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Water-supply options in arsenic-affected regions in Cambodia: Targeting the bottom income quintiles

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HIGHLIGHTS

• Hand dug wells and vendor-supplied water are the cheapest arsenic-safe water options using normalized present worth value
• Arsenic-removal using adsorptive media is competitive with large-scale public water supply and deep tubewell systems
• Both community- and household-scale arsenic-removal systems are generally affordable to the Q4 income quintile
• The life-cycle cost approach is useful for assessing water supply options as these relate to equity and the ability to pay

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ABSTRACT

In arsenic-affected regions of Cambodia, rural water committees and planners can choose to promote various arsenic-avoidance and/or arsenic-removal water supply systems. Each of these has different costs of providing water, subsequently born by the consumer in order to be sustainable. On a volumetric basis ($/m3-yr) and of the arsenic-avoidance options considered, small-scale public water supply – e.g., treated water provided to a central tap stand – is the most expensive option on a life-cycle cost basis. Rainwater harvesting, protected hand dug wells, and vendor-supplied water are the cheapest with a normalized present worth value, ranging from $2 to $10 per cubic meter per year of water delivered. Subsidization of capital costs is needed to make even these options affordable to the lowest (Q5) quintile. The range of arsenic-removal systems considered here, using adsorptive media, is competitive with large-scale public water supply and deep tube well systems. Both community level and household-scale systems are in a range that is affordable to the Q4 quintile, though more research and field trials are needed. At a target cost of $5.00/m3, arsenic removal systems will compete with the OpEx costs for most of the arsenic-safe water systems that are currently available. The life-cycle cost approach is a valuable method for comparing alternatives and for assessing current water supply practices as these relate to equity and the ability to pay.

1. Introduction

Global headlines were made by the onset of arsenicosis in Bangladesh and West Bengal, India, in the 1990s, the result of people consuming groundwater containing arsenic. Other areas of Southeast Asia are also affected. Nearly 60 million people live in areas of high geogenic (naturally-occurring) arsenic contamination, and many of them have no choice but to use this as their primary drinking water source, especially during the dry seasons (World Bank, 2005). Arsenicosis is evidenced by a variety of manifestations, including skin discoloration, cancers of the bladder, kidney and lung, diseases of the blood vessels, diabetes, high blood pressure and reproductive disorders (Ravenscroft et al., 2009). Although chronic arsenic exposure is mostly via groundwater supply, use of unprotected surface water sources produces an array of gastrointestinal illnesses, manifested in acute diarrhea. Safe drinking water should thus not only reduce the *acute* effects of diarrheal diseases, but also the *chronic* effects of arsenicosis. Positively, the supply of such water also provides numerous livelihood benefits for rural populations because time can be more gainfully spent, particularly for the lower income brackets (WHO, 2012).

In water-rich regions such as Cambodia, the provision of "arsenic-safe" water (defined as below the Cambodian standard of 50 ppb) may come through one or both of two pathways — i) *arsenic avoidance* using traditional surface water sources or re-drilling of a well and ii) *arsenic removal* by treating well water to remove the arsenic to safe levels. *Arsenic avoidance* schemes often rely on surface water that is naturally arsenic-safe but typically has mid- to high-level contamination with microbial pathogens that result in diarrhea and subsequent complications (Shantz, 2012). Conversely, *arsenic removal* using adsorption materials should produce water that has low or no associated microbial risk (assuming the well is not exposed to surface contamination and

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safe handling after treatment). Effective adsorption materials can range from higher-cost proprietary materials to lower-cost, amended natural materials that are locally-available but still under development.

Both arsenic-safe water pathways are available to the wealthy, but represent real challenges to those who live at or below the poverty level, which in Cambodia is about 3 million people (1/5 of the total population) (World Bank, 2012). This number includes the bottom two income quintiles of the population with annual incomes of \$82 to \$201 per capita (Cambodia National Institute of Statistics, 2011). For this part of the population, it has been assumed that arsenic removal technologies are too expensive. On the other hand, water of poor bacteriological quality accounts for many more deaths, annually and over time, than does arsenic contamination (WHO, 2012). Such disparity warrants a closer look at an optimal selection of water sources.

A significant study recently completed for the Water and Sanitation Program of the World Bank (Shantz, 2012) included in its recommendations the following:

1. Promote household (HH) drinking water treatment for microbiological contamination, as safe storage and hygiene will continue to be critical, regardless of the water source,
2. When promoting arsenic-safe drinking water, focus on (at least) three sources: large- and small-scale piped water systems with treatment, rainwater harvesting with year-round storage capacity, and vendor sale and delivery in self-contained water jugs.
3. Consider arsenic interventions that, even if slightly more costly, can also potentially reduce the risk of microbial contamination and gastrointestinal illness, providing substantial savings to individuals and society.

Though not all are available in every locale, rural Cambodian residents will likely select from one or more of the following arsenic avoidance water systems:

(1) Rainwater harvesting and storage,
(2) Purchase of water from a water vendor on an as-needed basis,
(3) Village-level treatment and distribution of network piped water, either small-scale (to a public tap, 3a) or large-scale (to individual households, 3b),
(4) Protected shallow hand-dug well, and
(5) New deep tube well, either shallow (<80 m in depth, 5a) or deep (>80 m in depth, 5b), in an arsenic-safe zone.

The water supplied can be from rainwater, surface water rivers and ponds, or from groundwater. Each of the above arsenic-safe water sources (with the possible exception of the new tube well) is likely to be contaminated with microbial pathogens. Domestic water sources and usage in rural Cambodia vary according to the season. During the rainy (wet) season, most families collect and use rainwater for both drinking and non-potable uses. During the dry season, drinking water comes both from tube wells (where available) and from remaining stored rainwater or vendor-supplied water (Shantz, 2012). Households that currently use a shared tube well are most likely to be poor, be less educated, and have a lower awareness of the health risks from arsenic-tainted water (Shantz, 2012).

Discussion of water provision often focuses on household-level treatment vs. community-scale treatment. In Bangladesh, household filters have been promoted to remove arsenic from shallow tube wells that yield arsenic-laden water. Even though the initial cost of the filters was highly subsidized, the project did not subsidize the replacement costs (~\$35–\$65 each) which were too high for many middle- and low-income households. Consequently, a quarter of the receiving households abandoned their filters after two years (Johnston et al., 2010).

Community-level filters can treat enough water for 50 or more households and can be more consistently cleaned and maintained, resulting in longer filter life (Johnston et al., 2010). A "first-generation" of community-based arsenic removal systems has been assessed in India using two types of adsorbent media and serving about two hundred families per unit (Sarkar et al., 2010). Both activated alumina and a proprietary hybrid anion exchanger (HAIX) media are regenerated by a few trained villagers, and arsenic-laden solids are contained in a coarse sand filter. (Sarkar et al., 2010). An emerging method for arsenic removal is the use of locally-produced/available media to remove arsenic via adsorption.

This study utilizes the life-cycle costing approach to evaluate and compare current arsenic-free safe water options with arsenic-removal technologies in rural Cambodia. The overall intent is to assess the level of affordability for the lowest three income quintiles and to assess an optimal suite of water source options for wet and dry season provision at the levels of water demand proposed in (Howard and Bartram, 2003). These levels are 7.5 l per capita per day (lpcd) for consumption via drinking and cooking and 20 lpcd for basic hygiene and health protection, including consumption.

The specific objectives are to:

1. Compare life-cycle costs of providing water using seven traditional arsenic avoidance options,
2. Generate life-cycle costs using currently-available arsenic adsorption media and compare on a community- and household-level scale, and
3. Evaluate equity using willingness-to-pay and affordability indicators for the lowest three income quintiles (Q5, Q4, Q3).

The results of this research can be used by water committees and stakeholders to compare water source systems and incentivize best options not only in Cambodia but also more broadly, and can be used by planners as a template for specific comparisons using local data.

2. Methodology

The study area is defined as the rural, arsenic-impacted region of the Mekong Delta in Cambodia, to the east and south of Phnom Penh. The three most highly-affected provinces and their exposed populations (greater than 50 ppb) are Kandal (~70,000 people), Prey Veng (~39,000) and Kampong Cham (~23,000) provinces (Shantz, 2012).

The selection of the options chosen for comparison is based on current and near-term likelihood of provision. Although many of the options represent a shared source, an added advantage is that each of these assumes either a near-household point of water collection (e.g., a dug well) or, at least, a central location point that is less than 1000 m (<30 min collection time) from each household (Howard and Bartram, 2003). Thus, in this analysis we did not include a time-savings benefit.

2.1. Life-cycle costs for water supply

The life-cycle costs approach (LCCA) is a cost accounting method that disaggregates costs into components that encompass the life of the system from design and planning to water provision. Costs may be analyzed in different ways — e.g., by household, per unit volume of water delivered (USD/m^3), or by a time period (USD/month) (Fonseca, 2011). The advantage of the approach is that, by maintaining the cost components separately, one is allowed a unit-level analysis of what it takes to plan, build, sustain, repair, and renew a water system throughout its life cycle. Future costs, such as operation and maintenance, are discounted back to their present worth. The result is a time-sensitive picture of all pertinent WASH costs needed to provide safe water.

We first distinguish between water supply *prices* (as seen by the consumer) and *costs* (as borne by the provider). These two quantities are often not the same, as the price for water is higher than that of the actual costs in the case of for-profit water providers and is lower than that of the actual costs in the case of subsidized water provision (Fonseca, 2011). When determining long-term sustainability of a water source option, the balance between supply and demand (functions of both cost and price) needs to be considered. Life-cycle costs for traditional water systems are tabulated based on published data

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