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Review Article

Agent-Based Approach on Water Resources Management: A Modified Systematic Review

Su Kaynakları Yönetiminde Etmen Tabanlı Yaklaşım: Uyarlanmış Sistematik Derleme

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Abstract

Social, economic, and ecological dimensions of water resources make water management a highly complex domain related to many intertwined human-nature systems. Therefore, the decision and implementation of sustainable policies require following the evidence-based approach. Agent-Based Modeling and Simulation is one of the latest computer-aided modeling and simulation applications widely used to understand the phenomena associated with water-related/human-oriented engineering systems. In this study, conducting a modified systematic review approach, a field-specific review of the 128 articles on water resources management with Agent-Based Modeling was presented. Application areas of Agent-Based Modeling in water resources management and examples of its use as a decision support tool were evaluated. As an integrative systematic review of Web of Science, Science Direct, and Google Scholar, this study summarizes the leading work of Agent-Based Modeling applications on water resources management. Current trends show that water research professionals have often used Agent-Based Modeling as a social simulation tool. Due to its role in facilitating interdisciplinary research, its application area is widening. However, there is a need for a comprehensible and open share of application-oriented information to guide the scientific community.
Keywords: *agent-based modeling, simulation, water resources management, sustainability*

Öz

Sosyal, ekonomik ve ekolojik boyutları, su yönetimini insan-doğa sistemiyle ilgili iç içe geçmiş oldukça karmaşık bir alan haline getirmektedir. Bu nedenle sürdürülebilir politikaların belirlenmesi ve uygulanması konusunda kanıta dayalı yaklaşımın izlenmesine ihtiyaç duyulmaktadır. Etmen Tabanlı Modelleme ve Simülasyon (ETM), suyla ilgili/insan odaklı mühendislik sistemleriyle ilişkili olguları anlamak için yaygın olarak kullanılan en güncel bilgisayar destekli modelleme ve simülasyon yaklaşımlarından biridir. Bu çalışmada, araştırma konusunun gerekleri doğrultusunda uyarlanmış bir sistematik derleme yaklaşımıyla, Etmen Tabanlı Modelleme metodolojisi ile su kaynakları yönetimine ilişkin 128 makalenin incelemesi sunulmuş, Etmen Tabanlı Modelleme'nin su kaynakları yönetimindeki uygulama alanları ve karar destek aracı olarak kullanım örnekleri gözden geçirilmiştir.

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Web of Science, Science Direct ve Google Scholar arama motoru/veritabanı kullanılarak yürütülen bu çalışma, su kaynakları yönetimi konusundaki önde gelen Etmen Tabanlı Modelleme çalışmalarını özetlemektedir. Mevcut eğilimler, bir sosyal simülasyon aracı olarak Etmen Tabanlı Modelleme'nin akademisyenlerce sıklıkla kullanıldığını ve disiplinlerarası araştırmaları kolaylaştıran rolü nedeniyle uygulama alanının genişlemekte olduğunu göstermektedir. Ancak, uygulamaya yönelik bilgilerin açık paylaşımına ihtiyaç duyulmaktadır.

Anahtar sözcükler: *etmen tabanlı modelleme, simülasyon, su kaynakları yönetimi, sürdürülebilirlik*

Introduction

Water research is a fundamental research domain of environmental science. One of the main reasons for this, from a systems perspective, the planet consists of sub-systems which are connected with each other in a complex way. But above all, human behavior is a complex phenomenon that is causing “coupled human-water systems” to become complicated in behavior and hard to predict. Thus, managing any nature-human system, including water resources, requires a perspective of “complex adaptive systems” (CAS).

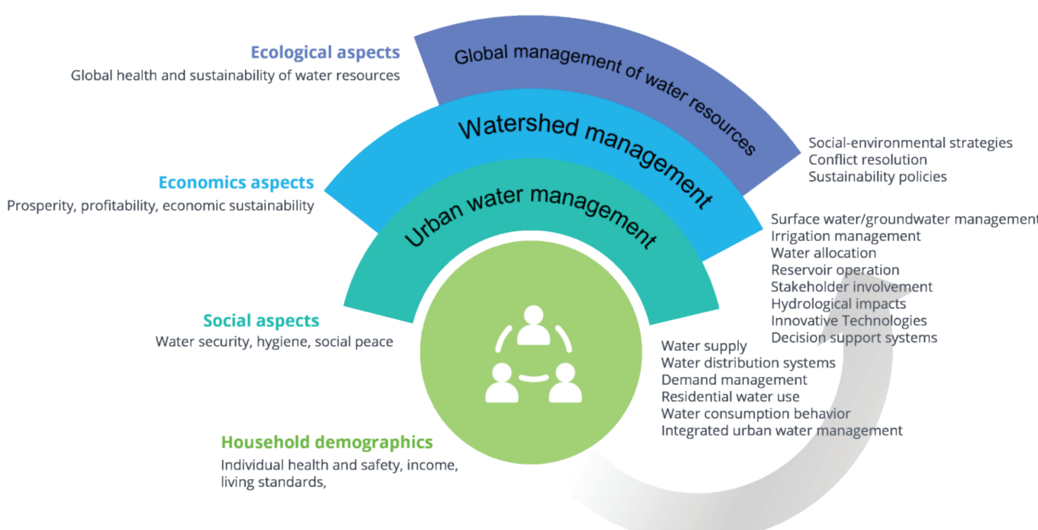
Water resources and the human systems dependent on them are so-called “socio-ecological systems” (SES) with natural and artificial features. According to this perspective, many phenomena seen at the macro scale emerge from interactions among agents at the micro-scale. However water resources are natural systems, those systems are conceptualized as SES, since humans are the foremost actors (agents) of the SES. The main reason for conceptualizing water resources as an SES is humans and their effect on these systems (Figure 1). Humans and societies have the willpower over natural systems, so those systems are rather coupled human-nature systems or socio-ecological systems.

Many phenomena that emerge on the social scale due to the choices individuals make in their daily lives affect the fate of water resources. The over-exploiting of water resources has many consequences on the households’living standards, income, and demographic characteristics. But household demographics also affect the status of water resources. In a way, demanding higher living standards means demanding more water. As a consequence of higher living standards, water resources inevitably become insufficient. Therefore, the sustainable management of water resources become an indisputable necessity today.

Water resource management consists of sustainable planning, development, distribution, and management of water resources and involves all levels of strategic, tactical, and operational enterprise/corporate management applications. Water resource management is one of the essential requirements in modern urban life, aiming to sufficiently supply and distribute fresh and clean water. Research attention to water management has grown over the years (Aydın & Keleş, 2021). However, engineering perspective of water management has come to a boundary of knowledge, unless the social aspects of water resources management (WRM) are studied. Social systems are considered as CAS in which individuals or other different social actors can change their behavior according to their level of survival and access to similar self-performance criteria. Social simulation is a sub-discipline that focuses on the processes, mechanisms and behaviors that reveal social phenomena. Computer simulations are used in research on these mechanisms and behaviors. In this approach, social processes are considered as complex (non-linear/adaptive) systems (Jager & Gotts, 2013). There are several modeling approaches to study social processes.

Figure 1

Emergent Nature of Water Resources Management from a SES Perspective



This study's main oebjective is to explore the Agent Based Modeling approach. There is a growing need and interest to investigate the complex interactions between water resources as socio-economic systems. The ABM is one of the most preferred approaches in researching these interactions in recent years. Agent-Based Modeling allows for determining individual behavior and how this behavior affects other individuals and also the environment. In ABM, systems studied are modeled as “a collection of autonomous decision-making entities”, named agents. Agents make decisions, assessing their state individually, and based on a set of rules (Bonabeau, 2001). This research was carried out to present a general view of the research subject to the reader by compiling ABM-based applications in WRM.

Method

This work was conducted by a modified version of the systematic review approaches (Palmatier et al., 2018; Watson et al., 2018). Modifications include the thematic and technical aspects of the systematic review method described in related papers. The most significant modification was the construction of the search string. Instead of using a predefined search terms list, this work implemented the approach of using a simple search string and investing more time in inspecting the papers. The main objective of the research was to compose a general view of the subject, revealing the historical progress and other technical details.

Synthesis of related articles starts with the investigation by quick browse and comparison. Quick browse consists of a preliminary search of possible resources and databases related to the subject matter. Its main objective was to grasp the possible sample size for the research. Comparison of available sample sizes from different databases gives an impression about which database to follow for further analysis. Another benefit of the browsing and comparison approach is to get an intuition of the general outline of the subject matter.

The searching process consisted of querying the selected databases for the subject matter and inspecting the results for a preliminary screening. Results with high relevancy were recorded in an MS Excel-based database for further investigation. The screening step was conducted by further inspection, aiming to narrow down the number of articles until the scope of the yielded results overlapped with the one of this research. Extracting and synthesis were conducted by compiling related information from selected articles regarding keywords, WRM category, geographical and temporal coverage, software used, the title of subject-specific model development if available, and contribution to the scientific literature. As a last step of the process, the relevance of results was scored.

Searching Process

Since WRM is a term related to many social and natural sciences research topics, a comprehensive examination of scientific literature is required to get the broadest results. All possible scientific indexes, including Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index (CPCI-S), Emerging Sources Citation Index (ESCI), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) were explored via Science Direct (SD) and Web of Science (WoS). The Google Scholar (GS) academic search engine was included for comparison. The specified search string was kept simple and static during all stages of research.

The search for relevant articles was implemented via an integrative approach to overcome the inconsistencies among different search engines/databases (Table 1). The search string for Science Direct was constructed as: "Agent Based Model" AND Water. And in addition, the search string for Web of Science was constructed as: "Agent Based" AND Water. After the first round of the search, the only consistent aspect of the yielded results was that the document numbers from all three databases decreased when the search string switched to "Agent Based" AND Water. Thus, instead of choosing one of the search strings, both were kept to avoid missing related articles.

Quotation marks were used to fetch the results, including "Agent" and "Based" strings. The "AND" operator concatenates previous and following strings. "Water", the only and the simplest word, was selected to represent "water world". "WRM" intentionally was not preferred to eliminate the algorithm-based differences between databases/search engines. Results are presented in Table 1.

Table 1

Selected Databases and Article Numbers

Database/Search Engine	Agent Based Model AND Water	Agent Based ANDWater	Shortlisted by Authors
GS (Articles with the exact phrase in the title of the article, Any type)	55	177	-
SD (Title, abstract, keywords)	183	345	70
WoS (Title, abstract, Keyword+)	256	735	71

Note. 13 of the selected articles were found on both WoS and SD.

After a quick browse and comparison of the results, it was clear that yielded sample coverage was too different among providers, both in numbers and context.

Especially for GS, yielded documents were far from fit to purpose by quickly browsing the results fetched on the first 50 pages. One comment on yielded documents was that the search algorithm could read most of the web page's content, bringing any result including the string "water". Besides, confusion including the term "water", which expresses the liquid form of water, rather than the term "water management", which is an administrative concept, was frequently encountered. Similarly, the terms "agent" (being a chemistry term) and "based", often appeared separately in the results, and that constituted another differentiation from the term "agent-based". Since providers have too many redundancies, the next step of the research was a one-by-one inspection, covering the WoS and the SD results, including 1080 articles found. Results from the GS engine were not advanced further since the ultimate objective of incorporating GS was already reached.

Screening

The screening process was conducted following the further inspection of the yielded results from SD and WoS. Initial screening was started by shortlisting articles throughout the criteria given in Table 2.

Initial screening of articles according to the criteria mentioned above resulted in 168 articles that were found to be essentially related to WRM. Following a cross-check of articles made by authors, results were evaluated to be included or excluded in the database. By conducting a scale of non-relevance to full relevance, the ultimate number of the shortlisted articles was obtained as 128.

Table 2

Criteria for Shortlisting and Selection

	Criteria
Study Type	Peer-reviewed empirical and theoretical/conceptual studies, journal, or conference manuscripts
Index	SCI-Expanded, SSCI, CPCI-S, ESCI, CPCI-SSH
Language	English
Date	All available history
Relevance	Not relevant; not related to WRM
	Low relevance; reference to auxiliary or technical aspects of WRM
	Moderate relevance; related to WRM with lack of application of ABM
	High relevance; complete theoretical consistency with WRM and practice of ABM
	Full relevance; main paper of the domain via scientific contribution and practice

Extraction and Synthesis

A summary of articles was compiled in an MS Excel spreadsheet, including the title, authors' names, publication year, publisher, keywords, and abstract. Articles were classified regarding WRM categories. Those categories included urban water management, irrigation management, watershed-river basin management, and global management of water resources. Issues such as conflict management, policy analysis, and socio-environmental strategies were subjected.

One other important perspective of this research was to compose technical aspects of the water-related ABM applications, including the geographical coverage of case studies, temporal coverage of simulations, software used, and supplements provided by researchers. Therefore, all available information on those parameters was collected and presented in a suitable format in the Results section.

Results

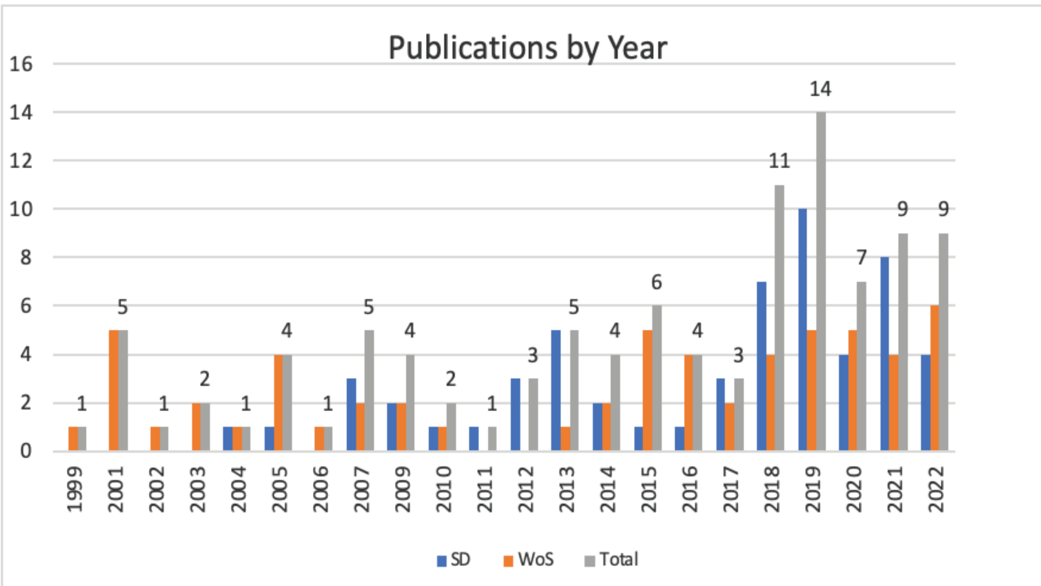
This research was carried out to present a chronological overview of agent-based methods in WRM. As expected, a broadly diverse view has emerged, both in the research discipline and the spectrum of practice. Selected articles consisted of broad coverage of articles of empirical and conceptual papers, including review articles, case studies, and perspective papers. For this reason, results were presented in a manner organized by descriptive, thematic, and methodological characteristics of articles. The descriptive analysis covers formal aspects of selected literature such as publications by years, journals with the largest collection of manuscripts, and country-based case study rankings. Thematic analysis shows the WRM aspects of the articles, such as emergent water-related terms and chronological contributions by authors. Lastly, articles were categorized by their software use as a technical part of the research. The status of the supplements provided by authors was also considered a contribution to the scientific community.

Descriptive Analysis

The use of the ABM method in research on the management of water resources has shown an increasing development since 1999. Starting from 1999, almost every year until 2022, one or more publications appeared, including journal articles, conference papers, and book chapters. However, starting from 2012, the numbers and diversity of the publications broadened (Figure 2). 2018-2019 seemed to be the densest period of the "WRM" related with ABM publications. 13 publications detected by both search engines were removed from the total.

Figure 2

Publications Shortlisted from both SD and WoS



Journals and Rankings

The distribution of publications showed the diversified and interdisciplinary nature of the research subject. Almost half of the publications appeared in 50 different journals with only one article (Table 3). For this reason, only the publishers with 2 or more manuscripts were presented in here. The top 4 publishers only provided 23% of total articles.

Case Study Country Based Rankings

Selected literature showed a wide range of geographical coverage of case studies (Table 4). AB methodology was applied to water resources management research in 29 countries worldwide. The top applications of 42 case studies came from USA, Iran, and China.

Table 3

Publications with Two or More Articles Relevant To WRM+ABM

Publication	Count
Environmental Modelling & Software	9
Sustainable Cities and Society	8
Agricultural Water Management	7
Journal of Hydrology	6
Water	4
Agricultural Systems	4
Water Resources Management	4
Journal of Environmental Management	4
Ecological Modelling	3
Journal of Water Resources Planning And Management	3
Science of the Total Environment	2
Water Resources Research	2
Simulation-Transactions of The Society For Modeling And Simulation International	2
Computers, Environment and Urban Systems	2
Physics and Chemistry of the Earth	2
Ecological Economics	2
Simulation Modelling Practice and Theory	2
International Journal of Critical Infrastructure Protection	2
Sustainability	2
JASSS-The Journal of Artificial Societies and Social Simulation	2
Water Science and Technology	2
Journal of Cleaner Production	2
Computers and Electronics in Agriculture	2
Other publications	50
	128

Table 4

Emergent Water-Related Terms under WRM

No. of Case Studies	Countries
22	USA
13	Iran
7	China
5	Australia, France
4	Greece
3	Switzerland
2	Brazil, Chile, Germany, Kenya, Morocco, Spain
1	Argentina, Cambodia, Canada, Colombia, Croatia, India, Indonesia, Israel, Italy, Mexico, New Zealand, Senegal, South Africa, Thailand

Note a. 34 publications were not case studies, or geographical coverage was not clear.

Note b. 5 of the case studies was conducted via virtual environments such as Hypothetical/Virtual.

Software Used

ABM application requires skills in advanced programming or dedicated software. However, software use was not related to all selected articles. Some articles were reviews, and some others were perspective papers offering recommendations. Thus 59 of reviewed publications did not contain software use, and the ones with software implementation were shown in Table 5.

Table 5

Emergent Water-Related Terms under WRM

Software	Articles Used
NetLogo	15
AnyLogic	7
Java / JADE	7
Python	4
MASON	4
C++	3
Repast Symphony	3
CORMAS	2
Web application	2
DynaMind	1
Envision	1
Julia	1
Others/unknown/project-based	19

Note. 58 publications were not using software, or used software was not explicit.

19 articles were related to software use, but no further information was offered via text or supplements. Software use contained broad diversity as well. Many programming languages or software packages were used to implement ABM, including software packages such as NetLogo, AnyLogic, MASON, and Repast Symphony and programming languages, especially Java, Python, and C++.

WRM Categories

From a complex adaptive systems perspective, water resources management is highly related to many human-nature coupled systems. Thus, it has social, ecological, and economic aspects. WRM categories in this study were constructed to present the transitive nature of the research domain, stemming from the associated keywords of articles provided by their authors. The objective was to show how water-related terms are sometimes used transitively, and reveal which keywords are widely subjected (Table 6). Not surprisingly, WRM was highly referred to in many articles. However, it is noteworthy that many other emerging research topics appear to be highly referred to, such as "demand management", "irrigation management", "groundwater management", and "supply management".

Table 6

Emergent Terms Related To WRM

Water-related terms	No. of Journals	Other related terms
Agricultural management	6	Agricultural economics, agricultural water management, agriculture
Conflict management	5	Conflict resolution
Demand management	13	Domestic water demand, Dynamic demand, Demand tree analysis, Water demand forecasting, Residential water demand, Water demand strategies, Water demand system
Groundwater management	10	Groundwater
Irrigation management	12	Agricultural irrigation, Irrigation system viability, Irrigation
Policy analysis	6	Policy assessment, Policy check, Water management policies, Sustainability policy
Public health hand sanitation	3	Water infrastructure safety, Contamination, Epidemics, Public health effects, Water sanitation
Public participation	2	Stakeholder engagement, Negotiation
Reservoir management	2	-
River basin management	2	-
Stakeholder behavior	6	Social learning, Participatory modeling, Participatory ABM, Role-playing games, Theory of planned behavior, Game theory
Stormwater management	1	-
Supply management	9	Water supply system, Urban water supply, Water distribution system, Water distribution system management,
Urban water management	8	Urban water resources management
Wastewater management	2	-
Water allocation	5	Water allocation optimization
Water infrastructure management	3	Coupled human-nature systems, Critical infrastructures, Water infrastructure planning, Interdependencies of critical infrastructures
Water quality management	8	Eutrophication, Risk management, Water quality, Water quality trading
Water-related innovation	3	Technology diffusion, Decentralized water technologies, Innovation adoption, Rainwater harvesting
Water resources management	16	Collaborative water management, Domestic water management, Water resources, Water resource management, Water governance
Water reuse	1	-
Water rights	1	-
Water scarcity	2	Water availability
Water security	7	-
Water trading	6	-
Watershed management	6	Wildlife support, Natural systems restoration

A Brief Chronology of ABM on Water Resources Management

Contributions to agent-based applications in water resources management were presented in Table 7, in which the title of the research and authors were contained. Contributions have consisted of summarized information that was compiled to be descriptive and as informative as possible. Abbreviations were used because of space restrictions and were written in open form in text where it was first introduced.

Table 7

Authors and Articles in Chronological Order

Author	Article
Tillman et al. (1999)	Modeling the actors in water supply systems
Berger (2001)	Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis
Tillman et al. (2001)	Interaction analysis of stakeholders in water supply systems
Le Bars & Attonaty (2001a)	A multi-agent system to the common management of a renewable resource: Application to water sharing
Mohring & Troitzsch (2001)	Lake Anderson revisited by agents
Le Bars & Attonaty (2001b)	A multi-agent system to simulate water attribution among farmers
Pahl-Wostl (2002)	Towards sustainability in the water sector - The importance of human actors and processes of social learning
Becu et al. (2003)	Agent based simulation of a small catchment water management in northern Thailand description of the CATCHSCAPE model
Barreteau et al. (2003)	Agent-based facilitation of water allocation: Case study in the Drome River Valley
Pahl-Wostl & Hare (2004)	Processes of social learning in integrated resources management
Barreteau et al. (2004)	Suitability of Multi-Agent Simulations to study irrigated system viability: application to case studies in the Senegal River Valley
Hare & Deadman (2004)	Further towards a taxonomy of agent-based simulation models in environmental management
Tillman et al. (2005)	Simulating development strategies for water supply systems
Athanasiadis et al. (2005)	A hybrid agent-based model for estimating residential water demand
Zhang et al. (2005)	Dynamic game theoretic model of multi-layer infrastructure networks
Barthel et al. (2005)	Large-scale water resources management within the framework of GLOWA-Danube. Part A: The groundwater model
Lopez-Parades et al. (2005)	Urban water management with artificial societies of agents: The FIRMABAR simulator
Nickel et al. (2005)	Large-scale water resources management within the framework of GLOWA-Danube-The water supply model
Niu & Wang (2006)	A simulation model framework of water resources multi-agent system
Schlueter & Pahl-Wostl (2007)	Mechanisms of resilience in common-pool resource management systems: an agent-based model of water use in a river basin
Barreteau et al. (2007)	Variable time scales, agent-based models, and role-playing games: The PIEPLUE river basin management game
Janssen (2007)	Coordination in irrigation systems: An analysis of the Lansing–Kremer model of Bali
Nichita & Oprea (2007)	An agent-based model for water quality control
Rixon et al. (2007)	Exploring water conservation behaviour through participatory Agent-Based Modelling
Galan et al. (2009)	An agent-based model for domestic water management in Valladolid metropolitan area
Schroeder et al. (2009)	The use of multi-agent based models to support water resources management The Moroccan case study
Smajgl et al. (2009)	Simulating impacts of water trading in an institutional perspective
Schwarz & Ernst (2009)	Agent-based modeling of the diffusion of environmental innovations –An empirical approach
Saqalli et al. (2010)	Investigating social conflicts linked to water resources through Agent-Based Modelling
Moglia et al. (2010)	Modelling an urban water system on the edge of chaos
Van Oel & Van der Veen (2011)	Using agent-based modeling to depict basin closure in the Naivasha basin, Kenya: a framework of analysis
Murphy (2012)	Exploring complexity with the Hohokam Water Management Simulation: A middle way for archaeological modeling
Isern et al. (2012)	Development of a multi-agent system simulation platform for irrigation scheduling with case studies for garden irrigation
Wise & Crooks (2012)	Agent-based modeling for community resource management: Acequia-based agriculture

Table 7

(*Continued*)

Author	Article
Akhbari & Grigg (2013)	A Framework for an Agent-Based Model to manage water resources conflicts
Belaqziz et al. (2013)	An agent based modeling for the gravity irrigation management
Nguyen et al. (2013)	Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation
Zhang et al. (2013)	Trade-offs in designing water pollution trading policy with multiple objectives: A case study in the Tai Lake Basin, China
Britz et al. (2013)	Modeling water allocating institutions based on multiple optimization problems with equilibrium constraints
Iftekhar et al. (2013)	Effects of competition on environmental water buyback auctions
Zhao et al. (2013)	Comparing administered and market-based water allocation systems through a consistent agent-based modeling framework
Yuan et al. (2014)	Urban household water demand in Beijing by 2020: An Agent-Based Model
Aguirre & Nyerges (2014)	An Agent-Based Model of public participation in sustainability management
Daloğlu et al. (2014)	Development of a farmer typology of agricultural conservation behavior in the American Corn Belt
Crooks & Hailegiorgis(2014)	An agent-based modeling approach applied to the spread of cholera
Berglund (2015)	Using Agent-Based Modeling for water resources planning and management
Kanta & Berglund (2015)	Exploring tradeoffs in demand- side and supply- side management of urban water resources using Agent- Based Modeling and evolutionary computation
Ponte et al. (2015)	Real-time water demand forecasting system through an agent-based architecture
Al-Amin et al. (2015)	Agent-based modeling to simulate demand management strategies for shared groundwater resources
Murphy et al. (2015)	Simulating regional hydrology and water management: An Integrated Agent-Based Approach
Wu et al. (2015)	A scenario-based approach to integrating flow-ecology research with watershed development planning
Koutiva & Makropoulos (2016)	Modelling domestic water demand: An agent based approach
Farhadi et al. (2016)	An agent-based-nash modeling framework for sustainable groundwater management: A case study
Tomicic & Schatten (2016)	Agent-based framework for modeling and simulation of resources in self-sustainable human settlements: a case study on water management in an eco-village community in Croatia
Al-Amin et al. (2016)	Coupling Agent-Based and groundwater modeling to explore demand management strategies for shared resources
Ramsey (2016)	Use of a household survey in the development of an Agent-Based Model to support water demand management in Jaipur, India
Shafiee (2016)	Agent-based modeling and evolutionary computation for disseminating public advisories about hazardous material emergencies
Mashhadi et al. (2017)	Agent-based modeling to simulate the dynamics of urban water supply: Climate, population growth, and water shortages
Darbandsari et al.(2017)	An Agent-based behavioral simulation model for residential water demand management: The case-study of Tehran, Iran
Bakarji et al. (2017)	Agent-Based Socio-Hydrological Hybrid Modeling for water resource management
Koutiva & Makropoulos (2017)	Exploring the effects of domestic water management measures to water conservation attitudes using agent based modelling
Chen (2017)	Spatially explicit modelling of agricultural dynamics in semi-arid environments
Nandi et al. (2017)	Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis
Noel & Cai (2017)	On the role of individuals in models of coupled human and natural systems: Lessons from a case study in the Republican River Basin
Castonguay et al. (2018a)	Modelling urban water management transitions: A case of rainwater harvesting
Xiao et al. (2018a)	Agent-Based Modeling Approach to Investigating the Impact of Water Demand Management
Anthony & Birendra (2018)	Improving irrigation water management using agent technology

Table 7

(*Continued*)

Author	Article
Xiao et al. (2018b)	Centralized and decentralized approaches to water demand management
Giri et al. (2018)	Water security assessment of current and future scenarios through an integrated modeling framework in the Neshanic River Watershed
Ohab-Yazdi et al. (2018)	Using the agent-based model to simulate and evaluate the interaction effects of agent behaviors on groundwater resources, a case study of a sub-basin in the Zayandehroud River basin
Hampf et al. (2018)	The biophysical and socio-economic dimension of yield gaps in the southern Amazon – A bio-economic modelling approach
Wang et al. (2018)	Intelligent simulation of aquatic environment economic policy coupled ABM and SD models
Castonguay et al. (2018b)	Integrated modelling of stormwater treatment systems uptake
Al-Amin et al. (2018)	Assessing the effects of water restrictions on socio-hydrologic resilience for shared groundwater systems
Monroe et al. (2018)	Allocating countermeasures to defend water distribution systems against terrorist attack
Hyun et al. (2019)	Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions
Nouri et al. (2019)	Agent-Based Modeling for evaluation of crop pattern and water management policies
Huber et al. (2019)	Agent-Based Modelling of a coupled water demand and supply system at the catchment scale
Mewes & Schumann et al. (2019)	The potential of combined machine learning and agent-based models in water resources management
Bakhtiari et al. (2019)	A coupled agent-based risk-based optimization model for integrated urban water management
Koutiva & Makropoulos et al. (2019)	Exploring the Effects of alternative water demand management strategies using an agent-based model
Nhim et al. (2019)	The resilience of social norms of cooperation under resource scarcity and inequality-An agent-based model on sharing water over two harvesting seasons
Castilla-Rho et al. (2019)	Sustainable groundwater management: How long and what will it take?
Baeza et al. (2019)	Operationalizing the feedback between institutional decision-making, sociopolitical infrastructure, and environmental risk in urban vulnerability analysis
Thompson et al. (2019)	Interdependent Critical Infrastructure Model (ICIM): An agent-based model of power and water infrastructure
Yang et al. (2019)	Impact of dam development and climate change on hydroecological conditions and natural hazard risk in the Mekong River Basin
Bonté et al. (2019)	Building new kinds of meta-models to analyse experimentally (companion) modelling processes in the field of natural resource management
Kandiah et al. (2019)	An agent-based modeling approach to project adoption of water reuse and evaluate expansion plans within a sociotechnical water infrastructure system
Pouladi et al. (2019)	Agent-based socio-hydrological modeling for restoration of Urmia Lake: Application of theory of planned behavior
Mishra et al. (2019)	A modeling framework for critical infrastructure and its application in detecting cyber-attacks on a water distribution system
García et al. (2019)	A linked modelling framework to explore interactions among climate, soil water, and land use decisions in the Argentine Pampas
Darbandsari et al. (2020)	An agent-based conflict resolution model for urban water resources management
Bitterman & Koliba (2020)	Modeling alternative collaborative governance network designs: An Agent-Based Model of water governance in the Lake Champlain Basin, Vermont
Lin et al. (2020)	Using Agent-Based Modeling for water resources management in the Bakken Region

Table 7

(*Continued*)

Author	Article
Tamburino et al. (2020)	Water management for irrigation, crop yield and social attitudes: a socio-agricultural agent-based model to explore a collective action problem
Kokay et al. (2020)	The application of role-playing games and agent-based modelling to the collaborative water management in peri-urban communities
Zamenian & Abraham (2020)	An Agent-Based Simulation Model for assessment of water consumption patterns during water rate ıncrease events
Yang et al. (2020)	Impact of climate change on adaptive management decisions in the face of water scarcity
Kaiser et al. (2020)	Identifying emergent agent types and effective practices for portability, scalability, and intercomparison in water resource agent-based models
Aghaie et al. (2020a)	Emergence of social norms in the cap-and-trade policy: An agent-based groundwater market
Aghaie et al. (2020b)	Agent-Based hydro-economic modelling for analysis of groundwater-based irrigation water market mechanisms
Perello-Moragues et al. (2021)	Modelling domestic water use in metropolitan areas using socio-cognitive agents
Wang et al. (2021)	An agent-based framework for high-resolution modeling of domestic water use
Aydin & Keles (2021)	A multi agent-based approach for energy efficient water resource management
Li et al. (2021)	Modeling spatial diffusion of decentralized water technologies and impacts on the urban water systems
Arasteh et al. (2021)	New hydro-economic system dynamics and agent-based modeling for sustainable urban groundwater management: A case study of Dehno, Yazd Province, Iran
Oliva-Felipe et al. (2021)	The Organisational Structure of an Agent-Based Model for the management of wastewater systems
Noori et al. (2021)	An agent-based model for water allocation optimization and comparison with the game theory approach
Jimenez et al. (2021)	Smart water management approach for resource allocation in high-scale irrigation systems
Fleming (2021)	Scale-free networks, 1/f dynamics, and nonlinear conflict size scaling from an agent-based simulation model of societal-scale bilateral conflict and cooperation
Yuan et al. (2021)	Effects of farmers' behavioral characteristics on crop choices and responses to water management policies
Ding et al. (2021)	Assessing food–energy–water resources management strategies at city scale: An agent-based modeling approach for Cape Town, South Africa
Anbari et al. (2021)	An uncertain agent-based model for socio-ecological simulation of groundwater use in irrigation: A case study of Lake Urmia Basin, Iran
Huber et al. (2021)	Agent-based modelling of water balance in a social-ecological system: A multidisciplinary approach for mountain catchments
Zolfagharipoor et al. (2021)	Agent-based modeling of participants' behaviors in an inter-sectoral groundwater market
Strickling et al. (2021)	Simulation of containment and wireless emergency alerts within targeted pressure zones for water contamination management
Granco et al. (2022)	Local environment and individuals' beliefs: The dynamics shaping public support for sustainability policy in an agricultural landscape
Du et al. (2022)	Evaluating distributed policies for conjunctive surface water-groundwater management in large river basins: Water uses versus hydrological ımpacts
Kadinski et al. (2022)	A hybrid data-driven-agent-based modelling framework for water distribution systems contamination response during COVID-19
Rojas et al. (2022)	Participatory and Integrated Modelling under Contentious Water Use in Semiarid Basins
James & Rosenberg (2022)	Agent-Based Model to manage household water use through social-environmental strategies of encouragement and peer pressure
Bahrami et al. (2022)	An agent-based framework for simulating interactions between reservoir operators and farmers for reservoir management with dynamic demands
Elhamian et al. (2022)	Quantitative and qualitative optimization of water allocation in no bandegan aquifer using an agent-based approach

Table 7

(*Continued*)

Author	Article
Nhim & Richter (2022)	Path dependencies and institutional traps in water governance – Evidence from Cambodia
Guo et al. (2022)	Modeling agricultural water-saving compensation policy: An ABM approach and application
Jimenez et al. (2022)	Intelligent IoT-multiagent precision irrigation approach for improving water use efficiency in irrigation systems at farm and district scales
Bourceret et al. (2022)	Adapting the governance of social–ecological systems to behavioural dynamics: An agent-based model for water quality management using the theory of planned behaviour

As being a computer-based simulation method, ABM was first introduced to water resources management by the work of a few pioneering researchers, including Tillman et al. (1999, 2001), Berger (2001), Le Bars & Attonaty (2001a, 2001b), and Pahl-Wostl (2002). Tillman et al. investigated the interactions among actors in water supply systems using ABM and introduced the agent-based participatory simulation term by analyzing stakeholder interactions in water utilities (Tillman et al., 1999; 2001). Berger (2001) introduced the "cellular automata" phenomenon to agricultural economic models. Pahl-Wostl (2002) described ABM as promising new developments to explore changes toward sustainability by pointing out that ABM does not disregard "complexity", "indeterminacy", and the "human dimensions".

As a main contribution of ABM, social aspects of water resources management were studied by many researchers, including Lopez-Parades et al. (2005), Rixon et al. (2007), Schroeder et al. (2009), and Smajgl et al. (2009).

The domain-specific modeling frameworks for water resources management also came into existence in the early 2000s. Becu et al. (2003) introduced CATCHSCAPE as a multi-agent system that simulates catchment features and farmers' decisions. Athanasiadis et al. (2005) presented DAWN as a hybrid model for evaluating water-pricing policies. Barthel et al. (2005) introduced the decision support tool DANUBIA for investigating the effects of climate change on the water cycle of a river basin. Barreteau et al. (2007) focused on the similarity of role-playing games (RPG) and ABM, testing their synergy via their PIEPLUE tool. Janssen (2007) argued the possibility of generalizing the success of "The Lansing-Kremer Model" in explaining the emergent interactions of a Balinese self-governing irrigation system. Saqalli et al. (2010) proposed a decision support tool named MAELIA. Jimenez et al. (2021) presented an Irrigation Agent-Based Model (IABM) for water distribution in an irrigation district. Noel & Cai (2017), Ding et al. (2021) developed ABM models of coupled human nature and nature systems (CHANS).

The conservation of water resources was also subjected to research at early stages. Mohring & Troitzsch (2001) replicated the experiments of Jay M. Anderson on a hypothetical lake, in which eutrophication by the discharge of fertilizers was studied. The idea of multi-agent simulation for water quality monitoring and control was introduced by Nichita & Oprea (2007).

Galan et al. (2009) combined social models, urban dynamics, and technological opinion diffusion with geographical information systems (GIS). Wise & Crooks (2012) implemented another GIS on complex irrigation systems called "acequia", in which ABM was used to represent interactions among actors. Akhbari & Grigg (2013) implemented an ABM that simulates the interactions among parties in a conflict scenario.

The 2010s were a period in which the economic aspects of the use of ABM in WRM were explored. Nguyen et al. (2013) examined the efficiency of water quality trading scenarios by ABM. Zhang et al. (2013) proposed a zonal-based trading ratios system to improve the cost-efficiency of the water quality trading system via an application of ABM. Iftekhar et al. (2013) studied the role of "market competition" in water buyback auctions using ABM. Zhao et al. (2013) compared the market-based water allocation systems to administered ones via ABM.

Water demand management was another research subject that emerged as a consequence of research on the human aspects of water supply management. Yuan et al. (2014) developed an ABM, "household water demand prediction model" to predict household water demand. Ponte et al. (2015) developed an ABM based prediction system for water demand forecasting. Al-Amin et al. (2015) analyzed the interactions of changing water demands and limited groundwater resources, Al-Amin et al. (2016) coupled an ABM and a groundwater model to simulate water demands under uncertainties, and Al-Amin et al. (2018) developed an ABM framework to capture the interactions of consumers and policy-makers. Murphy et al. (2015) presented a simulation framework in which the hydrological Water Balance Model (WBM) was linked to an ABM. Koutiva & Makropoulos (2016) studied the domestic water users' behavior in response to water demand management measures, using ABM, and they used an ABM tool named "Urban Water Agents' Behavior" tool (Koutiva & Makropoulos, 2019). Xiao et al. (2018a) proposed ABM approach to assess water demand management in a river basin, and they explored the centralized and decentralized procedures to assess the impact of water demand on a water supply system (2018b). Bakhtiari et al. (2019) developed a coupled risk-based ABM optimization model, which could account for water resources capacity and water demand uncertainties to determine the annual water allocation. Huber et al. (2021) applied the ABM of water supply and demand model Aqua.MORE.

Agriculture and irrigation management are among the most prominent topics of ABM applications in every period. Many scholars such as Barreteau et al., Janssen, Isern et al., Belaqziz et al., Noel & Cai, Anthony & Birendra, Mewes & Schumann, Jimenez et al., and Bahrami et al. studied the use of ABM for agriculture or irrigation management. Barreteau et al. (2004) studied the longevity of irrigation systems by describing them as a multi-agent system (MAS) virtual laboratory. Isern et al. (2012) presented a knowledge-based and distributed framework that simulates the behavior of an irrigation system. Anthony & Birendra (2018) proposed an ABM that could be used to prioritize irrigation allocation for different crops on a farm. Mewes & Schumann (2019) enhanced an ABM irrigation planning model with a machine learning-based training component. Bahrami et al. (2022) simulated the farmers' behavior toward changing cropping patterns and adaptation to new irrigation technology using the ABM framework. Jimenez et al. (2022) presented an internet of things (IoT) multi-agent irrigation approach for improving water use efficiency in irrigation systems.

The up-to-date research context on the use of the ABM method in WRM consists of interdisciplinary applications, both technically and thematically. In a technical manner, coupling ABM with another modeling or analysis approach offers many opportunities to discover and explain coupled human-nature systems. The ABM was coupled with many other methodologies such as "evolutionary computation based multi-objective methodology" (Kanta & Berglund, 2015), and "Urban Water Optioneering Tool" (Koutiva & Makropoulos, 2016), a groundwater model (Al-Amin et al., 2016; Noel & Cai, 2017; Al-Amin et al., 2018), a variable-length genetic algorithm (Shafiee, 2016), a hydrologic model (Giri et al., 2018), a Model of Nitrogen and Carbon Dynamics in Agro-ecosystems (MONICA) (Hampf et al., 2018), system dynamics models (Wang et al., 2018), a river-routing and reservoir management model (RiverWare) (Hyun et al., 2019), land use and phosphorus load accumulation models (Bitterman & Koliba, 2020), social, economic, and hydrological sub-models (Zolfagharipoor et al., 2021), a hydraulic model of a pipe network (Strickling et al., 2021), and a physically-based hydrological model (Du et al., 2022).

Discussion and Conclusion

This research composed the general view of ABM practices in WRM. We followed a modified version of the systematic review approach, adapting the method to the requirements of the research subject.

Our results suggested that the use of ABM approach in WRM has increased and expanded since 1999. Contributions came from a broad coverage of scientific research, including social and natural sciences. One or more publications appear almost every year, including journal articles, conference papers, and book chapters. However, starting from 2012, the numbers and diversity of the scientific publications have been broadened. The related publications were mostly published in between 2018 and 2019. In line with the historical development of the subject, we might say that the initial status of papers was composed of perspective papers, which the probability of using ABM in WRM was suggested. We observed that the researchs with case studies have steadily increased since the 2010s. The current trend shows that the numbers of interdisciplinary and systems approach-based research are increasing along with field studies. For instance, the interdependency of critical infrastructures such as logistics, water supply, and energy distribution systems are among the current research topics.

As a reflection of the field's interdisciplinary nature, publications appeared to come from a wide variety of publishers. Most of the publications belonged to research areas such as "environmental sciences", "ecology", "water resources", "engineering", "computer science", "geology", "mathematics", "agriculture", and "social sciences". The distribution of publications also showed the diversified and interdisciplinary nature of the research subject. Almost half of the publications appeared in 50 different journals with only one article. The top journals including "Environmental Modelling & Software", "Sustainable Cities and Society", "Agricultural Water Management", "Journal of Hydrology", "Water", "Agricultural Systems", "Water Resources Management", "Journal of Environmental Management", "Ecological Modelling", "Journal of Water Resources Planning and Management", "Science of Total Environment", and "Water Resources Research" published less than half of the related papers.

The broad geographical distribution of field studies shows that ABM methodology was applied to WRM researchs worldwide. The application scale of the studies was also diversified, ranging from water supply and distribution systems to irrigation regions, lakes, groundwaters, watersheds, and river basins. The top applications of 42 case studies came from USA, Iran, and China. Another notable point is that 10 of the proposed methodologies were examined in hypothetical or virtual environments, resulting from the flexibility of the ABM approach.

Technical aspects of the ABM approach were evaluated by software use of articles and supplements provided. Among 128 papers, 50 were related to software use, but no further information was offered via text or supplements. Since various computer programming languages or software packages are used to implement ABM, the diversity of used software was also broadened. Used software packages include NetLogo, AnyLogic, MASON, Repast Symphony, CORMAS, DynaMind, and Envision. And programming languages include Java, Python, web programming languages, Julia, and C++. 19 of the papers offered project-based software implementation or did not explicitly state the name of the software or programming language. 42 of the articles provided supplements, including "Overview, Design concepts, and Details" (ODD) documents, an explanation of methodology, or similar documents. Some of the articles systematically noted the software availability resulting from the publisher's obligation. However, a few articles offered the software to replicate the results via working download links. That means there is still a significant gap in providing the required information to replicate results or any other scientific benefit.

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References

Aghaie, V., Alizadeh, H., & Afshar, A. (2020a). Emergence of social norms in the cap-and-trade policy: An agent-based groundwater market. *Journal of Hydrology, 588*. **doi:10.1016/j.jhydrol.2020.125057**

Aghaie, V., Alizadeh, H., & Afshar, A. (2020b). Agent-Based hydro-economic modelling for analysis of groundwater-based irrigation Water Market mechanisms. *Agricultural Water Management, 234*. **doi:10.1016/j.agwat.2020.106140**

Aguirre, R., & Nyerges, T. (2014). An Agent-Based Model of public participation in sustainability management. *Journal of Artificial Societies and Social Simulation, 17*(1), 7. **doi:10.18564/jasss.2297**

Akhbari, M., & Grigg, N. S. (2013). A Framework for an Agent-Based Model to manage water resources conflicts. *Water Resources Management, 27*(11), 4039-4052. **doi:10.1007/s11269-013-0394-0**

Al-Amin, S., Berglund, E. Z., & Mahinthakumar, G. (2016). Coupling Agent-Based and Groundwater Modeling to Explore Demand Management Strategies for Shared Resources. In *World Environmental and Water Resources Congress 2016* (pp. 141-150).

Al-Amin, S., Berglund, E. Z., Mahinthakumar, G., & Larson, K. L. (2018). Assessing the effects of water restrictions on socio-hydrologic resilience for shared groundwater systems. *Journal of Hydrology, 566*, 872-885. **doi:10.1016/j.jhydrol.2018.08.045**

Anbari, M. J., Zarghami, M., & Nadiri, A.-A. (2021). An uncertain agent-based model for socio-ecological simulation of groundwater use in irrigation: A case study of Lake Urmia Basin, Iran. *Agricultural Water Management, 249*. **doi:10.1016/j.agwat.2021.106796**

Anthony, P., & Birendra, K. C. (2017). Improving irrigation water management using agent technology. *New Zealand Journal of Agricultural Research, 61*(4), 425-439. **doi:10.1080/00288233.2017.1402788**

Arasteh, M. A., & Farjami, Y. (2021). New hydro-economic system dynamics and agent-based modeling for sustainable urban groundwater management: A case study of Dehno, Yazd Province, Iran. *Sustainable Cities and Society, 72*. **doi:10.1016/j.scs.2021.103078**

Athanasiadis, I. N., Mentes, A. K., Mitkas, P. A., & Mylopoulos, Y. A. (2016). A Hybrid Agent-Based Model for estimating residential water demand. *Simulation, 81*(3), 175-187. **doi:10.1177/0037549705053172**

Aydin, M. E., & Keleş, R. (2021). A multi agent-based approach for energy efficient water resource management. *Computers & Industrial Engineering, 151*. **doi:10.1016/j.cie.2020.106679**

Baeza, A., Bojorquez-Tapia, L. A., Janssen, M. A., & Eakin, H. (2019). Operationalizing the feedback between institutional decision-making, socio-political infrastructure, and environmental risk in urban vulnerability analysis. *Journal of Environmental Management, 241*, 407-417. **doi:10.1016/j.jenvman.2019.03.138**

Bahrami, N., Afshar, A., & Afshar, M. H. (2022). An agent-based framework for simulating interactions between reservoir operators and farmers for reservoir management with dynamic demands. *Agricultural Water Management, 259*. **doi:10.1016/j.agwat.2021.107237**

Bakarji, J., O'Malley, D., & Vesselinov, V. V. (2017). Agent-Based Socio-Hydrological Hybrid Modeling for water resource management. *Water Resources Management, 31*(12), 3881-3898. **doi:10.1007/s11269-017-1713-7**

Bakhtiari, P. H., Nikoo, M. R., Izady, A., & Talebbeydokhti, N. (2020). A coupled agent-based risk-based optimization model for integrated urban water management. *Sustainable Cities and Society, 53*. **doi:10.1016/j.scs.2019.101922**

Barreteau, O., Garin, P., Dumontier, A., Abrami, G., & Cernesson, F. (2003). Agent-Based facilitation of water allocation: Case study in the Drome River Valley. *Group Decision and Negotiation, 12*(5), 441-461. **doi:10.1023/B:GRUP.0000003743.65698.78**

Barreteau, O., Bousquet, F., Millier, C., & Weber, J. (2004). Suitability of multi-agent simulations to study irrigated system viability: Application to case studies in the Senegal River Valley. *Agricultural Systems, 80*(3), 255-275. **doi:10.1016/j.agsy.2003.07.005**

Barreteau, O., & Abrami, G. (2007). Variable time scales, agent-based models, and role-playing games: The PIEPLUE river basin management game. *Simulation & Gaming, 38*(3), 364-381. **doi:10.1177/1046878107300668**

Barthel, R., Rojanschi, V., Wolf, J., & Braun, J. (2005). Large-scale water resources management within the framework of GLOWA-Danube. Part A: The groundwater model. *Physics and Chemistry of the Earth, Parts A/B/C*, *30*(6), 372-382. **https://doi.org/https://doi.org/10.1016/j.pce.2005.06.003**

Bars, M. L., & Attonaty, J. M. (2001). *Proceedings 13th IEEE International Conference on Tools with Artificial Intelligence.*

Becu, N., Perez, P., Walker, A., Barreteau, O., & Page, C. L. (2003). Agent based simulation of a small catchment water management in northern Thailand. *Ecological Modelling, 170*(2-3), 319-331. **doi:10.1016/s0304-3800(03)00236-9**

Belaqziz, S., Fazziki, A. E., Mangiarotti, S., Le Page, M., Khabba, S., Raki, S. E., Adnani, El M., & Jarlan, L. (2013). An Agent based modeling for the gravity ırrigation management. *Procedia Environmental Sciences, 19*, 804-813. **doi:10.1016/j.proenv.2013.06.089**

Berger, T. (2001). Agent-based spatial models applied to agriculture: A simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics, 25*, 245-260. **doi:10.1016/S0169-5150(01)00082-2**

Berglund, E. Z. (2015). Using Agent-Based Modeling for water resources planning and management. *Journal of Water Resources Planning and Management, 141*(11), 04015025. **doi:doi:10.1061/(ASCE)WR.1943-5452.0000544**

Bitterman, P., & Koliba, C. J. (2020). Modeling alternative collaborative governance network designs: An Agent-Based Model of water governance in the Lake Champlain Basin, Vermont. *Journal of Public Administration Research and Theory, 30*(4), 636-655. **doi:10.1093/jopart/muaa013**

Bonté, B., Farolfi, S., Ferrand, N., Abrami, G., Diallo, M. C., Dubois, D., Johannet, A., & Gaudi, W. A. (2019). Building new kinds of meta-models to analyse experimentally (companion) modelling processes in the field of natural resource management. *Environmental Modelling & Software, 120*. **doi:10.1016/j.envsoft.2019.07.011**

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *In Proceedings of National Academy of Sciences* 99(3): 7280-7287. **https://doi.org/10.1073/pnas.082080899**

Bourceret, A., Amblard, L., & Mathias, J.-D. (2022). Adapting the governance of social–ecological systems to behavioural dynamics: An agent-based model for water quality management using the theory of planned behaviour. *Ecological Economics, 194*. **doi:10.1016/j.ecolecon.2021.107338**

Britz, W., Ferris, M., & Kuhn, A. (2013). Modeling water allocating institutions based on multiple optimization problems with equilibrium constraints. *Environmental Modelling & Software, 46*, 196-207. **doi:10.1016/j.envsoft.2013.03.010**

Castilla-Rho, J. C., Rojas, R., Andersen, M. S., Holley, C., & Mariethoz, G. (2019). Sustainable groundwater management: How long and what will it take? *Global Environmental Change, 58*. **doi:10.1016/j.gloenvcha.2019.101972**

Castonguay, A. C., Iftekhar, M. S., Urich, C., Bach, P. M., & Deletic, A. (2018). Integrated modelling of stormwater treatment systems uptake. *Water Res, 142*, 301-312. **doi:10.1016/j.watres.2018.05.037**

Castonguay, A. C., Urich, C., Iftekhar, M. S., & Deletic, A. (2018). Modelling urban water management transitions: A case of rainwater harvesting. *Environmental Modelling & Software, 105*, 270-285. **doi:10.1016/j.envsoft.2018.05.001**

Chen, A. (2017). Spatially explicit modelling of agricultural dynamics in semi-arid environments. *Ecological Modelling, 363*, 31-47. **doi:10.1016/j.ecolmodel.2017.08.025**

Cheng, H., Dong, S., Li, F., Yang, Y., Li, Y., & Li, Z. (2019). A circular economy system for breaking the development dilemma of 'ecological fragility–economic poverty' vicious circle: A CEEPS-SD analysis. *Journal of Cleaner Production*, 212, 381–392. **doi:10.1016/j.jclepro.2018.12.014**

Crooks, A. T., & Hailegiorgis, A. B. (2014). An agent-based modeling approach applied to the spread of cholera. *Environmental Modelling & Software, 62*, 164-177. **doi:10.1016/j.envsoft.2014.08.027**

Daloğlu, I., Nassauer, J. I., Riolo, R. L., & Scavia, D. (2014). Development of a farmer typology of agricultural conservation behavior in the American Corn Belt. *Agricultural Systems, 129*, 93-102. **doi:10.1016/j.agsy.2014.05.007**

Darbandsari, P., Kerachian, R., & Malakpour-Estalaki, S. (2017). An Agent-based behavioral simulation model for residential water demand management: The case-study of Tehran, Iran. *Simulation Modelling Practice and Theory, 78*, 51-72. **doi:10.1016/j.simpat.2017.08.006**

Darbandsari, P., Kerachian, R., Malakpour-Estalaki, S., & Khorasani, H. (2020). An agent-based conflict resolution model for urban water resources management. *Sustainable Cities and Society, 57*. **doi:10.1016/j.scs.2020.102112**

Ding, K. J., Gilligan, J. M., Yang, Y. C. E., Wolski, P., & Hornberger, G. M. (2021). Assessing food–energy–water resources management strategies at city scale: An agent-based modeling approach for Cape Town, South Africa. *Resources, Conservation and Recycling, 170*. **doi:10.1016/j.resconrec.2021.105573**

Du, E., Cai, X., Wu, F., Foster, T., & Zheng, C. (2021). Exploring the impacts of the inequality of water permit allocation and farmers' behaviors on the performance of an agricultural water market. *Journal of Hydrology, 599*. **doi:10.1016/j.jhydrol.2021.126303**

Du, E., Tian, Y., Cai, X., Zheng, Y., Han, F., Li, X., Zhao, M., Yang, Y., & Zheng, C. (2022). Evaluating distributed policies for conjunctive surface water- groundwater management in large river basins: Water uses versus hydrological ımpacts. *Water Resources Research, 58*(1). **doi:10.1029/2021wr031352**

Elhamian, S. A. B., Rakhshandehroo, G., & Javid, A. H. (2021). Quantitative and qualitative optimization of water allocation in no bandegan aquifer using an Agent-based Approach. *Iranian Journal of Science and Technology, Transactions of Civil Engineering, 46*(1), 523-534. **doi:10.1007/s40996-021-00656-1**

Farhadi, S., Nikoo, M. R., Rakhshandehroo, G. R., Akhbari, M., & Alizadeh, M. R. (2016). An agent-based-nash modeling framework for sustainable groundwater management: A case study. *Agricultural Water Management, 177*, 348-358. **doi:10.1016/j.agwat.2016.08.018**

Fleming, S. W. (2021). Scale-free networks, 1/f dynamics, and nonlinear conflict size scaling from an agent-based simulation model of societal-scale bilateral conflict and cooperation. *Physica A: Statistical Mechanics and its Applications, 567*. **doi:10.1016/j.physa.2020.125678**

Galán, J. M., López-Paredes, A., & del Olmo, R. (2009). An agent-based model for domestic water management in Valladolid metropolitan area. *Water Resources Research, 45*(5). **doi:10.1029/2007wr006536**

García, G. A., García, P. E., Rovere, S. L., Bert, F. E., Schmidt, F., Menéndez, Á. N., Nosetto, M. D., Verdin, A., Rajagopalan, B., Arora, P., & Podestá, G. P. (2019). A linked modelling framework to explore interactions among climate, soil water, and land use decisions in the Argentine Pampas. *Environmental Modelling & Software, 111*, 459-471. **doi:10.1016/j.envsoft.2018.10.013**

Giri, S., Arbab, N. N., & Lathrop, R. G. (2018). Water security assessment of current and future scenarios through an integrated modeling framework in the Neshanic River Watershed. *Journal of Hydrology, 563*, 1025-1041. **doi:10.1016/j.jhydrol.2018.05.046**

Granco, G., Caldas, M., Bergtold, J., Heier Stamm, J. L., Mather, M., Sanderson, M., Daniels, M., Sheshukov, A., Haukos, D., & Ramsey, S. (2022). Local environment and individuals' beliefs: The dynamics shaping public support for sustainability policy in an agricultural landscape. *Journal of Environmental Management, 301*, 113776. **doi:10.1016/j.jenvman.2021.113776**

Guo, N., Shi, C., Yan, M., Gao, X., & Wu, F. (2022). Modeling agricultural water-saving compensation policy: An ABM approach and application. *Journal of Cleaner Production, 344*. **doi:10.1016/j.jclepro.2022.131035**

Hampf, A. C., Carauta, M., Latynskiy, E., Libera, A. A. D., Monteiro, L., Sentelhas, P., Christian, T., Thomas, B., & Nendel, C. (2018). The biophysical and socio-economic dimension of yield gaps in the southern Amazon – A bio-economic modelling approach. *Agricultural Systems, 165*, 1-13. **doi:10.1016/j.agsy.2018.05.009**

Hare, M., & Deadman, P. (2004). Further towards a taxonomy of agent-based simulation models in environmental management. *Mathematics and Computers in Simulation, 64*(1), 25-40. **doi:10.1016/s0378-4754(03)00118-6**

Head, B.W., & Xiang, W.-N. (2016). Working with wicked problems in socio-ecological systems: more awareness, greater acceptance, and better adaptation. *Landscape and Urban Planning, 154*, 1–3.

Huber, L., Bahro, N., Leitinger, G., Tappeiner, U., & Strasser, U. (2019). Agent-Based Modelling of a coupled water demand and supply system at the catchment scale. *Sustainability, 11*(21). **doi:10.3390/su11216178**

Huber, L., Rüdisser, J., Meisch, C., Stotten, R., Leitinger, G., & Tappeiner, U. (2021). Agent-based modelling of water balance in a social-ecological system: A multidisciplinary approach for mountain catchments. *Science of the Total Environment, 755*, 142962. **doi:https://doi.org/10.1016/j.scitotenv.2020.142962**

Hyun, J.-Y., Huang, S.-Y., Yang, Y.-C. E., Tidwell, V., & Macknick, J. (2019). Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions. *Hydrology and Earth System Sciences, 23*(5), 2261-2278. **doi:10.5194/hess-23-2261-2019**

Iftekhar, M. S., Tisdell, J. G., & Connor, J. D. (2013). Effects of competition on environmental water buyback auctions. *Agricultural Water Management, 127*, 59-73. **doi:10.1016/j.agwat.2013.05.015**

Isern, D., Abelló, S., & Moreno, A. (2012). Development of a multi-agent system simulation platform for irrigation scheduling with case studies for garden irrigation. *Computers and Electronics in Agriculture, 87*, 1-13. **doi:10.1016/j.compag.2012.04.007**

Jager W., & Gotts N., (2013), Simulating social environmental systems, Steg, L., van den Berg, A. E., & de Groot, J. I. M. (Eds.). (p. 283). BPS textbooks in psychology. *Environmental psychology: An introduction*. BPS Blackwell.

James, R., & Rosenberg, D. E. (2022). Agent- Based Model to manage household water use through social- environmental strategies of encouragement and peer pressure. *Earth's Future, 10*(2). **doi:10.1029/2020ef001883**

Janssen, M. A. (2007). Coordination in irrigation systems: An analysis of the Lansing–Kremer model of Bali. *Agricultural Systems, 93*(1-3), 170-190. **doi:10.1016/j.agsy.2006.05.004**

Jiménez, A.-F., Cárdenas, P.-F., & Jiménez, F. (2021). Smart water management approach for resource allocation in High-Scale irrigation systems. *Agricultural Water Management, 256*. **doi:10.1016/j.agwat.2021.107088**

Jiménez, A.-F., Cárdenas, P.-F., & Jiménez, F. (2022). Intelligent IoT-multiagent precision irrigation approach for improving water use efficiency in irrigation systems at farm and district scales. *Computers and Electronics in Agriculture, 192*. **doi:10.1016/j.compag.2021.106635**

Kadinski, L., Salcedo, C., Boccelli, D. L., Berglund, E., & Ostfeld, A. (2022). A Hybrid Data-Driven-Agent-Based Modelling Framework for Water Distribution Systems Contamination Response during COVID-19. *Water, 14*(7), 1088. Retrieved at 08.05.2022 from **https://www.mdpi.com/2073-4441/14/7/1088**

Kaiser, K. E., Flores, A. N., & Hillis, V. (2020). Identifying emergent agent types and effective practices for portability, scalability, and intercomparison in water resource agent-based models. *Environmental Modelling & Software, 127*. **doi:10.1016/j.envsoft.2020.104671**

Kandiah, V. K., Berglund, E. Z., & Binder, A. R. (2019). An agent-based modeling approach to project adoption of water reuse and evaluate expansion plans within a sociotechnical water infrastructure system. *Sustainable Cities and Society, 46*. **doi:10.1016/j.scs.2018.12.040**

Kanta, L., & Berglund, E. (2015). Exploring tradeoffs in demand-side and supply-side management of urban water resources using Agent-Based Modeling and evolutionary computation. *Systems, 3*(4), 287-308. **doi:10.3390/systems3040287**

Koutiva, I., & Makropoulos, C. (2016a). Exploring the effects of domestic water management measures to water conservation attitudes using agent based modelling. *Water Supply, 17*(2), 552-560. **doi:10.2166/ws.2016.161**

Koutiva, I., & Makropoulos, C. (2016b). Modelling domestic water demand: An agent based approach. *Environmental Modelling & Software, 79*, 35-54. **doi:10.1016/j.envsoft.2016.01.005**

Koutiva, & Makropoulos. (2019). Exploring the effects of alternative water demand management strategies using an Agent-Based Model. *Water, 11*(11). **doi:10.3390/w11112216**

Le bars, M., & Attonaty, J.-M. (2001). *Proceedings : 13th IEEE International conference on tools with artificial intelligence.*

Li, Y., Khalkhali, M., Mo, W., & Lu, Z. (2021). Modeling spatial diffusion of decentralized water technologies and impacts on the urban water systems. *Journal of Cleaner Production, 315*. **doi:10.1016/j.jclepro.2021.128169**

Lin, Z., Lim, S. H., Lin, T., & Borders, M. (2020). Using Agent-Based Modeling for water resources management in the Bakken Region. *Journal of Water Resources Planning and Management, 146*(1), 05019020. **doi:10.1061/(ASCE)WR.1943-5452.0001147**

López-Paredes, A., Saurí, D., & Galán, J. M. (2016). Urban water management with artificial societies of agents: The FIRMABAR Simulator. *Simulation, 81*(3), 189-199. **doi:10.1177/0037549705053167**

Mashhadi Ali, A., Shafiee, M. E., & Berglund, E. Z. (2017). Agent-based modeling to simulate the dynamics of urban water supply: Climate, population growth, and water shortages. *Sustainable Cities and Society, 28*, 420-434. **doi:10.1016/j.scs.2016.10.001**

Mariano, Dandara & Alves, Conceicao De Maria. (2020). The application of role-playing games and agent-based modelling to the collaborative water management in peri-urban communities. *Brazilian Journal of Water Resources, 25*, 1-14. **https://doi.org/10.1590/2318-0331.252020190100**

Markowska, J., Szali´nska, W., Dąbrowska, J., & Brząkała, M. (2020). The concept of a participatory approach to water management on a reservoir in response to wicked problems. *Journal of Environmental Management.* 259. **https://doi.org/10.1016/j.jenvman.2019.109626**

Mashhadi Ali, A., Shafiee, M. E., & Berglund, E. Z. (2017). Agent-based modeling to simulate the dynamics of urban water supply: Climate, population growth, and water shortages. *Sustainable Cities and Society, 28*, 420-434. **doi:10.1016/j.scs.2016.10.001**

Mewes, B. (2019). *AGU Fall Meeting Abstracts*. https://ui.adsabs.harvard.edu/abs/2019AGUFM.H52C..02M

Mishra, V. K., Palleti, V. R., & Mathur, A. (2019). A modeling framework for critical infrastructure and its application in detecting cyber-attacks on a water distribution system. *International Journal of Critical Infrastructure Protection, 26*. **doi:10.1016/j.ijcip.2019.05.001**

Moehring, M., & Troitzsch, K. (2001). Lake Anderson revisited by agents. *Journal of Artificial Societies and Social Simulation, 4*(3),1. **https://www.jasss.org/4/3/1.html**

Moglia, M., Perez, P., & Burn, S. (2010). Modelling an urban water system on the edge of chaos. *Environmental Modelling & Software, 25*(12), 1528-1538. **doi:10.1016/j.envsoft.2010.05.002**

Monroe, J., Ramsey, E., & Berglund, E. (2018). Allocating countermeasures to defend water distribution systems against terrorist attack. *Reliability Engineering & System Safety, 179*, 37-51. **doi:10.1016/j.ress.2018.02.014**

Murphy, J. T. (2012). Exploring complexity with the Hohokam Water Management Simulation: A middle way for archaeological modeling. *Ecological Modelling, 241*, 15-29. **doi:10.1016/j.ecolmodel.2011.12.026**

Murphy, J., Ozik, J., Collier, N., Altaweel, M., Lammers, R., Prusevich, A., . . . Alessa, L. (Eds). (2015). *Proceedings of the 2015 Winter Simulation Conference.*

Nandi, A., Megiddo, I., Ashok, A., Verma, A., & Laxminarayan, R. (2017). Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis. *Social Science Medicine, 180*, 181-192. **doi:10.1016/j.socscimed.2016.08.049**

Nguyen, N. P., Shortle, J. S., Reed, P. M., & Nguyen, T. T. (2013). Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation. *Resource and Energy Economics, 35*(1), 60-90. **doi:10.1016/j.reseneeco.2012.09.002**

Nhim, T., Richter, A., & Zhu, X. (2019). The resilience of social norms of cooperation under resource scarcity and inequality — An agent-based model on sharing water over two harvesting seasons. *Ecological Complexity, 40*. **doi:10.1016/j.ecocom.2018.06.001**

Nhim, T., & Richter, A. (2022). Path dependencies and institutional traps in water governance – Evidence from Cambodia. *Ecological Economics, 196*. **doi:10.1016/j.ecolecon.2022.107391**

Nichita, C., & Oprea, M. (Eds.), (2007). *Computer Aided Chemical Engineering,* 24, 1217-1222. Elsevier.

Nickel, D., Barthel, R., & Braun, J. (2005). Large-scale water resources management within the framework of GLOWA-Danube—The water supply model. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(6-7), 383-388. **doi:10.1016/j.pce.2005.06.004**

Niu, W. J., & Wang, H. M. (Eds.), (2006). *International Conference on Sensing, Computing and Automation.*

Nguyen, N. P., Shortle, J. S., Reed, P. M., & Nguyen, T. T. (2013). Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation. *Resource and Energy Economics, 35*(1), 60-90. **doi:https://doi.org/10.1016/j.reseneeco.2012.09.002**

Noël, P. H., & Cai, X. (2017). On the role of individuals in models of coupled human and natural systems: Lessons from a case study in the Republican River Basin. *Environmental Modelling & Software, 92*, 1-16. **doi:10.1016/j.envsoft.2017.02.010**

Noori, M., Emadi, A., & Fazloula, R. (2021). An agent-based model for water allocation optimization and comparison with the game theory approach. *Water Supply, 21*(7), 3584-3601. **doi:10.2166/ws.2021.124**

Nouri, A., Saghafian, B., Delavar, M., & Bazargan-Lari, M. R. (2019). Agent-Based Modeling for Evaluation of Crop Pattern and Water Management Policies. *Water Resources Management, 33*(11), 3707-3720. **doi:10.1007/s11269-019-02327-3**

Ohab-Yazdi, S. A., & Ahmadi, A. (2018). Using the agent-based model to simulate and evaluate the interaction effects of agent behaviors on groundwater resources, a case study of a sub-basin in the Zayandehroud River Basin. *Simulation Modelling Practice and Theory, 87*, 274-292. **doi:10.1016/j.simpat.2018.07.003**

Oliva-Felipe, L., Verdaguer, M., Poch, M., Vázquez-Salceda, J., & Cortés, U. (2021). The organisational structure of an Agent-Based Model for the management of wastewater systems. *Water, 13*(9). **doi:10.3390/w13091258**

Pahl-Wostl, C. (2002). Towards sustainability in the water sector – The importance of human actors and processes of social learning. *Aquatic Sciences, 64*(4), 394-411. **doi:10.1007/PL00012594**

Pahl-Wostl, C., & Hare, M. (2004). Processes of social learning in integrated resources management. *Journal of Community & Applied Social Psychology, 14*(3), 193-206. **doi:https://doi.org/10.1002/casp.774**

Palmatier, R. W., Houston, M. B., & Hulland, J. (2018). Review articles: purpose, process, and structure. *Journal of the Academy of Marketing Science, 46*(1), 1-5. **doi:10.1007/s11747-017-0563-4**

Perello-Moragues, A., Poch, M., Sauri, D., Popartan, L. A., & Noriega, P. (2021). Modelling domestic water use in metropolitan areas using socio-cognitive agents. *Water, 13*(8), 1024. Retrieved at 08.05.2022 from **https://www.mdpi.com/2073-4441/13/8/1024**

Rodriguez-Roda, I. R., Marre, S. M., Comas, J., Baeza, J., Colprim, J., Lafuente, J., Cortes, U., & Poch, M. (2002). A hybrid supervisory system to support WWTP operation: implementation and validation. *Water Science and Technology, 45*(4-5), 289-297. **doi:10.2166/wst.2002.0608**

Ponte, B.; de la Fuente, D.; Pino, R. & Rosillo, R. (2015): Real-Time water demand forecasting system through an agent-based architecture. *International Journal of Bio-Inspired Computation, 7*(3),147-156.

Pouladi, P., Afshar, A., Afshar, M. H., Molajou, A., & Farahmand, H. (2019). Agent-based socio-hydrological modeling for restoration of Urmia Lake: Application of theory of planned behavior. *Journal of Hydrology, 576*, 736-748. **doi:10.1016/j.jhydrol.2019.06.080**

Ramsey, E. (2016). *World Environmental and Water Resources Congress 2016*.

Rixon, A., Moglia, M., & Burn, S. (2007). Chapter 4 - Exploring water conservation behaviour through participatory agent-based modelling. In A. Castelletti & R. S. Sessa (Eds.), *Topics on System Analysis and Integrated Water Resources Management* (pp. 73-96). Oxford: Elsevier. **http://dx.doi.org/10.1016/B978-008044967-8/50004-X**

Rojas, R., Castilla-Rho, J., Bennison, G., Bridgart, R., Prats, C., & Claro, E. (2022). Participatory and ıntegrated modelling under contentious water use in semiarid basins. *Hydrology, 9*(3). **doi:10.3390/hydrology9030049**

Saqalli, M., Thiriot, S., & Amblard, F. (2010). Investigating social conflicts linked to water resources trhough agent-based modelling. *NATO Science for Peace and security series, 75*, 142-157. Retrieved at 08.05.2022 from **https://halshs.archives-ouvertes.fr/halshs-00918476**

Schlüter, M., & Pahl-Wostl, C. (2007). Mechanisms of resilience in common-pool resource management systems an Agent-based Model of water use in a river basin. *Ecology and Society, 12*(2). Retrieved at 08.05.2022 from **http://www.jstor.org/stable/26267867**

Schroeder, O. B., Manez, M., & Jeffrey, P. (2009). *The use of multi-agent based models to support water resources management The Moroccan case study*. Abingdon: Routledge.

Schwarz, N., & Ernst, A. (2009). Agent-based modeling of the diffusion of environmental innovations — An empirical approach. *Technological Forecasting and Social Change, 76*(4), 497-511. **doi:10.1016/j.techfore.2008.03.024**

Shafiee, M. E., & Berglund, E. Z. (2016). Agent-based modeling and evolutionary computation for disseminating public advisories about hazardous material emergencies. *Computers, Environment and Urban Systems, 57*, 12-25. **doi:10.1016/j.compenvurbsys.2016.01.001**

Smajgl, A., Heckbert, S., Ward, J., & Straton, A. (2009). Simulating impacts of water trading in an institutional perspective. *Environmental Modelling & Software, 24*(2), 191-201. **doi:10.1016/j.envsoft.2008.07.005**

Strickling, H., DiCarlo, M. F., Shafiee, M. E., & Berglund, E. (2020). Simulation of containment and wireless emergency alerts within targeted pressure zones for water contamination management. *Sustainable Cities and Society, 52*. **doi:10.1016/j.scs.2019.101820**

Tamburino, L., Di Baldassarre, G., & Vico, G. (2020). Water management for irrigation, crop yield and social attitudes: a socio-agricultural agent-based model to explore a collective action problem. *Hydrological Sciences Journal, 65*(11), 1815-1829. **doi:10.1080/02626667.2020.1769103**

Tillman, D., Larsen, T. A., Pahl-Wostl, C., & Gujer, W. (1999). Modeling the actors in water supply systems. *Water Science and Technology, 39*(4), 203-211. **doi:https://doi.org/10.1016/S0273-1223(99)00055-4**

Tillman, T., Larsen, T. A., Pahl-Wostl, C., & Gujer, W. (2001). Interaction analysis of stakeholders in water supply systems. *Water Science and Technology, 43*(5), 319-326. **doi:10.2166/wst.2001.0316**

Tillman, D. E., Larsen, T. A., Pahl-Wostl, C., & Gujer, W. (2005). Simulating development strategies for water supply systems. *Journal of Hydroinformatics, 7*(1), 41-51. **doi:10.2166/hydro.2005.0005**

Thompson, J. R., Frezza, D., Necioglu, B., Cohen, M. L., Hoffman, K., & Rosfjord, K. (2019). Interdependent Critical Infrastructure Model (ICIM): An agent-based model of power and water infrastructure. *International Journal of Critical Infrastructure Protection, 24*, 144-165. **doi:10.1016/j.ijcip.2018.12.002**

Tomičić, I., & Schatten, M. (2016). Agent-based framework for modeling and simulation of resources in self-sustainable human settlements: a case study on water management in an eco-village community in Croatia. *International Journal of Sustainable Development & World Ecology, 23*(6), 504-513. **doi:10.1080/13504509.2016.1153527**

Van Oel, P. R., & Van der Veen, A. (2011). Using agent-based modeling to depict basin closure in the Naivasha basin, Kenya: a framework of analysis. *Procedia Environmental Sciences, 7*, 32-37. **doi:10.1016/j.proenv.2011.07.007**

Wang, H., Zhang, J., & Zeng, W. (2018). Intelligent simulation of aquatic environment economic policy coupled ABM and SD models. *Science of the Total Environment, 618*, 1160-1172. **doi:10.1016/j.scitotenv.2017.09.184**

Wang, Y., Zhou, Y., Franz, K., Zhang, X., Ding, K. J., Jia, G., & Yuan, X. (2021). An agent-based framework for high-resolution modeling of domestic water use. *Resources, Conservation and Recycling, 169*. **doi:10.1016/j.resconrec.2021.105520**

Watson, R., Wilson, H. N., Smart, P., & Macdonald, E. K. (2018). Harnessing difference: A capability-based framework for stakeholder engagement in environmental ınnovation. *Journal of Product Innovation Management, 35*(2), 254-279. **doi:https://doi.org/10.1111/jpim.12394**

Wise, S., & Crooks, A. T. (2012). Agent-based modeling for community resource management: Acequia-based agriculture. *Computers, Environment and Urban Systems, 36*(6), 562-572. **doi:10.1016/j.compenvurbsys.2012.08.004**

Wu, H., Bolte, J. P., Hulse, D., & Johnson, B. R. (2015). A scenario-based approach to integrating flow-ecology research with watershed development planning. *Landscape and Urban Planning, 144*, 74-89. **doi:10.1016/j.landurbplan.2015.08.012**

Xiao, Y., Fang, L., & Hipel, K. (2018). Centralized and decentralized approaches to water demand management. *Sustainability, 10*(10). **doi:10.3390/su10103466**

Yang, J., Yang, Y. C. E., Chang, J., Zhang, J., & Yao, J. (2019). Impact of dam development and climate change on hydroecological conditions and natural hazard risk in the Mekong River Basin. *Journal of Hydrology, 579*. **doi:10.1016/j.jhydrol.2019.124177**

Yang, Y. C. E., Son, K., Hung, F., & Tidwell, V. (2020). Impact of climate change on adaptive management decisions in the face of water scarcity. *Journal of Hydrology, 588*. **doi:10.1016/j.jhydrol.2020.125015**

Yuan, S., Li, X., & Du, E. (2021). Effects of farmers' behavioral characteristics on crop choices and responses to water management policies. *Agricultural Water Management, 247*. **doi:10.1016/j.agwat.2020.106693**

Yuan, X.-C., Wei, Y.-M., Pan, S.-Y., & Jin, J.-L. (2014). Urban household water demand in Beijing by 2020: An Agent-Based Model. *Water Resources Management, 28*(10), 2967-2980. **doi:10.1007/s11269-014-0649-4**

Zamenian, H., & Abraham, D. M. (2020). An Agent-Based Simulation Model for Assessment of Water Consumption Patterns during Water Rate Increase Events. In *Construction Research Congress 2020* (pp. 800-808).

Zhang, P., Peeta, S., & Friesz, T. (2005). Dynamic Game Theoretic Model of multi-layer ınfrastructure networks. *Networks and Spatial Economics, 5*(2), 147-178. **doi:10.1007/s11067-005-2627-0**

Zhang, Y., Wu, Y., Yu, H., Dong, Z., & Zhang, B. (2013). Trade-offs in designing water pollution trading policy with multiple objectives: A case study in the Tai Lake Basin, China. *Environmental Science & Policy, 33*, 295-307. **doi:10.1016/j.envsci.2013.07.002**

Zhao, J., Cai, X., & Wang, Z. (2013). Comparing administered and market-based water allocation systems through a consistent agent-based modeling framework. *Journal of Environmental Management, 123*, 120-130. **doi:10.1016/j.jenvman.2013.03.005**

Zolfagharipoor, M. A., & Ahmadi, A. (2021). Agent-based modeling of participants' behaviors in an inter-sectoral groundwater market. *Journal of Environmental Management, 299*, 113560. **doi:10.1016/j.jenvman.2021.113560**

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Su Kaynakları Yönetiminde Etmen Tabanlı Yaklaşım; Uyarlanmış Sistematik Derleme

Bu araştırmada, su kaynakları yönetiminde Etmen Tabanlı Modelleme (ETM) uygulamalarının genel görünümü oluşturulmuştur. Araştırma yöntemi, sistematik derleme yaklaşımının araştırma konusunun gereklilikleri doğrultusunda uyarlanmış bir versiyonudur. Sonuçlar, su kaynakları yönetiminde ABM yaklaşımının 1999'dan günümüze genişleyen bir kapsama sahip olduğunu göstermektedir. Yayınlar, fen bilimleri ve sosyal bilimleri kapsayan geniş bir bilimsel literatürden derlenmiştir. Literatürde 1999 yılından günümüze hemen hemen her yıl su kaynaklarının yönetiminde ABM yaklaşımının araştırıldığı dergi makaleleri, konferans bildirileri ve kitap bölümleri ile karşılaşılabilmektedir. Ancak 2012 yılından itibaren yayınların sayısı ve çeşitliliği artmıştır. 2018 ve 2019 yılları ise ilgili yayınlara yönelik en yoğun dönemi teşkil etmektedir. Konunun tarihsel gelişimine paralel olarak, yayınların başlangıçta su kaynakları yönetiminde ABM kullanımına yönelik perspektif görüş bildiren makalelerden ibaretken, uygulamayı içeren çalışmaların 2010'lu yıllardan itibaren arttığı gözlemlenmiştir. Mevcut eğilim, saha çalışmalarıyla birlikte sistem yaklaşımı esaslı disiplinlerarası araştırmaların arttığını göstermektedir. Örneğin lojistik, su temini ve enerji dağıtım sistemleri gibi kritik altyapıların birbirine bağımlılığı güncel araştırma konuları arasındadır.

Bir bilgisayar temelli simülasyon yöntemi olarak ETM'nin su kaynakları yönetimi araştırmalarında kullanılması Tillman ve ark. (1999, 2001), Berger (2001), Le Bars ve Attonaty (2001a, 2001b), ve Pahl-Wostl (2002) gibi araştırmacılar tarafından gerçekleştirilen öncü nitelikteki araştırma ile gerçekleşmiştir. Tillman ve ark. geliştirdikleri etmen tabanlı katılımcı simülasyon uygulamasıyla su şebekeleri ve temin sistemlerindeki aktörlerin etkileşimlerini araştırmışlardır (Tillman ve ark., 1999; 2001). Berger (2001) tarafından "hücresel otomatlar" tarımsal ekonomik modellere uygulanmıştır. Pahl-Wostl (2002) ETM'nin su kaynaklarının "karmaşıklık", "belirsizlik" ve "insanla ilişkili boyutlarını" ihmal etmeyen bir yöntem olduğuna işaret ederek, sürdürülebilirlik araştırmalarında ETM'nin gelecek vaad eden bir yöntem olarak tanımlamıştır. ETM yönteminin temel bir özelliği olarak su kaynakları yönetiminin "toplumsal boyutları" Lopez-Parades ve ark. (2005), Rixon ve ark. (2007), Schroeder ve ark. (2009), ve Smajgl ve ark. (2009) gibi bir çok araştırmacı tarafından araştırılmıştır. 2000'li yılların başlarından itibaren, su kaynakları yönetimi araştırmalarına özgü pek çok modelleme çerçevesinin de oluşturulduğu görülmektedir. Becu ve ark. (2013) tarımsal su havzalarının özellikleri ve çiftçi davranışının modellendiği CATCHSCAPE isimli çoklu etmen modelini geliştirmişlerdir. Athanasiadis ve ark. (2005) su fiyatlandırma politikalarının değerlendirildiği DAWN hibrit modelini geliştirmişlerdir. Barthel ve ark. (2005) nehir havzalarındaki iklim değişikliği etkilerinin araştırılması konusunda DANUBIA isimli karar destek sistemini geliştirmişlerdir. Barreteau ve ark. (2007) bilgisayar oyunları ile ETM arasındaki benzerliklere odaklanarak, PIEPLUE isimli araçla ikisi arasındaki sinerjiyi test etmişlerdir. Janssen (2007) "Lansing-Kremer" modelinin, Bali adasındaki öz-yönetimli sulama sisteminin etkileşimlerini açıklamadaki başarısının genelleştirilmesini ele almıştır. Saqalli ve ark. (2010) MAELIA isimli bir karar destek sistemi, Jimenez ve ark. (2021) bir sulama bölgesindeki su dağıtımı için etmen tabanlı bir sulama modeli (IABM) geliştirmiştir. Noel ve Cai (2017) ile Ding ve ark. (2021) insan-doğa sistemleri için etmen tabanlı modeller geliştirmişlerdir.

Su kaynaklarının korunması da erken dönem uygulamaları arasında yer almaktadır. Mohring ve Troitzsch (2001) Jay M. Anderson'un göllerdeki ötrofikasyon durumuna ilişkin araştırmasının bir replikasyonunu ABM kullanarak gerçekleştirmişlerdir. Nichita ve Oprea (2007) su kalitesi kontrolünde çoklu etmen tabanlı simülasyon uygulaması gerçekleştirmişlerdir. Galan ve ark. (2009) sosyal modeller, kent dinamikleri ve teknolojik yeniliklerin yayılması konusunu, coğrafi bilgi sistemleri ile bir araya getirmişlerdir. Wise ve Crooks (2012) "acequia" isimli kompleks sulama sistemlerindeki aktörler arasındaki etkileşimleri temsil eden bir ETM geliştirmişlerdir. Akhbari ve Grigg (2013) su havzalarındaki farklı aktörler arasındaki etkileşimleri ETM yöntemiyle modellemişlerdir.

Su talebinin yönetimi, ETM'nin su kaynakları yönetimindeki uygulamalarından bir diğerine örnek teşkil etmektedir. Yuan ve ark. (2014), Ponte ve ark. (2015) hane halkı su talebinin tahminine ilişkin bir ETM geliştirmiştir. Al-Amin ve ark. kısıtlı yeraltı suyu rezervleri ve değişen su talepleri arasındaki etkileşimleri analiz etmiş, belirsizlik durumlarındaki su taleplerinin simülasyonuna yönelik bir eşlenik ETM ve yeraltı suyu modeli geliştirmiş ve politika geliştiriciler ve tüketiciler arasındaki etkileşimleri konu edinen ETM geliştirmiştir (Al-Amin ve ark., 2015; Al-Amin ve ark., 2016; Al-Amin ve ark., 2018). Murphy ve ark. (2015) hidrolojik su dengesi modeli (WBM) ile ETM'nin ilişkilendirildiği bir simülasyon çerçevesi oluşturmuşlardır. Koutiva ve Makropoulos (2016) evsel su kullanıcılarının yönetimsel tedbirler karşısındaki davranışlarının incelendiği "Urban Water Agents' Behavior" isimli bir ETM geliştirmişlerdir. Xiao ve ark. bir nehir havzasındaki su talebinin değerlendirilmesi konusunda ETM yaklaşımını önererek, dağıtık ve merkezi süreçlerin su talebi üzerindeki etkilerini değerlendirmişlerdir (Xiao ve ark. 2018a; 2018b).

Bakhtiari ve ark. (2019) su kaynaklarının kapasitesi ve su talebindeki belirsizliklerin göz önünde bulundurulduğu bir "yıllık su tahsis modeli" geliştirmişlerdir. Huber ve ark. (2021) su temini ve talep modeli olarak Aqua.MORE isimli modeli geliştirmiştir.

Tarımsal sulama yönetimi, ETM metodunun su kaynakları araştırmalarına uygulanması konusundaki en yaygın konuların başında gelmektedir. Barreteau ve ark. (2004), Janssen (2007), Isern ve ark. (2012), Belaqziz ve ark. , Noel ve Cai, Anthony ve Birendra (2018), Mewes ve Schumann, Jimenez ve ark., ve Bahrami ve ark. gibi pek çok araştırmacı, ETM'nin tarımsal sulama alanına uygulanması konusunda araştırmalar gerçekleştirmiştir.

Alanın disiplinlerarası doğasının bir yansıması olarak, makalelerin yarısından fazla bir bölümünün birbirinden farklı 50 dergide yayımlandığı görülmektedir. Geriye kalan kısmının "Environmental Modeling & Software", "Sustainable Cities & Society", "Agricultural Water Management", "Journal of Hydrology", "Water", "Agricultural Systems", "Water Resources Management", "Journal of Environmental Management", "Ecologic Modelling", "Journal of Water Resources Planning and Management", "Total Environment" ve "Water Resource Research" gibi önde gelen dergilerde yayımlandığı görülmektedir.

Saha çalışmalarının geniş coğrafi dağılımı, ABM metodolojisinin dünya çapında su kaynakları yönetimi araştırmalarına uygulandığını göstermektedir. Çalışmaların uygulama ölçeği de su temin ve dağıtım sistemlerinden sulama bölgelerine, göllere, yeraltı sularına, tarımsal havzalar ve nehir havzalarına uzanan bir kapsamda değişim göstermektedir. Öncü nitelikteki 42 vaka çalışması ABD, İran ve Çin'de gerçekleştirilmiştir. Dikkat çeken bir diğer nokta ise 10'dan fazla vaka çalışmasının, ABM yaklaşımının bir esnekliği olan varsayımsal veya sanal (hypothetical/virtual) ortamlar kullanılarak gerçekleştirilmiş olmasıdır.

ABM uygulaması için bir çok bilgisayar programlama dili ve paket yazılımlar kullanılabilmektedir. Bu nedenle literatürdeki uygulamaların da bu anlamda çeşitlendiği görülmektedir. NetLogo, AnyLogic, MASON, Repast Symphony, CORMAS, DynaMind ve Envision önde gelen paket yazılımlardır. Java, Python, web programlama dilleri, Julia ve C++ ise bu konuda kullanılan bilgisayar programlama dilleri arasında yer almaktadır. Bildirilerin 19'u proje tabanlı yazılım uygulaması sunmuş veya yazılımın veya programlama dilinin adını açıkça belirtmemiştir. 42 makalede, "Overview, Design concepts, and Details" (ODD) belgeleri, metodoloji açıklaması veya benzer belgeleri kapsayan ekler sunulmuştur. Bazı makalelerde sistematik biçimde araştırmada kullanılan yazılım bilgilerine yer verildiği görülmektedir. Bununla birlikte, sadece birkaç makalede, bulguların replikasyonu konusunda kullanılabilecek şekilde açık kaynak paylaşım siteleri üzerinden yazılımların okuyucuya sunulduğu görülmektedir. Bu durum, araştırmaların replikasyonu veya diğer herhangi bir bilimsel katkının sunulması için gerekli verilerin/bilgilerin eser sahiplerince açık biçimde paylaşılması konusunda hala önemli eksiklikler olduğu şeklinde değerlendirilmektedir.