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A novel planning approach for the water, sanitation and hygiene (WaSH) sector: The use of object-oriented bayesian networks

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ABSTRACT

Conventional approaches to design and plan water, sanitation, and hygiene (WaSH) interventions are not suitable for capturing the increasing complexity of the context in which these services are delivered. Multidimensional tools are needed to unravel the links between access to basic services and the socio-economic drivers of poverty. This paper applies an object-oriented Bayesian network to reflect the main issues that determine access to WaSH services. A national Program in Kenya has been analyzed as initial case study. The main findings suggest that the proposed approach is able to accommodate local conditions and to represent an accurate reflection of the complexities of WaSH issues, incorporating the uncertainty intrinsic to service delivery processes. Results indicate those areas in which policy makers should prioritize efforts and resources. Similarly, the study shows the effects of sector interventions, as well as the foreseen impact of various scenarios related to the national Program.

1. Introduction

Safe drinking water, adequate sanitation, and hygiene (WaSH) are pillars of human health and well-being. In consequence, the 2030 Agenda for Sustainable Development, adopted in September 2015, has water and sanitation at its core (United Nations General Assembly, 2015). The Sustainable Development Goal dedicated to water (SDG 6) will represent a huge challenge for many countries, and it will be the driving force to shape ambitious policies on which to base the development of sector strategies and national Programs. It will be essential to promote efficient and sound decision making when designing interventions for accelerating progress towards universal access to these basic services. Appropriate tools will thus be needed to plan service delivery, to measure performance, and to influence resource allocation (Cohen and Sullivan, 2010; Giné Garriga et al., 2015).

To date, there have been numerous approaches to provide a coherent strategic planning framework. In particular, efforts have been directed at addressing specific problems that range from improving the availability of reliable information, to improving access to information through data analysis, interpretation, and dissemination, and to encouraging the use of this information in decision-making processes (Giné Garriga, 2015). For instance, various methods are in place to collect WaSH primary data (Giné Garriga et al., 2013; United Nations Children's Fund, 2006; WaterAid and ODI, 2005). Furthermore, the sector has witnessed the development of a variety of conceptual frameworks to monitor service delivery, albeit from different perspectives (Cohen and Sullivan, 2010; Flores Baquero et al., 2013; Giné Garriga and Pérez Foguet, 2013a; Luh et al., 2013; Sullivan et al., 2003). Significant attempts have also been made to provide decision-makers with reliable information to support planning, targeting, and prioritization, particularly in decentralized contexts (Ghosh and Rao, 1994; Giné Garriga et al., 2015).

Despite the likely use of previous approaches to inform planning and decision-making processes, these suffer from a number of common weaknesses. First, indicators and aggregated indices tend to induce a somewhat narrow, issue-centered perspective on the service provision, which is not conducive to a good understanding of the complex cause and effect relations within WaSH variables. For instance, the direct link between "distance to the water source (access to water) – water consumption (use of water) – handwashing behavior (personal hygiene)" is rarely captured through an

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indicator-based approach. There is thus a need to adopt a conceptual model that allows indicators to be relevant for multiple causal chains and to incorporate the existing human behavior - service provision - environment interactions. Second, an adequate approach for targeting and prioritization would be to consider the proportion *p* of households verifying a given variable (e.g., access to improved sanitation) with its respective confidence interval (Giné Garriga et al., 2015). In composite indices, however, priority ranks and league tables are typically based on a measure of central tendency, which is rarely contrasted with the dispersion or variability of the population distribution (Giné Garriga and Pérez Foguet, 2013a; Sullivan et al., 2003; United Nations Development Programme, 2015). This jeopardizes an adequate identification of the neediest and most vulnerable populations (Flores Baquero et al., 2016; Giné Garriga et al., 2015). Third, representing a range of scenarios and assessing their potential impact may be a desirable feature of any planning tool (Bromley et al., 2005; Castelletti and Soncini-Sessa, 2007a, 2007b). Yet, impact assessment of different scenarios is not straightforward in an index framework, as cause and effect relationships between policy initiatives, remedial actions and their impact are not correctly integrated.

Against this background, this paper exploits the flexibility of Bayesian networks (BNs) to simultaneously exploit multiple cause-effect relationships and to unravel the links between poverty and WaSH services. In doing so, we seek to produce a valuable planning tool that takes into account the process uncertainties and guides decision-makers in evaluating decision options against multiple criteria and in choosing the most appropriate actions.

First, a WASH-focused approach is adopted through a multidimensional estimate, the WaSH Poverty Index (WaSH PI), which is taken as a starting point to define the conceptual framework. This index was proposed in a previous study by us (Giné Garriga and Pérez Foguet, 2013a), to integrate in measurement the socio-economic, physical, environmental, and institutional drivers that affect the sustainable access and use of water and sanitation services. Its theoretical foundations build on a combination of three composites that separately report on different service levels for drinking water, sanitation, and hygiene. The water-related index is founded on the Water Poverty Index (WPI) framework from Sullivan (2002) and Sullivan et al. (2003) and tackles the priority water-related challenges in low-income settings: availability of water (Resources, R_{WPI}), access to water (Access, A_{WPI}), capacity for sustaining access (Capacity, C_{WPI}), and ways in which water is used for different purposes (Use, U_{WPI}). The Sanitation Poverty Index (SPI) aims to assess whether or not people use basic sanitation, and not the mere existence of infrastructure. Therefore, SPI not only gauges the extent of access to sanitation, both in terms of accessibility and affordability (Access, A_{SPI}), but also assesses people's ability to construct and repair latrines (Capacity, C_{SPI}), and includes those hygienic factors that enable a continued use of the facility (Use, U_{SPI}). The Hygiene Poverty Index (HPI) is measured by the aggregation of four different components (Webb et al., 2006), each one representing a different transmission route by which oral–fecal contamination may occur: drinking water (DW_{HPI}), food (F_{HPI}), personal hygiene (PH_{HPI}), and domestic household hygiene (DH_{HPI}).

On the basis of the WaSH PI concept, an object-oriented Bayesian network (OOBN) model is then developed to identify the key determinants of sustainable access to water, sanitation and hygiene. Bayesian network (BNs) are graphically structured and thus exploit the duality between an interaction graph and a probability model based on Bayes' rule (Castelletti and Soncini-Sessa, 2007a). The graphical structure provides a visual representation of the logical relationship between variables, while conditional probabilities quantify this relationship and are thus required to fully run the network (Bromley, 2005). BNs are made up of three different elements: i) a series of nodes representing a set of variables relevant to the problem at hand, ii) the links between these variables that express cause-effect relationships among them, and iii) the conditional probability tables (CPTs) behind each node that are used to assess the extent to which one variable is likely to be affected by the others (Bromley, 2005; Cain, 2001). The BN approach is useful for incorporating data and knowledge from different sources and domains, including the economic, social, physical, and environmental (Bromley et al., 2005; Castelletti and Soncini-Sessa, 2007a; Henriksen and Barlebo, 2008); this key characteristic makes BNs particularly suited for monitoring WaSH services in an interdisciplinary, holistic way (Alok, 2002; Fisher et al., 2015). Similarly, this technique has gained a reputation of being helpful for simulating complex problems that involve uncertain knowledge (Henriksen et al., 2007). In the field of water resources, where many variables are highly interlinked and uncertainty plays a key role (Bromley et al., 2005; Castelletti and Soncini-Sessa, 2007a), BNs have been increasingly applied as an aid to decision making (Bromley et al., 2005; Castelletti and Soncini-Sessa, 2007a; Henriksen and Barlebo, 2008; Molina et al., 2013, 2009). One weakness of conventional BNs, however, is that they are unable to receive or transmit information from outside the system (Molina et al., 2010). Alternatively, an OOBN model offers a suitable framework that allows different networks to be linked together. OOBNs are therefore appropriate for use as organizational applications, which is the focus of this research (Molina et al., 2013).

Here we present a case study from Kenya, on a national program that the Kenya government launched in 2010 (hereafter referred to as the "program" or the "intervention") to improve the access to safe drinking water, adequate sanitation infrastructure, and hygiene for the rural population. In light of its implementation, we first adopt the WaSH PI conceptual framework, due to its ability to integrate all relevant WaSH issues. We then apply an OOBN model as a management tool to support planning and decision making. With this study, we aim to judge the validity and relevance of this approach to assist planners and managers in i) capturing a comprehensive picture of the key elements that determine access to WaSH and their interlinkages, ii) making rational and informed choices between alternative actions, and iii) estimating the impact of these choices on key WaSH variables.

The article is structured as follows: Section 2 describes the methods and the process of OOBN construction and presents the case study; Section 3 presents and discusses the achieved results and the network system, simulates two different scenarios to predict the impact of the program, and gives various recommendations for improving design, planning, and implementation of the intervention; and Section 4 highlights the major findings and conclusions of the study.

2. Methodology

This section deals with the construction stages of the decision support system (DSS) based on an OOBN. To this end, a commercial software package produced by HUGIN® (v7.2) was used in this study. The first stage defines the problem and describes the transition process from an index to a network system. The second stage names the set of variables and identifies their interlinkages, to illustrate the context in which WaSH services are delivered. The third stage processes data from all available information sources. The fourth stage assigns the states for all variables, and then constructs the conditional probability tables. Finally, the fifth stage validates the model and its outcomes.