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Review

Food and water security: Analysis of integrated modeling platforms

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ABSTRACT

Food and water security are directly linked through the agricultural sector and food production and processing. Increasing stresses on food and water resources, influenced by factors such as population growth and climate change, threaten global food and water security. Previous studies have attempted to address this issue with the development of various modeling frameworks, often combining food security and water security models to address the inter-relationship between the two concepts. This study first introduces some of the background and foundational principles behind food and water security models, then critically reviews models that jointly analyze the two concepts. Initially, the dynamic definitions and historic development of water and food security concepts are reviewed. Current global hydrological models and food production/consumption models are then discussed to provide requisite background on available modeling platforms that separately assess water and food security. This study then focuses on an evaluation of ten models that assess food and water security from an interdisciplinary perspective, providing in-depth analysis regarding input parameters, model processes, advantages and limitations. Results suggest that there is a need to further develop input datasets as well as spatial and temporal resolution in existing food and water security models. This will provide the foundation for the development of effective policies and strategies to mitigate future food and water security issues, while considering the protection of the natural environment.

Contents

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1. Introduction

Globally, both food and water resources are under significant pressure to meet the needs of a growing population. Millions of people worldwide face considerable threats to their food and water security, and the impacts of these issues will only be intensified with future effects of global climate change and changes to land-use. It has thus become apparent in recent years that the connections between food and water supply must be explored in order to work toward a state of global food and water security.

Water supply and availability directly affect food production through agricultural practices. Sufficient water supply is vital to ensure crop growth and livestock survival, and agriculture accounts for approximately 70% of global freshwater use (United Nations Department of Economic and Social Affairs, 2014). Conversely, improper management practices in the agricultural sector can result in runoff and contamination by excess nutrients or chemicals entering into the water supply. As a consequence, neither food or water security can realistically be achieved on a global scale without the other. It is therefore important to consider food and water security from an interdisciplinary perspective in the pursuit of global security. In order to work toward global food and water security, it is first necessary to have an understanding of how global food and water systems operate, how they are affected by various drivers, and how they will be expected to change in the future. Modeling platforms allow researchers to simulate and understand current systems, identify key drivers and their potential impact, and make specific parameter alterations to predict future scenarios. They also provide the basis for critical thought necessary to design and simulate solutions for system improvement.

Previous research has led to the development of a number of modeling platforms to jointly analyze food and water security (Alcamo et al., 2001; Amarasinghe, 2005; Blanco et al., 2012; Bondeau et al., 2007; de Fraiture, 2007; Grafton et al., 2015; Liu et al., 2007; Rosegrant et al., 2008; Siebert and Döll, 2008; Wei et al., 2009). These models have been developed for a variety of circumstances and conditions, and have vast differences in their operation and overall purpose. This review and analysis is intended to provide a basis for research studies concerned with the application or adaptation of interdisciplinary food and water security models. A fundamental understanding of the depth of potential modeling platforms, and their various capabilities and uses, is required prior to selecting the appropriate tool for a particular application. This manuscript attempts to identify key drivers of food and water security models, and offers a basis for comparison of several of the models according to these key drivers, input requirements, model limitations and advantages.

This manuscript initially discusses the fundamental concepts of food and water security to provide the broader context and requisite background on these topics. In doing so, the manuscript summarizes current hydrological and food production and consumption modeling structures that have been applied independently for either water or food security analyses. This information serves as a foundation for research and provides insight into more detailed and complex interdisciplinary models. The paper then focuses on ten food and water security models to critically review and analyze their application, processes, input data and information, advantages and limitations. Results from this analysis will provide guidance for model selection and development to improve understanding of the interdisciplinary nature of food and water security.

2. Overview of water security

Globally, fresh water may be our most precious resource; however, threats to global water security continue to impact the health of our fresh water resources. The global water cycle is being significantly altered by land development and the resulting effects to runoff, evapotranspiration and groundwater recharge processes. In urban and other developing areas, population growth decreases the availability of fresh water while urbanization decreases recharge to groundwater and increases stormwater runoff. Urbanization also impacts water quality, as the high volume of stormwater runoff transports contaminants from urban areas to groundwater and surface water bodies. The conversion of natural vegetation to agricultural land results in the over-extraction of water to support crop production (Siebert and Döll, 2010), thereby decreasing fresh water availability. Additionally, chemical agricultural controls including fertilizers and pesticides have been used indiscriminately to promote food growth, resulting in violations of water quality standards (Poincelot, 1986).

Climate change is another significant threat to global water security. Changes in the frequency, pattern and volume of precipitation events will affect water quality and availability, as well as the ability of current infrastructure to respond to extreme weather hazards. Rising temperatures also threaten seasonal availability and quality of fresh water resources. Successfully addressing the challenge of global water security will require a holistic and interdisciplinary approach that incorporates all factors influencing the availability, accessibility, and sustainability of water resources.

2.1. Water security definition

The concept of water security is dynamic and multidimensional. According to Jansky et al., 2008, the term “water security” should consider “all aspects of human security pertaining to the use and management of water” (Jansky et al., 2008, p. 289). This view is somewhat anthropocentric, however, in that it overlooks the importance of environmental considerations in its definition of water security (Cook and Bakker, 2012). The definition of water security has since evolved, and the provision of water resources to sustain and enhance ecosystem functions has become a priority (Cook and Bakker, 2012). The definition of water security now encompasses “sustainable access... to adequate quantities of water of acceptable quality to ensure human and ecosystem health”(Norman et al., 2010, p. ii).

By this definition, all aspects of water security can be summarized in three dimensions: availability, accessibility and sustainability. In this manuscript, the assessment of water security has been generalized and incorporates the availability aspect of the definition of water security. Water availability is given by the total supply of both renewable and nonrenewable water sources leftover after water demands are satisfied. Supply must outweigh demand in order to avoid water stress and insecurity. Increasing pressures on fresh water resources have prompted the development of several global assessment models which attempt to evaluate the overall water balance.