

Review

Multiagent System and Rainfall-Runoff Model in Hydrological Problems: A Systematic Literature Review

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Abstract: Typically, hydrological problems require approaches capable of describing and simulating part of the hydrological system, or the environmental consequences of natural or anthropic actions. Tools such as Multiagent System (MAS) and Rainfall-Runoff Model (RRM) have been used to help researchers to develop and better understand water systems. Thus, this study presents a Systematic Literature Review (SLR) on the joint use of MAS and RRM tools, in the context of hydrological problems. SLR was performed based on a protocol defined from the research question. Initially, 79 papers were found among six bibliographic databases. This total was reduced over four stages of selection, according to exclusion criteria. In the end, three papers were considered satisfactory within the scope of the research, where they were summarized, analyzed, and compared. While the MAS and RRM tools can interact with their results in a coupled model, SLR showed that there are still major challenges to be explored concerning the dynamics between them, as the steps of scales and validation. However, the coupling of MAS and RRM can provide an interesting alternative tool to analyse decision-making about water resources management systems.



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Keywords: multiagent system; rainfall-runoff model; systematic literature review; water resources management

1. Introduction

Hydrology is the area of study of the natural phenomena of the hydrological cycle, which considers the dynamics from the origins to the destinations of water on the planet [1]. A significant increase in hydrological problems has been occurring due to environmental changes carried out by natural or anthropic actions. As a consequence, serious risks to human life, the environment, and economic development can occur [2]. In this sense, water systems have been widely explored based on simulation tools, to understand the systems or generate predictions about changes in the hydrological dynamics of a region.

To prevent or solve hydrological problems, approaches are often required that are capable of describing part of the hydrological system, and also simulating the consequences of human actions on a given hydrographic region [3]. According to Pouladi et al. [4], decision-making on the use of water resources is responsible for changes in water condition and availability. Sustainable systems and integrated water management are quite complex and require the union of tools such as physical, ecological, social and economic sciences [5].

Some methods have been coupling social and water systems. One of them is integrated water resources management, which since the early 1990s has been providing interdisciplinary, quantitative, and qualitative methods, which assist decision-makers in water resources management [6]. Another approach, defined as a science called socio-hydrology, considers the coevolution of hydrological and social systems, aiming to analyze the consequences of decision-making, individual or collective, on water systems [7].

Computational hydrological models are widely used to describe the behavior of hydrological processes in a simplified form of reality [8]. Particularly, the rainfall-runoff

models (RRM) aims at calculating and accurately describing the flow, based on hydrological processes at different spatial and temporal scales [9]. Researchers have developed and refined these models to better understand the hydrological physical processes involved in real water systems [10]. In addition, many studies investigate decision-making regarding the management of water resources, to analyze the environmental consequences of water use [11].

Besides that, artificial intelligence (AI) tools are often used to assist in the research of water systems [12]. Multiagent systems (MAS) are one of the AI tools and can serve to simulate complex adaptive systems through the behavior of emerging systems [13]. MAS is composed of a set of autonomous agents that interact with each other and with the environment in which they are inserted, generating consequences for each action within the system [14]. In this way, MAS is considered a bottom-up approach, the local instructions of the agents generate an adaptive behavior that results in the dynamism of the system [2].

Seeing that the joint use of RRM and MAS tools can be a coupled social and hydrological model, it is possible to solve specific problems of water systems. Furthermore, as it is a hybrid method, the results tend to be better in terms of precision, time and scale [15]. In this sense, it is intended to develop a tool that integrates the RRM and the MAS in order to support the management of water resources.

In particular, it is intended to contribute to the project Participatory Management of Water Resources using Computer Games and Multiagent Systems (<http://gprh.c3.furg.br/>, accessed on 30 November 2021). (Gestão Participativa de Recursos Hídricos—GPRH), whose objectives are to develop, formalize and apply a tool, in game format, to assist in decision making about water uses. The GPRH project also aims to realize a pilot application of the tool with the Lagoa Mirim and Canal São Gonçalo Hydrographic Basin Management Committee, which is responsible for organizing and planning the uses of water in the basin, in the extreme south of Brazil.

Some of the stages of the GPRH project have already been completed, such as: the definition of the main agents, and their actions and interactions in the context of the basin [16]; the first steps for analyzing the modeling of decision-making in the basin [17,18]; the search for the main works involving MAS and role-playing games (RPG) in the context of natural resources management [19]; the construction of the computational game modeling, called GORIM, involving MAS and RPG [20,21] and; the analysis of strategies and data on the RPG developed [22,23].

Some of the needs of the GPRH project are the characterization, modeling, and scenarios plan for the Mirim-São Gonçalo Hydrographic Basin (MSGHB). In addition, it is intended to explore decision-making on the water resources of the basin. An alternative to the development of these processes is the joint use of MAS, to model and simulate the social behavior of the system, and RRM, to provide the behavior of the MSGHB water processes.

However, to understand the main steps and challenges of developing a coupled modeling between RRM and MAS, we search and explore the main works that integrate these two tools. Therefore, a literature review was developed, which, in addition to providing historical advances on the subject, presents the main challenges, methods, and results found.

For a literature review to be considered rigorous and valid, it is necessary that its development involves systematic processes [24]. With a systematic literature review (SLR), it is possible to identify, select and produce evidence on a given subject, assisting researchers in the search for relevant works on a theme [25]. The SLR method ensures that the research process is executed in a direct way and that all relevant works are considered and analyzed in each review step [26]. For this reason, and because it is a replicable scientific method, this methodology differs from traditional narrative reviews [27].

To assist in the investigation and analysis of certain themes, several areas have been explored with the use of SLR, as biology [28,29], education [30,31], sustainability [32,33], politics [34,35] and health [36,37]. In addition, some works were developed using SLR applied to natural resources management, as Vázquez Osorio et al. [38] about water quality

monitoring systems using MAS, and Farias et al. [19] about MAS and RPG tools to solve different types of problems.

The main purpose of an SLR is to develop and obtain answers about a research question, based on a defined protocol. This protocol guides the search for the main works included in the literature on the subject [39]. Individual papers obtained through a systematic review are called primary studies, and a systematic review is considered a form of secondary study. There are some methods that serve to develop an SLR. However, the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [40,41] was used to guide the steps of this work.

This paper presents an SLR that addresses three themes: multiagent system; rainfall-runoff model; and hydrology. The objective was to summarize the main conclusions on the topic and determine the main gaps in the research, in order to understand which are the most necessary investigations in the area at the moment. Based on what is known, there are no studies in the literature that use SLR in the context of the themes presented.

Therefore, the objective of this work is to present the methodology of an SLR to answer the following research question: *What were the processes and challenges when engaging MAS and RRM to solve hydrological problems?* Moreover, to explore the primary studies, five quality evaluation questions and five specific questions were considered, which lead to the research question.

In order to meet the demands of users regarding precision and simulation of hydrological models, several models have been developed through new software and couplings [42]. Due to computational advances and the increase in big data, computational techniques have been explored, in order to develop efficient hydrological models [43]. Some examples of this are the Support Vector Machine (SVM) [44,45], and machine learning techniques [46–48]. In addition, some works are developed with the joint use of these techniques and conventional hydrological models [49–51]. Yuan and Forshay [49] used the Soil and Water Assessment Tool (SWAT) model and a seasonal model based on SVM, with the objective of improving the accuracy of monthly flow forecasting in 13 sub-basins of the Illinois River. Kwon et al. [50] investigated a hybrid RRM, based on a conceptual tank model and a Least Squared Support Vector Machine (LSSVM) framework. The work of Kraft et al. [51] presents a global hybrid hydrological model, which simulates and generates forecasts of hydrological variables. This model is determined through a dynamic neural network and a traditional conceptual model of water balance.

While there are several computational methods that solve problems in hydrology, the focus of this work encompassed only MAS and RRM, not excluding those that also involve other tools. This was due to the interest in developing an integrated approach, involving models that aim to describe the behavior of the social and hydrological systems with, respectively, MAS and RRM. However, new studies can be carried out, considering exclusively one or more approaches aimed at the development of hydrological models linked to the MAS.

MAS and RRM tools have great potential to generate responses to the socio-hydrological system of a hydrographic region, given the concepts and methodologies involved. Thus, this systematic review seeks to determine the possibilities of coupling these two tools.

This article was structured in five sections, including this one. Section 2 presents a brief review of the use of the MAS and RRM tools in the context of hydrology, and the SLR methodology adopted in this work is presented in detail. Section 3 presents the results of the SLR, as well as a synthesis of the primary studies found. Section 4 presents an analysis of the results. Section 5 presents the conclusions of this work.

2. Materials and Methods

2.1. MAS

An agent can be defined as an entity that perceives the environment through sensors and acts from stimulus [52]. In Figure 1, there is an illustration of the relationship between the agent and its environment. The agent makes decisions autonomously, that is, it reacts

from pre-established characteristics and rules, and also from external inputs, according to perceptions and responses of interactions in the system. According to Crooks and Heppenstall [53], these interactions of agents cause impacts that can generate changes at different scales, spatial and temporal. In this way, for interactions to be successful, agents must be able to cooperate, coordinate and negotiate with each other to achieve a global or individual goal [14].

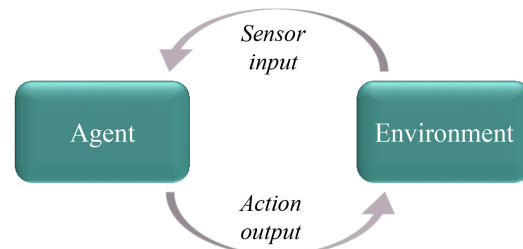


Figure 1. Abstract view of an agent in its environment adapted from [14].

An agent can have four distinct properties: autonomy; social skill; reactivity; and proactivity [54]. Autonomy is the ability to act without the control of other agents or the environment. When an agent has social skills, it can interact with other agents, using commands from the programmed language. Agents are reactive when they perceive and interact just with the environment. Agents who are proactive when interacting with the environment and reacting, aiming to achieve goals.

A MAS is a computational tool composed of an environment (which can be physical, social, or any other means of interaction), and agents that interact with each other and/or with the environment [55]. In this way, the MAS help to build models capable of operating independently and representing the interests and actions of agents in a common environment, as well as the consequences generated [14]. When a MAS is computationally simulated, we call this technique Multi-Agent Based Simulation (MABS), and with it, we can model complex systems for multiple domains [56].

The processes for building a MABS are illustrated in Figure 2. The dynamic model is built from a question about a real system. In order to solve this problem, theoretical modeling is defined and computationally programmed, generating simulations. After, the model goes through an experimentation process through simulations, and these simulations are evaluated in two processes: verification and validation of the model. The first is to search for errors or failures. The second one compares the model with the real system, using data and observations [14].

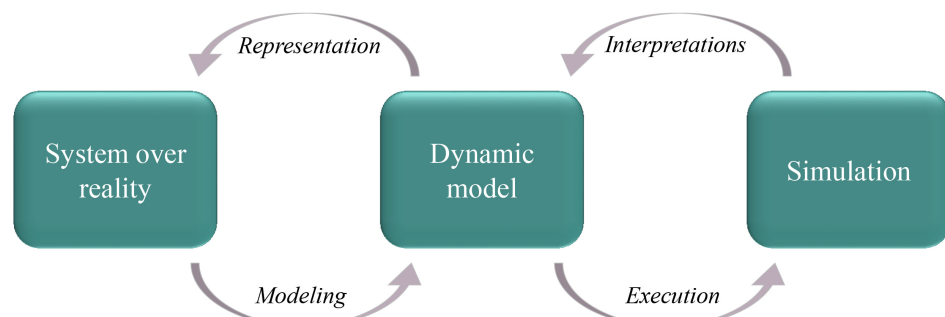


Figure 2. Representation of MABS steps adapted from [14,57].

In the hydrological context, a MAS can usually be modeled considering two different types of agents. In the first case, the agents of the system are considered as regions of the studied environment, such as rivers or hydrographic regions [18]. In this case, the MAS models and simulates these regions based on changes in system parameters, and on the interactions between agents. In a second case, the agents are considered characters

that have behaviors similar to human beings, who use and negotiate water resources [55]. Thus, these systems generate emerging organizations in a hydrological environment. The impacts of decision-making and interactions between agents are analyzed.

In hydrological problems, some researchers use MAS as a tool to simulate, predict or generate answers that help in the management of water resources, both in terms of infrastructure and political decisions. For example, Barthel et al. [3] used a MAS, called DeepActor, to represent stakeholder decision-making processes about water use. DeepActor has been integrated into a coupled simulation system of 16 individual models, which simulate the impacts of changes in the water cycle of a watershed in Germany.

The work of Schreinemachers and Berger [58] describes the agent-based software package, called Mathematical Programming-Based Multiagent Systems (MP-MAS), to simulate decision-making in agricultural systems. The system is based on dynamic models of decision-making by farmers, coupled with various dynamic models of environmental processes, such as models of water flows and changes in soil fertility.

Berglund [13] explores water resource systems as complex adaptive systems, through the use of MAS. The work presents a review of the literature on the use of MAS in water resource management problems, and also two case studies. The first case study addressed an analysis of the interactions of reactive agents in water scarcity and their demands. The other study was developed using active agents and aimed to analyze the effects of interactions between a regional manager and water polluters in an estuary, which modify the self-organization of the system, and the quality and cost reduction goals of water.

A socio-hydrological modeling was proposed by Pouladi et al. [4], to provide information about how psychological factors of farmers can influence a decision-making process in an agricultural system. In this study, the behavior of agents was determined based on a MAS and the Theory of Planned Behavior. A dynamic hydrological model was used to represent the hydrological processes

2.2. RRM

A hydrological model consists of a mathematical model that describes the behavior of the water flow in a given hydrographic region and aims to parameterize the hydrological processes and their interactions in the system [59]. Usually, hydrological modeling is performed in the context of a hydrographic basin, in order to represent the physical hydrological processes. As the input of the model, there is the precipitation (stimulus), and as output, the flux in the mouth of the basin (response), where the hydrological cycle is the mechanism of the system [60].

According to Caldeira et al. [61] the hydrological modeling process can be divided into four stages: definition, estimation, verification and forecast. The definition process corresponds to the purpose of the modeling and the proper choice of model. In other words, the variables that will be modeled and simulated must be determined, considering the quality and availability of data for model calibration and the operating steps.

In the estimation step, the main parameters of the model are determined. In this process, the relationship between the change in value and the influence of different parameters on output variables is analyzed, where the parameters that generate the greatest change in the model are those chosen for calibration [62]. From the sensitivity analysis, it is possible to find some unknown or indirectly measurable parameters. In order to more realistically represent the physical processes of the system, the model calibration aims to adjust these input parameters, refining their values for a certain set of local conditions based on the observed data [63,64].

The validation of parameters is realized in the verification step, from a new set of data and calibrated parameters, and the model is simulated [65]. At this stage, the objective is to analyze the accuracy of the simulation through a method that must be chosen based on the objective of the model, with statistical and graphical comparison methods being the most used. Finally, in the prediction stage, the simulation is carried out with the parameters

already adjusted and verified, and the output variables are represented from different inputs in the model.

In particular, an RRM aims to describe quantitatively the processes involved in the water balance of a hydrographic basin [66]. Normally, to implement a hydrological model database, we must determine the temporal and the spatial data. A part of these data are used on the calibration model, and the rest on validation step, as illustrated in Figure 3.

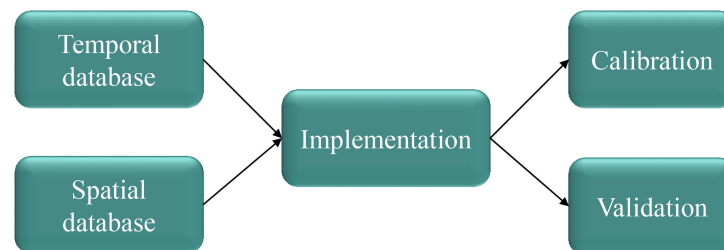


Figure 3. Representation of database implementation in a hydrological model.

Rainfall-runoff hydrological models have been developed with different characteristics and properties, and they are exploited to achieve different goals. According to Wasson et al. [5], among the uses of this model, three important goals are: reservoir management; detection of human impacts; and flow forecast. The first goal aims to predict the behavior of the basin based on the amount of water available from it. The second goal refers to the impacts not naturally caused on the basin, where the input data of the model must be considered forcing data. With this, the RRM tends to help in detecting the consequences of anthropic actions, but this can interfere with the accuracy of the model. The last goal refers to the favorable execution time to generate the water availability forecast for a region.

Different hydrological models may have different characteristics. These models can have the following typology [67]: stochastic or deterministic; concentrated or distributed and; empirical, physically-based models or conceptual. The first category involves choosing the type of formulation of the variables used in the model. In the situation that the chance of occurrence of the variables involved is considered, it is implemented through probability concepts, and the model is called stochastic. Otherwise, the model is considered deterministic [68].

The second group determines whether or not the model considers the spatial dependence of the hydrographic region. In the lumped model, the parameters, inputs and outputs are modeled with single average values that represent the basin in a homogeneous way. In other words, spatial variations of physical characteristics of the relief, soil and vegetation in the region are not considered. On the other hand, when spatial variability is considered, the model is said to be distributed. In this case, divisions are made into homogeneous, irregular, or regular spatial units, throughout the area of the hydrographic region. Examples of distributed models are Gridded Surface Subsurface Hydrologic Analysis (GSSHA) [69], European Hydrological System (or *Système Hydrologique Européen - MIKE SHE*) [70], and Topography Based Hydrological Model (TOPMODEL) [71].

Lumped models tend not to realistically represent the behavior of hydrographic basins since they do not consider the spatial variability of the characteristics of the region. Distributed models, on the other hand, can generate a large computational expense in the spatial discretization process, in addition to requiring a lot of input data. Thus, many models are developed through a semi-distributed spatial discretization. In them, the hydrographic basin is divided into subwatersheds and in each of them, it is considered a lumped model. Some examples are Lavras Simulation of Hydrology (LASH) [66], SWAT [72], and Annualized Agricultural Non-Point Source (AnnAGNPS) [73].

The third group of hydrological models typology is related to the type of formulation used in the model. In the empirical models, mathematical equations from time series are used, simultaneously with input and output data. These equations can be obtained through functional relationships with techniques such as regression and neural networks [74].

Physically based models are used to obtain solutions to governing equations. In this case, the parameters or state variables can be considered as monitored and tabulated data. In conceptual models, simple mathematical equations are used that ideally describe the hydrological phenomena and processes of the system [75]. Some examples of this type of model are Hydrologiska Byråns Vattenbalansavdelning (HBV) [76], Topography TOPMODEL [71] and Hydrological Simulation Program—FORTRAN (HSPF) [77].

2.3. SLR Methodology

SLR can be defined as a method that aims to identify, evaluate and interpret the state of the art of a specific research question or area of a subject or phenomenon of interest [39]. The processes of an SLR can be grouped into three major groups, called planning, execution, and report [25,39]. In Table 1, each of these categories is presented, where there are the ordered steps for the development of SLR. According to Budgen and Brereton [26], based on the research question, a systematic review of the literature aims to answer this question based on a defined protocol. The protocol is a set of rules that provides methods for conducting the execution [27].

Table 1. The SLR processes.

Process	Information
Planning	Specification of the research question Development of the review protocol
Execution	Primary studies identification Primary studies selection Primary studies evaluation
Report	Data extraction Data synthesis

In this work, we have used the PRISMA 2020 [41] methodology to develop our SLR. In order to avoid errors, the protocol must be examined at each step of execution and, if necessary, restarted in each process again. The protocol defined for this work was structured and divided into parts. Tables 2–5 present the information used to generate the protocol. Table 2 presents the main topics to start the protocol: main question, which aims to guide SLR; main objectives; keywords; inclusion criteria; and exclusion criteria.

Table 2. SLR protocol: main topics.

Topic	Information
Research question	What were the processes and challenges when engaging MAS and RRM to solve hydrological problems?
Main objective	Through the SLR, determine and analyze papers published between 2001–2021, which used MAS and RRM in the context of hydrology.
Keywords	- Multiagent System; - Rainfall-Runoff Model; - Hydrology or Hydrological.
Inclusion criteria	The paper presented the keywords or their variations.
Exclusion criteria	- The paper is not in the searched databases; - The paper is not in English; - The paper was not published between 2001 and 2021; - The paper was not based on MAS or RRM to solve a problem in hydrology.

The research question (RQ) was defined based on the need to search works from the last 20 years, which aim to solve hydrological problems using MAS and RRM tools together. If these works exist, the intention is to analyze how and why they were developed. Then,

understand the processes and challenges of the subject. Thus, the objective of SLR was to determine and analyze these works, in order to answer the RQ. To facilitate and conduct the strategies to answer this question, five specific questions (SQ) were considered:

SQ 1. How were the MAS agents defined and what was the objective(s) of this model?

SQ 2. What RRM used, and what was the objective(s) of this model?

SQ 3. Were other techniques necessary to generate the study? If so, which ones and how were they used and related to the MAS and RRM tools?

SQ 4. How did the work integrate the use of MAS and RRM techniques?

SQ 5. Are the main challenges encountered related to the MAS and/or RRM modeling processes?

SLR was developed through three themes: multiagent system; rainfall-runoff model; and hydrology. With the objective of expanding the research, in the last theme the word hydrological was inserted. Thus, the keywords were defined. Figure 4 shows the diagram of keywords, where the MAS and RRM and HH region represents the intersection between the three areas and it is the focus of this SLR.

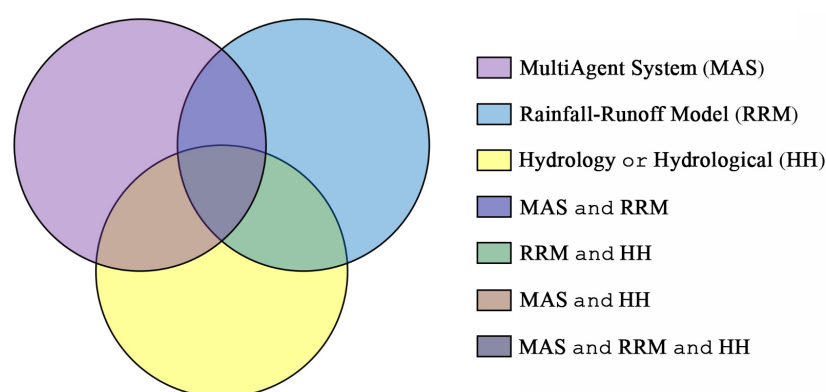


Figure 4. Diagram of keywords.

To identify the main works on the theme, the bibliographic databases of the literature were chosen, which contains a large number of papers published in journals relevant to the theme proposed here. These databases are presented in Table 3. The most recent search for publications was in October 2021. In each of the databases, variations of keywords were considered and can be seen in Table 4. With these variations, different strings were constructed for each bibliographic database. The words *or* and *and* are defined as the union and intersection of the keywords, respectively.

To select and analyze the primary studies, four steps were performed, which can be seen in Table 5. In the selection strategy stage, the Mendeley (<https://www.mendeley.com/>, accessed on 2 October 2021) software was used to organize and remove duplicate papers. Through the inclusion and exclusion criteria, presented in Table 2, the primary studies were selected or discarded, based on the steps of: reading the titles and abstracts, reading the introduction, and full reading. The selection strategy was realized by the two authors of this work.

Table 3. SLR protocol: selected bibliographic databases.

Bibliographic Database Name	URL
ACM Digital Library	https://dl.acm.org/ , accessed on 2 October 2021
ASCE Library	https://ascelibrary.org/ , accessed on 2 October 2021
IEEE Xplore	https://ieeexplore.ieee.org/ , accessed on 2 October 2021
ScienceDirect	https://sciencedirect.com/ , accessed on 2 October 2021
Scopus (Elsevier)	https://scopus.com/ , accessed on 2 October 2021
SpringerLink	https://link.springer.com/ , accessed on 2 October 2021

Table 4. SLR protocol: strings defined by keywords variations.

“multiagent system”	or	“multiagent systems”	or
“multiagents system”	or	“multiagents systems”	or
“multi-agent system”	or	“multi-agent systems”	or
“multi-agents system”	or	“multi-agents systems”	or
“multiagent simulation”	or	“multiagents simulation”	or
“multiagent simulations”	or	“multiagents simulations”	or
“multi-agent simulation”	or	“multi-agent simulations”	or
“multi-agents simulation”	or	“multi-agents simulations”	or
“multiagent based simulation”	or	“multi-agent based simulation”	or
“multiagents based simulation”	or	“multi-agents based simulation”	or
“multiagent based simulations”	or	“multi-agent based simulations”	or
“multiagents based simulations”	or	“multi-agents based simulations”	or
“multiagent-based simulation”	or	“multi-agent-based simulation”	or
“multiagents-based simulation”	or	“multi-agents-based simulation”	or
“multiagent-based simulations”	or	“multi-agent-based simulations”	or
“multiagents-based simulations”	or	“multi-agents-based simulations”	or
and			
“rainfall runoff model”	or	“rainfall runoff models”	or
“rainfall runoff modeling”	or	“rainfall runoff modelings”	or
“rainfall runoff modelling”	or	“rainfall runoff modellings”	or
“rainfall-runoff model”	or	“rainfall-runoff models”	or
“rainfall-runoff modeling”	or	“rainfall-runoff modelings”	or
“rainfall-runoff modelling”	or	“rainfall-runoff modellings”	or
and			
hydrology	or	hydrological	

Table 5. SLR protocol: selection and analysis of primary studies.

Stage	Information
Selection strategy	- Find works; - Remove duplicate works; - Read and analyze the title and abstract of the works; - Read and analyze the introduction of the works; - Read the full papers.
Data extraction	Objective results extraction.
Quality evaluation	Assist in data analysis and synthesis.
Data summary	- Answer the specific questions; - Answer the research question; - Answer the quality assessment questions; - Compare the works.

The total number of papers found in the six bibliographic databases was 79, 4 of which were duplicates. In the ACM Digital Library, ASCE Library and IEEE Xplore databases, no studies were found. 9 papers were found in the ScienceDirect database; 64 papers in Scopus; and 6 papers in SpringerLink. In Figure 5, it can be observed the number of works found per year, in each of the databases. The highest number of publications is between 2016–2021, mainly in the Scopus database.

Figure 6 shows the total number of studies obtained in each stage of the selection strategy, according PRISMA methodology. In the first stage, reading the title and abstract, 52 papers were discarded according to exclusion criteria. Of the remaining 23 studies, 13 were eliminated in the reading and analysis stage of the introduction. Finally, in the reading and complete analysis of the remaining 10 works, 3 of them were selected as the main studies in this SLR.

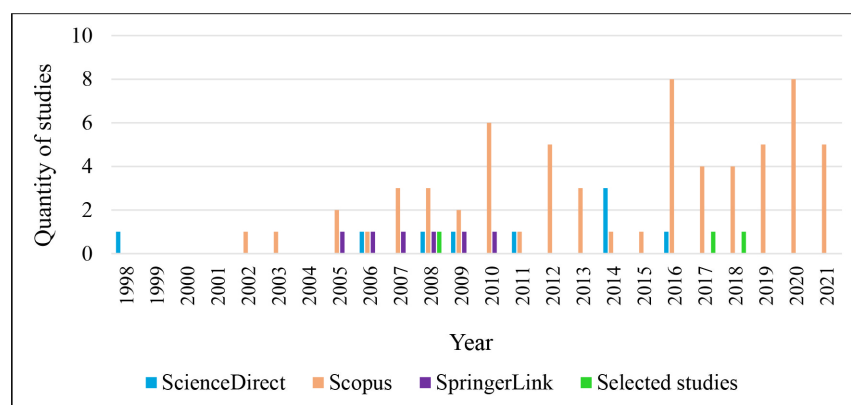


Figure 5. Quantity of works for databases.

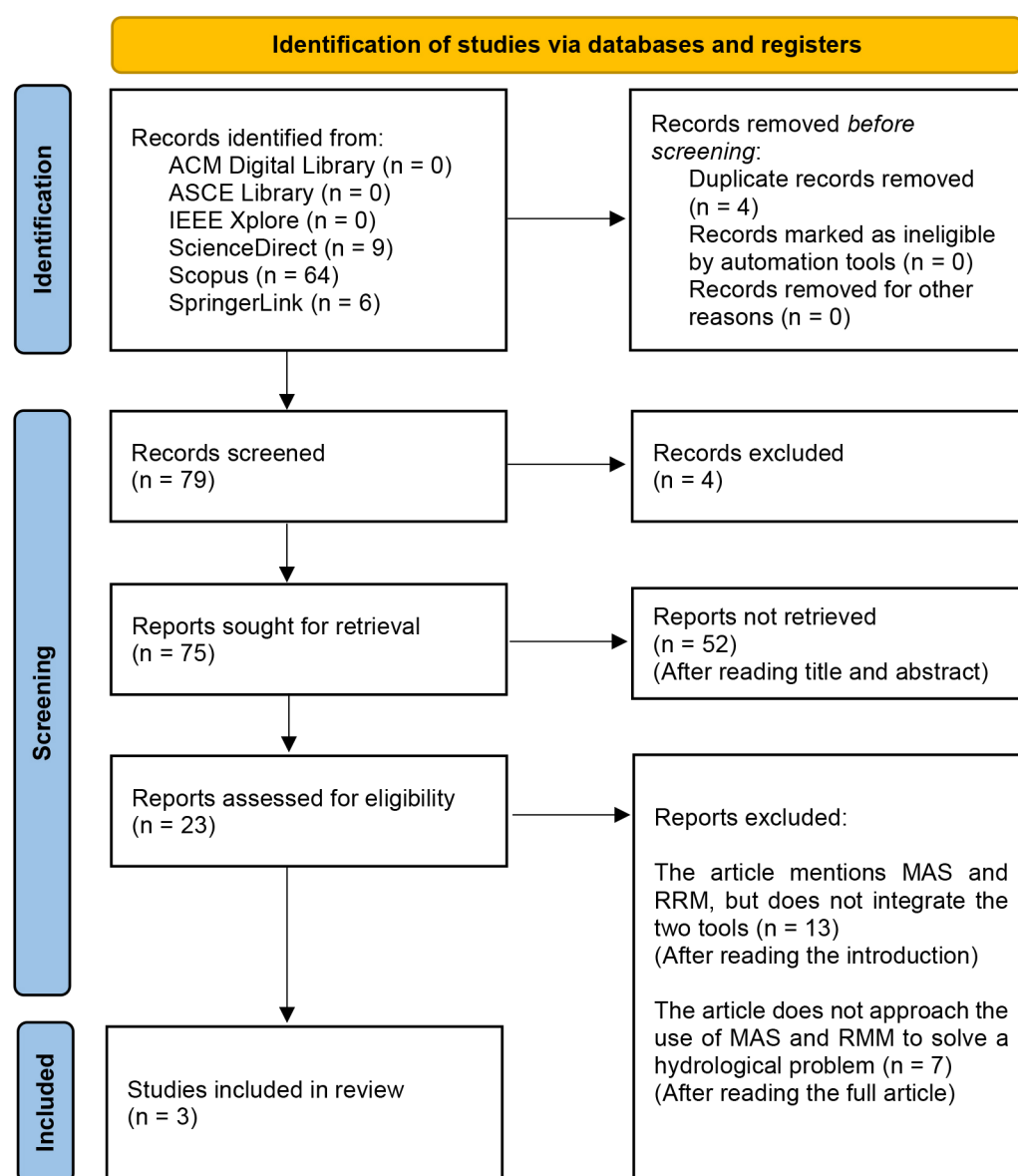


Figure 6. Systematic review processes from the selection strategy using the PRISMA 2020 flowchart.

With the selection of the final studies, the stages of quality analysis, data extraction, and synthesis can be realized. According to Kitchenham et al. [39], the quality assessment of each work can be determined to achieve two different goals. The first goal is related to

the selection stage of primary studies, where the results of the quality assessment should serve to assist in the construction of the inclusion and exclusion criteria. The second goal is used to assist in the analysis and synthesis of the data, where it is investigated whether differences in quality are associated with differences in the found results on primary studies.

In this work, the second objective was used, because it allows the analysis and discovery of the main challenges and gaps in each of the primary study. To achieve the goal of quality assessment, five quality questions (QQ) were defined:

QQ 1. Do the results satisfy the objectives of the study?

QQ 2. Does the study present an analysis of the results obtained?

QQ 3. Is the adopted methodology presented in a clear and detailed way?

QQ 4. Does the study analyze the advantages and disadvantages of the methods used?

QQ 5. Does the study present an analysis on the integration of MAS and RRM modeling?

The data extraction of each work can be determined directly or indirectly [25]. Through the direct form, there is the objective results extraction. In this way, the data collection is obtained directly from the works found. This process comprises four stages: (i) identification of the work (the title of the publication, authors, and the source); (ii) work methodology; (iii) work results; (iv) challenges encountered at work. In the indirect form of data extraction, subjective results are extracted, and data extraction is performed with extra information from the work. In this way, subjective results can be collected through information: (i) collected directly from the authors of each work; (ii) generated from conclusions after reading the work. In this work, the method chosen was the direct form.

To summarize the data, it is recommended a summary of the final primary studies, followed by a comparison between them [39]. For this, a complete reading of each work was realized, where the data were extracted and were answered: the specific questions; the quality questions; and the research question. These results and analyzes are presented in the next sections.

3. Results

The primary studies obtained, through the SLR protocol, are presented in Table 6. The data regarding the methodology, results, and challenges encountered in each of the primary studies will be commented on below. In order to present the analysis of the works in a more objective way, the answers to the specific and quality questions of each work are shown in Appendix A.1.

Table 6. Final papers identification.

Authors	Title	Source
Mike Bithell and James Brasington	Coupling agent-based models of subsistence farming with individual-based forest models and dynamic models of water distribution	Scopus
Ang Yang, Dushmanta Dutta, Jai Vaze, Shaun Kim and Geoff Podger	An integrated modelling framework for building a daily river system model for the Murray–Darling Basin, Australia	Scopus
Sayantan Majumdar, Shashwat Shukla and Abhisek Maiti	Open agent based runoff and erosion simulation (oares): a generic cross platform tool for spatio-temporal watershed monitoring using climate forecast system reanalysis weather data	Scopus

The work of Bithell and Brasington [78] presents an exploratory and explicate approach, which aims to investigate the influence of annual changes in land use that are induced by human societies, on the structure of the forest and its deforestation, as well as its impact on the hydrological dynamics. For this, a coupling of human, ecological, and landscape modeling was implemented, which are complex, non-linear, and multicompo-

nent systems. The authors mention that the study does not present a descriptive approach. Therefore, it does not have the capacity to simulate the real processes of a system, and its reproduction is not recommended.

The methodology was based on a coupled model of three small-scale sub-models. This was including a multiagent system for subsistence farming, an individual-based model to represent the dynamics of the forest, and a spatially distributed hydrological model to predict soil moisture and water fluxes at the basin scale. The study was applied to a small hydrographic basin, where the simulation was executed on a time scale of hundreds to thousands of years. In addition, the sub-models were defined using the digital elevation model (DEM) of the study region, which generated compatibility between them. In this way, the environment was divided into evenly spaced regular cells. For the modeling, data from the hydrological model, topography, and the social system of the region were used.

The first result was generated from the data obtained at the beginning of the modeling. It was observed that in a hydrological year, the climate of the region is highly seasonal, with approximately 90% of the precipitation occurring at a specific time of the year. This factor is closely related to the pattern of land use, as well as forest cover. To examine how the evolution of the forest model affects the hydrological system, the authors defined three experiments, gradually increasing the number of components involved. The first experiment did not include families in the model, only trees. In this way, it was possible to understand the forest behavior, where the peak became constant over time, and the different types of trees had different behaviors in the long run. With the inclusion of a family, the authors were able to examine how the work of searching for resources has been affected by deforestation over time. Afterward, the forest dynamics and the population of families varied. Thus, the dispersion and competition among families regarding the availability of resources in the environment were analyzed.

For the authors, two initial challenges for the development of coupled modeling are: determining the main interactions between the systems and understanding the relationship between the time scales in which the processes operate, as well as the ideal time scale for the coupled model. With regard to MAS in the forest context, the authors emphasize, through a brief bibliographic review, the challenge of developing a system that has a dynamic environment. The dynamism of the coupled systems is taken into account, where the MAS has enough data to generate a behavior similar to the real behavior of the forest, which changes with time and represents the variations generated through the connections between the systems, in particular, the water system. A mentioned problem is the coupling direction, where it is possible to analyze the model when the output of one sub-model is used as the input of another, but there is no feedback in the opposite direction. In addition, one of the problems raised is what the authors call the model compatibility problem. When the correct combination of the sub-models does not occur, the system can contain serious stability problems. The authors state that the coupled model developed in the work has good compatibility between the sub-models, since they use the complete source code of each sub-model, and rely on the flexibility of the multiagent and individual-based systems, in relation to spatial scales. However, there are still issues related to the proper adoption of time scales.

The integration time necessary between the models is another challenge addressed. Among the three sub-models, the authors found that the hydrological and forest models have a high cost of execution, with the forest model the one that generates a longer processing time. These problems make it difficult to experiment and analyze the coupling of the models, making it necessary to generate previously planned and well-defined scenarios. Furthermore, the validation of the coupled model with respect to time proved to be a large challenge, as the system has a wide range of components that change over time, often for long periods. The authors comment that a possible solution would be to consider an ergodic hypothesis, however other challenges appear when considering this possibility.

The work of Yang et al. [79] aimed to present the development of an integrated model for the management of water resources. The authors developed a homogeneous MAS based

on the eWater Source river system and with a node-link structure based on the Simplified Murray Darling Basin River Model (SMDBRM). The coupled model was calibrated in each region, where a sequential self-calibration tool was integrated. RRM was used to estimate unmeasured flows in the basin. Several models were developed separately to assist in the management of water resources in the Murray-Darling basin, whose area is approximately 1 million km². The models generated responses from the fluvial and rainfall-runoff systems, including projects aimed at developing integrated modeling between individual models. In order to assist in reducing the challenges generated by this integration, and to increase consistency and clarity in the modeling, the authors presented integrated homogeneous modeling based on agents.

A river system model called eWater Source was developed as a national hydrological modeling platform in Australia, to replace the old and non-integrated models. From it, a daily conceptual hydrological model called SMDBRM was developed, which represents the river system through a node-link approach, where each node represents the end of a river network and all nodes are interconnected by links. This model uses some tools to obtain the hydrological response, and conceptual rainfall-runoff models to estimate the contribution of runoff from calibrated and uncalibrated basins. In addition, different operational and management rules are incorporated to assist in water planning. The basin was divided into 18 regions using the SMDBRM model system and for each of them, one or two individual models were built. The work presents the architecture, the functionalities, and the implementation of the agent-based approach that integrates the individual models of each region of the basin. To optimize the computational time, parallel computing techniques were used.

According to the authors, the complexity of the system was reduced by the homogeneity of the MAS, because the agents were modeled by the same model of the river system. All agents have the same conceptual modeling structure (governed by physical processes and management rules), and temporal and spatial scales, but their parameters vary according to the results of the calibration. The simulation was recorded in a log file. In addition, an agent behavior controller controls the regions directly, by modifying the XML file or programmed command lines. With that, it was possible to analyze different changes and consequences of the relationships of agents with the behavior of the system. In addition, the MAS made it possible to analyze the feedback from upstream-downstream regions. In this way, through the interactions of agents, the availability and need for water resources between regions became more clear.

Through the self-calibration process of the system, it was possible to calibrate the regional models separately. As a result, processing time and complexity have decreased. In addition, as it is a homogeneous model, the authors claim that it partially overcomes some of the difficulties faced, in comparison to the heterogeneous system. An example of this is the differences in spatial and temporal scales, which do not occur in the homogeneous system. The authors analyzed the model with 477 nodes and links. The nodes were used for model calibration and validation, which depended on observed daily flow data. The results of the model showed a satisfactory processing time and good performance in almost all regions of the basin. However, the performance and validation statistics were not satisfactory in some regions. The authors mention that the modeling structure can be reproduced and implemented for another basin, as long as the original software is used.

The work was developed to try to solve some of the challenges encountered regarding the integrated modeling of the basin, which had several types of models for different regions. Some of these challenges were: the high computational cost obtained; the different spatial and temporal concepts and scales adopted in each model; inconsistencies with respect to the lack of calibration capacity on the part of some models; and difficulty in collaboration between the authorities involved due to the analysis and understanding of the various models presented. Regarding the dynamics of coupled socio-environmental systems, the authors state that the complexity is very large, due to the non-linearity and the emerging behaviors presented. However, they claim that the multiagent system approach

is one of the ways to reverse this problem because it reduces the complexity of the system. Regarding the results of the model, the authors mention that a challenge was the limited number of calibration meters, and poor quality and high quantity of records missing from the observed flow data. According to them, these features directly affect the performance of the model and consequently interfere in the validation process.

The work of Majumdar et al. [80] presented a MAS to model and simulate rainfall-runoff and soil erosion from the Asan watershed, in Uttarakhand, India. They used data from the hydrological region, the Soil Conservation Service (SCS) method, to estimate direct flow, and the open-source cross platform tool called Open Agent Based Runoff and Erosion Simulation (OARES) to simulate and analyze the hydrological data. The work divides the methodology into three phases: data preparation; model simulation; and quantitative analysis. In the data preparation, the parameters for the simulation of the model are generated. The simulation occurs through the concentrated OARES model, which integrates the Python, R, and NetLogo libraries to provide an interface for the automatic generation of input parameters. The results are observed through statistical analysis of the data obtained.

For the authors, there are four main factors that affect runoff: volume and intensity of rain; soil types and properties; the slope of the relief; and patterns of land use and management. To model, it was necessary to obtain available meteorological data, land use maps, and the DEM data. In addition, through an empirical equation, runoff and erosion are estimated by integrating the SCS and the soil conservation number method (Curve Number—CN), or the SCS CN method.

The authors present a series of analyzes, where the basin presented different classes of land use. To generate a supervised classification of the land use maps, the variance and covariance of the identification of each class were analyzed, based on the use of the Maximum Likelihood Classifier on the available Landsat 8 images. In addition, the flow simulation was executed through the relationship between precipitation and a direct flow, which were adjusted using a regression method on the dispersion graph. With the average rainfall, the regression adjustment was satisfactory, but with years of low rainfall, the adjustment was inadequate to provide the rainfall-runoff relationship. The runoff was estimated using the total amount of rain generated through the raindrops, considered as agents and which interacted in the MAS. An analysis of the temporal data obtained showed that the pattern of rain flow underwent significant changes in some periods over time. According to the authors, they were caused by the oscillations generated by changes in environmental conditions, which consequently generated variations in rainfall.

The simulation of soil erosion was generated from OARES and from three parameters: rain; elevation; and height of the water. Through a comparison of the MAS modeling with conventional hydrological models, the authors found that the flow data obtained were satisfactory. However, a difference between them is that in the conventional models the simulated flow data are obtained for an exit location in the region, while the OARES model generates the same flow for the entire region. At the end of the paper, the authors comment on the need to improve the model and perform the statistical significance test. They only recommend tools that solve this problem. For them, the platform is considered generic, making it possible to reproduce it in other basins.

The authors comment on a challenge about the hydrological changes that occur in the basin, in view of the anthropic actions generated on the terrestrial surface. Many of the results considered inadequate, were associated with the sudden changes in the annual precipitation series. This, according to the authors, was directly related to changes in the environmental structure. Thus, it is necessary to consider land use and land cover as important input parameters of the model. Furthermore, they addressed the difficulties generated when using traditional distributed RRM, which often require a large amount of data, a complex configuration, and a high computational cost, especially in the calibration stage. Thus, they highlight the advantages of using semi-distributed models, which reduce the complexity of hydrological modeling.

According to the authors, one of the greatest difficulties from the development of the OARES tool was the integration of DEM and multiagent system. The DEM was resampled on the NetLogo platform with the closest neighbor approach. For studies that require high accuracy of measurements, this approach may harm the results of the model. In addition, the OARES platform is considered concentrated, thus the region is spatially discretized in a homogeneous way.

4. Discussion

To answer the research question of this SLR, one must answer this question in a broad way, based on the final works obtained. In this way, through the summary of each of the primary studies, it is possible to answer this question separately, and then compare the main data, methods, and challenges addressed. Among some of the difficulties to generating a coupled social and hydrological modeling, reference [78] mentions the process of determining the main interactions between the systems, and it must be objective and well defined. The authors of [79] mention that a common problem is the low quantity and quality of hydrological data available, which often interfere directly in the calibration and validation of the model. The authors of [80] affirm that the complexity due to the integration of different models is great, and often generates results with low precision.

Regarding the objectives, and integration of data and tools, the three works show different methodologies and approaches. The authors of [78] analyzed the land use change induced by anthropic actions, based on three coupled models. The authors of [79] developed a homogeneous MAS for water resource management using the eWater Source and SMDBRM models. The authors of [80] developed the OARES platform, to integrate a MAS, a calibration tool, and data from the region to model and simulate the rainfall-runoff process and soil erosion. In this sense, it can be observed that different hydrological problems can be explored using the integration of MAS and RRM.

The data needed to develop and integrate the models depended on the objectives and needs of each work. Data from the study region proved to be important input and validation data for the models, such as meteorological and hydrological data. The authors of [78] used an RRM to model the system and input the data into the MAS. The authors of [79] used an automatic calibration process although the SMDBRM model, where RRM was used to generate unmeasured flow in some regions of the study area. In the work of [80], the necessary parameters for the model are generated before being inserted in the MAS. In this way, the calibration processes were executed independently, and in order to generate hydrological responses for the respective MAS.

The studies addressed the difficulties of generating a coupled modeling that relates the spatial and temporal scales between the sub-models. In the works of [78,80], the generated MAS was based on the integration of the DEM as a multiagent modeling environment, where the hydrological changes were connected to the cells or sub-regions. This process generated spatial stability between the models, but for [80], this process was a wide challenge due to the difficulty in resampling the data from the DEM on the multiagent platform NetLogo. Furthermore, the relationship of time scales between the sub-models was a challenge, which again emphasized the idea of developing a model that first prepares the input data for the hydrological model, and then simulates the MAS.

The validation of the models has become the biggest challenge among the works presented. The difficulty is to develop a model coupled with well-defined spatial and temporal scales, which normally require a large amount of data and a high computational cost to generate the necessary responses in the sub-models. The authors of [78] claim that the possibility of generating a sensitivity analysis of these models is almost impossible. In addition, these problems create an obstacle in integrating tools such as MAS and RRM, which is to maintain the dynamics between the models. This is because the data is changed quickly, and the sub-models take turns in the need and obtaining data.

Among the primary studies obtained in the SLR presented in this work, it can be seen that few studies have been addressing the joint use of MAS and RRM techniques.

One of the reasons for the scarcity of studies in this line of research is the high complexity presented. In addition, some processes are needed and challenges are faced. In this sense, it is possible to answer the research question addressed in this SLR. The main processes involving MAS and RRM to solve hydrological problems are summarized in: determining the main interactions between the models; determining the spatial and temporal scales of the sub-models and the coupled model; calibrating the necessary parameters of the model; validating the model; and simulate the model. The biggest challenges are: high computational cost; the interaction between the spatial and temporal scales of the models; dynamics between models; and model validation.

The processes involved in developing a model that integrates MAS and RRM proved to be coherent with the methodology of these tools. In this sense, there are no new steps or unexpected adversities. However, the challenges obtained and presented, show the obstacles that must be firmly explored and solved to implement the integrated modeling, considering mainly the relationship between characteristics, data, and scales.

Given what has been presented in this work, several positive points can be presented regarding the subject discussed. Furthermore, based on the detected challenges, there are problems that should be explored in the future, so that the coupled modeling between MAS and RRM is more efficient and precise. Table 7 lists the strengths and research points that were identified.

Table 7. Strengths and research detected in the coupled modeling process.

Strong Points	Research Points
Coupling of several different systems	Interaction between models
Analysis from different perspectives	Stability
Direct contribution between models	Coupling direction
Better visualization of processes	Processing
Reduced complexity due to the use of MAS	Validation

The SLR results indicates the potential of coupled modeling, through different systems. In that case, the models can be more complete and provide more realistic results. Furthermore, this hybrid model contemplates different areas and objectives and, consequently, allows the analysis of different aspects of the coupled model. Thus, it is possible to verify the influence that each system exerts on the whole.

This also generates other positive point, which is the direct contribution that occurs between the systems. When considering more than one system, the responses from each of them can have several implications. For example, decisions about water resources in a social system impact a hydrological region, and it generates changes in hydrological processes. On the other hand, changes in the hydrological region must cause changes in the decision-making of social systems. Thus, in addition to being possible to understand the aspects of a system, it is possible to analyze decisions about it and, consequently, the benefits and risks that they may entail.

From the coupled modeling process using MAS and RRM, other positive point is the MAS simulation. A MAS must be simulated on a specific platform for this type of model so that it is possible to visualize the simulation in each step. In this way, the change in the environment is directly perceived. In hydrological systems, it is possible to analyze the impact of each action in a region, which favors better forecasts and analyzes of the use of water resources. Furthermore, the use of MAS can generate models with less complexity, due to the flexibility that these systems have.

Regarding the points that still need to be explored, one of them is the difficulty in the integration process between the models. In this case, the relationship and language between the models must be carefully established. Moreover, compatibility between systems is very important. Spatial and temporal scales directly influence the stability of the model.

In addition to choosing the model, it is necessary to have a good knowledge of the study region and the available hydrological data. Furthermore, the impacts of environ-

mental changes occur due to different factors and characteristics of the study region. In the process of coupling RRM and MAS, spatial and temporal scales that adjust to the mechanism of the models involved must be considered. Otherwise, the processing of spatial data and the accuracy of the coupled model may be impaired.

Another important point is the direction of coupling. The question is how to develop a coupled model in which the models involved mutually generate inputs and outputs. In this case, it should be considered that the responses of each system generate changes in the coupled model.

The processing is one of the most important points to be analyzed, as it comes from the aforementioned problems. Depending on the computational cost of a model, execution, and analysis can be quite compromised. Because of this and the need for a large amount and quality of data, validation is also still a big challenge in coupled modeling between MAS and RRM.

5. Conclusions

This paper addressed SLR focused on the coupled use of MAS and RRM in hydrological problems. For this, the main stages of the protocol were described, and the primary studies obtained were summarized and analyzed. The first result was the scarce number of publications found on the topic, considering the six bibliographic bases chosen for the research. Based on the inclusion and exclusion criteria, of 75 studies obtained, only 3 related MAS and RRM in the hydrological context. In recent years, the number of works exploring the joint use of MAS and RRM techniques has been growing, but this growth is slow due to the complexity of bringing together the concepts and dynamics between them.

The occasional use of joining MAS and RRM, coupled with the low number of publications, becomes a factor of complexity, due to the fact that there are not many examples, methodologies, and applications that relate the two tools. This tends to generate difficulties, both in the coupled modeling development processes, as well as in the implementation and computational simulation steps. Furthermore, although the MAS and RRM tools have separately a vast theoretical basis and several applications, each one has its peculiarities and challenges, which are led to the coupled approach. However, the primary studies presented in this review, as well as the intent related to each of the two tools discussed, show a promising path for the development of an approach that aims to describe the socio-hydrological behavior of systems.

Separately, MAS and RRM are powerful tools that provide modeling resources that lead to simulations close to reality. MAS is a tool widely used to understand social interactions and changes based on the decision-making of the agents. On the other hand, RRM serves to explore the optimal management of water resources and the consequences of environmental changes in hydrological processes. By involving these tools to solve hydrological problems, many works can be explored for different purposes. However, for this to be possible, the steps of this coupled modeling must be well defined and the challenges obtained must be faced.

The systematic review processes led to an analysis of the main studies related to the theme, to become possible to answer the research question defined in the protocol. The specific and quality issues defined based on the SLR protocol were important steps to describe and analyze the stages of the primary studies. The results showed several processes and challenges necessary for the development of social and hydrological modeling, based on MAS and RRM. Among the challenges, the main ones were the relationship of the spatial and temporal scales between the models, and the dynamism of the coupled model. Usually, the models complement each other, where the computational response of one serves as an input to the other. However, the high computational cost and the amount of data required for the modeling to present accurate results, prejudice the dynamics between the models.

The systematic literature review, proposed here, proved to be a good method to search the main works on a proposed theme. The protocol used was a simple and fast mechanism

that guided the processes to solve the research question. The results present open questions that still need to be explored and these challenges must be mitigated.

From future perspectives, the integration of social and hydrological systems has great potential to assist water resources management, as they complement each other in relation to use and demand, and in the consequences of decision-making on water and land. For this, they must be modeled in a way that the interconnection data between them evolve dynamically. Through the processes and challenges exposed, it is possible to conduct research and generate case studies, with a view to expanding the use of these techniques and providing new mechanisms to solve the problems that may be faced. In this way, a coupled model that integrates MAS and RRM will be able to simulate social interactions and hydrological processes concurrently.

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Appendix A

Appendix A.1. Answers to the Specific and Quality Questions of the Primary Studies

Table A1. Answers of specific questions about the work of Bithell and Brasington [78].

Question	Response
SQ 1	The agents of the MAS are the families of farmers, whose interaction occurs through competition for land and wood. There is no interaction between agents, only between individuals and the environment. The model has a more direct interaction with the forest dynamics model, where families are established in a part of the region, and each individual can keep the cells free from trees and allocate a type of landuse, such as rice or corn. Agents consume timber and replant trees elsewhere in the region.
SQ 2	For the coupled model, the distributed RRM based on terrain of brasington et al. [81] was adopted. From the regular discretization of the DEM in cells of 20 m, a three-dimensional cell model was used. Precipitation is considered to be uniformly distributed throughout the region, and its annual time series is reproduced in a standard way, year after year in the model. Each cell receives information that serves as input for the hydrological model. It returns parameters such as hydraulic conductivity, canopy capacity of the vegetation, and the response of the calculations on the soil moisture flows, which is generated from a finite volume solver per a four-layer structure.
SQ 3	The use of a model based on individuals was used to represent the forest dynamics of the trees. Trees grow according to a dynamic competition model called SORTIE, which uses allometric relationships of the trees. It provides the availability of wood for farmers, which modifies the MAS. However, it has no direct interaction with the hydrological model.

Table A1. *Cont.*

Question	Response
SQ 4	From the results of the farmer and forestry systems, a land use map is generated and implemented in the RRM. This model operates independently and returns the hydrological components to the MAS. Land use define the amount of soil moisture in a spatially distributed manner, as well as flows and floods. Information on changes in canopy capacity and hydraulic conductivity is necessary to generate the coupling between MAS and RRM.
SQ 5	As mentioned earlier, the dynamics, the spatial and temporal scales, the processing time, and the validation between the sub-models and the coupled model are major challenges encountered. Separately, MAS and RRM do not present all of these challenges, as it is possible to generate modeling, parameter calibration, and validation without relying on data obtained by other systems. The integration between MAS and RRM, on the other hand, depends on analysis and planning to minimize the challenges.

Table A2. Answers of quality questions about the work of Bithell and Brasington [78].

Question	Response
QQ 1	The main objective was to develop small-scale dynamic models, to build a coupled model that represents the large-scale behavior of the forest, analyzing the main spatial interactions, and how spatial distributions interfere with the dynamism of the system. The results showed that although there are several challenges and possible improvements for the model, it describes the behavior of the system when relating the actions of the agents, the hydrological data, and the forest dynamics. However, it is understood that with faster processing and more interactions between models, the results would be better and more detailed.
QQ 2	In work, the results are analyzed through experiments, as the components of the models are changed. The analysis performed refers to the changes generated in the coupled model, without bringing a quantitative or qualitative analysis of the data obtained. This is explained in the conclusions of the work, where the authors emphasize that it is not possible to generate a sensitivity analysis of the model due to computational time, the large number of parameters that must be explored, and the non-linearity of the coupled system.
QQ 3	It can be seen that the work presents the methodology in relation to the developed models, and interactions, including an appendix that explains part of each submodel. However, previous publications are mentioned, in which the models are detailed, as well as applications and analyzes focused on the research in question. In addition, it is mentioned that topographical, rainfall and soil characteristics used were obtained through previous work.
QQ 4	Throughout the explanation of the models and their interactions, some advantages and disadvantages are commented on. However, the authors reflect on some possible and important changes that, even bringing challenges, can be made to generate more detailed and better results about the study, being one of the sections focused on this theme.
QQ 5	The integration of MAS and RRM is briefly analyzed in the results section and in the work appendix. As the insertion of agricultural agents in the model, some important changes occur in relation to soil moisture, due to the use of wood from the trees and the change in the landuse. In addition, with the increase in population, the greater the variation in the equilibrium of simulated flow components. Furthermore, it was observed that both runoff and evapotranspiration were highly sensitive to the increase in agriculture generated by farmers.

Table A3. Answers of specific questions about the work of Yang et al. [79].

Question	Response
SQ 1	The MAS is a homogeneous hydrological simulation system, which serves to link the individual regional models in a single model of the basin. 18 sub-regions of the basin were defined as the system agents, modeled by the eWater Source river system. The behavior of each agent is determined as a nascent river model and is modified only through the calculated parameter values. Each agent is given a name or ID and must be represented by four status in different colors so that the simulation is easily understood. The status are: configured; running; done; and failed. The interactions of the agents are implemented from three processes related to the flow data between the regions, and to the types of interactions that can be of two forms: when the exits of a region A affect the entrance of another region B; and when the output of two regions A and B affect, respectively, the inputs of regions B and A.
SQ 2	Sacramento RRM of Burnash et al. [82] was used for the development of the work. The objective was to integrate RRM into the SMDBRM structure, to generate unmeasured flow from each sub-basin.
SQ 3	The work is based on the hydrological modeling eWater Source, which was used to develop the daily conceptual hydrological model SMDBRM with seven calibration parameters. The SMDBRM model provides the framework for the MAS, where the agents are the sub-regions of the basin. In addition, an automatic stepwise calibration procedure is used, where each sub-region is calibrated in a sequential order using the water balance equation. One of the calibrated values is generated from the Sacramento RRM. The optimized values of the calibration parameters are obtained before the simulations and updated in each region through an agent behavior controller. In addition, parallel programming techniques were used at three levels to decrease computational time, as follows: unconnected agents are run in parallel; agent connections are performed in parallel; and different simulations can be run in parallel.
SQ 4	The agents represent the regions and interact from the hydrological connectivity between the river systems. Each agent has a node-link structure project, based on the SMDBRM model. In the integrated modeling platform, the calibration script is embedded, including the calibration generated in RRM. Each agent has a behavior controller that updates the values already calibrated, before the simulation.
SQ 5	The authors do not comment on challenges when coupling MAS and RRM. The difficulties exposed throughout the work are related to what the model proposes to solve. Thus, there are no mentions of challenges related to MAS or RRM, only on specific issues of model calibration and validation.

Table A4. Answers of quality questions about the work of Yang et al. [79].

Question	Response
QQ 1	The objective of the work was to develop a homogeneous river modeling platform based on agents to link the individual models of the basin regions. Despite the statistical analysis showing that some results are not satisfactory, the authors mention that it was possible to achieve the objectives, as the time and performance of the model were good in almost all regions. In addition, they claim that the tool presents consistent, explainable, and comparable results.
QQ 2	The execution time and performance of the model are analyzed in a section of the work. The calibration time was not mentioned, but after obtaining the values of the calibrated parameters, the model simulation had fast processing. The performance of the model was analyzed statistically, considering the steps of calibration and validation, proving to be highly satisfactory in most regions. In addition, the authors present a discussion on the modeling platform. However, possible improvements to the model or future work are not mentioned.

Table A4. *Cont.*

Question	Response
QQ 3	The work presents sections of explanation about the approached methodology and the interactions between the techniques. However, it is based on existing models, the authors direct the methodology to the development of the MAS and the self-calibration process of the model. The structure of the agents, their interactions, and the way they are executed are explained in detail. Hydrological models are mentioned, including RRM, but are not explicitly presented.
QQ 4	The authors only mention the advantages of using MAS. Among them are the ease in executing the parallel computing processes; the possibility to model complex environmental systems; and simulate and analyze the nonlinear behavior of social and natural systems. In addition, they comment that the choice of RRM Sacramento was made through an analysis among six models, but did not address the advantages and disadvantages of the tools.
QQ 5	Integrations between MAS and RRM were not discussed. Integration was mentioned when explaining the relationship between agents and calibrated data from regional models.

Table A5. Answers of specific questions about the work of Majumdar et al. [80].

Question	Response
SQ 1	The main agents defined were the raindrops, the soil, the altitude, and the amount of water. The main objective of the MAS was to simulate the processes of the rainfall-runoff system and soil erosion in the basin. For this, the open-source, multi-agent programmable modeling environment NetLogo was used. The environment was divided into cells, and in each one, a soil class was considered based on the DEM, which is resampled in NetLogo by the approach of the nearest neighbor. The amount of water used is programmed for each cell. Raindrops are generated according to the rainfall data. Depending on the corresponding altitude of each cell, the droplets accumulate in the region and become agents of the amount of water. The soil changes based on the effect of raindrops. The DEM is modified according to the variation of altitude and soil.
SQ 2	The final RRM is the tool based on OARES agents, which aims to simulate the rainfall-runoff interaction and soil erosion. The model provides data such as: total rainfall-runoff along with the regression adjustment; landuses total change; and soil erosion in image and color scales.
SQ 3	The Soil Conservation Service model was chosen to model and simulate the direct flow of the basin. Images from Landsat 8 tool were used to generate the landuse maps. To obtain information on the slope, the DEM ASTER was used. To be able to analyze the climate forecasting system, meteorological data from 36 years of the basin were obtained. These data and tools were coupled to generate the OARES platform. To validate the model, comparisons between OARES and conventional Hydrologic Modeling System (HEC-HMS) and SWAT models were performed.
SQ 4	The integration between MAS and RRM was generated from the development of the OARES tool. The simulation occurs from the integration of the Python, R, and NetLogo libraries. The environment is divided into cells, which receive input data prepared from meteorological, hydrological and DEM data. The agents move around the environment using adopted flow criteria, load a soil unit according to an algorithm, modify their amount of water depending on the conditions of the environment and elevation.
SQ 5	In order to generate data on flow and soil erosion, tools and equations were needed to generate the responses for the system. However, the results showed differences in the estimates of the variables. In addition, to use the DEM it was necessary to resample it on the NetLogo platform, which decreases the accuracy of the model.

Table A6. Answers of quality questions about the work of Majumdar et al. [80].

Question	Response
QQ 1	The objective of the work was to explore the modeling of a MAS to analyze the rainfall-runoff processes and soil erosion in the Asan watershed. By analyzing the results, the OARES tool proved to be practical and lightweight. In addition to running in open source libraries, it can be run with large numbers of data.
QQ 2	The study performs a quantitative analysis of the output of the OARES model. More precisely, the maps of landuse, the rainfall-runoff relationship and estimated runoff, and soil erosion are analyzed. Moreover, in the work, the validity of the model is analyzed through comparison with conventional models. Additional simulations at OARES were performed to quantitatively measure the decay variations in the obtained precipitation data and the estimated runoff, and an analysis of the results was presented in an appendix.
QQ 3	The approached methodology is presented from three stages. The first details the preparation of the necessary data to serve as a parameter for the model. In the second part, the simulation of the model is exposed through the equations and methods used in OARES, where an appendix is mentioned to explain the interactions between the agents. However, it is mentioned that OARES integrates the Python, R, and NetLogo libraries, but the processes on each platform and how they were integrated are not explained. Finally, an analysis of the model is performed.
QQ 4	The authors emphasize the advantages of using the MAS and RRM tools but do not mention the disadvantages. They mention that the use of MAS in the hydrological context is, sometimes, compared with other computational methodologies. However, they claim that agent-based systems make it possible to use physically realistic parameters, without the need to consider a large amount of data. In addition, they can have a flexible programming module, and obtain computational time savings. Regarding RRM, the authors mention the advantages of using semi-distributed models, which generate satisfactory modeling of the hydrographic region and are less complex than approaches with distributed structure.
QQ 5	The developed MAS generated hydrological rainfall-runoff and soil erosion modeling over the basin. Thus, the analysis on the integration of MAS and RRM was executed based on the results of the agent-based model.

References

1. Chow, V.T.; Maidment, D.R.; Mays, L.W. *Applied Hydrology*; McGraw-Hill: New York, NY, USA, 1988; p. 572.
2. Simmonds, J.; Gómez, J.; Ledezma, A. The role of agent-based modeling and multi-agent systems in flood-based hydrological problems: A brief review. *J. Water Clim. Chang.* **2020**, *11*, 1580–1602. [\[CrossRef\]](#)
3. Barthel, R.; Janisch, S.; Schwarz, N.; Trifkovic, A.; Nickel, D.; Schulz, C.; Mauser, W. An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain. *Environ. Model. Softw.* **2008**, *23*, 1095–1121. [\[CrossRef\]](#)
4. Pouladi, P.; Afshar, A.; Afshar, M.; Molajou, A.; Farahmand, H. Agent-based socio-hydrological modeling for restoration of Urmia Lake: Application of theory of planned behavior. *J. Hydrol.* **2019**, *576*, 736–748. [\[CrossRef\]](#)
5. Wasson, J.G.; Tusseau-Vuillemin, M.H.; Andréassian, V.; Perrin, C.; Faure, J.B.; Barreteau, O.; Bousquet, M.; Chastan, B. What kind of water models are needed for the implementation of the European water framework directive? Examples from France. *Int. J. River Basin Manag.* **2003**, *1*, 125–135. [\[CrossRef\]](#)
6. Le Page, M.; Fakir, Y.; Aouissi, J. Chapter 7—Modeling for integrated water resources management in the Mediterranean region. In *Water Resources in the Mediterranean Region*; Zribi, M., Brocca, L., Tramblay, Y., Molle, F., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 157–190. [\[CrossRef\]](#)
7. Sivapalan, M.; Savenije, H.H.G.; Blöschl, G. Socio-hydrology: A new science of people and water. *Hydrol. Process* **2012**, *26*, 1270–1276. [\[CrossRef\]](#)
8. Davie, T. *Fundamentals of Hydrology*, 2nd ed.; Taylor & Francis: New York, NY, USA, 2008; p. 200.
9. Hromadka, T. Rainfall-runoff models: A review. *Environ. Softw.* **1990**, *5*, 82–103. [\[CrossRef\]](#)

10. Moradkhani, H.; Sorooshian, S. General Review of Rainfall-Runoff Modeling: Model Calibration, Data Assimilation, and Uncertainty Analysis. In *Hydrological Modelling and the Water Cycle: Coupling the Atmospheric and Hydrological Models*; Sorooshian, S., Hsu, K.L., Coppola, E., Tomassetti, B., Verdecchia, M., Visconti, G., Eds.; Springer: Berlin/Heidelberg, Germany, 2008; pp. 1–24. [\[CrossRef\]](#)
11. Huber, L.; Bahro, N.; Leitingner, G.; Tappeiner, U.; Strasser, U. Agent-Based Modelling of a Coupled Water Demand and Supply System at the Catchment Scale. *Sustainability* **2019**, *11*, 6178. [\[CrossRef\]](#)
12. Kingston, G.B.; Maier, H.R.; Dandy, G.C. AI techniques for hydrological modeling and management. I: Simulation. In *Water Resources Research Progress*; Nova: New York, NY, USA, 2008; pp. 15–65.
13. Berglund, E.Z. Using Agent-Based Modeling for Water Resources Planning and Management. *J. Water Resour. Plan. Manag.* **2015**, *141*, 04015025. [\[CrossRef\]](#)
14. Wooldridge, M. *An Introduction to Multiagent Systems*; John Wiley & Sons: New York, NY, USA, 2002.
15. Tan, L.; Guo, J.; Mohanarajah, S.; Zhou, K. Can we detect trends in natural disaster management with artificial intelligence? A review of modeling practices. *Nat. Hazards* **2020**, *107*, 1–29. [\[CrossRef\]](#)
16. Leitzke, B.; Farias, G.; Melo, M.; Gonçalves, M.; Born, M.; Rodrigues, P.; Martins, V.; Barbosa, R.; Aguiar, M.; Adamatti, D. Sistema Multiagente para Gestão de Recursos Hídricos: Modelagem da Bacia do São Gonçalo e da Lagoa Mirim. In *Workshop de Computação Aplicada à Gestão do Meio Ambiente e Recursos Naturais—WCAMA*; Sociedade Brasileira de Computação: Porto Alegre, Brazil, 2019; pp. 87–96. [\[CrossRef\]](#)
17. Farias, G.; Born, M.; Leitzke, B.; Aguiar, M.; Adamatti, D. Modelagem Baseada em Agentes para Análise de Recursos Hídricos. In *XIII Workshop-Escola de Agentes, seus Ambientes e Aplicações—WESAAC*; UFSC: Santa Catarina, Brazil, 2019; pp. 1–12.
18. Farias, G.; Leitzke, B.; Born, M.; Aguiar, M.; Adamatti, D. Water Resources Analysis: An Approach based on Agent-Based Modeling. *Rev. Inform. Teor. Apl.* **2020**, *27*, 81–95. [\[CrossRef\]](#)
19. Farias, G.; Leitzke, B.S.; Born, M.; Aguiar, M.S.; Adamatti, D. Systematic Review of Natural Resource Management using Multiagent Systems and Role-Playing Games. *Res. Comput. Sci.* **2019**, *148*, 91–102. [\[CrossRef\]](#)
20. Leitzke, B.; Farias, G.; Aguiar, M.; Melo, M.; Gonçalves, M.; Born, M.; Rodrigues, P.; Martins, V.; Barbosa, R.; Adamatti, D. Sistemas Multiagente e Jogos de Papéis para Gestão de Recursos Naturais. In *XIII Workshop-Escola de Agentes, seus Ambientes e Aplicações—WESAAC*; UFSC: Santa Catarina, Brazil, 2019; pp. 1–6.
21. Martins, V.; Adamatti, D. Multiagent Systems and Role-Playing Games Applied to Natural Resources Management. In *Advances in Intelligent Systems and Computing*; Dong, Y., Herrera-Viedma, E., Matsui, K., Omatsu, S., González Briones, A., Rodríguez González, S., Eds.; Springer: Berlin/Heidelberg, Germany, 2021; Volume 1237, pp. 221–230. [\[CrossRef\]](#)
22. Mota, F.; Born, M.; Aguiar, M.; Adamatti, D. Mapping needs, motivations, habits and strategies of RPG players in the context of water resources management. In *Proceedings of the 2020 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, 21–24 October 2020; pp. 1–8. [\[CrossRef\]](#)
23. Mota, F.; Born, M.; Aguiar, M.; Adamatti, D. The Strategies of the Players of an RPG Game in the Context of Water Resources Management: An analysis based on the Discourse of the Collective Subject. *Rev. Eletrônica Gestão Educ. E Tecnol. Ambient.* **2021**, *25*, 1. [\[CrossRef\]](#)
24. Lilyea, B.V.; Cooper, R.; Rice, J.; DuPraw, M.; Allsop, S.R. Conducting A Systematic Literature Review on Water-Related Attitudes, Behaviors, and Stakeholder Engagement Approaches in Florida: Strategies and Tools. *Int. J. Interdiscip. Soc. Sci. Annu. Rev.* **2016**, *11*, 87–102. [\[CrossRef\]](#)
25. Biolchini, J.; Mian, P.G.; Natali, A.C.C.; Travassos, G.H. Systematic review in software engineering. *Syst. Eng. Comput. Sci. Dep. COPPE/UFRJ Tech. Rep. ES* **2005**, *679*, 31.
26. Budgen, D.; Brereton, P. Performing systematic literature reviews in software engineering. In *Proceedings of the 28th International Conference on Software Engineering*, Shanghai, China, 20 May 2006; pp. 1051–1052. [\[CrossRef\]](#)
27. Mengist, W.; Soromessa, T.; Legese, G. Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX* **2020**, *7*, 100777. [\[CrossRef\]](#) [\[PubMed\]](#)
28. Rodrigues-Manica, S.; Silva, J.; Cruz-Machado, R.; Coelho, C.; Duarte, J.; Vieira, S.E.; Tavares, C.J.; Pimentel, S.F.M. Biologic disease-modifying anti-rheumatic drugs and patient-reported outcomes in axial SpA: A systematic review and a call for action. *Clin. Rheumatol.* **2021**, *40*, 33–41. [\[CrossRef\]](#) [\[PubMed\]](#)
29. Dohos, D.; Hanák, L.; Szakács, Z.; Kiss, S.; Párnitzky, A.; Eross, B.; Pázmány, P.; Hegyi, P.; Sarlós, P. Systematic review with meta-analysis: The effects of immunomodulator or biological withdrawal from mono- or combination therapy in inflammatory bowel disease. *Aliment. Pharmacol. Ther.* **2021**, *53*, 220–233. [\[CrossRef\]](#) [\[PubMed\]](#)
30. Verbruggen, S.; Depaepe, F.; Torbeyns, J. Effectiveness of educational technology in early mathematics education: A systematic literature review. *Int. J. Child-Comput. Interact.* **2021**, *27*, 100220. [\[CrossRef\]](#)
31. Chen, L.; Xiao, S. Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educ. Res. Rev.* **2021**, *32*, 100377. [\[CrossRef\]](#)
32. Malek, J.; Desai, T.N. A systematic literature review to map literature focus of sustainable manufacturing. *J. Clean. Prod.* **2020**, *256*, 120345. [\[CrossRef\]](#)
33. Boar, A.; Bastida, R.; Marimon, F. A Systematic Literature Review. Relationships between the Sharing Economy, Sustainability and Sustainable Development Goals. *Sustainability* **2020**, *12*, 6744. [\[CrossRef\]](#)

34. Dacombe, R. Systematic Reviews in Political Science: What Can the Approach Contribute to Political Research? *Political Stud. Rev.* **2018**, *16*, 148–157. [CrossRef]
35. Reis, J.; Santo, P.; Melão, N. Influence of artificial intelligence on public employment and its impact on politics: A systematic literature review. *Braz. J. Oper. Prod. Manag.* **2021**, *18*, 1–22. [CrossRef]
36. McCarty, E.B.; Soldatova, L.; Brant, J.A.; Newman, J.G. Innovations in otorhinolaryngology in the age of COVID-19: A systematic literature review. *World J. Otorhinolaryngol.-Head Neck Surg.* **2021**, 1–16. Available online: <https://www.sciencedirect.com/science/article/pii/S2095881121000032> (accessed on 22 January 2021). [CrossRef] [PubMed]
37. Köhnen, M.; Dreier, M.; Seeralan, T.; Kriston, L.; Härter, M.; Baumeister, H.; Liebherz, S. Evidence on Technology-Based Psychological Interventions in Diagnosed Depression: Systematic Review. *JMIR Ment. Health* **2021**, *8*, e21700. [CrossRef] [PubMed]
38. Vázquez Osorio, A.; Soto Barrera, C.A.; Soto, J.P.; Rolón Aguilar, E.; Rolón Aguilar, J.C. Water Quality Monitoring Systems Based on Intelligent Agents: A Systematic Literature Review. In Proceedings of the VXII Mexican International Conference on Artificial Intelligence, Guadalajara, Mexico, 27 October–2 November 2018; pp. 106–116. [CrossRef]
39. Kitchenham, B.; Charters, S.; Budgen, D.; Brereton, P.; Turner, M.; Linkman, S.; Jørgensen, M.; Mendes, E.; Visaggio, G. *Guidelines for Performing Systematic Literature Reviews in Software Engineering*; Technical Report EBSE-2007-01; Keele University: Newcastle, UK; University of Durham: Durham, UK, 2007.
40. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Moher, D. Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement. *J. Clin. Epidemiol.* **2021**, *134*, 103–112. [CrossRef]
41. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, 372. [CrossRef]
42. Qiang, M.; Guomin, L.; Sijia, H.; Xiaoyan, Z.; Wenchuan, W.; Changjun, L. A New Generation Numerical Modelling Tool for Hydrological Simulation: Spatiotemporal-Variied-Source-Mixed Runoff Model for Small Watershed. In Proceedings of the 2021 International Conference on Control and Intelligent Robotics, New York, NY, USA, 18–20 June 2021; Association for Computing Machinery: New York, NY, USA, 2021; pp. 325–330. [CrossRef]
43. Ibrahim, K.S.M.H.; Huang, Y.F.; Ahmed, A.N.; Koo, C.H.; El-Shafie, A. A review of the hybrid artificial intelligence and optimization modelling of hydrological streamflow forecasting. *Alex. Eng. J.* **2022**, *61*, 279–303. [CrossRef]
44. Ch, S.; Anand, N.; Panigrahi, B.; Mathur, S. Streamflow forecasting by SVM with quantum behaved particle swarm optimization. *Neurocomputing* **2013**, *101*, 18–23. [CrossRef]
45. Meng, E.; Huang, S.; Huang, Q.; Fang, W.; Wang, H.; Leng, G.; Wang, L.; Liang, H. A Hybrid VMD-SVM Model for Practical Streamflow Prediction Using an Innovative Input Selection Framework. *Water Resour. Manag.* **2021**, *35*, 1321–1337. [CrossRef]
46. Sharma, P.; Kar, B.; Wang, J.; Bausch, D. A Machine Learning Approach to Flood Severity Classification and Alerting. In Proceedings of the 4th ACM SIGSPATIAL International Workshop on Advances in Resilient and Intelligent Cities, New York, NY, USA, 2 November 2021; Association for Computing Machinery: New York, NY, USA, 2021; pp. 42–47. [CrossRef]
47. Aoulmi, Y.; Marouf, N.; Amireche, M.; Kisi, O.; Shubair, R.M.; Keshtegar, B. Highly Accurate Prediction Model for Daily Runoff in Semi-Arid Basin Exploiting Metaheuristic Learning Algorithms. *IEEE Access* **2021**, *9*, 92500–92515. [CrossRef]
48. Huang, P.C.; Lee, K.T. Influence of topographic features and stream network structure on the spatial distribution of hydrological response. *J. Hydrol.* **2021**, *603*, 126856. [CrossRef]
49. Yuan, L.; Forshay, K. Enhanced streamflow prediction with SWAT using support vector regression for spatial calibration: A case study in the Illinois River watershed, U.S. *PLoS ONE* **2021**, *16*, e248489. [CrossRef] [PubMed]
50. Kwon, M.; Kwon, H.H.; Han, D. A Hybrid Approach Combining Conceptual Hydrological Models, Support Vector Machines and Remote Sensing Data for Rainfall-Runoff Modeling. *Remote Sens.* **2020**, *12*, 1801. [CrossRef]
51. Kraft, B.; Jung, M.; Körner, M.; Reichstein, M. Hybrid modeling: Fusion of a deep learning approach and a physics-based model for global hydrological modeling. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2020**, XLIII-B2-2020, 1537–1544. [CrossRef]
52. Russell, S.; Norvig, P. *Artificial Intelligence: A Modern Approach*; Prentice Hall: Hoboken, NJ, USA, 2002; p. 932.
53. Crooks, A.T.; Heppenstall, A.J. Introduction to Agent-Based Modelling. In *Agent-Based Models of Geographical Systems*; Heppenstall, A.J., Crooks, A.T., See, L.M., Batty, M., Eds.; Springer: Dordrecht, The Netherlands, 2012; pp. 85–105. [CrossRef]
54. Gilbert, N.; Troitzsch, K. *Simulation for the Social Scientist*; Open University Press: Buckingham, UK, 2005; p. 295.
55. Farolfi, S.; Müller, J.P.; Bonté, B. An iterative construction of multi-agent models to represent water supply and demand dynamics at the catchment level. *Environ. Model. Softw.* **2010**, *25*, 1130–1148. [CrossRef]
56. Adamatti, D.F. An Overview of the MABS and RPG Techniques in Natural Resources Management. In Proceedings of the 2009 International Conference on Computer Engineering and Technology, Singapore, 22–24 January 2009; Volume 2, pp. 538–542. [CrossRef]
57. Adamatti, D.F. *Inserção de Jogadores Virtuais em Jogos de Papéis para Uso em Sistemas de Apoio a Decisão em Grupo: Um Experimento no Domínio da Gestão de Recursos Naturais*; University of São Paulo: São Paulo, Brazil, 2007.
58. Schreinemachers, P.; Berger, T. An agent-based simulation model of human–environment interactions in agricultural systems. *Environ. Model. Softw.* **2011**, *26*, 845–859. [CrossRef]

59. Clark, M.P.; Bierkens, M.F.P.; Samaniego, L.; Woods, R.A.; Uijlenhoet, R.; Bennett, K.E.; Pauwels, V.R.N.; Cai, X.; Wood, A.W.; Peters-Lidard, C.D. The evolution of process-based hydrologic models: Historical challenges and the collective quest for physical realism. *Hydrol. Earth Syst. Sci.* **2017**, *21*, 3427–3440. [\[CrossRef\]](#)
60. Bras, R.L. *Hydrology: An Introduction to Hydrologic Sciences*; Addison-Wesley Publishing Company: Cambridge, MA, USA, 1990; p. 643.
61. Caldeira, T.L.; Oliveira, V.A.; Steinmetz, A.A.; Viola, M.R.; Beskow, S. Modelagem hidrológica determinística chuva-vazão em bacias hidrográficas: Uma abordagem introdutória. *Rev. Bras. Eng. E Sustentabilidade* **2018**, *5*, 22–32. [\[CrossRef\]](#)
62. White, K.; Chaubey, I. Sensitivity analysis, calibration, and validations for a multisite and multivariable SWAT model. *JAWRA J. Am. Water Resour. Assoc.* **2005**, *41*, 1077–1089. [\[CrossRef\]](#)
63. Wang, S.; Zhang, Z.; Sun, G.; Strauss, P.; Guo, J.; Tang, Y.; Yao, A. Multi-site calibration, validation, and sensitivity analysis of the MIKE SHE Model for a large watershed in northern China. *Hydrol. Earth Syst. Sci.* **2012**, *16*, 4621–4632. [\[CrossRef\]](#)
64. Daggupati, P.; Pai, N.; Ale, S.; Douglas-Mankin, K.R.; Zeckoski, R.W.; Jeong, J.; Parajuli, P.B.; Saraswat, D.; Youssef, M.A. A recommended calibration and validation strategy for hydrologic and water quality models. *Trans. ASABE* **2015**, *58*, 1705–1719.
65. Arnold, J.G.; Moriasi, D.N.; Gassman, P.W.; Abbaspour, K.C.; White, M.J.; Srinivasan, R.; Santhi, C.; Harmel, R.; Van Griensven, A.; Van Liew, M.W.; et al. SWAT: Model use, calibration, and validation. *Trans. ASABE* **2012**, *55*, 1491–1508. [\[CrossRef\]](#)
66. Caldeira, T.L.; Mello, C.R.; Beskow, S.; Timm, L.C.; Viola, M.R. LASH hydrological model: An analysis focused on spatial discretization. *CATENA* **2019**, *173*, 183–193. [\[CrossRef\]](#)
67. Devia, G.K.; Ganasri, B.; Dwarakish, G. A review on hydrological models. *Aquat. Procedia* **2015**, *4*, 1001–1007. [\[CrossRef\]](#)
68. Milad Jajarmizadeh, S.H.; Salarpour, M. A Review on Theoretical Consideration and Types of Models in Hydrology. *J. Environ. Sci. Technol.* **2012**, *5*, 249–261. [\[CrossRef\]](#)
69. Downer, C.W.; Ogden, F.L. GSSHA: Model to simulate diverse stream flow producing processes. *J. Hydrol. Eng.* **2004**, *9*, 161–174. [\[CrossRef\]](#)
70. Sandu, M.A.; Virsta, A. Applicability of MIKE SHE to Simulate Hydrology in Argesel River Catchment. *Agric. Agric. Sci. Procedia* **2015**, *6*, 517–524. [\[CrossRef\]](#)
71. Umar, F.; Zulkafli, Z.; Yusuf, B.; Nurhidayu, S. Assessment of Streamflow Simulation for a Tropical Forested Catchment Using Dynamic TOPMODEL—Dynamic fluxEs and Connectivity for Predictions of HydRology (DECIPHeR) Framework and Generalized Likelihood Uncertainty Estimation (GLUE). *Water* **2021**, *13*, 317. [\[CrossRef\]](#)
72. Bandi, A.; Rao, Y.R.S.; Kumar, S. Rainfall runoff modelling in Ephemeral river basin using SWAT. *J. Crit. Rev.* **2020**, *7*, 1589–1597. [\[CrossRef\]](#)
73. Momm, H.; Bingner, R.; Wells, R.; Moore, K.; Herring, G. Integrated Technology for Evaluation and Assessment of Multi-Scale Hydrological Systems in Managing Nonpoint Source Pollution. *Water* **2021**, *13*, 842. [\[CrossRef\]](#)
74. Aghakouchak, A.; Habib, E. Application of a conceptual hydrologic model in teaching hydrologic processes. *Int. J. Eng. Educ.* **2010**, *26*, 963–973.
75. Liu, Z.; Wang, Y.; Xu, Z.; Duan, Q. Conceptual Hydrological Models. In *Handbook of Hydrometeorological Ensemble Forecasting*; Duan, Q., Pappenberger, F., Thielen, J., Wood, A., Cloke, H., Schaake, J., Eds.; Springer: Berlin/Heidelberg, Germany, 2017. [\[CrossRef\]](#)
76. Xu, M.; Han, H.; Kang, S. Modeling Glacier Mass Balance and Runoff in the Koxkar River Basin on the South Slope of the Tianshan Mountains, China, from 1959 to 2009. *Water* **2017**, *9*, 100. [\[CrossRef\]](#)
77. Yan, C.A.; Zhang, W.; Zhang, Z. Hydrological modeling of the Jiaoyi watershed (China) using HSPF model. *Sci. World J.* **2014**, *2014*, 672360. doi: 10.1155/2014/672360. [\[CrossRef\]](#) [\[PubMed\]](#)
78. Bithell, M.; Brasington, J. Coupling agent-based models of subsistence farming with individual-based forest models and dynamic models of water distribution. *Environ. Model. Softw.* **2009**, *24*, 173–190. [\[CrossRef\]](#)
79. Yang, A.; Dutta, D.; Vaze, J.; Kim, S.; Podger, G. An integrated modelling framework for building a daily river system model for the Murray—Darling Basin, Australia. *Int. J. River Basin Manag.* **2017**, *15*, 373–384. [\[CrossRef\]](#)
80. Majumdar, S.; Shukla, S.; Maiti, A. Open Agent Based Runoff and Rrosion Simulation (OARES): A generic cross platform tool for spatio - temporal watershed monitoring using climate forecast system reanalysis weather data. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2018**, *IV-4*, 125–132. [\[CrossRef\]](#)
81. Brasington, J.; El-Hames, A.; Richards, K. Hydrological modelling in humid tropical catchments. In *The Sustainable Management of Tropical Catchments*; Harper, D., Brown, A., Eds.; John Wiley & Sons Limited: Chichester, UK, 1998; pp. 313–336.
82. Burnash, R.J.; Ferral, R.L.; McGuire, R.A. *A Generalized Streamflow Simulation System: Conceptual Modeling for Digital Computers*; Joint Federal & State River Forecast Center: Sacramento, CA, USA, 1973.