Hydrological modeling in mexico as a basis for sustainable agricultural development: A review

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ABSTRACT

The goal was to analyze hydrological modeling as strategic tool to assess the impact of land use and climate change on hydrological resources in agricultural systems. The documentary research technique was applied, through the process of collecting and systematizing information. A bibliometric study was carried out to know the scientific production between 2013 and 2023 registered in SCOPUS. Bibliometric network maps were built and indicators were generated. Results showed that hydrological modeling has increased in the last decade both internationally and in Mexico. In the international context the following lines of research have been developed: i) surface runoff at the basin level (37%), ii) hydrological models for comprehensive water management (22%) and iii) impact of climate change on the hydrological balance (20%). In Mexico, they have mainly been developed on: i) vulnerability and risk to floods (25%); ii) surface runoff (18%) and iii) impact of climate change on the hydrological balance (17%). Our findings show that the use of the SWAT model stands out in most of the research topics worldwide and in Mexico. This is because it is the most robust model according to the review. There are evidence on the need to delve deeper into the impact of the hydrological balance in agricultural production systems and the effect they will have under climate change conditions.

Keywords: *Agricultural crops, Global change, Land use, Water management, Water use, Hydrological balance, Water resource.*

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Highlights of this paper

- Human activities, such as agriculture and land use changes, cause imbalances in the hydrological cycle.
- Hydrological models are essential for evaluating the effects of climate change on the water balance.
- Topics of interest include surface runoff, climate change, and water management.

1. INTRODUCTION

Agriculture relies heavily on water resources [1]. While it is crucial for feeding the world's population, its expansion and intensification have led to rapid changes in land use and overexploitation of water resources. The actions are significantly altering the hydrological cycle, affecting both water quality and quantity. This will have ecological consequences that could threaten global food security and the sustainability of agriculture [2].

Agriculture uses about 70% of the world's freshwater [1] making it crucial for sustainable development. Effective water management is crucial in agriculture for several reasons. Firstly, water is a finite and limited resource, and unsustainable exploitation of water resources can have serious consequences for future generations [3]. Secondly, inefficient water use in agriculture contributes to water resource depletion and climate change [4]. Inefficient irrigation results in water waste and increased greenhouse gas emissions due to the energy required for pumping and distributing water [5] and third, sustainable water management in agriculture is essential to address water scarcity and inequality in water distribution [6]. Lack of access to clean and safe water is a major obstacle to sustainable development in many regions of the world [7].

To ensure that all communities have access to drinking and agricultural irrigation water, it is necessary to balance demands in a fair and sustainable manner. Agriculture frequently competes with other sectors for access to water resources. To achieve sustainable water management in agriculture, it is essential to promote sustainable agricultural practices. This includes using efficient irrigation techniques, investing in water storage infrastructure, and promoting conservation agriculture [8]. Governments, international organizations, and communities must collaborate to establish policies and regulations that promote sustainable water management in agriculture and ensure equitable access to water resources [9].

Scenario modeling is a useful approach for achieving sustainable water resource management globally and in Mexico. This technique provides a simplified and understandable representation of the world. Hydrological models are crucial tools for water resource and environmental planning, management, prediction, and evaluation. [10, 11]. This paper reviews the application of hydrological models to identify the impacts of land use and climate change on hydrological resources. The purpose is to emphasize the need for hydrological modeling as a basis for sustainable agricultural development in Mexico, with a focus on agricultural production systems. The first part presents the methodological design. A review of hydrological modeling was conducted to aid in understanding the results. The findings are presented quantitatively to define the main and less developed lines of research. The study's conclusions are then presented.

2. METHODOLOGICAL DESIGN

2.1. Data Acquisition

Documentary research is a qualitative technique that involves collecting, compiling, and selecting scientific articles to analyze data and identify, select, and articulate the object of study [12, 13]. The objective of using the documentary research technique was divided into two parts [14] reviewing and analyzing information sources related to hydrological models used as strategic tools to identify the impacts of land use change and climate change on the hydrological balance, finding relationships between the analyzed sources, and [15] generating a global and systematic vision of hydrological modeling to contextualize the importance of its study and development [16, 17].

The research process involved collecting and organizing information sources [18]. Relevant material was selected to contextualize hydrological modeling. The search was conducted in various journal collections, including Elsevier, Google Scholar, Science Direct, Scopus, and Springer, using specific keywords. "Hydrologic models", "hydrologic model", "water balance", and "hydrologic balance" were searched along with "agricultural systems", "farming", and "climate change". The search period was not limited to any specific year of publication, although preference was given to information generated in the last ten years. The located papers were then reviewed and those with irrelevant material were discarded.

2.2. Data Processing and Analysis

The information was collated to compare and organize original articles and official information from around the world. This was done to obtain citations and references related to hydrological models, which are used as strategic tools to identify impacts. The collected material was analyzed and systematized to develop the following topics of interest: hydrological balance in agricultural systems, hydrological modeling, types of hydrological models, factors influencing hydrological modeling, hydrological modeling and agricultural systems, hydrological modeling and climate change, and selection of the hydrological model. This led to the generation of conclusions based on the contextualization of hydrologic modeling.

2.3. Bibliometric Analysis

Bibliometrics has made significant progress in recent decades and is now an established and innovative area of research within information science [19]. Text mining is the application of mathematical and statistical methods to books and other written media [20]. It is used to examine the progress of science, guide research, anticipate scientific development, and identify the productivity of researchers or institutions [21, 22]. Thus, this research conducted a bibliometric analysis to determine the impact and visibility of the scientific production related to the topic.

The selected search keywords for the international and Mexican context were: hydrological models, hydrological balance, climate change, agricultural systems, and Mexico. The analyzed database was obtained from the Scopus platform, which includes rich metadata records of scientific articles and complete profiles of authors and institutions [23]. The platform performed an advanced search using the specified keywords, limited to the 'title', 'keywords', and 'abstract' of the collected sources.

The following equation was used to conduct the search in an international context: TITLE-ABS-KEY: "Hydrologic models" OR "Hydrologic model" OR "Hydrological modeling" AND "Water balance" OR "Hydrologic balance" AND "Climatic change" AND "Agricultural systems" OR "Farming" AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")). In the previous equation, "Mexico" was added to limit the search to the context of Mexico. The search was limited to scientific and review articles published between 2013 and 2023. Metrics and units were strictly adhered to. A total of 307 scientific articles and 48 review articles were found for hydrological modeling at the international level. In the context of Mexico, 136 scientific articles and 3 review articles were found, totaling 139 studies.

2.4. Analysis

The information obtained from Scopus databases was exported in CSV format, which is compatible with the VOSviewer tool [24]. VOSviewer is a software tool used for creating and exploring bibliometric network maps. Although it is primarily intended for analyzing scientific articles, it can be used for any type of network data. VOSviewer is a tool that can be used to explore co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation links. It offers three possible representations: network, overlay, or density visualization [25]. In this study, we used VOSviewer to construct and visualize bibliometric network maps based on keyword co-occurrence, citation, and co-authorship. To enhance the bibliometric analysis, we used the 'Bibliometrix' tool [26] within the Rstudio program to generate bibliometric indicators. Bibliometrix is a powerful tool for bibliometric analysis that allows for data import and conversion to R format, analysis of a dataset, and construction of matrices. Matrices serve as input data for network analysis, multiple correspondence analysis, and other data reduction techniques [25]. Bibliometrix indicators were used to identify and compare the main lines of research, as well as those that are less explored internationally and in Mexico.

3. RESULTS

3.1. Hydrological Balance in Agricultural Systems

The hydrological balance in agricultural systems refers to the management and balance of water in agricultural production and is therefore strongly influenced by management practices: planting, irrigation, fertilization and harvesting [27]. However, the development of agricultural activity is generating environmental externalities, causing a significant imbalance in the hydrological balance, which could compromise the future of agricultural crops [2, 5, 28]. The speed at which externalities of agricultural activity are occurring is being reflected in the elevation of evapotranspiration levels [29, 30] and in the decrease in rainfall interception levels, which will directly affect crop yield and establishment [31, 32].

3.2. Hydrologic Modeling

Hydrological models are increasingly used to determine the environmental impacts of climate variability and land management [33] through scenario analysis and risk assessment [34] to understand and predict more clearly and accurately the processes involved in the distribution of water flows of the hydrological balance [30]. With the aim of establishing an adequate management of the resource, both in terms of drinking water supply and agricultural irrigation [10]. Similarly, they can provide essential information for the study of food security, sustainability, ecosystem services and climate change [35].

3.3. Hydrological Models

There are many hydrological models available for simulating soil and water processes at the basin level, both currently and in the future [36]. These models can be classified based on their approach, structure (metric, conceptual, physically based, hybrid), spatial distribution (aggregated, distributed, and semi-distributed), and time scale [37]. The most commonly used classification for models is based on spatial scale. This allows for analysis of model characteristics and behavior based on data needs, expected accuracy, required experience, and ease of use.

Models can be classified as either concentrated or distributed, depending on the spatial discretization of parameters. Concentrated models treat the entire basin as a single unit, discarding spatial variability of input data, parameters, and outputs. Distributed models can handle varying quantities in space by dividing the basin into subunits, allowing for spatial variation in parameters, inputs, and outputs [38].

3.4. Factors Influencing Hydrologic Modeling

Hydrologic modeling is a complex process that considers multiple factors that affect its behavior [36]. The precision and accuracy of simulations depend on various factors, including the spatio-temporal scales of input data, relief, geomorphology, bedrock, soil and vegetation properties [15] as well as climatic characteristics such as rainfall, temperature, relative humidity, and wind speed [39]. Other important considerations include the availability and quality of data, required expertise, ease of use, and time constraints [37].

Calibration techniques [33] basic performance criteria, efficiency, and sensitivity analysis [11] are significant influencing factors. However, there is a lack of studies that explore how sensitivity analysis design and calibration affect simulation outcomes. It is important to note that there are currently no universally accepted procedures for model calibration due to differences in objectives and input data. These procedures vary in both temporal and spatial scale from the point of origin to the watershed level [33].

3.5. Hydrological Modeling and Agricultural Systems

To ensure efficient crop production, hydrological modeling tools should be included in the sustainable management of agricultural systems [40]. The models should produce results that enable the development of proposals to increase crop profitability without compromising water resources. Additionally, they should establish procedures to determine hydrological parameters, such as soil moisture, over time and space to estimate specific crop water requirements [41].

Hydrological models can help address issues related to sustainable agricultural production, resource scarcity [38] food security [35] environmental degradation, and climate change [42]. However, many current hydrological models lack sufficient representation of croplands and oversimplify cultivation without considering management practices [27].

3.6. Hydrological Models and Climate Change

Hydrological modeling is essential in evaluating the effects of climate change on water resources [10]. These models simulate various climate scenarios and evaluate how changes in temperature, precipitation, and other climatic factors will impact the hydrological cycle. Specifically, they analyze the behavior and distribution of hydrological balance fluxes, including surface runoff, evapotranspiration, and soil moisture Cruz-Arevalo, et al. [43]; Wang and Yang [44]; Yonaba, et al. [45]. Bazzi, et al. [46] demonstrate the ability to predict and locate agricultural regions that will experience extreme drought due to changes in precipitation, temperature, and groundwater levels.

3.7. Selection of Hydrological Model

The outcome of a hydrological study is contingent upon the model chosen [15]. However, with a vast array of models available, selecting the most appropriate one to couple with the specific data processing method can be challenging [38]. To choose the appropriate model, review the characteristics described in the model classifications. It is important to consider that the performance and validity of hydrological models can vary depending on the size of the basin and the physical processes governing the system [10]. In data-poor regions, the most reliable models are those that accurately represent reality with limited complexity [47].

While the ideal selection of a hydrological model should be based on its suitability to the research question, in practice, models are often chosen for their practicality, convenience, and familiarity. This can prevent the use of more suitable models that could better achieve the study's objectives [15]. It is important to note that many developing countries use hydrological models designed for developed countries.

3.8. Bibliometric Analysis

3.8.1. International and Mexico Context

In the last ten years, 368 scientific articles on hydrological modeling and its relationship with agricultural production, hydrological balance, and climate change have been published mainly in Asia. This productivity corresponds to 24.2% of the total number of publications from the top 10 countries. The United States follows with 21.8% (322 articles) and Germany with 15.2% (231 articles) (Figure 1). Manuscripts published in the United States receive the highest number of citations worldwide, with 1,865, surpassing China and Germany, which received 223 and 415 citations, respectively.

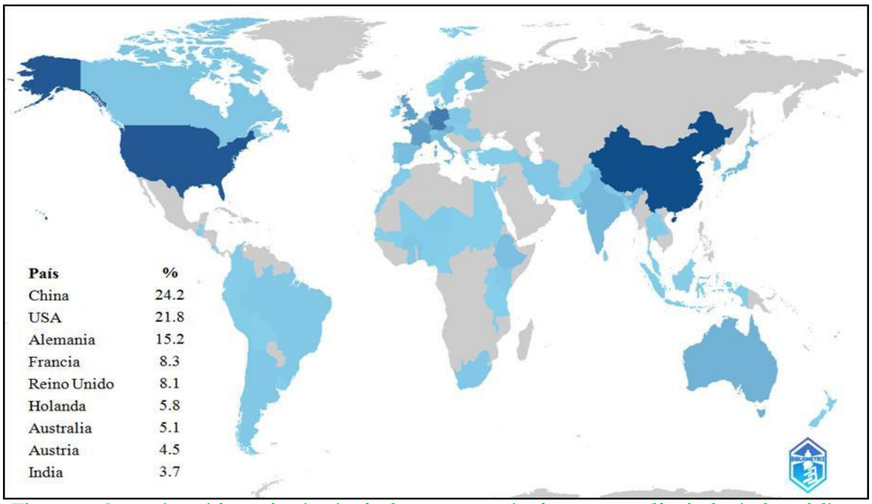

Figure 1. Countries with production in the last ten years in the context of hydrological modeling.

Over the past decade, Mexico has seen a rise in the production of hydrologic modeling studies, following a global trend. Figure 2 illustrates that 2022 had the highest number of publications at 15.1%.

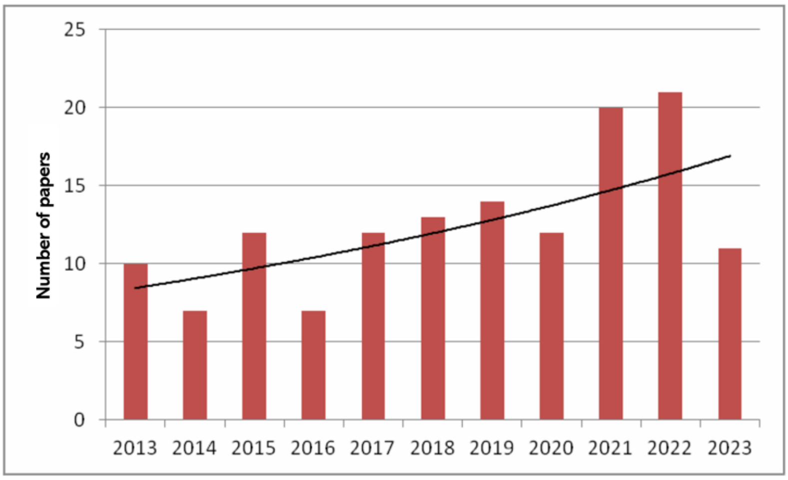

Figure 2. Scientific production on hydraulic modeling in Mexico for the period 2013-2023.

3.9. Co-Occurrence Analysis

The co-occurrence analysis in VOSviewer found 3,284 keywords globally, but only 135 met the minimum threshold of 10 repetitions. The map shows that the most frequently used keyword was 'hydrological modeling', followed by 'climate models', 'runoff', 'water supply', 'land use', 'water management', 'evapotranspiration', 'soil moisture', and 'soil and water assessment tool'. Additionally, four major thematic groups can be identified (Figure 3) that shape the main lines of research related to the topic studied.

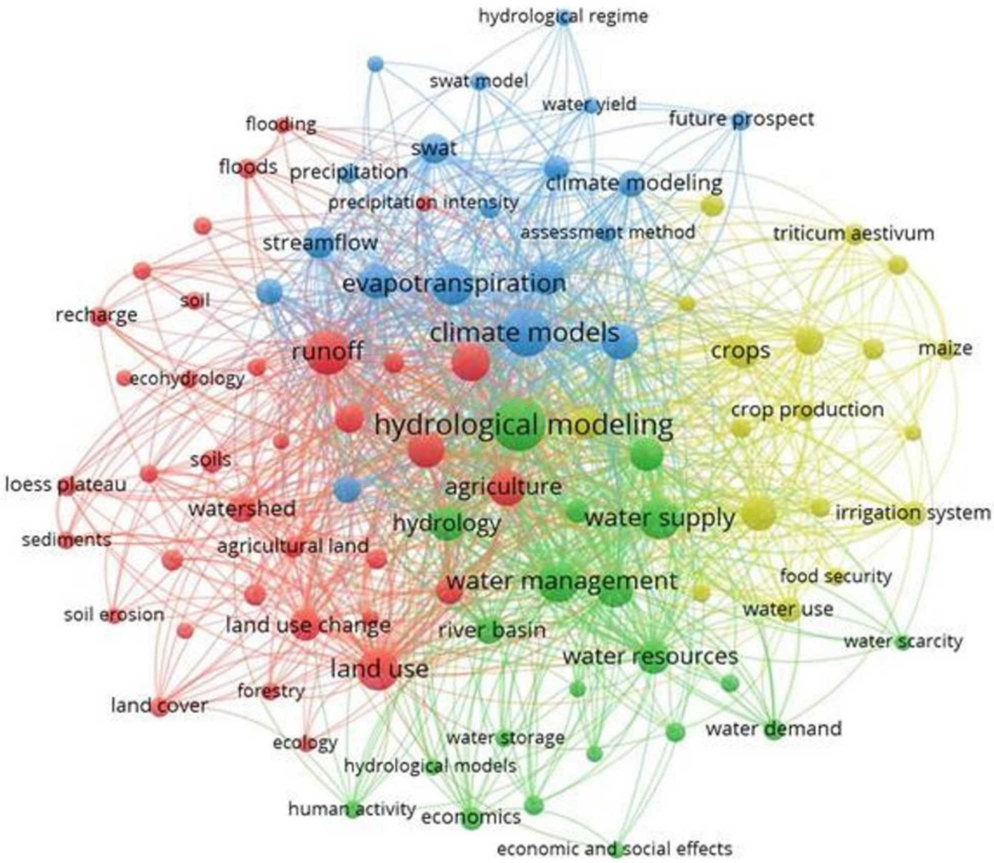

Figure 3. Keyword co-occurrence analysis in the context of hydrological modeling worldwide.

During the co-occurrence analysis at the national level in Mexico, we identified 112 keywords that met the minimum threshold of 10 repetitions. The bibliometric map shows that the most frequently used keyword is Mexico, followed by hydrological models, climate change, water management, runoff, basin, groundwater, water supply, aquifers, land use, and floods. The close proximity of these terms indicates a strong correlation between the research that contains them (see Figure 4). Compared to the global analysis, the key words show a high level of similarity, with the only difference being the mention of evapotranspiration at the global level and flooding at the Mexican level.

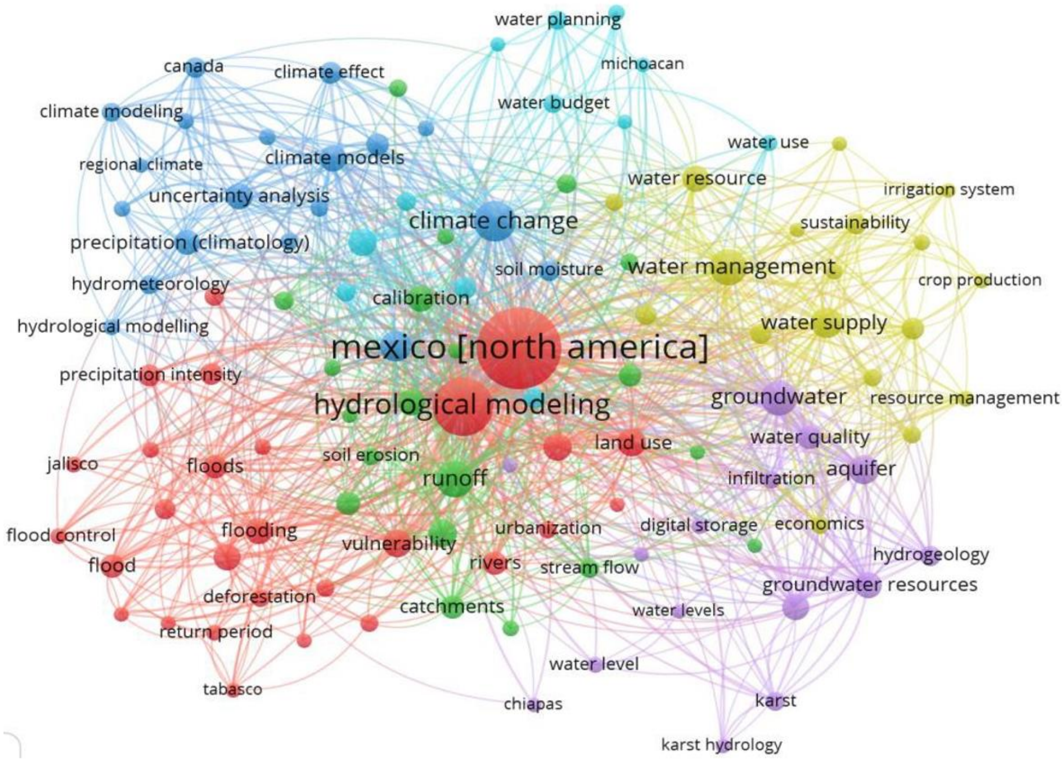

Figure 4. Keyword co-occurrence analysis in the context of hydrological modeling in Mexico.

3.9.1. Research Priorities

The bibliometric map of co-occurrence at the global level shows that research has focused on four major thematic groups (Table 1).

Table 1. Main lines of research visualized in the bibliometric map.

Group	Line of research	%	Items	Key words
1	Surface runoff behavior at the basin level	37.6	35	Runoff, land use, watersheds, soil moisture, land use change, agricultural land, soils, land cover, sediments, recharge, water balance
2	Hydrologic modeling for integrated water management	22.6	21	Hydrological modeling, water supply, water management, hydrology, water resources, river basin, water demand, water storage, global change
3	Impact of climate change on the hydrological balance	20.4	19	Climate models, evapotranspiration, streamflow, swat, climate effect, water yield, future prospect, hydrological regime, climate change, global climate
4	Management of water resources for crop irrigation	19.4	18	Crops, irrigation, irrigation system, food security, water use, crop production, T*riticum aestivum*, corn, maize, crop yield, agricultural management

The primary area of research worldwide focuses on hydrological flows and land use, and their relationship with surface runoff, soil moisture, groundwater recharge, land cover, land use, and watersheds. This research addresses the significance of water security, which is crucial for social development, ecosystem sustainability, and environmental management [48, 49]. It also recognizes the influence that land cover has on the balance of the hydrological cycle [50]. It addresses the impacts of land use change on surface runoff and water yield [51]. And it highlights that the conversion of bare areas to cropland decreases surface runoff [45] and thus increases soil moisture and groundwater recharge [52].

The second line of research focuses on the relationship between hydrological models and the supply, management, storage, and demand of hydrological resources. Hydrological models are an important tool in addressing the challenges associated with the impacts of global change [53]. Developing accurate and reliable global hydrological forecasts is crucial for managing drinking water supply and agricultural irrigation, especially in light of future vulnerability to hydrological hazards and water scarcity due to climate change [10, 54].

The third line of research focus to climate change. It is observed that the strongest links are occurring with evapotranspiration, SWAT, scenario projection, and global change. It is highlighted that extreme weather can have a significant impact on the social, environmental, and economic development of human life [42]. Climate variations, particularly precipitation and temperature, can impact the hydrological regime, leading to significant changes in evapotranspiration distribution, flow, and surface runoff [55-57]. The hydrological responses of watersheds to climate change require detailed examination to ensure sustainable management of both water resources and natural ecosystems. This examination can be conducted through the SWAT model. The fourth line of research focuses on irrigation systems of agricultural production is constituted by direct links with management, production, crop yield and water use mainly. Crop yield analysis remains a central input in climate change risk assessment [42]. Similarly, it has been determined that global agricultural production is highly dependent on irrigation, but the efficiency of irrigation systems is often surprisingly low [58]. Thus, it is critical to improve irrigation strategies, as full irrigation could mitigate reductions in crop yields caused by climate change [59]. However, it should be considered that agricultural water use in highly irrigated regions may reduce surface water flow [60] affecting its availability in surrounding areas.

While in Mexico, the bibliometric map of co-occurrence shows that research has focused on six major thematic groups (refer to Table 2). However, there is a research gap related to evaluating the individual impact of different agricultural production systems within a micro-watershed on the hydrological balance, as well as analyzing how variations in the hydrological cycle under conditions of climate change will affect the water requirements of agricultural systems.

Table 2. Research priorities developed in the context of hydrologic modeling in Mexico.

Group	Line of research	%	Items	Key words
1	Vulnerability and risk to flooding due to extreme weather events	25	28	Mexico, hydrological modeling, land use, land use change, vulnerability, flooding, extreme event, precipitation intensity, deforestation
2	Surface runoff behavior at the basin level	18	20	Runoff, sreamflow, soil erosion, SWAT, watershed, catchments, spatial analysis, rain, calibration
3	Impact of climate change on the hydrological balance	17	19	Climatic change, climate effect, regional climate, precipitation, hydrometeorology, soil moisture, evapotranspiration, hydrology
4	Management of water resources for crop irrigation	16	18	Water management, water supply, water resource, resource management, agriculture, irrigation system, crop production, sustainability
5	Groundwater measurement	13	15	Groundwater, aquifer, water quality, groundwater, resources, water level, infiltration, infiltration, hydrogeology
6	Distribution and behavior of the hydrological balance	11	12	Water balance, water planning, water viability, water balance, spatiotemporal analysis, simulation, river basin, hydrological cycle

In Mexico, the primary research focus is on hydrological modeling studies to identify areas at risk and highly vulnerable to floods along rivers or at the basin level. These floods are caused by meteorological uncertainty and extreme weather events [61, 62] as well as anthropogenic activities such as changes in land use due to the expansion of the agricultural frontier and increased urbanization, and the lack of monitoring systems [63]. The hydrological models consider historical points of affectation to issue more accurate potential overflow points and determine if the river can handle overloads [62]. Therefore, it is necessary to continue modeling to establish integrated watershed management that considers the impacts of land use change on the increased prevalence of floods and the economic and social costs involved [64] in all risk zones. This information aims to assist decision-makers in mitigating damages [65]. This research topic is being studied globally within the research line of 'Behavior of surface runoff at basin level'. It is directly related to surface runoff as a consequence.

The second area of research focuses on analyzing the spatio-temporal behavior of surface runoff through simulations. This analysis is based on various factors such as topography, vegetation cover, land use change, and climate change. The study is conducted at both the catchment hydrological unit and basin levels [40, 66]. According to models, climate change will significantly impact surface runoff, leading to decreased quantities in arid and semi-arid zones [9] and increased risk of flooding in tropical zones [67]. This can cause sediment entrainment [68] and flooding [63]. However, it is possible to restore the original hydrological conditions to a large extent by conserving and increasing vegetation cover. This is because vegetation cover reduces the velocity of surface runoff, leading to increased soil moisture and groundwater recharge [52, 69, 70]. This research is closely related to the global development of line 1, which emphasizes the issues caused by uncontrolled surface runoff.

The third area of research examines how watersheds respond to climate change, with a focus on the social, environmental, and economic impacts [71]. The use of the SWAT model for climate change projections is particularly noteworthy in this field. The model simulates climate change scenarios with acceptable resolution and focuses on obtaining a detailed examination to ensure sustainable water resource management [10]. The studies' results highlight significant changes in water quantity in monthly mean flows, evapotranspiration [55] groundwater recharge processes [72] and surface runoff [63]. The goal is to create sustainable water management policies and effective adaptation strategies at the basin level, in line with global efforts to address the impact of climate change on the planet [9].The goal is to create sustainable water management policies and effective adaptation strategies at the basin level, in line with global efforts to address the impact of climate change on the planet. The goal is to create sustainable water management policies and effective adaptation strategies at the basin level, in line with global efforts to address the impact of climate change on the planet. This aligns with the main topics being discussed globally.

The fourth area of research focuses on managing, supplying, and conserving hydrological resources to optimize irrigation and meet agricultural demands [73]. However, irrigation systems are often inefficient, leading to decreased water availability in agricultural areas [60] and environmental externalities that threaten the availability and quality of water resources [5]. Due to overexploitation of the resource, meeting the growing demand for water with current agricultural schemes will be difficult [74]. Improving irrigation strategies is essential to mitigate reductions in crop yields caused by climate change. Constant monitoring of aquifer capacity and piezometric levels, along with projecting water scarcity scenarios, can help achieve this [75]. The objective is to generate hydrological information for the optimization and efficient planning of irrigation resources. This aligns with the global trend of better management of hydrological resources for agricultural crops.

The fifth line of research focuses on hydrological modeling to measure groundwater resources [76] and water quality [77] using infiltration levels [78] and hydrogeology [79] as references. Currently, the sustainability of aquifers is threatened by the increase in water demand for population consumption and agricultural irrigation, as well as the decrease in recharge rates [79]. Hydrological models accurately replicate natural aquifer conditions and provide dependable monitoring of piezometric levels [34]. This information is valuable for designing and evaluating management strategies for overexploited groundwater [80]. Further research is needed to improve the applicability of impact assessment models in tropical contexts since most models are designed for temperate zones [81]. Although groundwater measurement is not a primary topic in global analysis, numerous studies are currently focusing on this subject.

The sixth line of research involves modeling spatio-temporal simulations of the hydrological balance to establish water management, determine water availability, and plan water use. Water planning models have become an essential part of water resources management to overcome current and future challenges [40, 82-84]. Otherwise scenarios suggest that if current trends persist, water availability will become critical due to complete depletion of aquifers caused by minimal recharge [85]. The hydrological balance analysis is currently under development.

3.10. Hydrological Models – Research Areas

In recent decades, various hydrological models have been developed, each with unique characteristics and parameters [14, 86, 87]. These models aim to predict and understand the connections between crop development, climate, and soil. Some of the widely used models include HEC-HMS [88], MIKE SHE [89], SWAT, TOPMODEL [90], AnnAGNPS [91] and WEAP [92], among others.

However, the SWAT model is widely used in research worldwide and in Mexico due to its robustness, as confirmed by the results of this study. SWAT provides reliable and accurate hydrological forecasts, which are valuable for sustainable water resource management [72], particularly under conditions of climate and land use changes [69]. The hydrological model SWAT (Soil & Water Assessment Tool), developed by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA), is utilized to simulate hydrological balance flows and assess the interactions between land use and climate scenarios. The WEAP (Water Evaluation And Planning) model, developed by the Stockholm Environment Institute (SEI), is being used to simulate water allocation, use, and management within a watershed. It models the water balance and simulates climate change scenarios and land use changes [92, 93].

4. CONCLUSIONS

Hydrological modeling is essential for optimal water resource management, maintaining balance, ensuring agricultural production, and strengthening crop resilience to climate change impacts.

The bibliometric analysis identified four global research areas that are significantly linked: water balance flows in correlation with land use, hydrological modeling, climate change, and agricultural production systems. There is a research gap in evaluating all agricultural production systems within a micro-watershed and their direct link to variations in water balance under climate change conditions using hydrological models.

Research on hydrologic modeling in Mexico has significantly increased in the last decade. This topic is relevant due to its implications for human beings. The research can be grouped into six main topics: vulnerability and risk of flooding due to extreme climatic events; surface runoff behavior at the basin level; impact of climate change on the water balance; water resource management for crop irrigation; groundwater measurement, distribution, and behavior of the water balance. Two gaps were identified in the research: a lack of focus on the individual impact of different agricultural production systems, particularly at the micro-basin scale, and the challenge of incorporating climate change scenarios into hydrological modeling and assessing their impact on agricultural production.The lines of research that coincide in both bibliometric studies are those based on surface runoff, climate change and irrigation in agricultural crops.

Global trends in hydrological modeling topics are reflected in studies conducted in Mexico. Hydrological modeling is a tool that enables the detailed identification of the impacts of anthropogenic activities, including climate change, on the distribution and quality of hydrological resources. Therefore, future studies should extensively address crops, agricultural areas, and the modifications caused by climate change. This will provide better data to ensure the availability and sustainable management of water for the agricultural sector, which is essential for sustainable development in Mexico.

The study confirms that few precedents address all types of agricultural production and hydrological balance at the microbasin level under climate change conditions. This was evaluated using hydrological modeling.

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