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Targeting investments in small-scale groundwater irrigation using Bayesian networks for a data-scarce river basin in Sub-Saharan Africa

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ABSTRACT

Irrigation for smallholder farming systems is an important approach for sustainable intensification and increased productivity in Sub-Saharan Africa, provided investments in irrigation are properly targeted and accompanied by complementary improvements. Many GIS-based tools have been developed to identify suitable areas for investments in different types of small scale irrigation (SSI), but they do not explicitly address uncertainty on the data input and on the determination of factors that affect success of an investment in a given context. This paper addresses this problem by presenting an application of a decision-support targeting tool based on Bayesian networks (BNs) that can be used by non-expert policy-makers and investors to assess the potential success of specific technologies used for groundwater-based SSI. A case study application for the White Volta Basin in West Africa is presented to illustrate the BN approach.

1. Introduction

The case for prioritizing agriculture in public and donor investments is strong in Sub-Saharan African (SSA) countries where agriculture generates a large proportion of national income and food supply. Growth in the contribution of agriculture to GDP is far more effective in reducing poverty in developing countries than growth in other sectors (Cervantes-Godoy and Dewbre, 2010; The World Bank, 2007). Although absolute levels of investment in agriculture are important, it is even more essential to ensure that the investments being made are targeted, efficient, and equitable to produce the best returns. However, for many years, inadequate technology transfers and policy and investment environments have acted to hamper successful transitions out of poverty (Lybbert and Sumner, 2012).

The positive impact of small-scale irrigation (SSI) investments on agriculture intensification, increased crop productivity and farm income has been well documented (Domenech, 2015; Hussain and Hanjra, 2004). The norm for SSI investments has been to take localized success stories and scale them up and out to other places. But this has had mixed results due mostly to a lack of knowledge or consideration of the applicability of a successful technology or intervention to a different context (Hounkonnou et al., 2012). In particular, while the open access nature of shallow groundwater has made it a powerful tool in the fight against poverty (Moench, 2002), this has led to widespread and uncontrolled over-abstraction of the resource or to the use of inappropriate irrigation methods (de Fraiture and Giordano, 2014; Roy and Shah, 2002).

Unsuccessful out-scaling of technological innovations, due to political, cultural, environmental and other barriers, created a demand for decision tools to improve investments in agricultural water management. Various spatial decision-support tools are available for identifying potential areas where certain SSI investments may be successful. Some are more locally focused, whereas others are national to sub continental (Andersson et al., 2009; Altchenko and Villholth, 2014; Mati et al., 2006; Mbilinyi et al., 2007; You et al., 2011). However, existing tools are limited in three main ways: (i) they are too complex and/or do not allow customization by non-expert users, thus decreasing their chance of being endorsed by intended users; (ii) they focus on surface water irrigation technologies, thus ignoring the potential of groundwater for lasting agricultural growth in SSA; and (iii) they do not explicitly address uncertainty in the determination of the factors that affect success of an investment, thus becoming less effective in uncertain and data scarce-environments.

To elicit the likelihood of success of groundwater irrigation

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technologies in data-scarce environments where information about the factors and their relationship to success is uncertain or incomplete, we developed an application of a Bayesian-based mapping tool called TAGMI (Targeting AGricultural water Management Interventions) and presented the mapping results on an interactive online platform accessible to the general public (http://iwmi-tagmi.cloudapp.net). The TAGMI decision support tool is an evidence and knowledge-based tool constructed in a participatory manner and based on the sustainable livelihoods framework. TAGMI improves on previous decision-support tools by presenting results in a simple and customizable interface and by explicitly modelling uncertainty in the relationship between factors and chances of success of a specific investment through the use of a BN. The original model was developed as a proof of concept and mapped the regional to national likelihood that broad management practices such as small scale irrigation, conservation agriculture and small reservoirs will be successful in given locations across the Volta and Limpopo Basins in West and Southern Africa respectively (Barron et al., 2015).

This study brings the TAGMI tool one step forward in the transition from proof of concept to a tool used on the ground by non-expert users as a pre-scoping method to guide their investments. We aid this transition by: (i) focusing on the targeting of specific technologies (rather than broader management practices) and on groundwater-based irrigation; and (ii) collecting data on several factors at finer scales of disaggregation. This paper illustrates the value of these advancements for a data-scarce river basin in West Africa where shallow groundwater irrigation is an important economic activity for dry season farming. Using BNs in a consultative approach, geographical areas that are suitable for adoption of specific technologies were identified based on critical biophysical, socioeconomic and institutional conditions. This targeting exercise may be useful to non-expert users of local governments, donors, NGOs and the private sector not only to ensure success of public and private technology investments but also to identify supporting investments for the socio-economic and institutional context in certain locations.

The paper starts by describing in the next section how TAGMI improves on alternative spatial targeting tools for SSI investments, by assisting decision makers in explicitly addressing uncertainty and data scarcity. Next, the paper includes a description of the steps to construct the tool and a selection of results from the study. A discussion of the contribution of the tool to target policy decisions and investments in the context of the case study application is presented in the final section, alongside suggestions on how the tool can be further developed.

1.1. Tools for spatial targeting of SSI investments in SSA

A number of GIS-based studies have assessed the potential for SSI investments in Africa. At the continental-scale, Bousquet et al. (1997) and FAO (1997) assessed the irrigation potential of Africa, based on a river basin approach and a combination of GIS and water balance calculation programs at regional level. However, no distinction is made among different types of irrigation and technologies. Irrigation cropping patterns zones are not precise enough at the country level and they rely on a low number of climate stations. Mati et al. (2006) presented a continental-scale suitability assessment for rainwater harvesting, taking into account rainfall, population, topography, soils, crop water requirements and domestic user demand. Faures et al. (2008) introduced the concept of "livelihood zoning", and stress the need for a context-specific approach to interventions in water for poverty reduction. The potential of water-related interventions is assessed in each livelihood zone by overlaying GIS layers on the prevalence of poverty, water as a limiting factor for rural livelihoods and the potential for water intervention. Finally, You et al. (2011) improved on these studies by analyzing the potential of different types of irrigation development in Africa based on agronomic, hydrologic, and economic factors while explicitly modelling water availability for irrigation, and the costs and benefits associated with each irrigation type. Although their analysis provides a first filter to help identify the areas of greatest potential, other factors (institutional, agronomic, human, and environmental) that ultimately determine the success of irrigation investments were not considered.

At the local or national-level, Mbilinyi et al. (2007) presented an ArcView tool for targeting of rainwater harvesting technologies, tested in the Makanya catchment in Tanzania, which could be transferred to any location as they used remotely sensed layers that are available globally at medium resolution. Only biophysical factors are included. Kahinda et al. (2008) improve their spatial ArcView-based decision support tool for rainwater harvesting technologies in South Africa by incorporating socio-economic as well as biophysical layers. Finally, the Agricultural Water Solutions project maps the opportunities to invest in agricultural water management (AWM) at the country level in Ethiopia, Ghana, Burkina Faso, Tanzania and Zambia, and at the regional level in Sub-Saharan Africa (Xie et al., 2014). The analysis gathers available thematic maps and district statistics, and combines them with national livelihood maps which were established through an in-depth consultation process to identify opportunities to invest in AWM in support to rural livelihoods.

In terms of interactive SSI suitability or potential mapping tools publicly available for exploration, two are currently available for SSA that combine biophysical and socioeconomic information. One is the Nile-Goblet software, developed by the Nile Basin Development Challenge Project of the CGIAR Challenge Program of Water and Food, which creates suitability maps for rainwater management technologies by overlaying GIS layers (Notenbaert et al., 2013). Users can create their own suitability maps by selecting the layers and defining the thresholds. The second is the HarvestChoice research initiative which has developed publicly available interactive tools to explore different topics related to the improvement of food supply of the world's poor (HarvestChoice, 2015). One of these tools, the AgriTechToolbox, allows the user to explore how key agricultural and food security parameters will change in 2050 by selecting a country or region along with a technology, climate scenario and crop and water management practice. This information may be used to develop investment strategies and scale up agricultural technologies in key food insecure but also breadbasket regions. However, the user is advised that the spatial resolution of the underlying data varies and to interpret the results accordingly (HarvestChoice, 2014).

The incorporation of BN models into GIS-based modelling frameworks for spatial targeting has underpinned the creation of useful tools for policy modelling of livelihoods and natural resources in several different contexts because of the appealing features of BNs (Aguilera et al., 2011; Bacon et al., 2002; Cain, 2001; Henriksen et al., 2007). First, BNs provide an effective way to combine diverse information that draw on several pools of knowledge and consider both social and biophysical factors, (Castelleti and Soncini-Sessa, 2007; Kelly et al., 2013). Second, BNs allow for uncertainty in the factors and relationships in the model, as well as in the input data, because they calculate the conditional probability of the result occurring (successful adoption) rather than the absolute knowledge of whether it will occur or not. Finally, BNs are able to handle missing data because they build on prior probability distributions which can be elicited from experts. This final aspect is particularly useful as policy-relevant contexts often are also those with sparse or non-continuous data.

TAGMI addresses the shortcomings of other GIS-based tools by