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Bibliometric analysis of spatio-temporal model using a general product-sum based on a hydrological distance

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In the last two decades, the number of model developments in the field of Geostatistics increased rapidly, especially in the Spatio-temporal models. Almost of these models are based on Euclidean distance, only a few which based on non-Euclidean distance. The purpose of this study is to analyze and visualize the types of literatures on stationary Spatio-temporal models that utilize General Product-sum and Hydrological distance through bibliometric analysis methods, by considering a set of bibliometric metrics, including productive and impact measures, methods analysis, and co-authorships analysis. Scientific research works related to Spatio-temporal models using the product-sum field that consider hydrological aspects, published between 2002 and 2022 are reviewed. Some of the most relevant research works in this field and some of the newest trends are collected during September 2022 from Google Scholar, Scopus and Dimensions databases. The literature search method is carried out in two steps. Firstly, literature sources were obtained from Google Scholar, Scopus and Dimensions. Secondly, meta-analysis is performed using Harzing's Publish or Perish and VOSviewer software program. Total of 488 articles related to Spatio-temporal product-sum, and 8 articles related to Spatio-temporal product-sum based on hydrologic distance are selected. The analysis result shows that the proposed topic "Spatio-temporal model using product-sum based on hydrologic distance" has a different significant attribute from the existing research works, i.e., the hydrologic distance. Therefore, the proposed topic can be considered has a novelty.

KEYWORDS
bibliometric analysis, spatio-temporal model, general product-sum, hydrologic distance, spatio-temporal covariance function, spatio-temporal semivariogram

1. Introduction

The processes of Spatio-modeling development are very important in many fields of geostatistics, meteorology, reservoir engineering and environmental science. In addition of hydrologic studies, the variogram is significant correlation measure and a convenient tool for Spatio-temporal modeling. Even though many variogram or space-time covariance models are presented, Product-sum and General Product-sum model coined by De Iaco et al. [1] are commonly used from its simplified function of two parameters into one parameter.

However, studies that focused on Spatio-temporal Product-sum based on hydrologic distance yet quite uncommon. Literature review conducted in this study aims to gain insights from existing research works and find a novelty in studies related to Spatio-Temporal using General Product-Sum based on hydrologic distance.

Literature review is a piece of academic writing demonstrating knowledge and understanding of the academic literature on a specific topic placed in context. A literature review also includes a critical evaluation of the material. Thus, the research questions of this work are as follows:

1. How the Spatio-temporal model using product-sum or general product-sum studies are developed during 2002–2022;
2. What known methods were applied for the spatio-temporal general product-sum based on the river distance or hydrologic distance during 2002–2022.

While the aims of this study are as follows:

1. Conducting bibliometric analysis to gain insights about Spatio-temporal model using product-sum or general product-sum publications developed during 2002–2022;
2. To identify known methods applied on Spatio-temporal model using product-sum based on river distance or hydrologic distance during 2002–2022.

The rest of the paper is structured as follows: Section Literature review describes briefly the Spatio-temporal models and concept, literature review process and literature review method. Section Analysis results presents the analysis results. Lastly, Section Discussions presents discussion along with the strengths and limitations of this study.

2. Literature review

2.1. Spatio-temporal model concept

An auto-covariance or a covariance function is a basic concept in the Spatio-temporal model, especially in the field of Geostatistics, either the spatial model or the Spatio-temporal model because it is related to a concept of a semivariogram function and Kriging method. In general, there are several types of Spatio-temporal covariance models, i.e.,(1) Sum model [2], (2) Combined metric-sum model, (3) Product model [3, 4], (4) Product-sum model, [1, 5–7], (5) General product-sum [8], (6) Mixture-based models [9], (7) Integrated product and product-sum models [8], and (8) Metric models [10].

Several contributions to the development of Spatio-temporal models over the past two decades, particularly non-separable models have been carried out [1, 5–8].

Rationale for developing a Spatio-temporal model using the general product-sum auto-covariance function based on hydrological distance comes from the article of De Iaco et al. [1, 8] and Ver Hoef et al. [11–13]. Cressie et al. [9] developed a spatial auto-covariance function based on hydrological distance with a moving average function approach for stream networks, while De Iaco et al. [1, 8] developed a Spatio-temporal with the product-sum model [5] based on Euclid's distance, which is more general (general product-sum model) and has a simpler function of two parameters into one parameter.

Developed Spatio-temporal function is based on the main theoretical of spatial model for stream networks based on a hydrologic distance or a river distance [11–13], and also the Spatio-temporal model using the general product-sum based on Euclidean Distance [1]. Combining these theoretical provides the developed Spatio-temporal model. Thus, this section outlines the conceptual theory of Spatio-temporal model.

Spatial auto-covariance functions generally use Euclidean distance [14]. However, there is no guarantee that the auto-covariant function is valid, such as in case of conditionally negative definite or positive-definite, for stream networks or a non-Euclidean distance [15]. The non-Euclidean distance for stream network is often called as the hydrological distance, or stream distance [11–13] or the river distance [14]. Applying moving average approach in the field of Geostatistics can be found in [11–13, 16].

Hydrological distance is an important keyword in this research. Ver Hoef et al. [11–13] proposed a moving average construction method that incorporates both hydrologic distance and flow direction. Incorporating flow direction can be achieved by choosing moving average functions whose tails go along with or against the flow direction and named as tail-down and tail-up models, respectively. The tail-up model is valid only for flow-connected. This investigation will be focused on the tail-up model. The application of this hydrological distance-based spatial model is generally applied to the prediction of river water quality, for example in [17–22].

Function of moving average in the field of spatial models was introduced by [11–13, 16] and those formulated by [17] as a large class of auto-covariance functions with the formulation in (1) and (2)

$$Z(s) = \int_{-\infty}^{\infty} g(x - s|\theta) W(x)\, dx \tag{1}$$

$$C(h|\theta) = \begin{cases} \int_{-\infty}^{\infty} \left[g(x|\theta)\right]^2 dx + \theta_0 & \text{if } h = 0 \\ \int_{-\infty}^{\infty} g(x|\theta)\, g(x - s|\theta)\, dx & \text{if } h > 0 \end{cases} \tag{2}$$

where W(x) is white noise process and $g(x - s|\theta)$ is moving average function and is defined at $\Re^1$ and covariance between random variables $Z(s_k)$ dan $Z(s_l)$ for tail-up model is expressed as (3) and (4)

$$C(h|\theta) = \begin{cases} 0, & \textit{if flow} - \textit{unconnected} \\ C_1(0) + v_j^2, & h = 0 \\ k \in B_{s_i,s_j}^{\prod} \sqrt{\omega_k}\, C_1(h), & h > 0 \end{cases} \quad (3)$$

and

$$C(h|\theta) = \begin{cases} \theta_0 + \theta_1, & h = 0 \\ \theta_1 \rho\left(\frac{h}{\theta_2}\right), & h > 0 \end{cases} \quad (4)$$

and

$$\theta = (\theta_0, \theta_1, \theta_2)^t$$

where, h is the hydrological distance, $\rho(.)$ represents the correlation function, and $\theta = (\theta_0, \theta_1, \theta_2)^t$ is a vector, the elements of which are nugget, sill, and range, respectively. To ensure a stationary in Equation (3), $\omega_k + \omega_l = 1$must be satisfied. Spatial auto-covariance function based on hydrologic distance in Equation (3) [23], can also be represented by (5)

$$C_{TU}(s_i, s_j|\theta) = \begin{cases} 0 & \textit{if } s_i, s_j \textit{ are not flow connected} \\ C_u(h)\,\omega_{ij} & \textit{if } s_i, s_j \textit{ are flow connected} \end{cases} \quad (5)$$

where, $C_u(h)$ is the unweighted tail-up auto-covariance model between the two sites and $\omega_{ij}$is the spatial weight between the two sites $s_i$dan s_j, which is determined by the structure branching process.

There are two questions addressed in the modeling of Spatio-temporal in product-sum: (1) how to ensure one has a valid model, and (2) how to fit data to the model [24]. The product model was used in De Cesare et al. [4] which was extended to a product-sum model [5, 6]. De Iaco et al. [1] was subsequently developed the product-sum which is less in the number of parameters to become a general product-sum model. The general product-sum model serves a large class of models that is not attainable by Cressie and Huang [14] and which are easily modeled using techniques similar to those used for modeling spatial variogram [1]. In a decade, the Spatio-temporal model has accrued fast in a different approach. A Covariance model is a basic concept in the Spatio-temporal model, especially in the field of Geostatistics because it is related to the concept of semivariogram functions and a Kriging method.

In general, there are several types of Spatio-temporal covariance models [26], i.e., (1) Sum model [2], (2) Combined metric-sum model, (3) Product model [3, 4], (4) Product-sum model [1, 5, 6], (5) General product-sum [1, 7, 8], (6) Mixture-based models [9], and (7) Integrated product and product-sum models [8], Metric models [10], Ma mixture [27, 28], Ma linear combination [29, 30], Stein [31], and Gregori [32]. All of these covariances, in addition to the separable and product-sum covariance rely on an assumption of full-symmetry. A Spatio-temporal covariance is fully symmetric if the covariance between two Spatio-temporal locations does not depend on the specific pairing of the two spatial locations and two time points [26]. There has been a great deal of research in constructing covariance that are not fully symmetric [24, 31, 33–36], are not stationary [9, 18, 19], or are not isotropic [9, 21, 23], but we do not focus on this paper.

Although there are many Spatio-temporal models, in this study, the Spatio-temporal with the general product-sum model was used [1]. This model has several advantages over other models, including:

1) the model is more flexible and practical in its use [9];
2) the model serves a large class of models that is not attainable by Cressie and Huang [14] and which are easily modeled using techniques similar to those used for modeling spatial variogram [1]; and
3) Xu and Shu [25] claim the product-sum covariance is the most widely used Spatio-temporal covariance in practical applications.

Space-time data is assumed to be the realization of a stochastic process:

$$\{Z(s,t)\,;\, s \in D, t \in T\}$$

with the domain $D \subseteq \Re^d, d \leq 3$, and $T = (1, 2, \ldots)$is viewed as a time series data of spatial processes, each process occurs at points that have the same interval.

Stationary Spatio-temporal product-sum model based on Euclid's distance was first developed by De Cesare et al. [1] as (6).

$$C_{s,t}(h_s, h_t) = k_1 C_s(h_s)\, C_t(h_t) + k_2 C(h_s) + k_3 C_t(h_t) \quad (6)$$

and semivariogram is stated as in (7)

$$\begin{aligned} \gamma_{s,t}(h_s, h_t) = & \left(k_2 + k_1 C_t(0)\right) \gamma_s(h_s) \\ & + \left(k_3 + k_1 C_s(0)\right) \gamma_t(h_t) \\ & - k_1 \gamma_s(h_s)\, \gamma_t(h_t) \end{aligned} \quad (7)$$

where, $h = s_i - s_j$ and $u = t_i - t_j$ denote the spatial distance between two locations and the distance between two times, respectively. Equations (7) that $C_s$and C_t spatial and temporal covariance models are positive-definite, respectively. The covariance model of Equation (6) is declared a positive-definite if $k_1 > 0, k_2 \geq 0,\ and\ k_3 \geq 0$, while Equation (7) is said to be valid if it meets a conditionally negative-definite requirements [26]. The product-sum model has something to do with a marginal Spatio-temporal (8) and (9).

$$\gamma_{s,t}\left(h_s,0\right)=\left(k_2+k_1C_t\left(0\right)\right)\gamma_s\left(h_s\right)=k_s\gamma_s\left(h_s\right), \tag{8}$$

and

$$\gamma_{s,t}\left(0,h_t\right)=\left(k_3+k_1C_s\left(0\right)\right)\gamma_t\left(h_t\right)=k_t\gamma_t\left(h_t\right) \tag{9}$$

It follows that $\left(k_2+k_1C_t\left(0\right)\right)=k_s$ and $\left(k_3+k_1C_t\left(0\right)\right)=k_t$, and $\gamma\left(h,0\right)$ and $\gamma\left(0,u\right)$ are respectively proportionality of $\gamma\left(h,0\right)$ and $\gamma_s\left(h\right)$, as well as $\gamma\left(0,u\right)$ and $\gamma_t\left(u\right)$. Assuming both of the relationships are in (10)—(12).

$$\left(k_2+k_1C_t\left(0\right)\right)=1 \tag{10}$$
$$\left(k_3+k_1C_s\left(0\right)\right)=1 \tag{11}$$

and,

$$\left(k_1+k_2+k_3\right)=1 \tag{12}$$

Therefore, $\gamma\left(h,0\right)$ *and* $\gamma\left(0,u\right)$ can be estimated by $\gamma_s\left(h\right)$ *and* $\gamma_t\left(u\right)$, and also estimation of k_1, k_2 *and* k_3.

The restricted in Equation (10), (11), and (12) are not necessary [1] because examining the asymptotic behavior of $\gamma(h,0)$, $\gamma(0,u)$, and $\gamma_{s,t}\left(h,u\right)$ that their theorem shows that these variograms do not reach the same sill value. De Iaco et al. [1] mention that Equations (13) and (14) remain maintained without making the restriction, and De Iaco et al. [1] extended to the general product-sum.

General product-sum model in the form of covariant function and semivariogram is given as in (13) and (14)

$$C_{s,t}\left(0,0\right)=k_1C_s\left(0\right)C_t\left(0\right)+k_2C_s\left(0\right)+k_3C_t\left(0\right) \tag{13}$$

and

$$\begin{aligned}\gamma_{s,t}\left(h_s,h_t\right)=&\left(k_2+k_1C_t\left(0\right)\right)\gamma_s\left(h_s\right)\\&+\left(k_3+k_1C_s\left(0\right)\right)\gamma_t\left(h_t\right)\\&-k_1\gamma_s\left(h_s\right)\gamma_t\left(h_t\right)\end{aligned} \tag{14}$$

where $C_s\left(h\right), C_t\left(u\right),$ *and* $C_{s,t}\left(h,u\right)$ are respectively a covariant function of space, time, and space and time.

The Equation (14) is said to be a valid if k meets the below inequality as follows:

$$0<k\le\frac{1}{\max\left\{sill\left[\gamma_s\left(h,0\right)\right],sill\left[\gamma_t\left(0,u\right)\right]\right\}} \tag{15}$$

where

$$k=\frac{k_1}{k_sk_t}=\frac{k_sC_s\left(0\right)+k_tC_t\left(0\right)-C_{s,t}\left(0\right)}{k_sC_s\left(0\right)k_tC_t\left(0\right)} \tag{16}$$

If $C_{s,t}$ is expressed as product-sum of purely spatial and temporal with coefficients, namely$k_1>0, k_2\ge 0,$ *and* $k_3\ge 0$, and the constant k in Equation (16), then it results that $k>0$. Conversely, if k satisfies in Equation (15), then Equation (14) will be a valid variogram. In the process of estimating and modeling $\gamma_s\left(h,0\right)$ *and* $\gamma_t\left(0,u\right)$ one will have already obtained the sill values$k_sC_s\left(0\right)$ *and* $k_tC_t\left(0\right)$.

There was a publication on the general product-sum that has potentially a negative definite theoretically by Gregori et al. [32], but De Iaco et al. [37] disputed his publication through mathematical analysis and concluded that there was no potentially negative-definite.

2.2. Bibiliometric literature review

Many bibliometric literatures analysis in different fields have been carried out [38–41]. We discuss here, three of hot bibliometric researches. Yu et al. [42] conduct bibliometric literatures analysis on development in the field of Fuzzy theory in China. The authors collected samples of 12,936 publications authored by Chinese scholars on the field researches during the past 3 decades and explore the patterns and dynamics by analyzing the geographic distribution of publications, international collaboration, research hot spot, subject categories and journals, and publication contributors. The results indicate that the scientific publications are highly unbalanced at regional levels in China, and the USA is China's most important partner in Fuzzy theory cooperative researches. The analysis results indicate that the scientific publications are highly unbalanced at regional levels in China, and the USA is China's most important partner in Fuzzy theory cooperative researches. The emerging trends of Fuzzy theory researches from Chinese scholars have shifted away from basic Fuzzy theory researches to the applications, such as the areas of decision making, optimization, modeling and design.

He et al. [43] performed bibliometric literature analysis on Ordered weighted averaging (OWA) operator on Web of Science (WOS). The authors anlyze the publications on OWA operator between 1988 and 2015, and it is based on 1213 bibliographic records obtained by using topic search from WOS. The disciplinary distribution, most cited papers, influential journals, as well as influential authors are analyzed through citation and cocitation analysis. The emerging trends in OWA operator research are explored by keywords and references burst detection analysis. The research methods and results in this paper are meaningful for researchers associated with OWA operator field to understand the knowledge domain and establish their own future research direction.

Yu et al. [44] study on an analysis of collaboration evolution in analytic hierarchy process (AHP) research in the period of 1982–2018. As an important developed approach of AHP, analytic network process (ANP) is also considered in the review. 9,859 publications are harvested from Web of Science to conduct the bibliometric analysis. Country and institution are the two primary objectives to investigate the collaboration pattern of the 9,859 publications. The most prolific countries and institutions are identified based on bibliometric indicators, and the collaboration relationships between connected countries or institutions are explored based on science mapping techniques. The study assists in developing the collaboration evolution analysis in the AHP field.

2.3. The proposed literature review method

Literature review is a piece of academic writing demonstrating knowledge and understanding of the academic literature on a specific topic placed in context. A literature review also includes a critical evaluation of the material; this is why it is called a literature review rather than a literature report. There are three types of literature reviews: (1) bibliometric analysis, (2) meta-analysis, and (3) systematic literature review [45]. This study is focused on bibliometric analysis and systematic literature review.

Bibliometric analysis has acquired immense fame for conducting the literature review in recent years. Applying for this kind gives results: (1) handling a large volume of scientific data, and (2) producing a high research impact. The bibliometric analysis can be analyzed in quantitative ways [46]. Conversely, the systematic literature review is a classic method that applies to a narrow scope of the study and is used for a number of papers for review relatively small in number (e.g., between tens) and low hundreds [47]. The systematic review is generally analyzed in a qualitative way, therefore, it can be an adverse effect because of the different interpretations among scholars that give biased outcome.

Bibliometric analysis of this study provides an overview in spatio-temporal models that use the product-sum or General product-sum studies, and systematic literature review examine hydrological distance studies specifically.

This literature review adheres the most recent Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) tools and guide [48]. In general, four inclusion criteria were used on this study: (1) publications with article, journal or proceeding document types; (2) publications with published date between January 2002–July 2022; (3) publications with English language; and (4) publications with at least 1 citation. While for exclusion criteria, we consider: (1) publications with book, e-magazine, blog etc.; (2) publications beyond the time range; (3) publications with non-English languages; (4) publications with zero citation.

Two-step screening is used in this study. First step is using keywords for bibliometric analysis to find relevant publication in the title or abstract of the articles as follows.

1. ("Spatio-temporal" OR "space-time")
2. ("product-sum" OR "general product-sum")
3. 1 AND 2.

In the second stept, keywords are used in systematic literature review to find relevant publication in the title or abstract of the articles.

1. ("Spatio-temporal" OR "space-time")
2. ("product-sum" OR "general product-sum")
3. ("hydrologic distance" OR "river distance" OR "stream networks")
4. 1 AND 2 AND 3.

Articles obtained from applying the above keywords are sorted automatically and manually. Dataset were obtained during September 2022 from Google Scholar, Scopus and Dimensions databases. These databases were used from its simplicity of use and open-source. Moreover, mentioned databases have comprehensive search methods for detailed results. Furthermore, hand-searching methods are conducted to search articles that deemed fit in this study but did not include in mentioned databases due to lack details in titles and abstracts. After automatic filter process, data were manually reviewed to ensure relevancy of this study. Papers reviewing are performed manually for checking title, abstract and keywords, then followed by full paper analysis whenever the full papers are available. Harzing's Publish or Perish Version 8 software program is used in this study to retrieve raw citation from databases and analyze the academic citations [49]. The input for the software is bibliographic records. Having done filtering process, the publications data were processed with VOSViewer to construct and visualize articles data [50]. Since we focus on spatio-temporal general product-sum model as the main keywords, potential articles that should fit in this study could be excluded as it is automatic filtered by databases and not found in hand-searching method.

Bibliometric analysis is conducted to exhibit the development of spatio-temporal product-sum model studies

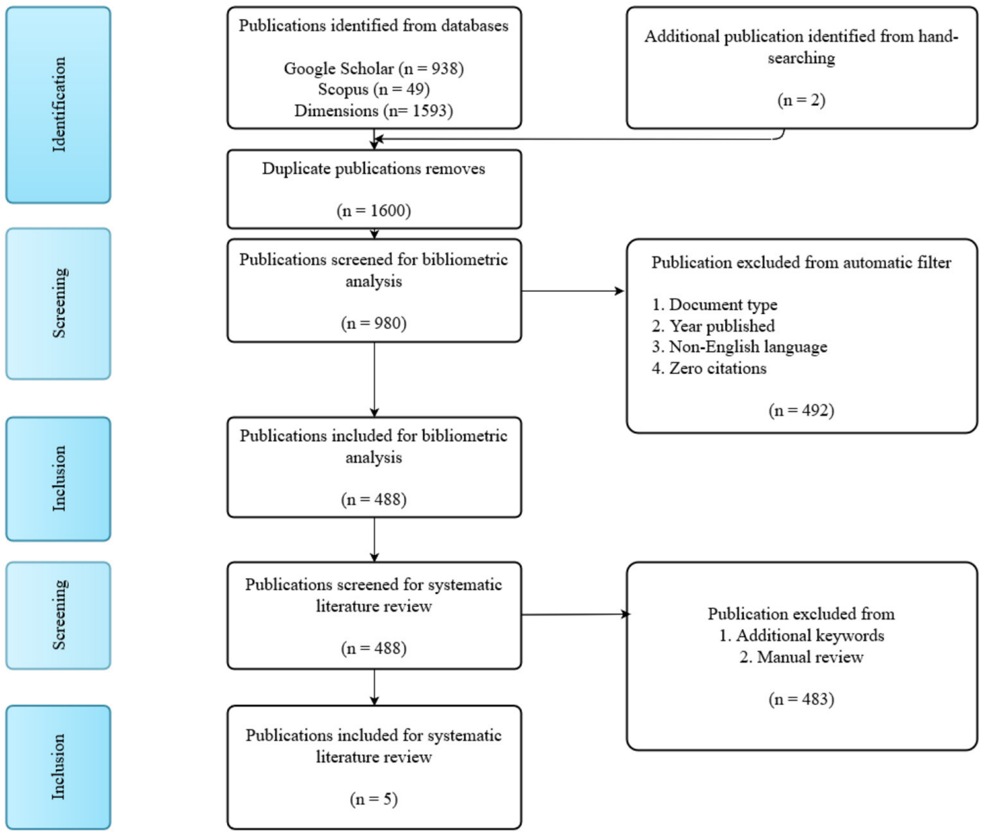

FIGURE 1
Flow diagram of identification and inclusion of spatio-temporal general product-sum research works.

over time. Moreover, systematic literature review is also conducted to gain specific insights by adding inclusion criteria of hydrologic distance studies related. Specific keywords also used in publication search to narrow down articles that have broad subject other than the focus of the literature review.

3. Analysis results

Searching of Spatio-temporal product sum related studies resulted 2,582 publications, with 2,580 publications identified from databases and two publications identified through hand-searching. As many as 1,600 duplicate publications found, leaving 980 publications to screen for eligibility. Applying step-one screening, 492 publications excluded from the review, leaving 488 publications included for bibliometric data extraction. Then for the step-two screening, we found 5 publications included for systematic literature review. Flow diagram in Figure 1 represents the steps to retrieve publications in this study.

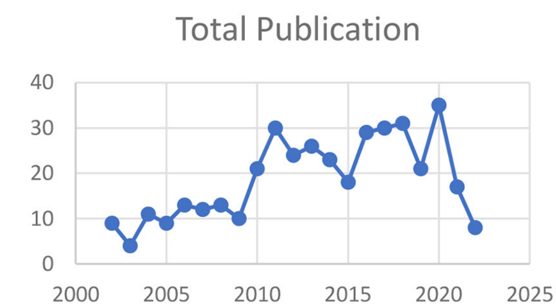

FIGURE 2
Total publications on spatio-temporal product-sum model.

3.1. Bibliometric analysis

From 488 extracted data, we conduct bibliometric analysis to gain insights of Spatio-temporal product-sum studies. After product-sum model terms coined by De Iaco [1], publication related to spatio-temporal product-sum model has become much more active in recent years globally. Figure 2 points

TABLE 1 Most productive authors.

Author	TP	TC	CPP
S. De Iaco	31	945	30.48
D. Posa	26	872	33.54
D. E. Myers	13	660	50.77
J. Mateu	12	385	32.08
M. Palma	12	168	14.00
C. Cappello	10	65	6.50
E. Porcu	10	375	37.50
L. Lei	9	194	21.56
E. A. Varouchakis	7	70	10.00
H. Shu	7	60	8.57

out annual publication starting from Year 2002 with nine publications. Number of research works increase and decrease over time, with notable increase in Year 2011 with 30 publications, peaked at 2020 with 35 publications, before declining in 2021 with only 17 publications and 2022 with eight publications, with a note that the publication may increase toward year-end of 2022.

From the extracted data, we identify the most productive authors shown in Table 1. De Iaco is the most productive author with 31 total publications (TP), accumulated 945 total citations (TC) and average of 30.44 citations per paper (CPP) score. Posa in the second place with 26 TP, accumulated 872 TC, and average 33.54 score of CPP. In the third place of publication productivity is Myers that has published 13 TP, accumulated 660 TC and average of 50.77 CPP score.

We also identify institute with highest productivity presented in Table 2. University of Salento have the highest contributor with five authors publishing spatio-temporal product-sum studies, while University of Tehran have four authors publishing related studies, and Technical University of Crete, National Center for High-Performance Computing, Aristotle University of Thessaloniki, Aarhus University, Tunis El Manar University, University of Pittsburgh, and Shanghai Jiao Tong University have three authors each publishing spatio-temporal product-sum studies.

Other than the most productive institute mentioned above, we identify top five sources or journals that publish articles related to spatio-temporal product-sum, as well as top five publisher containing spatio-temporal product-sum studies. Table 3 presents the top sources or journals and publishers, with the first source is Journal of Spatial Statistics with 13 publications, and IEEE Transaction on Geoscience and Remote Sensing Journal in second place with 12 publications, and International Journal of Applied Statistics with eight total publications. Top publisher that containing spatio-temporal product-sum studies is Springer publisher with 90 total publications, while Elsevier publisher in the second most top publisher with 78 publications, followed by IIEE Explore publisher in the third place with 43 publications related to spatio-temporal product-sum studies.

TABLE 2 The most productive institute.

University	Total author
University of Salento	5
University of Tehran	4
Technical University of Crete	3
National Center for High-Performance Computing	3
Aristotle University of Thessaloniki	3
Aarhus University	3
Tunis El Manar University	3
University of Pittsburgh	3
Shanghai Jiao Tong University	3

TABLE 3 Top source and publisher.

Source	Total	Publisher	Total
Spatial Statistics	13	Springer	90
IEEE Transactions on Geoscience and Remote Sensing	12	Elsevier	78
International Journal of Applied Statistics	8	IEE Explore	43
Geoderma	6	Taylor and Francis	21
Water Resources Research	6	Wiley Online Library	17

TABLE 4 Top discipline covered by spatio-temporal product-sum studies.

Discipline	Total
Information and computing sciences	95
Mathematical sciences	93
Earth sciences	78
Artificial intelligence and image processing	60
Statistics	42

We conduct manual filtering to determine which disciplines category uses spatio-temporal product-sum studies the most. Table 4 shows top five disciplines, with Information and Computing Sciences in the first place with 96 publications on product-sum methods, while Mathematical Sciences in the second spot with 93 publications, and Earth Science in the third spot with 78 publications related to spatio-temporal product-sum studies.

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TABLE 5 Top 10 total link strength of co-citation analysis.

Author	Documents	Total link strength
S. De Iaco	31	65
D. Posa	26	57
D. E. Myers	13	23
J. Mateu	12	15
M. Palma	12	30
C. Cappello	10	25
E. Porcu	10	14
L. Lei	9	27
E. A. Varouchakis	7	5
H. Shu	7	12

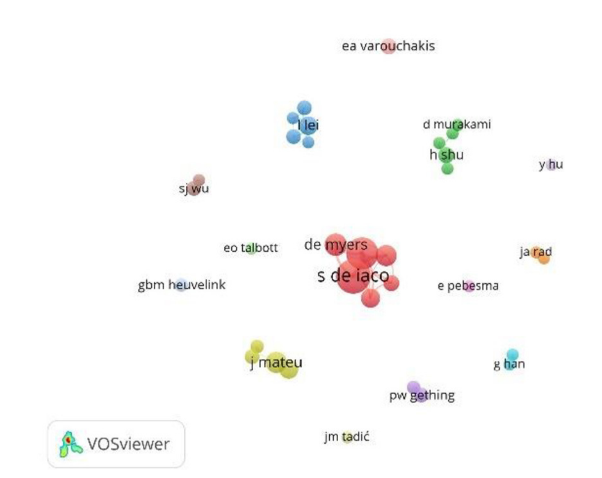

FIGURE 3
Network visualization of co-citation analysis.

To gain insights about co-citation, dependence of the authors in spatio-temporal product-sum studies, we use VOSViewer to visualize the cooperation between researchers. With five minimal publications as the threshold, Table 5 represent the top 10 total link strength of co-citation analysis and Figure 3 presents the network visualization of co-citation analysis of spatio-temporal product-sum studies. According to VOSviewer manual, strength of each link can be explained by representing by a positive numerical value. Stronger the link will increase the total link strength value. Total link strength shows the number of publications in which two author or more occur together. With 31 documents published and 65 total link strength, S De Iaco is the most influential author on spatio-temporal product-sum studies, follows by D Posa with 26 documents with 57 total link strength and DE Myers with 13 documents and 23 total link strength. Overall, there are 14 clusters that separated from each other, with six clusters only have one dot, meaning there are no other author collaborating with researcher with minimal five documents threshold related to spatio-temporal product-sum related studies. For cluster 1 (red color), there are six authors collaboration, namely S De Iaco, D Posa, C Capello, DE Myers, M Palma, and S. Maggio. While cluster 2 (green color) there are five authors collaboration, i.e., D Murakami, DA Griffith, H Shu, J Xu, and S Li. In cluster 3 (dark blue color) there are 5 authors collaboration, i.e., L Guo, L Lei, L Li, Z Zeng, and ZC Zeng. In cluster 4 (yellowish green color) there are four authors collaboration, i.e., E Porcu, G Fernandez-Avilles, J Mateu and JM Montero. In Cluster 5 (purple color) there are two collaborators, i.e., AM Noor and PW Gething. In cluster 6 (cyan color) there are two collaborators, i.e., G Han and J Rosenthal. In cluster 7 (orange color) there are two collaborators, i.e.: JA Rad and K Parand. Lastly in cluster 8 (brown color) there are two collaborators, i.e., CT Hsu and SJ Wu. For single author without collaboration, there are E Pebesma, EA Varouchakis, EO Talbott, GBM Heuvelink, JM Tadic and Y Hu. Figure 4 presents the time overlay visualization of co-citation analysis. The darker the dot indicated the longer average publication year since author published spatio-temporal product-sum related studies. For example, DE Myers with average publication of Year 2006, we can see that the dot is the darkest in, while EA Varouchakis that average publication of Year 2019, the dot is the lightest among other dots.

3.2. Systematic literature review

Five publications are included for systematic literature review. Table 6 describes the publications used for systematic literature review. Publication from JO Skøien and G Blöschl [52] with the title "Catchments as space-time filters–a joint spatio-temporal geostatistical analysis of runoff and precipitation" is the oldest publication that mentioning hydrologic distance in their study, while publication from Fernandez et al. [23] with the title "Bayesian Spatio-temporal models for stream networks" is the most recent publication that uses hydrologic distance in their study. From five publications, three publications are sourced from statistics journal discipline, while publication from Boergens et al. [21] titled "Combination of multi-mission altimetry data along the Mekong River with Spatio-temporal kriging" sourced from Geodesy discipline and publication from Skøien and Blöschl [52] with the title "Catchments as space-time filters–a joint spatio-temporal geostatistical analysis of runoff and precipitation" is sourced from hydrology journal discipline and earth science journal discipline.

Methods used in each publication listed on Table 7. All publications focused on tail up method to compute the hydrologic distance in each study, but no publications focused on modeling product-sum. Boergens et al. [21] used the Spatio-temporal product-sum model with the two parameters set fixed, $k_2 = k_3 = 0$, and the application of the spatial model based

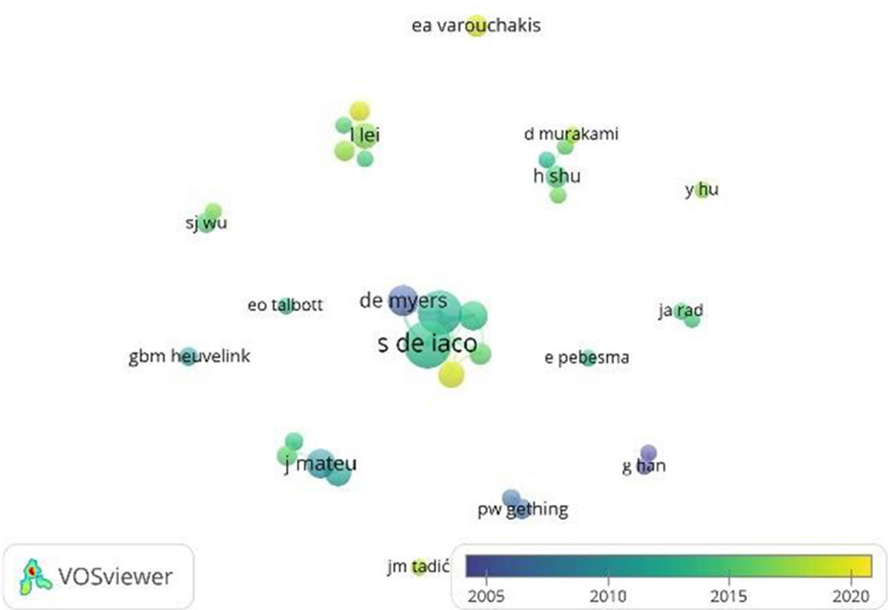

FIGURE 4
Time overlay visualization of co-citation analysis.

TABLE 6 Spatio-temporal product-sum hydrologic distance publication.

No	Authors	Title	Year	Source	Publisher
1	Boergens et al. [21]	Combination of multi-mission altimetry data along the Mekong River with Spatio-temporal kriging	2016	Journal of Geodesy	Springer
2	Tang and Zimmerman [22]	Space-time covariance models on networks with an application on streams	2020	Statistics Methodology arXiv preprint arXiv:2009.14745	arxiv.org
3	Fernandez et al. [23]	Bayesian Spatio-temporal models for stream networks	2022	Computational Statistics and Data Analysis	Elsevier
4	O'Donnel [51]	Flexible regression models over river networks.	2014	Journal of Royal Statistical Society	Applied statistics
5	Skøien and Blöschl [52]	Catchments as space-time filters–a joint spatio-temporal geostatistical analysis of runoff and precipitation	2006	Hydrology and Earth System Sciences	hess.copernicus.org

TABLE 7 Spatio-temporal product-sum hydrologic distance methods used in publications.

No.	Authors	Tail-up	Tail-down	Product-sum	General product-sum	Hydrologic distance	Euclidean distance
1	Boergens et al. [21]	√	×	√	×	√	√
2	Tang and Zimmerman [22]	√	√	√	×	√	√
3	Fernandez et al. [23]	√	×	√	×	√	√
4	O'Donnel [51]	√	×	√	×	√	×
5	Skøien and Blöschl [52]	√	×	√	×	√	√

on hydrological distance was used for non-stationarity. The spatial model theoretically can be applied to non-stationarity with weights as in Equation (3), when water flows into its two branches. It does not require the constraint of weight, namely $\omega_k + \omega_l = 1$. Furthermore, Tang and Zimmerman [22] developed a mixture model based on hydrological distance, with the Tail-up autocovariance function as in Equation (3) and Ver Hoef et al. [12] and Ver Hoef, and Peterso [13] introduced Tail-down autocovariance function in Equation (4). Meanwhile, when Euclid's distance is used, then the model is a product-sum [1]. O'Donnel [51] also developed a Spatio-temporal model for hydrological distance based on a river network with a non-parametric approach, namely penalized splines. The hydrological distance-based autocovariance function in the tail-up model is used in Equation (5). Fernandez et al. [23] used a Spatio-temporal model for a river network with a Bayesian framework. This proposed model was carried out using a sum model whose components of the covariance function with distance are: Euclidean, as well as hydrological in the tail-up and tail-down models. By comparing all the attributes of the topic, certain similarities and dissimilarities were found. For example, there was a difference in the proposed topic with four publications, which all used the product-sum model. Therefore, it can be concluded that the proposed topic of Spatio-temporal Model using Product-Sum Based on Hydrologic Distance is a novelty.

4. Discussions

Spatio-temporal product-sum model first developed by De Cesare et al. [6] two decades ago, and De Iaco et al. [1] coined the general product-sum model. Bibliometric analysis was conducted to gain insights about spatio-temporal product-sum or general product-sum model. Product-sum model have upward trend but in latest year it declining with only 17 publications in 2021 and eight publications in 2022, meaning that two models were not widely applied by researchers as shown in Figure 2.

One of the possible reasons for this decline is that it has started to become saturated and applied by collaborations only between researchers. University of Salento as the leading institute have a solid team of five authors publishing spatio-temporal product-sum studies, namely De Iaco, Posa, Myers, Capello and Porcu in University of Salento as seen in Table 2 and Figure 3.

Journal of Spatial Statistics are considered the top source while Springer considered as the top publisher that covers spatio-temporal product-sum studies. Disciplines that use the most the spatio-temporal product sum model is Information and Computing Sciences, Mathematical Sciences and Earth Sciences. The overview of co-citation analysis was presented to observe the dynamic between researchers.

One of the benefits of this study is to assist researchers in developing a spatio-temporal model using a general product-sum based on stream, river, or hydrologic distances. Systematic literature review was conducted to seek similarities and difference from each publication so a novelty of the method can be concluded through literature review on research works by Boergens et al. [21], Tang and Zimmerman [22], Fernandez et al. [23], O'Donnel [51] and Skøien and Blöschl [52]. There still few publications of the spatio-temporal models based on the stream distance and both models are applied based on Euclidean or linear distance. Thus, the model that will be developed following this study can dilute the saturation of the two models so that this study could attract other researchers, either in theoretical as well as practical aspects. Other works on spatial temporal covariance models have been carried out in [33–36]. The developed model also considers stationary covariance models [53–58].

To the best of our knowledge, this is the first comprehensive bibliometric literature review that focuses on Spatio-Temporal Model using a General Product-Sum Based on a Hydrological Distance.

Some limitations of this study are noteworthy for future research. Future studies have to consider using publications with zero citation for broader result. While our study focused on hydrologic distance that included in the earth science disciplines, diversify of broader studies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fams.2022.994287/full#supplementary-material

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