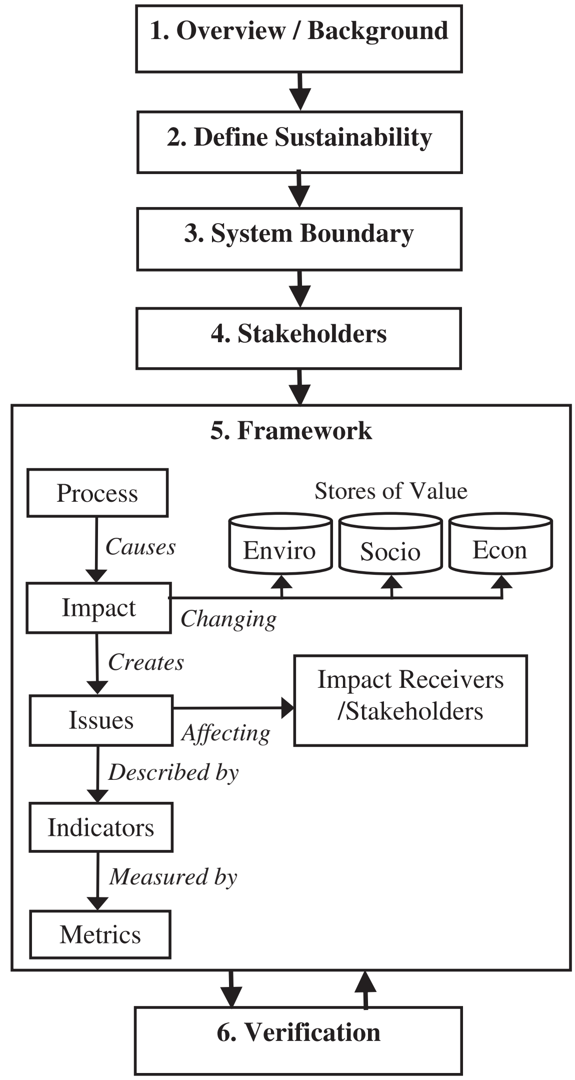

Fig. 1. The PAM flow chart (modified from Chee Tahir and Darton, 2010).

(GRI Portal, 2002). The European Environment Agency has adopted the use of a framework that distinguishes Driving forces, Pressures, States, Impacts and Responses (DPSIR) in its environmental reports. In this framework the chain linking the DPSIR elements is identified (Kristensen, 2004). The PAM bears some resemblance to the DPSIR approach in linking cause to effect, but is simpler in not requiring a model of this linkage. Neither the GRI reporting guidelines nor the DPSIR are appropriate for our problem. The PAM is suitable because it describes how to build up an indicator set for a particular system using a transparent methodology with stakeholder involvement.

2.2. PAM step 1: overview and background

The region of interest is the arsenic-affected rural area in West Bengal, India, largely adjacent to the Ganges River and its tributaries. Clean-water options vary widely across this area. In many villages a communal arsenic-removal project has been initiated with government and/or NGO support, so that a single technology is in operation. In villages where household level technology is used, this is often a single technology from a particular supplier. A village may have access to municipally treated water from a community shared standpipe ('time-water'), hand-dug wells which supply very young, near-surface water which is commonly free of arsenic, or a village-shared, arsenic-free deep

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