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Review

Research Trends of Hydrological Drought: A Systematic Review

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Abstract: The frequency and severity of global drought-induced impacts have led to raising awareness of the need for improved river management. Although academic publications on drought have proliferated, a systematic review of literature has not yet been conducted to identify trends, themes, key topics, and authorships. This study aims to evaluate the scientific evidence for the hydrological drought characteristics and the methodologies by performing as a framework. This systematic review performed three-stage screening of literature review for current applicable hydrological drought studies that have been conducted since the year of 2000 concerning methodologies, literature research gaps, and trends, and contribute to future studies. The analysis shows the increasing trends of research and publications in the hydrological drought assessment. The primary research themes are hydrological drought is drought severity, drought vulnerability, and drought forecast. Despite the current research findings, spatial and temporal variability, low flow analysis and regional modelling are the most important to encourage a holistic approach and international collaborations. The finding identified the shortcomings of most research, which are the use of non-standardized methodological and distinct sample sizes, resulting in data summary challenges and unrealistic comparisons.

Keywords: systematic review; hydrological drought; research trends; drought vulnerability; drought severity; drought forecast

1. Introduction

Climate change is a natural phenomenon, but the increase in greenhouse gases due to human activities, which alters the climatic system, have become triggers for more rapid changes and influences the occurrence of extreme climatic events [1]. Climate change contributes to increased frequency of extreme weather events, such as drought [2]. The severity of the drought is likely to increase in many parts of the world. Drought, because of its insidious nature, is generally difficult to define and explain. Droughts are recognized as a natural environmental catastrophe and have attracted multidisciplinary attention across all researcher fields [3]. Globally, demand for water and even water scarcity has risen owing to population increase and industrial development. Other factors, such as climate change, have added to the water shortage [4].

The choice of a suitable drought characteristic for particular drought research depends on the hydro-climatology in the selected region, the type of drought regarded, the vulnerability of nature in that region, the purpose of the research study and the accessible information for the drought evaluation [5]. Limited or lacking adequate quantifiable occurrence, frequency and severity information remains an issue in this respect. Furthermore, there is a lack of sufficient and appropriate methods for evaluating and forecasting drought. To prepare for effective risk and management of drought mitigation, it is vital to assess the conditions of drought.

The classification system for the drought of four types is based on the nature of water deficiency [6]. Meteorological, hydrological and agricultural droughts are considered environmental droughts according to this classification and are defined as periods with insufficient precipitation, river flow or groundwater, and soil moisture, respectively [7,8]. The fourth type of drought is socio-economic drought, which is associated with water resource systems failing to meet water demands [9]. Figure 1 presents the classification system for drought was derived from [10]. Droughts are long-term phenomena that affect large regions and cause severe damage to human lives and economic losses [11].

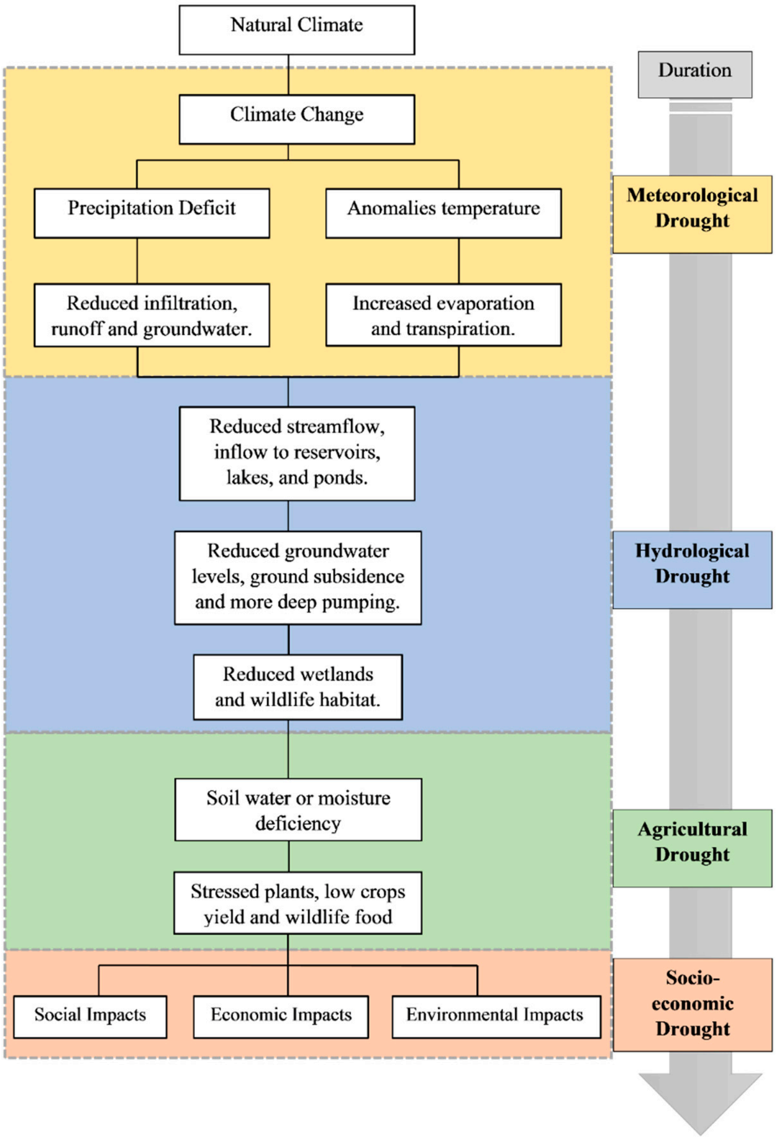

Figure 1. Different classification of drought.

This study mainly focuses on hydrological drought. Hydrological drought is usually characterized by water loss over time from both underground and surface supplies [12,13]. It usually affects water levels from average to low, making it inadequate to meet human and ecosystem requirements [14]. Streamflow is the most crucial water quantity variable [15]. Streamflow is the most crucial variable in quantity of water that expresses the resources of surface water. Therefore, in terms of normal conditions, a hydrological drought occurrence is linked to the streamflow deficit [16].

The assessment of hydrological drought plays an essential role in water resources management [4]. Hydrological drought assessment is necessary because human activities depend on either surface water or groundwater resources [17]. Data on streamflow is generally used for hydrological drought analysis [18–21]. Recovery from hydrological drought is usually prolonged, considering the time it takes to recharge streams and lakes. Increased water consumption has also significantly increased the magnitude of hydrological drought by 10–50% and increased the frequency of global drought by 30% [14,22]. Hydrological drought characteristics, including groundwater and streamflow, will change due to climate change in the 21st century. There will be increased duration and severity of hydrological drought and more significant impacts of events, including on groundwater and streamflow, will be evident. Therefore, there is an urgent need for the management of water resources to design proactive measures to reduce these significant issues.

Assessment approaches for hydrological drought can be separated into two groups. The first group consists of the characteristics of low flow and the second approach to analyse drought is to use the attributes of the deficit analysis [23]. Most hydrological drought evaluation techniques are based on hydrological parameter analysis of the actual time series of streamflow [24]. In comparison, the values from the measured time series are taken below a defined threshold level when determining the deficit characteristics [25]. The drought deficit index is computed from deficit characteristics such as the duration of the deficit period and volumes of the deficit. The vulnerability of the area of interest in the risk of drought can then be assessed based on two defined indices [26].

There is a lack of adequate and suitable techniques for evaluating and forecasting drought. Furthermore, there is also restricted or insufficient quantifiable data of the event, frequency, and severity of the drought. To prepare for efficient risk and management of drought mitigation, it is crucial to evaluate the conditions of the drought. Despite the growing interest in drought evaluation and forecast, there is a lack of consideration of the need to review what has been established in the literature. Therefore, a systematic review of the literature on critical success factors is of importance for the assessment of drought. Recently, an expanding number of publications have emerged in scholarly journals around the field of hydrological drought research, but it is still a relatively new study discipline without any systematic review of early attempts. This paper attempts to review systematically and analyse the existing research on hydrological drought. The detailed assessment of existing research has led to identifying the research gaps in the hydrological drought that have been studied. The finding of this study will contribute to effective determination, planning, and design of water resources management in the future.

The aim is to collate published academic literature on hydrological drought within this systematic review. The findings will be interpreted by categorizing targeted papers according to different indicators and providing a thematic content analysis. The specific aims are first to provide an overview of current scientific articles on hydrological drought over time. Next, to build a database of existing scientific papers that explore hydrological drought from 2000 to 2018 and to categorize them according to specified criteria. The final objective is to make recommendations for future studies based on observed study trends and prospective areas.

2. Materials and Methods

This study consists of three stages for the screening process of literature review in articles published between 2000 and 2018, identifying the coverage of publications, active authors and research concentrated on a variety of criteria for the study. Figure 2 shows a framework for this approach.

2.1. Screening Stage

The Scopus search engine was used as the primary platform for "titles/abstract/keyword" in stage 1. The first phase of screening was to obtain articles that found the selected keywords in the article's title, abstract or keywords (TITLE-ABS-KEY). On the Scopus website, the full search code relevant to hydrological drought was identified as follows: TITLE-ABS-KEY ('hydrological drought'

OR 'streamflow drought' OR 'low flow') AND ('hydrological index' OR 'streamflow index') AND DOCTYPE(ar) AND PUBYEAR > 1999 AND PUBYEAR < 2019.

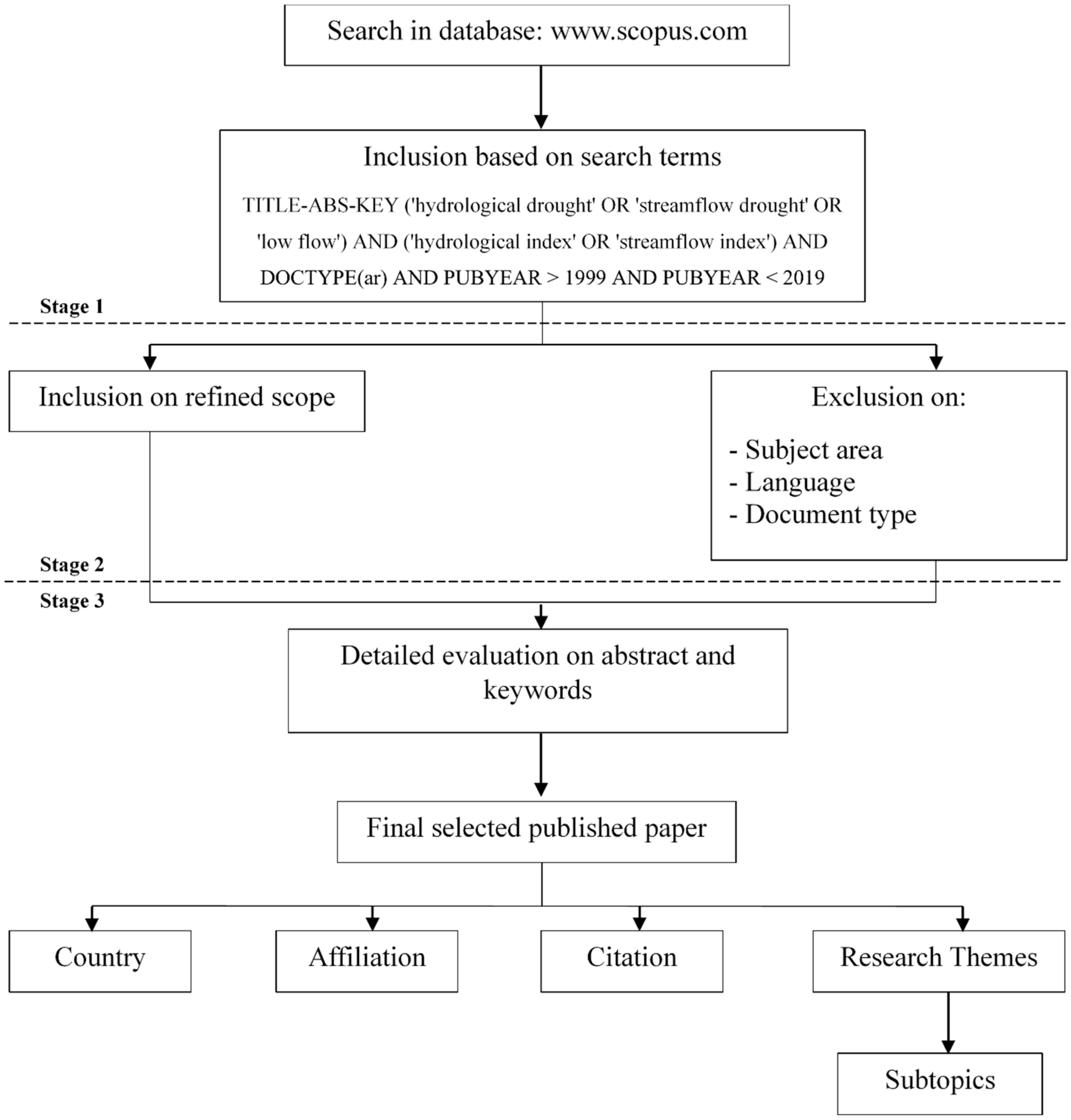

Figure 2. Research methodology framework for this study.

Stage 1 concentrates on testifying the level of interest of researchers in hydrological drought research as well as establishing study boundaries based on the number of articles published annually. The search terms used in the initial screening were comprehensive enough to capture all of the literature surrounding the hydrological drought since 2000. Stage 2 of the screening process, visual evaluation of the papers ' abstracts and keywords followed the first screening process. Only the abstracts related to the scope of the study will be used for the third screening. This stage reduced the number of papers, but the result of this study did still not provide the exact targeted articles. Finally, in the third screening stage, only the research documents covering hydrological drought were extracted from the second screening as targeted documents. These targeted papers have been analysed and categorized by their prolific author(s), journal, affiliated research institution and country of origin, number of citations and themes of research. A score was given to each author in targeted paper contributing to the published articles [27].

2.2. Examining Target Papers

The research productivity score based on the weightage authors' contributions was calculated using the method developed by Howard et al. [28]. One point was given to each publication, regardless, the number of authors in the published articles. If the paper was produced by more than one author, the one point for each author was divided into corresponding parts, assuming the degree of contribution in a multi-author paper is suggested by the authorship list order. If there are more authors involved in the published documents, each contributing author will obtain the lower score value. Consequently, the score is given as:

$$\text{Score} = \frac{1.5^{n-i}}{\sum_{i=1}^{n} 1.5^{n-i}}, \quad (1)$$

where;

n = the total number of authors in the article,
i = the order of the specific author.

Table 1 provides a detailed score distribution based on the formula for authors.

Table 1. Score Matrix for Multi Authored Papers.

No of Authors	Order of Authors						
	1	2	3	4	5	6	7
1	1.000						
2	0.600	0.400					
3	0.470	0.320	0.210				
4	0.420	0.280	0.180	0.120			
5	0.380	0.260	0.170	0.110	0.080		
6	0.370	0.240	0.160	0.110	0.070	0.050	
7	0.354	0.236	0.157	0.105	0.070	0.047	0.031

3. Results

3.1. Annual Publications on Hydrological Drought from 2000 to 2018

The trend analysis of targeted papers published between 2000 and 2018 on hydrological drought has been conducted. Stage 1 of the Scopus search produced 369 documents. The number of articles has decreased to 132 after the second stage, and finally, 76 papers were obtained in the third stage. Annually, the number of documents rose from 26 in 2014 to 45 in 2015. In stages 2 and 3, similar trends occurred. Over the past decade, these trends in hydrological drought determination have received expanding interest as a research concern (Figure 3). Between 2015 and 2017, there was an increasing number of articles published, perhaps in response to the tragedy of the El Nino phenomena worldwide in 2016. Since 1900, there have been at least 30 El Niño events, with the significant ENSO events recorded among the severe records in 2014–2016 events [29].

3.2. CiteScore and Number of Papers Published

Based on the result, only 10 journals in the last 18 years have published more than one article. The journal name, the corresponding CiteScore and the number of papers published are shown in Table 2. CiteScore tracks and monitors journal achievement and performance in Scopus where it contains the mean citations per paper over a period of three years. Hydrology and Earth System Sciences are the first journal-title with 28 published articles, and the 2017 CiteScore is 4.10. Water Resources Research and Water (Switzerland) with nine (9) and eight (8) articles, respectively, were ranked second and third. The rest of the journals consist of Journal of Hydrology Regional Studies, Environmental

Research Letters, Geophysical Research Letters, Hydrological Sciences Journal, International Journal of Climatology, Journal of Hydrology and Sustainability Switzerland.

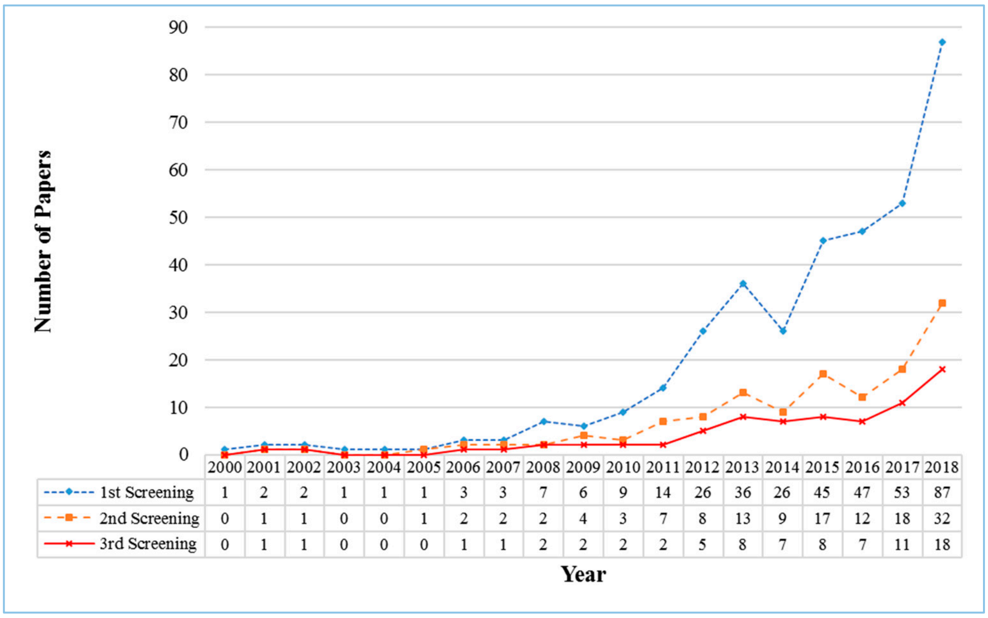

Figure 3. The number of articles published between 2000 and 2018.

Table 2. Journal title that published two or more targeted papers.

Source Title	Number of Papers	CiteScore 2017 [a]
Hydrology and Earth System Sciences	28	4.10
Water Resources Research	9	4.39
Water (Switzerland)	8	2.32
Journal of Hydrology Regional Studies	3	3.21
Environmental Research Letters	2	4.83
Geophysical Research Letters	2	4.51
Hydrological Sciences Journal	2	2.01
International Journal of Climatology	2	3.7
Journal of Hydrology	2	4.06
Sustainability (Switzerland)	2	2.37

[a] CiteScore is as per published on www.scopus.com in 2017.

3.3. Authors' Origin and Active Authors' Contributors

The score matrix of multi-authored papers presented in Table 1 has been used to determine the origin of researchers and active contributors. For each author, the score was accumulated for each country in a multi-authored or single-authored publication and contributions based on this scoring matrix. Table 3 lists the origin of the research of published targeted papers along with the study area, the number of research institutions, researchers, targeted articles identified, and the cumulative score for each research origin.

Table 3 clearly shows how active and widespread hydrological drought has been in these countries over the past 18 years, leading to more researchers from various centres studying hydrological drought assessment. A low score could be due to the publication in other journals, which were not considered in this analysis. The United States has the highest cumulative score at 15.28%, with 51 researchers from 29 different research institutions with the 13 published papers on the Scopus database. This was followed by the Netherlands, United Kingdom and China, with contributions of 12.26%, 7.40% and 5.89% respectively. Table 3 presents the country of affiliation of the authors and the study areas in which they are based. This analysis was cataloguing the study areas examined, which could provide insights into either bias in the literature regarding more commonly studied areas due to data availability and areas where drought has become of increasing concern because of its impacts in that area.

Table 3. Research origin of the targeted papers.

Country Origin	Number of Research Institutions	Number of Researchers	Study Area	Number of Papers	Cumulative Score
United States	29	51	United States Ethiopia	12 1	15.28
Netherlands	12	44	Netherlands South Africa	11 1	12.26
United Kingdom	11	36	United Kingdom South Africa United States	4 1 1	7.40
China	12	25	China	6	5.89
Canada	2	6	Canada	3	3.42
Germany	6	18	Germany United Kingdom United States	2 1 1	3.34
Italy	6	13	Italy Spain	4 1	3.27
France	14	34	France	3	3.17
Spain	9	26	Spain Portugal	2 1	3.01
South Korea	7	8	South Korea United States	2 1	2.65
Norway	3	12	Norway	3	2.48
Australia	4	13	Australia	2	2.00
Austria	3	6	Austria	1	1.66
South Africa	4	8	South Africa	2	1.56
Switzerland	3	5	Switzerland	2	1.53
Brazil	2	5	Brazil	1	1.34
Argentina	4	4	Argentina	1	1.00
Denmark	3	5	Denmark	1	1.00
Iran	4	5	Iran	1	1.00
Poland	2	4	Poland	1	1.00
Uganda	1	1	Uganda	1	1.00
Lithuania	1	3	Lithuania	1	0.79
Taiwan	1	3	Taiwan	1	0.72

Of the active contributors of hydrological drought for the 76 targeted papers, 160 researchers were involved from 2000 to 2018, but there are only 30 active researchers in the targeted documents. In order to determine the involvement of a researcher, the researchers were classified based on the number of articles in their repository. As an active researcher, a researcher with more than one published article was defined, indicating an extensive involvement in the study area. The names of the active researchers are listed in Table 4 along with their respective affiliations, their countries of origin, the number of papers and the associated scores.

The author, who is the most active, is Sharma, T.C. from Lakehead University, who published two sole-authored papers. This explained the highest score with 3 articles compared with other active researchers. Other active contributors are Panu, U.S., Van Loon, A.F. and Sung, J.H. with an individual score of 1.40, 1.37 and 1.20, respectively. It is observed that even though countries like Norway has contributed 6 articles to a large number of publications, the contributions of their individual researchers are meagre due to a large number of researchers contributing to a particular paper. Hence, individual contribution scores are also deficient.

Table 4. Active researchers who authored more than one paper.

Author Name	Affiliation	Country	No of Paper	Score
Sharma, T.C.	Lakehead University	Canada	3	1.60
Panu, U.S.	Lakehead University	Canada	3	1.40
Van Loon, A.F.	Wageningen University	Netherlands	5	1.37
Sung, J.H.	Han River Flood Control Office	South Korea	2	1.20
Van Lanen, H.A.J.	Wageningen University	Netherlands	5	1.18
Stahl, K.	University of Oslo	Norway	6	1.09
Tallaksen, L.M.	University of Oslo	Norway	5	0.89
Tijdeman, E.	University of Freiburg	Germany	2	0.89
Feyen, L.	Joint Research Centre	Italy	2	0.84
Parry, S.	Loughborough University	United Kingdom	2	0.84
Hisdal, H.	Norwegian Water Resources and Energy	Norway	3	0.83
Vicente-Serrano, S.M.	Pyrenean Institute of Ecology	Spain	3	0.75
Hannaford, J.	Centre for Ecology and Hydrology	United Kingdom	4	0.75
Laaha, G.	University of Natural Resources and Life Sciences	Austria	2	0.73
Vidal, J.P.	Hydrology-Hydraulics Research Unit	France	3	0.71
Zhang, Y.	CSIRO Land and Water	Australia	2	0.70
Barker, L.J.	Centre for Ecology and Hydrology	United Kingdom	2	0.70
Wanders, N.	University Utrecht	Netherlands	4	0.69
Prudhomme, C.	Loughborough University	United Kingdom	4	0.57
Werner, M.	Department of Water Science and Engineering	Netherlands	2	0.56
López-Moreno, J.I.	Pyrenean Institute of Ecology	Spain	3	0.49
Teuling, A.J.	Wageningen University	Netherlands	2	0.42
Caillouet, L.	Hydrology-Hydraulics Research Unit	France	2	0.38
Singh, V.P.	Texas University	United States	3	0.30
Demuth, S.	University of Freiburg	Germany	3	0.27
Bierkens, M.F.P.	Utrecht University	Netherlands	2	0.24
Sauquet, E.	Hydrology-Hydraulics Research Unit	France	3	0.22
Uhlenbrook, S.	Delft University of Technology	Netherlands	2	0.21
Soubeyroux, J.M.	Météo-France	France	2	0.08
Fendekova, M.	Comenius University	Slovakia	2	0.02

3.4. Average of Total Citations Per Year of The Targeted Published Paper

References from the primary source are often recommended when referring to any factual content that is not original. Research results can also be supported by appropriate references [30]. As a consequence, analysing the citation of targeted articles is necessary in order to determine furtherly a specific author's contributions and their publications. Table 5 lists the most frequently cited articles. From Table 5, the highest average of total citations per year is the paper by Van Loon and Laaha [31] that has been cited 55 times per year. This paper is related to the hydrological drought severity explained by climate and catchment characteristics based on a comprehensive Austrian dataset consisting of 44 catchments with long time series of hydro-meteorological data and information on a large number of physiographic catchment characteristics. This article highlights the capacity of a hydrological drought deficit, however, is governed by average catchment wetness (mean annual precipitation) and elevation.

Shukla and Wood [32] produced the second-highest average cited papers per year related to the using of the hydrological drought index for determination and characteristics of drought in Feather River basin, United States. This article highlights the capacity of a runoff-based index as it can be forecast, and its predictability depends not only on climate perspectives, for which seasonal skills are usually minor but also on initial hydrological conditions, which in some seasons mainly determine future runoff [32].

The third highest average cited publication per year is the study by Forzieri et al. [33]. This paper, therefore, addresses the issue of future developments in streamflow drought characteristics across Europe. Using extreme value analysis like derive minimum flow and deficit indices and evaluate how the magnitude and severity of low flow conditions may evolve throughout the 21st century. This analysis shows that streamflow droughts will become more severe and persistent in many parts of Europe due to climate change, except for northern and north-eastern parts of Europe [33].

Table 5. Targeted Papers with the Highest Average of Total Citations per Year.

Author	Paper Title	Average of Total Citations/Year
Van Loon and Laaha [31]	Hydrological drought severity explained by climate and catchment characteristics	55.0
Shukla and Wood [32]	Use of a standardized runoff index for characterizing hydrologic drought	33.9
Forzieri et al. [33]	Ensemble projections of future streamflow droughts in Europe	30.0
Stahl et al. [34]	Streamflow trends in Europe: Evidence from a dataset of near-natural catchments	27.3
Wada et al. [35]	Human water consumption intensifies hydrological drought worldwide	24.5
Van Lanen et al. [15]	Hydrological drought across the world: Impact of climate and physical catchment structure	19.0
Panu and Sharma [36]	Challenges in drought research: Some perspectives and future directions	16.7
Van Loon and Van Lanen [37]	Making the distinction between water scarcity and drought using an observation-modelling framework	16.3
Hisdal et al. [38]	Have streamflow droughts in Europe become more severe or frequent?	14.4
Vidal et al. [39]	Multilevel and multiscale drought reanalysis over France with the Safran-Isba-Modcou hydrometeorological suite	14.0
Feyen and Dankers [25]	Impact of global warming on streamflow drought in Europe	13.3
Fleig et al. [5]	A global evaluation of streamflow drought characteristics	13.0
Majone et al. [40]	Modelling the impacts of future climate change on water resources for the Gallego river basin (Spain)	10.0
López-Moreno et al. [41]	Dam effects on droughts magnitude and duration in a transboundary basin: The lower river Tagus, Spain and Portugal	9.9
Singh et al. [42]	A trading-space-for-time approach to probabilistic continuous streamflow predictions in a changing climate-accounting for changing watershed behaviour	8.7
De Wit et al. [43]	Impact of climate change on low flows in the river Meuse	6.9

3.5. Research Themes in Assessment of Hydrological Drought

Contents of the 76 targeted papers were analysed following the major themes and sub-topics in the years from 2000 to 2018 in the full text of each journal were extracted, as shown in Table 6. There are three research themes for hydrological drought assessment, namely, drought vulnerability, severity and drought forecast. Each theme provides the analysis by using various analysis methodologies. Table 6 shows the number of published papers according to different themes from 2000 to 2018.

Based on the assessment and review, the main objective of this paper is to identify knowledge gaps in hydrological drought. The analysis shows the increasing trends of research and publications in the hydrological drought, including drought severity, vulnerability, and drought forecast. The highest percentage for significant research theme is drought severity (54.55%), which represented 42 papers out of 76 total targeted papers. Drought vulnerability and drought forecast followed with 25.67% and 19.48% respectively. Each major theme consists of subtopics for data analysis and interpretation.

Table 6. The Major Research Themes and Subtopics.

Major Themes	Subtopics	Year															Total	Percentage (%)
		2001	2002	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018		
Drought vulnerability	Anomaly Analysis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1.30
	Bivariate correlations	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1.30
	Copulas Method	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	2.60
	Drought duration and deficit	0	0	0	0	0	0	0	0	0	1	0	0	1	1	2	5	6.49
	Spatial and temporal	1	0	0	0	0	1	1	1	0	1	1	3	2	0	0	11	14.29
	Total	1	0	0	0	0	1	1	1	0	3	1	5	3	1	3	20	25.97
Drought Severity	Hydrological Indices	0	0	0	0	1	0	0	0	0	2	0	1	2	2	5	13	16.88
	Hydrological Trends	0	0	0	0	0	0	0	0	0	0	1	0	0	4	1	6	7.79
	Low Flow analysis	0	0	0	1	0	0	1	1	1	0	1	1	1	2	4	13	16.88
	Threshold Level Method	0	0	1	0	0	1	0	0	1	1	1	0	1	0	4	10	12.99
	Total	0	0	1	1	1	1	1	1	2	3	3	2	4	8	14	42	54.55
Drought Forecast	Artificial Neural Network	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2.60
	Markov-chain Model	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	3	3.90
	Monte-Carlo Simulation	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1.30
	Regional hydrological	0	0	0	0	1	0	0	0	1	1	0	1	0	1	0	5	6.49
	Regression Analysis	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	4	5.19
	Total	0	1	0	0	1	0	0	0	2	1	3	2	0	2	3	15	19.48

4. Discussion

4.1. Drought Vulnerability

The first theme discussed from 2000 to 2018 in 20 articles from 76 is vulnerability to drought. This theme began with just 1 report in 2001, whereas until 2018, it continues to increase each year. This theme was widely investigated by researchers in 2015, particularly in spatial and temporal variability sub-topics with a total number of 11 articles. This is because the recent changes in the frequency, duration and intensity of droughts require a comprehensive understanding of water scarcity at various time and space scales. The researchers have used a wide range of research methodologies based on research objectives, issues, and interests.

Hydrological drought event can be defined in several drought characteristics such as duration, occurrence period, magnitude and minimum flow, and drought frequency or return time. Many different methods have been established to obtain these characteristics, which implies varying definitions of what precisely is classified as a drought. This is primarily because the hydrological drought is a global phenomenon that occurs in all types of climatic regions and affects streams with various kinds of hydrological systems.

Feyen and Dankers [25] emphasized the interdisciplinary approaches for assessing hydrological drought impacts. Fleig et al. [5] state that the choice of suitable drought characteristics for a specific study depends on hydro-climatology of the regions. Different approaches are dominant, depending on the spatial scale and local catchment attributes. For instance, elevation variations in large catchments lead in a significant variation over the basin in precipitation and temperature. This results in high spatial variability, which dampens hydrological drought spatial development. Spatial difference can be substantial even in a small basin. Stahl et al. [34] addressed a recently assembled European streamflow dataset from small basins of direct significance to catchment-scale water management with near-natural flow regimes from 441 small catchments in 15 European countries. This research finds that the small watershed near the stream is more severe and are attenuated at greater distances.

Spatial components of drought are synchronicity, clustering and breaking up of clusters of droughts [44]. Most studies concentrated on spatial meteorological drought elements whereas, in contrast, analysing the spatial aspects of the hydrological drought was restricted. The algorithm established by Andreadis et al. [45], was one of the first clustering methods suitable for hydrological droughts in soil humidity and runoff in the USA [32]. Subsequently, this clustering algorithm was implemented by Hurkmans et al. [46] to explore and compare the precision of water balance from streamflow simulations, and a land surface model applied to the Rhine basin using the regional climate model. Methods based on L-moment have been recommended for hydrological regional frequency analysis, including for determining goodness-of-fit of parent distributions [39,44,47–49]. Sung and Chung [49] concluded that the L-moments method is much better than conventional regional frequency analysis methods. Conventional moment estimators are also biased for extensive samples from highly skewed distributions, but L-moment ratio estimators are nearly unbiased for all underlying distributions. L- moment methods also are not limited to small sample sizes and are more reliable for discerning homogeneous regions and identifying likely parent [48].

However, a very limited study was carried out to evaluate the effects of droughts on the impacted systems and to revise strategies to preserve these systems. Tsakiris [50] proposed three stages of drought risk management, which include (1) the vulnerable systems are identified, the concepts, the methods, the criteria and the prioritization of measures are adopted by all participating bodies; (2) decisions are taken based on the established monitoring system and the agreed criteria; and (3) contingency plan, incorporates all the decisions regarding the short and long-term mitigation measures taken by the responsible body with the participation of all stakeholders.

4.2. Drought Severity

Drought characteristics such as timing, length, severity and spatial magnitude of a drought occurrence need to be recognized to comprehend hydrological drought methods and impacts. The second and most studied theme is drought severity with 42 of papers or 54.55% from the analysed targeted documents. Thirteen (13) published articles are based on low flow analysis and hydrological indices such as Standardized Streamflow Index, Streamflow Drought Index, and Standardized Runoff Index. These indices quantify a region's spatial coherence of drought, as a measure of the severity of drought [51]. The severity of the drought is defined as the ratio between flow volume deficit and volume of normal flow conditions or the rate of maximum deficit duration to normal flow duration conditions [52]. Drought indices can be divided into standardized indices and threshold level indices. Commonly, drought severity investigations used hydrologically based flow indices and exceedance percentiles to recommend low flow. Hydrological indices and low flow analysis have been used extensively and are a suitable method at the planning level of water resources development and management [53]. Some researchers have been developing a hydrological indices method that provides a specific spatial and temporal comparison of hydrological requirements [54–62]. Drought indices are significant features of monitoring and evaluation of drought as they simplify interrelationships between many climate-related parameters in terms of their intensity, duration, frequency and spatial extent [63].

Laaha [64] used the low flow characteristic as the indices for the comprehensive characterization of hydrological drought. Low flow analysis is a standard method for characterization of hydrological drought events that may be characterized by their duration and deficit volume [30,35]. These characteristics of drought may be associated with impacts on different water-related sectors in water management. The first understanding of the spatial and temporal attributes of hydrological drought is given by the low flow analysis. Hisdal et al. [65] indicated that low flow characteristics should be distinguished from hydrological drought characteristics. Engeland et al. [66] determined the regression for low flow and catchment characteristics. Furthermore, a paper by Laaha et al. [67] analysed 800 streamflow records across Europe based on a range of low flow to determine the hydrological footprint. The analysis indicates the usage of low flow characteristics for drought severity (magnitude) and spatial extent. The finding stated that the evaluation of drought occurrences and water resource impacts needs hydrological inputs to climate data-driven indices.

The main characteristic of drought indices is that they must allow the severity of drought to be compared independently of local climate characteristics in specific areas. The cumulative distribution function corresponding to each value of the hydrological variable of concern can be used to obtain hydrological indices from a long series of streamflow [68]. There is no guidance on which methodologies are best suited to preserve instream characteristics under different circumstances. However, low flows estimated using various methods can be very different, and even minor differences in minimum flows can have significant implications for resource management and users. Therefore, it is essential to compare the performance of alternative techniques and to evaluate variations.

Exceedance methods, including standard and regional frequency analysis using statistical models, are often used to evaluate the probability or risk of low flows for given durations and return periods. This is commonly achieved using the probability distribution that fits the streamflow data. Several studies have shown the ability of the function distribution such as Gamma distribution [7,69–72], Pearson distribution [46,73–77] and Weibull distribution [71,78,79] to fit the time series of streamflow. A hybrid fuzzy probabilistic approach proposed by Spiliotis et al. [80] to improve the couple between the observed probabilities and the adopted theoretical probability distribution. Log-normal and Weibull distributions were usually recommended and most frequently used for low flow evaluation, but there are no specific standards on which techniques to use for which data. The most commonly used and recommended log-normal and Weibull distributions [39,81–83]. The Weibull distribution for low values occurs when the extreme value is from a parent distribution which is restricted in the interest direction which is in the event of low flows, they are bounded by zero flow on the left. The log-normal distribution was commonly used for both high and low flows because it is straightforward, easily accessible for assessment, and many hydrological factors are bounded by zero on the left and skewed positively [84,85]. This model was recommended for low-flow frequency analysis in general [68].

4.3. Drought Forecast

The last theme in the assessment of hydrological drought is a drought forecast. In operational water management, drought forecasts are essential [86]. Drought prediction and forecast are aimed at assessing and reducing uncertainties in drought prediction and structure [87]. In particular, prediction research focused on prediction model evaluation and improvement. Global and regional climate models and hydrological models are the modelling tools used. Hydrological models are driven by atmospheric model output, ongoing research site data, and product reanalysis. Most of the literature focused on analysing historical and generated streamflow data for hydrological drought, including estimating the probability density function of the drought characteristics [82,88,89].

Drought Forecast is based on the stochastic behaviour of drought according to the multiplicative autoregressive integrated moving average model [71]. The highest publications subtopic in drought forecast is the regional hydrological model. The early prediction and forecast of hydrological drought will prompt initiation of drought mitigation action. Another approach is to predict hydrological drought by using simulation modelling such as Markov-chain Model [71,90]. Markov chains are frequently used to assess the probability of drought occurrence and to forecast when a drought event occurs. This approach was used to investigate changes in the severity of drought at specific period scales and to predict the probability of occurrence for each severity degree [91]. Several statistical criteria have also been considered for better judgement. Statistical criteria are found to be insufficient for model assessment to address the distribution of errors [92]. Thus, the accuracy of forecasts was evaluated using graphical and non-parametric test. One of the most important findings was the forecasting of SHDI drought index was considerably more accurate than forecasting streamflow and then converting the values to the SHDI [92].

The different methods of deriving hydrological drought characteristics are required in order to accurately represent the full range of hydrological droughts. Selecting a suitable technique can be even more complicated when evaluating the drought events of multiple rivers in one region. But it might be beneficial to analyse and compare them in attempt to acquire a good understanding of the mechanisms associated with the development of hydrological drought. This information eventually decreases the damage induced by droughts through accurate forecast of drought occurrences and more sustainable water management.

4.4. Recommendation for Future Research

As a natural hazard, drought can be very damaging, but its slow onset and growth provide a huge opportunity to avoid and mitigate its impact. Understanding and evaluating vulnerability to drought is critical to the development of appropriate management, policies and should, therefore, encourage and improve its practice. Iglesias et al. [93] have developed a risk management framework for water scarcity oriented on the assessment of current water scarcity adjustment policies in Mediterranean countries. A framework is a systemic approach to the prevention and/or minimization of human effects of drought. The framework in the context of present vulnerability to drought, laws, governance, and technologies. These components are sufficiently broad to integrate new requirements for prioritization as scientific and technological elements of drought management enhance.

Hydrological drought assessment was extensively established and applied to water resource development [94]. Various techniques have been recommended to analyse the hydrological drought characteristics such as low flow frequency, threshold level method and drought indices. Researchers in different regions of the world have to deal with a variety of distinct characteristics and impacts of hydrological droughts. For example, in the semi-arid region, the duration of zero-flow periods may be a good way to characterize drought events, but in other regions, streams never fall dry, and it would be concluded that such streams never experience drought. The observational data records are often not long enough; some variables are not tracked at all; data quality is too minimal; or human activity influences observations.

Hydrological models can be used to solve these issues by extending data series, filling gaps and naturalizing disturbances to time series [72]. Hydrological models are ranging from simple statistical models with a few variables through to theoretical models with varying complexity to complex models. Hydrological models are generally designed to simulate average to high flows and show good results in global catchments. Unfortunately, hydrological models often fail to capture low flows sufficiently, although there have been several recent efforts to improve low flow modelling using existing models.

Research over the past decade has shown a shift in focus from reporting problems to theory and model building based on theoretical assessment and quantitative calculations by defining variables and trends. According to the target publications, three significant study themes have been pursued by researchers, including (1) vulnerability to drought; (2) severity of drought; and (3) predicting and forecasting hydrological drought. Future research attempts are likely to concentrate on the management and effects of hydrological drought. Towards this end, it will involve either the adaptation of current techniques or the development of new components to efficiently handle and assess the particular problems and elements of hydrological drought. The review continues to be statistically inadequate on a scope of observations, not only due to the complexity of the problem but also due to the absence of adequate research and inconsistent views reported. Most researches lacked the required methodological foundation, did not follow standardized methods and were of different sample sizes, making it difficult to summarize the information, which was also patchy and incomplete, making any comparisons unrealistic.

The hydrological drought was introduced to distinguish it from meteorological drought. Hydrological drought assessment is crucial for water resource management. Differences between meteorological and hydrological droughts were explored in propagation research. Differences were related to the features of climate and catchment. Single and multi-model studies have been used in an estimated future climate to project droughts analysis. Multiple regions around the world are likely to suffer from more severe drought, although the chosen benchmark has a significant impact on this. Drought study was based on natural hydrological conditions. However, stakeholders, policymakers, and water regulators were concerned only with natural drought. It was necessary to consider the impact of drought on human being and other ecosystems.

It was also necessary to establish a more user-centred perspective. In order to take account for individuals alleviating/aggravating of natural drought, climate-induced drought and human-modified drought were implemented. Approaches for distinguishing between natural and human components have been established. Human beings have worsened drought in many instances. Global model findings complement catchment conclusions to provide an indicative comprehensive overview of common drought impacts. Clearly, models need to be improved in areas such as the processes and spatial resolution, whereas more catchment conditions are required in order to advance the model efficiency and eventually achieved accurate results.

5. Conclusions

This systematic review paper performed a three-stage screening of literature review of journal papers published in the field of hydrological drought between 2000 and 2018. The Scopus search engine was used with a combination of title, abstract and keyword searches to define 76 articles as target journals to analyse current trends, recognize patterns and make predictions of future directions in hydrological drought. To introduce a description of the significance of hydrological drought and the distribution of research activities, analysis of content was assisted by straightforward statistics.

This paper has given a holistic assessment of hydrological drought in academic research by performing as a framework to deploy this growing new field for other researchers. Knowledge about the primary themes, patterns trends and active individuals will allow researchers and professionals to explore new concerns as well as present collaborative possibilities. They may use the data described in this article to recognize the network of international partners with comparable research interest and regional concerns.

Hydrological drought assessment consisting of a variety of scope, objectives and methodology requirements used in evaluations hinder dominant knowledge of the vulnerability of drought. In this paper, a systematic literature review was conducted for current applicable hydrological drought assessments in order to identify literature research gaps, the pattern of trend and contribute to future studies in practice on hydrological drought evaluation. The review identified and analysed 76 of hydrological drought assessments from different perspectives: Location, scale, and features that were frequently used in conceptual frameworks, methodologies used to select evaluation factors and methods of validation. The review showed that hydrological drought assessment is not a common practice primarily in the construction of the conceptual model used to assess drought vulnerability, as well as those models used in indicator selection.

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