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Research papers

Integrated water assessment and modelling: A bibliometric analysis of trends in the water resource sector

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ABSTRACT

There are substantial challenges facing humanity in the water and related sectors and purposeful integration of the disciplines, connected sectors and interest groups is now perceived as essential to address them. This article describes and uses bibliometric analysis techniques to provide quantitative insights into the general landscape of Integrated Water Resource Assessment and Modelling (IWAM) research over the last 45 years. Keywords, terms in titles, abstracts and the full texts are used to distinguish the 13,239 IWAM articles in journals and other non-grey literature. We identify the major journals publishing IWAM research, influential authors through citation counts, as well as the distribution and strength of source countries. Fruitfully, we find that the growth in numbers of such publications has continued to accelerate, and attention to both the biophysical and socioeconomic aspects has also been growing. On the other hand, our analysis strongly indicates that the former continue to dominate, partly by embracing integration with other biophysical sectors related to water – environment, groundwater, ecology, climate change and agriculture. In the social sciences the integration is occurring predominantly through economics, with the others, including law, policy and stakeholder participation, much diminished in comparison. We find there has been increasing attention to management and decision support systems, but a much weaker focus on uncertainty, a pervasive concern whose criticalities must be identified and managed for improving decision making. It would seem that interdisciplinary science still has a long way to go before crucial integration with the non-economic social sciences and uncertainty considerations are achieved more routinely.

1. Introduction

There are substantial challenges facing humanity in the water and related sectors and purposeful integration of the disciplines, connected sectors and interest groups is now perceived as essential to address them. This paper deals with integrated assessment (IA) and modelling (IAM) in the water resource sector, conveniently referred to here as Integrated Water Assessment and Modelling (IWAM). IA is a scientific field, sometimes referred to as a meta-discipline, that aims to understand complex problems that arise from the interactions between humans and environmental systems (Parker et al., 2002). According to Rotmans and Van Asselt (1996), "*Integrated Assessment is an interdisciplinary and participatory process of combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena.*" Given that the complex nature of these problems defies the capacity of a single scientific field (Rotmans, 1998; Ravetz, 1999), IWAM provides a framework (i.e. theories, methods, tools) for amalgamating, structuring and sharing knowledge about water resource assessment from multiple scientific disciplines (e.g. hydrology, economics, ecology and the social sciences). IWAM is built on the fundamental principles of stakeholder engagement, leveraging the strengths of conceptual and numerical methods, focusing on policy questions, as well as characterization and management of uncertainties (Jakeman and Letcher, 2003).

The number of publications on IA and IAM has grown rapidly since Rotmans (1998) presented one of the earliest discussions and reviews of IA methods. Many authors have since presented reviews focusing on some aspects or methodological approaches within the field of IAM. The review and synthesis papers discussed immediately in the following helped to set the keywords for our analysis. Parker et al. (2002) discussed various definitions of IAM and identified five different types of integration that are needed

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for the effective management of environmental problems, which are integration of issues, models, scales, disciplines and stakeholders. The paper Croke et al. (2006) discussed the various frameworks and methods of IAM, their suitability and unfulfilled potential for these purposes, based on three Australian IA case studies. Pahl-Wostl (2007) articulated IAM as a multi-level learning process (i.e. individual, group, community levels), and described the role of hard and soft systems analysis in achieving the desired learning outcomes. More recently, Kelly et al. (2013) reviewed different IAM papers to identify the most common modelling approaches and introduced a framework to assist modellers and model users in the choice of an appropriate modelling approach for their integrated assessment applications to enable more efficient learning in interdisciplinary settings. Hamilton et al. (2015) reviewed available research on IAM, identified the key dimensions for architecting integration, and mapped how these dimensions can be incorporated into the four main phases of an IAM process: scoping, problem framing and formulation, assessing options, and communicating findings. Such literature review articles as the above address interesting and useful aspects of IWAM, yet none provides an overarching view of the field. At present, the rate of publishing IWAM research results as papers, reports, books and book chapters is accelerating rapidly. Thus, it is timely for a comprehensive, quantitative review of IWAM literature covering its general landscape in order to provide a more structured picture of IWAM topics and generate insights into crucial gaps and potential opportunities.

Moreover, traditional approaches to literature review can identify the knowledge gaps within a problem domain and give an indication of its current status (Maier, 2013), but they are time-consuming and highly subjective. A bibliometric analysis, while potentially more limited in depth, can provide a holistic and objective picture of the structure, topics, and gaps in a field of research. Bibliometric research refers to the study of the quantitative aspects of the production, dissemination, and use of recorded information through the use of quantitative methods and mathematical models for these processes (Broadus, 1987; Tague-Sutcliffe, 1992). As a body of research and methods, bibliometric analysis uses approaches developed in library and information sciences. It evaluates physical units of publication, citations, and surrogate measures from a corpus of literature to discover and describe patterns within publications in a topic, field, journal, institute or even country (Broadus, 1987). The bibliometric approach to literature analysis is valuable in that it can effectively illustrate the stages of development and help researchers navigate through a body of knowledge (Wang et al., 2014), and establish a reproducible workflow for analyses as the field advances over time. In this paper, we focus on IAM publications in the water resource sector as it is a large environmental sector worthy of analysis in itself, and hopefully our analysis will provide guidance for authors intending to study IAM in other sectors.

A very limited number of bibliometric studies have been published in research areas related to environmental assessment and modelling applications. Depending on their objectives, these studies vary according to the analysis focus or the topic under investigation, the level (e.g. field of study, journal) at which the analysis is conducted, the time span and the methods employed for the analysis. For example, Li and Zhao (2015) completed a keyword analysis of 20 years of global Environment Impact Assessment research revealing gradual transitions over time towards research focused on Strategic Environmental Assessment. Niu et al. (2014) used statistical and bibliometric methods to describe the growth in the global groundwater research over the past two decades.

Wang et al. (2010) conducted a keyword frequency analysis, with a focus on publications in "Water Research" journal publications over the period (1967–2008) to elicit the changes in research topics of interest. Through this bibliometric approach, the authors discovered the progression of a topic's development, for example, the increased attention on "drinking water" through the "adsorption" method. Later, Wang et al. (2014) conducted a bibliometric analysis of 3004 papers on climate change vulnerability research. It revealed that the most widely focused research topics in this field include health issues in the socioeconomic system, food security in the field of agricultural systems, and the issue of water resource management.

Most recently, Barthel and Seidl (2017) applied a bibliometric analysis to ascertain to what degree interdisciplinary collaboration has taken place in groundwater research. They covered papers from 1990 to 2014 and used several indicators together with their personal expertise in groundwater and interdisciplinary research, discovering that only a low, single-digit range of papers were really multidisciplinary and a large number of the analyzed papers was authored primarily by an individual researcher, which indicates that they are mono-disciplinary. These studies showcase the contributions and insights that bibliometric analysis can offer for profiling a body of knowledge.

In this article, bibliometric methods are described and used to investigate the landscape of IWAM research through publication. We investigate the nature of the progression of IWAM research to its current status. The aim is to reveal underlying patterns in its scientific outputs. Pertinent results include the number of articles, the main journals for publications, key authors, international spread of first authors, noteworthy trending topics, common keywords and an evaluation of influential publications, in order to provide a comprehensive picture of IWAM research.

2. Research methodology

Similar to any research process, the reliability and robustness of results are determined by the methodology employed. It is essential to have a transparent and reproducible workflow to allow for replication of the study. In this section, we describe the adopted methodology (Section 2.1), and how it has been applied in this study (Sections 2.2 and 2.3).

2.1. Bibliometric analysis steps

We employed a stepwise procedure commonly used in bibliometric studies to complete the analysis in this article (e.g. Morris and Van der Veer Martens, 2009; Börner et al., 2005). The approach adopted consists of eight steps which are illustrated in Fig. 1. These include (1) defining the topic, (2) bounds of the study, selecting sources of data, (3) retrieving and (4) pre-processing data, followed by (5) analysis, (6) quality checking, (7) visualization, and finally (8) evaluation. These steps are further described in the following.

Similar to any type of analysis, the results obtained from the bibliometric analysis are influenced by the decisions that the analyst makes through the process (e.g. keywords selection). To address this, we explicitly report the followed workflow, and the decisions made along the way, and how the results can be interpreted in that context.

Step 1 Topic definition: As with any research problem, the research question and topic of interest must be defined prior to starting a bibliometric analysis. Elements that make up the research question and help bound the problem may include the phenomenon of interest and geographic area. Clearly articulated research questions help refine the boundary of the inquiry and narrow analyses later in the process. This article is focused on examining peer-reviewed publications on Integrated Water Assessment and Modelling (IWAM).

Step 2 Boundary Definition: The main search terms and common synonyms or other forms (noun, verb and adjective) are