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Decision support system for economic assessment of water improvements in remote, low-resource settings

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A B S T R A C T

Since most people without access to safe water services live in remote areas of developing countries, assessing the economics of rural water developments poses a globally pressing challenge. This study seeks to: (1) outline the rural (non-networked) water development decision process in a systematic way; (2) incorporate that process into a modeling tool in order to conduct consistent economic analysis of developments across a wide range of contexts, and (3) assess the performance and potential applications of this tool. We introduce *AWARE*, a recently developed Decision Support System, to provide a generalized model of the processes and constraints related to the advancement of rural water services. *AWARE* enables robust comparisons to be made across a wide range of social, economic, physical, technical and management approaches. We demonstrate that it performs adequately, and propose that, despite its generalized approach, it will be useful for informing both development strategies and field projects.

Software availability

The *AWARE* software is available for download at no cost at: https://dl.dropboxusercontent.com/u/24352729/DSS.zip
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E-mail: dr.adam.abramson@gmail.com
Year first available: 2013
Hardware requirements: Microsoft Windows PC
Software requirements: Microsoft Excel, HYDRUS-1D
Program language: VBA
Program size: 8.1 MB

1. Introduction

Providing access to improved water sources in remote areas differs in important ways from such efforts in more urban settings: low population densities, together with a lack of centralized infrastructure, including grid electricity, prohibit the economies of scale associated with water networks from being achieved. As a result, expanding access within such communities involves many unique constraints, including a wide range of spatial dimensions further limited by a dependence on non-networked, local water sources, the economic challenges associated with a low willingness to pay in remote areas (as demonstrated, for example, by a meta-analysis conducted by Abramson et al., 2011), and the technological requirements of accessing and pumping water.

The dearth of sophisticated water infrastructures in remote areas attests to these challenges. Recent estimates suggest that only 24% of households in rural areas of developing countries use a tap in their home, compared to 73% of their urban counterparts (UNICEF and WHO, 2012). In regions with extremely low levels of infrastructure development, such as rural Sub-Saharan Africa where the rate of electricity access is less than one-fourth that of the rural developing world, this figure is proportionately reduced (OECD and IEA, 2012). As a whole, most (55%) remote communities fetch water from stand-pipes or hand-operated borehole pumps. The rest (20%) use unimproved water sources, including surface water.

With such a high dependence on non-networked, localized water services, providing insights into the economic dimensions of rural water improvements is a challenge, especially when extrapolating regional or global insights from a wide range of local

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contexts. Indeed, assessing the costs and benefits of reaching global drinking water targets has been a primary objective of many studies since the United Nations Millennium Development Goals (MDGs) were formulated in 2000 (www.un.org/millenniumgoals; Cosgrove and Rijsberman, 2000; GWP, 2000; WHO and UNICEF, 2000; WSSCC, 2000; Devarajan et al., 2002; Smets, 2003; Winpenny, 2003; Mehta et al., 2005; Haller et al., 2007; Hutton et al., 2007; Hutton, 2012). Due to the high variability of the technical, environmental, and managerial aspects of non-networked rural water services, various simplifications and assumptions were applied in these studies within vastly different social, political and economic contexts. A good example is the use of mean unit costs of past improvements to extrapolate the costs of developments for any given unreached population. These assumptions severely limit the ability of such assessments to align with the actual dynamics of the modeled communities, and prohibit the direct comparison of novel approaches with past efforts. Clearly, more robust approaches are needed.

Decision support tools offer a promising solution, since they are holistic, computerized frameworks for aiding decision-making involving multiple disciplines, constraints and objectives. Due to the complexity and multi-disciplinary nature of water resource management, such tools have yielded a high number of applications in this field (Keedwell and Khu, 2005; Makropoulos et al., 2008; Chung and Lansey, 2008; Liu et al., 2009; Pereira et al., 2012). For optimizing remote water services, one tool has been developed for a rural area in India by Olsen (2005) and another, only partially developed, for communities in South Africa (Sami and Murray, 1998). To our knowledge, however, no decision support tool has been developed to investigate remote, non-networked water services from a generalizable perspective, with potential for global application.

To develop an effective Decision Support System (DSS), all parameters relevant to the rural water development process should be simultaneously incorporated. While the above approaches include some relevant parameters (capital cost, economic demand, and water quantity requirements), they lack the following: (1) the ability to investigate groundwater-based sources – the most common water source in remote areas of developing regions—as well as a variety of feasible water pumping approaches; (2) spatial parameters, including population density, a water map outlining the spatial configuration of the community, and a water-fetching time target; (3) the ability to incorporate adequate economic data, including sound estimates of demand for water service improvements; and (4) a coherent water development algorithm that incorporates a wide range of parameters and moves logically through the water development process. In short, these multi-criteria approaches are useful for providing general assessments across various disciplines, but fall short in their ability to draw meaningful policy conclusions from robust, consistent, and disaggregated data and modeling mechanisms. Unlike the existing tools described above, the various social, environmental and economic dimensions of remote water configurations should be incorporated within a consistent modeling framework by a single (economic) metric, rather than by multiple criteria.

The major objectives of this study are: (1) to outline the rural (non-networked) water development decision process in a systematic way; (2) to incorporate that process into a modeling tool in order to conduct consistent economic analysis of developments across a wide range of contexts, and (3) to assess the performance and potential applications of this tool. This study presents the methodological framework of *AWARE* (**A**ssessing **W**ater **A**lternatives for **R**emote **E**conomies), a DSS for exploring the economics of non-networked water developments for providing access to improved water services in remote areas. The application of the DSS is focused on cases where developing new water sources is more cost-effective than creating a water network. The tool is intended for (1) policymakers wishing to assess the economics of water improvements across a wide range of contexts, and (2) water practitioners needing to make preliminary assessments of field projects. Section 2 introduces the conceptual dimensions and components of the decision process. Section 3 outlines the integration of these dimensions into the DSS. Section 4 explores the validation of the framework through an example, and Section 5, through a parameter uncertainty analysis. Section 6 identifies and discusses potential applications of the DSS.

2. Components of the rural water decision process

This section outlines the main components of the decision process for rural water developments. This process consists of three main components: (1) parameters, both variable and constant, that are manipulated by (2) an algorithm to obtain (3) desired results. *AWARE* performs an exhaustive search of a combinatorial optimization procedure to identify the water service configurations that provide the lowest cost and highest net benefit under the technical alternatives and parameter values considered (Fig. 1).

The general relation of the social, physical, economic, management, technological and agronomic parameters to the decision process is shown in Fig. 1. A complete list of all 88 parameters is supplied in the supporting information, Tables A.1–A.6. The main process involves first describing the existing and targeted water service levels and then describing the array of technologies, along with their specifications, to be considered for reaching the targeted service level. Since the technologies are decomposed into their relevant attributes (*i.e.*, pumping rate, cost, maximum yield), any technological solution, including water source, extraction and/or treatment method, that is defined appropriately, can be considered. *AWARE* then applies these technologies across all possible configurations in the given community, first by considering all feasible improvements to existing water services, and then, by developing the necessary number of new water sources to reach the water service target. The economic demand for the service improvement is compared with the cost under each water service configuration considered. The main results are the details of the configuration that achieves the targeted service level at: (1) the lowest cost, and (2) the highest net benefit.

2.1. Quantity, quality, and fetching time: existing and targeted service levels

In order to assess the improvement of water services, it is first necessary to define the current state of a community's water services, as well as the target to be reached by the improvement. The most widely used and accepted target for drinking water is the notion of access to "safe" water, which is measured by the indicator of "access to an improved water source." This is defined by the World Health Organization (WHO) and adopted into the MDGs (WHO and UNICEF, 2013). This serves as an important concept, therefore, for the rural water decision process. According to the WHO, this concept is defined by three primary attributes of a water source: the quality of the water, the quantity available and its distance in relation to the household. We, therefore, incorporate these attributes into the DSS framework. These align with previous studies of attribute-based economic demand for water service improvements (Hensher et al., 2005; Echenique and Seshagiri, 2009; Abramson et al., 2011), allowing such approaches to be incorporated into the decision process for demand estimation. We explore this in detail in Section 2.2.