Spatio-temporal analysis of scientific research on models to estimate water balance in hydrographic basins

Salinas-Castro, Alfredo[1,2]; Tadeo-Noble, Alfredo E.[3]; Vera-López, Javier E.[4]; Santillán-Fernández, Alberto[3*]

[1] Universidad Internacional Iberoamericana. Doctorado en Proyectos, Desarrollo Sostenible y Energías Renovables. Campeche, Campeche, México. C.P. 24500.
[2] Universidad Científica del Sur. Facultad de Ciencias Ambientales. Lima, Perú. C.P. 15001.
[3] Investigador por México CONAHCyT y Colegio de Postgraduados campus Campeche. Sihochac, Champotón, Campeche, México. C.P. 24450.
[4] Colegio de Postgraduados campus Campeche. Sihochac, Champotón, Campeche, México. C. P. 24450.
* Correspondence: santillan.alberto@colpos.mx

ABSTRACT

Objective: To identify in the world the main models or tools used to evaluate changes in water regulation, through a bibliometric review in the especialized in scientific information, Scopus database, in order to know the main variables evaluated that affect the hydrological regime of the basins.

Design/methodology/approach: With the help of bibliometric techniques, scientific articles available until December 2022 in the Scopus database were collected using the SUBJAREA (envi) TITLE-ABS-KEY ("water balance" AND "land use") AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (DOCTYPE, "ar")).

Results: 407 scientific articles were collected from 1965 to 2022, this scientific production shows an exponential growing trend that was concentrated above all in countries with agricultural traditions such as the United States (89 publications), China (33), Germany (28), the United Kingdom (25) and Australia (21).

Limitations on study/implications: Most of the research was developed on topics associated with land use change (82 texts), climate change (48), hydrological processes (44), subsoil water (34) and evapotranspiration calculation (33). The most recurrent models for calculating the water balance were the Direct Water Balance (230 texts) and the Soil and Water Assessment Tool (83).

Findings/conclusions: No research development was found in Latin American and African countries, so these results can help redirect efforts in the research centers of these countries, with the aim of generating new knowledge that helps make decisions about how to improve the efficient use of water in the face of climate change scenarios and dynamics of land use change.

Keywords: content analysis, bibliometrics, hydrological model, SCOPUS, SWAT.

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INTRODUCTION

The Water Balance (WB) measures the amount of water available in an ecosystem (Ruíz-Álvarez *et al.*, 2012). Through WB, it is possible to estimate the potential evapotranspiration, humidity index, and water surplus or deficit in a given area for a specific period (Sentelhas *et al.*, 2008). However, studies on WB have mainly focused on the analysis of potential

evapotranspiration, opening up opportunities for research on the effects of climate change and land use change dynamics on the hydrology of ecosystems with some utility for anthropogenic activities (González-Pérez *et al.*, 2023).

Climate change and land use changes are altering water cycles and regimes within basins. The increase in temperatures and changes in extreme weather conditions could reduce the availability of natural water resources in many parts of the world (Allan *et al.*, 2020). Therefore, understanding the potential impacts of climate change and land use changes on water resources is crucial for planning (Wang *et al.*, 2019).

In this context, the water balance has become one of the most useful tools for measuring the effects of climate change and land use changes in basins that supply human settlements (Ruíz-Álvarez *et al.*, 2012). Among these models, the Soil and Water Assessment Tool (SWAT) is one of the most widely used models for water quality in river basins and basins around the world. This is due to its supportive software application and open-source code, which can be adapted by model users to meet specific application needs (Akoko *et al.*, 2021).

However, Malamos *et al.* (2015) found that the models proposed by Thornthwaite (1948) and Thornthwaite and Mather (1957) for estimating the water balance are the most commonly used due to the simplicity of their calculations, as they require only temperature and precipitation data. Nevertheless, despite the importance of the water balance in water regulation and land use change, there is little research evaluating the relevance of publications on this topic (González-Pérez *et al.*, 2023).

To assess the importance of publications on a specific topic of interest, bibliometric studies are often a valuable tool. They allow for an objective evaluation of scientific interest topics, observe the trends they follow, and generate useful information to improve their management, quality, and performance (Peng, 2017). In this context, the objective of this study is to identify the main models or tools used worldwide to evaluate changes in water regulation through a bibliometric review in the specialized scientific information database, Scopus, in order to understand the main evaluated variables that affect the hydrological regime of basins.

MATERIALS AND METHODS

Source of Information

In this study, scientific articles that calculated the flow of basins affected by land use change were considered. To collect the publications, the Scopus database of journal articles was reviewed due to its larger number of indexed scientific articles within the various bibliographic databases (Scopus, 2023).

The algorithm used for the search was: SUBJAREA (envi) TITLE-ABS-KEY ("water balance" AND "land use") AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (DOCTYPE, "ar")). Only articles in English were considered, as it is more likely that scientific articles in English are cited, allowing for the capture of the vast majority of relevant publications (Leipold, 2014).

Scientific articles were collected from January 1965 to December 2022. Publications with open access in the subfield of environmental sciences —ecology, geology, meteorology,

hydrology, and agronomy— were selected. Only scientific articles were considered, and through a content analysis, those without data, with errors, or duplicates were excluded (Aguado-López *et al*., 2009).

Bibliometric Indicators

Following the methodology proposed by Santillán-Fernández *et al*. (2021), the variables analyzed from each of the collected scientific articles were: authors, year of publication, title, journal name, research topic according to Scopus classification (2023), and bibliographic citations. Through a content analysis, the institution and country of origin of the first author were identified for each article, along with the methodology applied for calculating the flow of basins affected by land use change. Data collection was conducted in a spreadsheet.

Text Mining Analysis

The methodology described by González-Pérez *et al*. (2023) was followed. A timeline graph of scientific production was constructed using the variables of year of publication and number of citations. For the variable of the frequency of scientific articles per year, an ordinary least squares regression model was estimated to determine the trend in the frequency of publications (Gujarati, 2007).

Using Excel® tools, the countries of origin of the first authors were spatially mapped to identify where research on methods for estimating the flow of basins affected by land use change has been developed. The topics with the highest number of publications by country were also determined, as well as the most common methods for estimating basin flows, and bibliometric indicators for the journals and authors with the highest publication frequency were generated.

RESULTS AND DISCUSSION

Spatio-Temporal Evolution

A total of 407 scientific articles were collected that presented some methodology for estimating the flow of basins affected by land use change. All articles corresponded to the area of environmental sciences in the open access Scopus database (2023). The 407 scientific publications generated 9,203 bibliographic citations (Figure 1).

The period from 2012 to 2022 accounted for 83% of the publications (338) and 62% of the bibliographic citations (5,698). According to Malamos *et al*. (2015), the exponential growth (R^2=0.9791) in the number of publications can be attributed to the importance of changes in the hydrological flow of a basin due to land use change. Additionally, Santillán-Fernández *et al*. (2021) found that when the temporal growth between scientific publications and their bibliographic citations is directly proportional, it indicates topics of high relevance for the scientific community.

According to the country of origin of the first author of the research, the 407 scientific publications originated from 64 countries (Figure 2). Of these, 48.16% (196 articles) were concentrated in five countries: the United States (89 publications, 21.87%), China (33, 8.11%), Germany (28, 6.88%), the United Kingdom (25, 6.14%), and Australia (21, 5.16%).

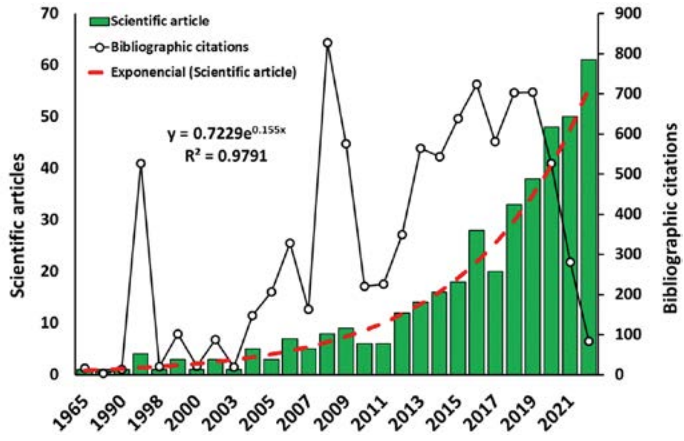

Figure 1. Temporal evolution of scientific production and bibliographic citations on methodologies for estimating the water balance affected by land use change, from 1965 to 2022.

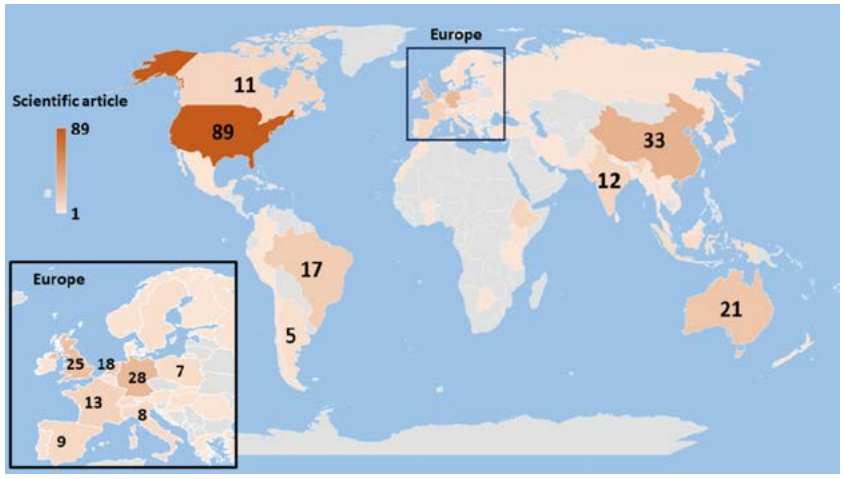

Figure 2. Spatial relationship of scientific production on methodologies for estimating the water balance affected by land use change, from 1965 to 2022.

In America, Brazil (17 articles, 4.18%) and Canada (11, 2.70%) were also notable. In Asia, India contributed 12 articles (2.95%), while in Europe, the Netherlands (18, 4.42%) and France (13, 3.19%) were significant contributors.

The countries with the most publications on methodologies for estimating the water balance affected by land use change were found to be the countries with the highest agricultural production in the world (FAOSTAT, 2024). This is explained, according to González-Pérez *et al.* (2023), by the fact that these countries have turned to methods to make water use more efficient in agricultural activities in the face of the sector's threats from the effects of climate change (Sandoz, 2016).

Bibliometric Indicators

In terms of the main research topics on methodologies for estimating the water balance affected by land use change, the most recurrent topic was land use change (82 articles,

20.15%), followed by climate change (48, 11.79%), hydrological processes (44, 10.81%), groundwater (34, 8.35%), and evapotranspiration calculations (33, 8.11%) (Table 1). A total of 63 topics were recorded; however, these five topics accounted for 241 articles, representing 59.21% of the total articles analyzed. A total of 63 topics were recorded; however, these five topics accounted for 241 articles, representing 59.21% of the total articles analyzed.

Santillán-Fernández *et al.* (2023) found that topics associated with climate change, land use change dynamics, and efficient water use in environmental processes are trending among the international scientific community due to concerns about generating new sustainable modes of production. However, González-Pérez *et al.* (2023) highlight that despite these advancements, there are still research gaps and propose the use of algorithms based on current technology as a helpful tool.

The 407 analyzed articles were published in 107 scientific journals. Eighty percent of the publications were published by high-impact journals belonging to the first quartile (Q1) of the Journal Citation Reports (WoS, 2021). However, 51.85% (211) of the total articles were concentrated in 10 journals, which contributed to 63.95% (5,886) of the bibliographic citations, in specific topics of hydrology (6) and environmental sciences (3) (Table 2).

These journals belong to the most prestigious publishers at the international level: MDPI (Multidisciplinary Digital Publishing Institute) with four journals, Elsevier (3), and John Wiley & Sons Ltd (2). According to Santillán-Fernández *et al.* (2021), this helps improve the impact of publications by increasing the likelihood of reaching a larger number of users.

Table 1. Main Research Topics by Country of Scientific Publications on Methodologies for Estimating the Water Balance Affected by Land Use Change, from 1965 to 2022.

Country	Topics						Total (%)	
	Land use change	Climate change	Hydrological process	Groundwater	ETP	Others		
USA	11	16	9	7	9	37	89	(21.87)
China	9	5	3	0	5	11	33	(8.11)
Germany	10	3	1	2	1	11	28	(6.88)
UK	3	3	2	3	0	14	25	(6.14)
Australia	3	0	2	5	1	10	21	(5.16)
NL	2	0	1	1	4	10	18	(4.42)
Brazil	7	0	3	0	3	4	17	(4.18)
France	1	1	3	1	1	6	13	(3.19)
India	3	1	2	4	0	2	12	(2.95)
Canada	0	2	0	1	2	6	11	(2.70)
Others (53)	33	17	18	10	7	55	140	(34.40)
Total (63)	82	48	44	34	33	166	407	(100.00)
(%)	(20.15)	(11.79)	(10.81)	(8.35)	(8.11)	(40.79)	(100.00)	

ETP: Evapotranspiration; USA: United States of America; UK: United Kingdom; NL: Netherlands.

Table 2. Bibliometric indicators of the main journals that published scientific articles on methodologies for estimating the water balance affected by land use change, ordered by the number of published articles.

Journal	Country	Editorial	WoS (2021)			Topics	Article		Citations	
			IF	H	Q		Number	%	Number	%
Hydrology ESS	Germany	European GU	6.3	147	Q1	Hydrology	62	15.23	2066	22.45
Water	Switzerland	MDPI	3.4	69	Q1	Environmenal	51	12.53	628	6.82
Water RR	USA	Wiley	5.4	231	Q1	Hydrology	19	4.67	1669	18.14
Sustainability	Switzerland	MDPI	3.9	109	Q1	Geography	14	3.44	149	1.62
J Hydrology RS	Netherlands	Elsevier	4.7	43	Q1	Hydrology	13	3.19	325	3.53
Hydrological P	UK	Wiley	3.2	169	Q2	Waters	12	2.95	381	4.14
Hydrology	Switzerland	MDPI	3.2	21	Q2	Hydrology	12	2.95	47	0.51
J Hydrology	Netherlands	Elsevier	6.4	241	Q1	Hydrology	12	2.95	293	3.18
Land	Switzerland	MDPI	3.2	32	Q2	Environmenal	8	1.97	39	0.42
ST Environment	Netherlands	Elsevier	9.8	275	Q1	Environmenal	8	1.97	289	3.14
Others (97)							196	48.16	3317	36.04
Total							407	100.0	9203	100.0

IF: Factor Impact; H: H Index; Q: Quartile; Hydrology ESS: Hydrology and Earth System Sciences; European GU: European Geosciences Union; Water RR: Water Resources Research; USA: United States of America; UK: United Kingdom; J Hydrology RS: Journal of Hydrology - Regional Studies; Hydrological P: Hydrological Processes; J Hydrology: Journal of Hydrology; ST Environment: Science of the Total Environment; Wiley: John Wiley & Sons Ltd.

Regarding the methods used to estimate the water balance affected by land use change, 58 methodologies were documented. However, 76.90% of the articles (313) relied on two methods: Direct Water Balance (DWB, 230 articles, 56.51%) and the Soil and Water Assessment Tool (SWAT, 83, 20.39%) (Table 3). Del Toro-Guerrero *et al.* (2014) describe DWB as an empirical method that assumes that soil water is lost over time until its reserves are depleted, thereby meeting the water needs of the system.

While Akoko *et al.* (2021) consider the SWAT method to be more accurate for estimating the flow of basins affected by land use change because it is based on the water balance in a

Table 3. Main methodologies for estimating the water balance affected by land use change in a basin.

Method	Formula	Variables
DWB Del Toro-Guerrero *et al.* (2014)	$P = ETR + Infiltration + Surface\ runoff$	P is the hydrological balance of the basin. ETR is the reference evapotranspiration *Infiltration* is the excess water moving into the groundwater *Surface runoff* is the excess water that flows into natural watercourses (*e.g.*, rivers). *ETR*, *Infiltration* and *Surface runoff* are variables calculated using the Thornthwaite (1948) method.
SWAT Akoko *et al.* (2021) Gassman *et al.* (2014)	$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a + W_{seep} - Q_{gw}\right)$	SW_t is the final soil water content (mm H_2O). SW_0 is the initial soil water content on day i (mm H_2O). t is time (days). R_{day} is the precipitation on day i (mm H_2O). Q_{surf} is the surface runoff on day i (mm H_2O) E_a is the evapotranspiration on day i (mm H_2O). W_{seep} is the water percolating through the soil profile on day i (mm H_2O). Q_{gw} is the groundwater flow on day i (mm H_2O).

system, Malamos *et al.* (2015) argue that DWB is more frequently used due to the simplicity of its calculations, requiring only precipitation and temperature data.

Finally, regarding the authors who published scientific articles applying a method to estimate the water balance affected by land use change in a basin, a total of 1,772 different authors were counted in the 407 publications. 21.06% of the articles were written by four authors, 17.95% by three, 15.25% by five, 14.64% by two, and 10.76% by six. 90.13% of the authors were affiliated with a university. Six of the ten authors with the highest number of publications conducted their research activities in the USA (Table 4).

Gersbach and Schneider (2015) found that the USA tends to invest more resources in its research centers, which has allowed for greater technological development and, consequently, for it to be considered an international agricultural engine. In this regard, González-Pérez *et al.* (2023) found that in Latin America, most research on water balance in an ecosystem has focused on calculating potential and reference evapotranspiration, leaving an opportunity for research on the calculation of flows in basins affected by land use change.

Finally, it should be noted that this research only analyzed scientific articles published in English, where Mexico's participation was not significant. This can be explained, according to Santillán-Fernández *et al.* (2021), by the tendency of researchers in Mexico to publish in institutional journals edited in Spanish, which restricts the constructive critique of peer review and limits the impact of publications, as English is the officially adopted language by the international scientific community. This leaves an area of opportunity for Mexican researchers to publish in English and in higher-impact journals (Santillán-Fernández *et al.*, 2023).

Table 4. Bibliometric indicators of the main authors with publications on methodologies for estimating the water balance affected by land use change in a watershed.

Author	Article		Country	Afiliation	Google Scholar (2024)		
	WB	Others			H-Index	Citations	Coauthor
Sun, G.	10	272	USA	USDA_FS	61	12201	868
Chen, J.	6	424	USA	Michigan_U	77	25125	1712
Bernhofer, C.	4	233	Germany	TU_Dresden	62	29872	1127
van Griensven, A.	4	131	Belgium	VU_Brussel	36	6634	328
Zhang, Y.	4	87	China	Southern_UST	24	2588	99
Chen, X.	3	20	USA	U_Cincinnati	13	457	47
Diekkrüger, B.	3	159	Germany	Universität Bonn	38	3978	349
Driscoll, C.T.	3	515	USA	Syracuse University	88	31765	853
Dulai, H.	3	74	USA	U_Hawaii	30	3012	180
El-Kadi, A.I.	3	77	USA	U_Hawaii	22	1199	73

WB: Water Balance; USDA_FS: USDA Forest Service; Michigan_U: Michigan State University; TU_Dresden: Technische Universität Dresden; VU_Brussel: Vrije Universiteit Brussel; Southern_UST: Southern University of Science and Technology; U_Cincinnati: University of Cincinnati; U-Hawaii: University of Hawai'i at Mānoa.

CONCLUSIONS

From 1965 to 2022, 407 articles on methods for calculating changes in the flow of a watershed due to land use changes were compiled. This scientific production showed an exponential growth trend (R^2=0.9791) that was concentrated mainly in countries with agricultural traditions such as the United States (89 publications, 21.87%), China (33, 8.11%), Germany (28, 6.88%), the United Kingdom (25, 6.14%), Australia (21, 5.16%), the Netherlands (18, 4.42%), Brazil (17, 4.18%), France (13, 3.19%), India (12, 2.95%), and Canada (11, 2.70%). The research focused on topics related to land use change (82 articles, 20.15%), climate change (48, 11.79%), hydrological processes (44, 10.81%), subsurface water (34, 8.35%), and evapotranspiration calculations (33, 8.11%). The most commonly used models for calculating the water balance were BHD (Direct Water Balance, 230 articles, 56.51%) and SWAT (Soil and Water Assessment Tool, 83, 20.39%). However, a lack of research development was also found in countries in Latin America and Africa. Therefore, these results can help redirect efforts in research centers in these countries to generate new knowledge that aids in making decisions on how to improve the efficient use of water in the face of climate change scenarios and land use change dynamics.

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