Conceptual Modelling of Sustainable Water resource management and Agricultural development under uncertainty: The Case of the Breede River Catchment Area, South Africa

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ABSTRACT

The issue of global water scarcity and food insecurity has become a major cause of concern to governments, international and local organisations, policy-makers, water-users, and water managers (Owusu-Sekyere et al., 2017). The complex relationship that exists between water resources and agricultural production has been increasing constantly globally (Sauer et al., 2008). Water resources are essential for agricultural production because they can limit food production, energy generation, and economic activities in other sectors in the economy (Wallace, 2000) . South Africa is a water scare country and has been ranked the 30th driest country in the world. The 2014–2019 drought catalysed a national conversation in South Africa regarding water security and enabled policy debate regarding water management and agricultural development in the country. The drought also highlighted existing vulnerabilities that exist in South Africa's water system, the dependence of agricultural development on water resources management and properly frame the magnitude of the challenge of ensuring water security for the country. It is therefore very important to sustainably manage water resources in South Africa in order to promote efficient food production. A bottom-top approach to water management is needed to effectively manage water resources in South Africa because including the stakeholders affected by policies in the decision making process will ensure that policies are toilored to the needs of the stakeholders. Participatory modelling (PM) was introduced to remove the bureaucracy ("top-down" approach) in the implementation of decision making in water resource management by involving all relevant stakeholders in the decision making process. The PM and stakeholder engagement have become a very important tool that has been used to facilitate strategic decision-making in complex environmental/natural resource management systems (Kotir et al., 2017).

Participation by all involved stakeholders in policy development and decision-making is very important and forms a crucial part of Integrated Water Resource Management (IWRM). Participatory modelling and stakeholder engagement has become a very important tool that has been used to facilitate strategic decision-making in complex environmental/natural resource management systems.

Several studies have used PM to model water resource management around the world (e.g. Carmona et al., 2013a,b; Basco-Carrera et al., 2017; Beall et al., 2011; Butler and Adamowski, 2015; Lopes and Videira, 2015; Pluchinotta et al., 2018; Davies and Simonovic, 2011; Videira et al., 2009). Furthermore, some studies have PM to model water resource management in Africa (e.g. Kotir et al., 2017; Simonovic et al., (1997); Daré et al., 2018). The previous examples except for Kotir et al. (2017) were not used within a systems dynamic approach, or when system dynamic modelling was adopted, it followed a different methodology with respect to the one presented in this study.

Several studies have used PM in South Africa to model water resource management and as part of the IWRM (e.g. Farolfi et al., 2010; Brown, 2011; Claassen, 2013; Sherwill et al., 2007; de Lange et al., 2010 and Du Toit et al., 2011). However, these studies did not examine the feedback processes operating within a dynamic system.

The purpose of this paper is to develop an integrated qualitative, conceptual model using causal loops diagrams (CLDs) to highlight the relationships and interconnectedness of drivers of change in water resources management and sustainable agricultural development in the Breede River Catchment, Western Cape Province, South Africa. This process involves the use of participatory modelling methods, often referred to as integrated water resource management (IWRM).

Conceptual modelling is one of the methods that have been used in the PM process. This modelling approach is preferable because it increases the understanding of complex dynamic systems where there are several drivers of change interacting with each other to develop multiple feedbacks and processes. According to Horlitz (2007:1098), “PM is characterized by the fact that stakeholders are directly involved into the design of the models in order to ensure that the models are aiming at the problems and stakeholders are able to use them and potential users are actually asked to help develop and test the models”. Conceptual modelling provides a suitable methodology for capturing the option of all relevant stakeholders and represent visually for easy understanding of complex system especially when there is uncertainty about the system or limitations of quantitative data (Argent et al., 2016). Despite the importance of conceptual modelling, very few studies have attempted to use this modelling approach to understand the feedback processes that exist among the drivers of change influencing water resource management and agricultural development in South Africa.

A knowledge gap exists and needs to be filled in order to understand the relationships and feedback processes that exist between the multiple drivers that exist in the management of water resources and agricultural development in South Africa. Thus, this paper presents the participatory and methodological processes involved in the development of an integrated qualitative, conceptual model that captures the causal non-linear relationships between the key and multiple biophysical and socio-economic drivers and processes in the Breede River Catchment, Western Cape Province South Africa, highlighting the key or dominant feedback loop.

Methodology

Modelling Approach

The Western Cape in general and the Breede River Catchment is characterised by a well-developed large commercial farming sector and the smallholder farming sector. In most cases, the issues, trends, and processes affecting these sets of farmers are quite different in relation to the management and distribution of water resources for agricultural purposes. Therefore, any modelling approach adopted should incorporate the perspectives of these farmers in such a way that would represent the overall situation of the catchment. Therefore, this study followed the modelling approach proposed by Inam et al. (2015) and Kotir et al. (2017). The proposed approach for this study consist of six main stages. The overall process comprised of: (1) preparatory activities; (2) stakeholder analysis to determine key stakeholders; (3) mental modelling process during stakeholder workshop; (4) digitising individual CLDs in Vensim; and (5) merging the individual CLDs to form the integrated model; (6) evaluation of the modelling process. Each stage involves several key activities that guided the implementation of the overall modelling process. Detail discussion of the stages is included in the full paper.

To begin the process of stakeholder identification, invitations were sent to farmers' orgnisations (e.g AgriSA, National African Farmers Union (NAFU), African Farmers Association of South Africa (AFASA)), the Department of Water and Sanitation (DWS), Department of Environmental Affairs (DEA), Department of Agriculture (DoA) and other private organisations such as Greencape to nominate stakeholders who would be eligible to participate in the modelling process. A preliminary meeting was organised with the leaders of the farmers' organisations to explain the purpose of the project, system dynamics, the modelling process, and vensim software. In attendance was the head of Natural resources, AGRISA, president of AgriWC, Vice-President of AgriNC, chairperson of Natural Resources, AgriEC, Water, Trade officers at AGRISA, head of NAFU and AFASA. These are all professionals and experts in the agricultural sector in South Africa. Subsequent meetings were organised with officials of DWS, DEA, and DoA. These organisations were required to nominate stakeholders within their organisation with prolonged years of experience through research or practice (i.e., more than 10 years) and their likely availability ability to discuss problems of the catchment with knowledge of water and agricultural related issues in the catchment. Independent farmers (i.e. commercial and smallholder farmers) were also consulted through referrals to check their conpetencies and availability to be included in the modelling process. Participants to be inlcuded in the modelling process doesn't always need modelling aptitude or experience (Kotir et al., 2017). In total, 100 potential stakeholders were identified to be included in the modelling process. Several workshops were planned so as to have smaller groups of participants in the workshops for effective results. The profile of the workshop participants ranged from agricultural economists, disaster managers, water modellers, farmers (commercial and smallholder), senior researchers and bankers in South Africa.

Preliminary Results

Figure 1 shows the integrated conceptual model developed for the Breede River Catchment. The denotes ("+") indicating a positive link; ("-") indicates a negative link. (R) denotes a Reinforcing (or positive) loop; (B) denotes a Balancing (or negative) loop. The \\ on the arrows denotes time delay (that is change over time) in the model. The model has 36 variables (drivers of change) representing several causal relationships. The model shows 11 reinforcing loops and 8 balancing loops. Loop R1 and R2 show the relationship between agricultural production, crop yield, food availability, food demand, crop prices, and farm income. As agricultural production increases, it leads to crop yield food availability, food demand, crop price, and farm income are reinforced. Loop R3 shows part of the population dynamics. An increase in population will increase food demand which influences food availability and population growth. This loop is balanced by loop B4 and B5, where food availability will increase population growth and population growth, will decrease food availability. Futhermore, food availability will increase food demand and an increase in food demand will reduce food availability. Loop R4 shows labour dynamics. An increase in population will over increase labour availability which will positively influence agricultural production, crop yield, food availability, and pupolation growth. Loop B7 shows demand dynamics. An increase in food demand, all things being equal will lead to an increase in food prices. An increase in food prices on the otherhand will lead to a decrease in demand.

Loop B1 and B2 show water demand dynamics. B1 shows that an increase in water demand for various purposes will reduce surface water availability and surface water availability will increase water demand for various purposes. B2 shows that an increase in water demand for various purposes will reduce surface water availability, total water supply, and water demand.

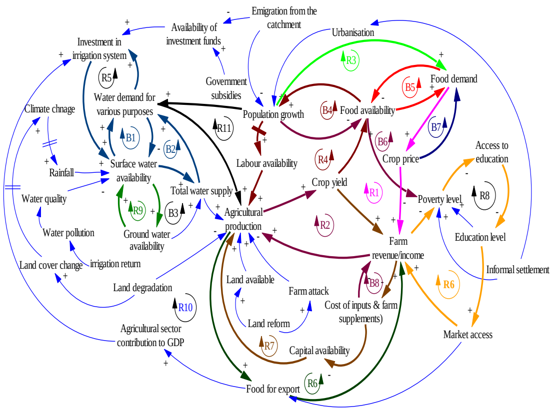

Figure 1: Integrated Conceptual model of the Breede River Catchment

Loop R5 shows investment dynamics. An increase investment infrustructures (such as effcient irrigation scheme, waste water, and salination plants, dams, etc.) will positively influence surface water availability, total water supply, water demand for various purposes and investment in water infrastracture. Loop R7 is another important loop. This loop is the agricultural profitability loops which show that farm income will influence input prices, capital availability, food production, and crop yield. This loop is balanced by loop B8 which shows that farm income will increase input cost and input cost will reduce farm income. Loop R6 shows poverty dynamics. An increase in poverty levels will influence access to education, educational levels, access to information and formal markets and farm income.

Stakeholders' feedback after the modelling workshops showed that the process contributed provided a better understanding of the catchment’s water and agriculture related problems. A detailed discussion of the sub-models, integrated model, lessons learned and challenges are presented in the full paper.

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