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RESEARCH ARTICLE

MODELLING APPROACHES TO SEDIMENT TRANSPORT CAPACITY IN OPEN CHANNELS: BIBLIOMETRIC ANALYSES OF SCOPUS-DATA BASED PAPERS FROM 2003 TO 2023

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ABSTRACT

In this study, a bibliometric analysis was used to identify important trends, focus areas, and regions in open channel sediment transport research from 2003 to 2023. The data used in this analysis were taken from the online version of the Scopus database and 495 publications met the selection criteria. A database of all peer reviewed paper was then created, including the year of publication, authors' names, countries, publication type, journal name, number of citations per paper, the number of citations per journal, the percentage of publications by the topic cluster name and subject area. Most of the publications were from countries with large areas irrigated with open channel system and with great pressure to overcome problems induced by sediment transport. To solve the above-mentioned problem, existing technical conditions of open channel systems, new technology and technical means of modelling sediment transport capacity in the irrigation zone are necessary. Bibliometric analysis revealed that international research on irrigation and sediment transport would benefit from expanded scientific exchange on this topic, as well as from long-term, continuing studies and the sustainable integration of irrigation and sedimentation research into future agricultural and open channel system management concepts.

KEYWORDS

Scopus database, citations, subject area, Bibliometric analysis

1. INTRODUCTION

The role of open channels in supplying water from sources to fields and other agricultural sectors is extremely important (Hu et al., 2023). Sediment transport capacity of open channels depends on several factors such as cross-sectional shape, turbidity of water, velocity and depth (Qiu et al., 2023; Arifjanov et al., 2023). When natural disasters such as global warming are observed around the world, the effective operation of open channels to reduce evaporation and filtration of water consumption is focused of many scientists (Constantinescu, 2020). One of the main factors that negatively affect the operation of channels is the amount of sediment in the water (Dralle et al., 2023). For instance, the increase in turbid sediments in streams lead to the deformation of channels and the failure of infrastructures such as pipelines and pumping stations (Khasanov et al., 2021; Khuntia et al., 2018). For many years, scientists have been conducting many studies aimed at studying the movement of small turbid particles in the flow. Many numerical models are also used to study the dynamics of sediment distribution (Yang et al., 2023).

The impact on canal bed changes by sedimentation have been analyzed with 1D, 2D and 3D hydrodynamic and sediment transport modeling. Mathematical and physical models have been used to solve problems related to turbid sediments (Barati, 2016). In some cases, it was necessary to use a combination of mathematical and physical models to describe complex processes related to the distribution of sedimentation (Daneshfaraz et al., 2020). A large number of mathematical hydrodynamic/sediment transport models have been developed in the

last three decades (Ferreira et al., 2015). The research process involved choosing the variables that impact of sediment transport models is based on sensitivity of the outputs to the input parameters. The most suitable methods are then selected according to both qualitative and quantitative criteria (Önder, 2018). The advantage of mathematical models is that they can be adapted to different physical situations and networks more easily than physical models (Biru and Kumar, 2018).

Physical are usually constructed to represent specific conditions. The movement of sediment in open channels with flowing water is important for designing pipes that drain or carry sewage (Safari and Rahimzadeh Arashloo, 2021). It is very important for a channel to be designed so that the flow does not let the sediment particles to deposit (Samiev et al., 2024). Deposition of sediment has numerous unpleasant effects on the performance of open channels (Kaletova et al., 2021; Samiev et al., 2021). For instance, it changes the shear stress on the sidewall of the channel and reduces the velocity of the flow, resulting in a decrease in the transport capacity of the flow (Arifjanov et al., 2021). Hence, it is important to comprehensively study in open channels to be able to achieve an efficient and sustainable water management (Yang et al., 2022a).

Bibliometric analyses used various subject areas, engineering, agriculture mechanization; environmental science, and marginal land development (Jumaniyazov et al., 2023; Xaliqulov et al., 2023; Ruzmetov and Ibragimov, n.d.; Kannazarova et al., 2024). In this analysis, we have examined the research that has completed related to open channels and flow capacity, and the countries and scientists that are performing the work. Many

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countries, including the China and the USA, are devoting more attention and financial resources than other countries. Bibliometric analysis identifies collaborations within documents, among authors, between countries, and amongst journals, institutions and funding sponsors. Bibliometric studies are a useful analytical tool to gain a deeper understanding of research methods (e.g., journals, authors, countries) and characteristics of the study of turbid particle behavior in water.

2. METHODS

The global library of open channel and sediment transport research was analyzed in the Scopus database for the period of 2003-2023. Firstly, we searched “open channel and sediment transport capacity” as a keyword within article title, abstract and keyword section and found 495 published documents between within the mentioned time period. We found that most papers are not fully devoted to the issue of open channel flow and sediment transport. Then the following filters were applied as a retrieval strategy on November, 2023: TITLE (open OR channel OR sediment OR transport OR capacity) AND PUBYEAR (2003-2023) AND (LIMIT-TO (SUBJAREA, "ENGI, ENVI, EARTH AND AGRI")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final")) (Figure 1). With this, we recorded 495 papers and exported the results to CSV and RIS formats. VOSviewer soft version 1.6.18 citation needed is used to analyze bibliographic coupling, themes, co-authorship, co-occurrence, citation, and co-citations.

2.1 Article review and study eligibility criteria

During the search process, relevant information, such as keywords “open channel” and “sediment transport capacity”), and all articles in English, were added to a spreadsheet. Article = (“open channel and sediment transport capacity”), document type = “article”, timespan = “2003-2023”, Subject area = Engineering, Environmental Science, Agricultural and Earth and Planetary Sciences Engineering and deadline = November 2023. Figure 1 illustrates the selected methodology for the research. During the screening process, the following exclusion criteria were used:

- Only the title and abstract of the article are reported in English, but the rest of the manuscript is in another language
- Articles related to other research areas
- Lack of definition of search terms (stability, sensitivity, resistance).
- for articles without a DOI, the ability to find articles is limited. In general, it was not possible to exclude these articles using the filter options in Scopus.

2.2 Bibliometric Analysis

Data were uploaded to Excel and subsequently, imported to the bibliometric analysis. Before starting the analyses, the data was thoroughly checked for errors. The articles were analysed and the most relevant ones were identified, as well as corresponding authors. The articles from the search were assessed and classified according to the number of papers per year, document type, top list of papers, list of journals, list of top funding agencies, distribution by subject categories and by journals, and affiliation by country and institution. Finally, the co-authors and co-occurrence of keywords were analysed to explore clusters of the most common keywords in the literature.

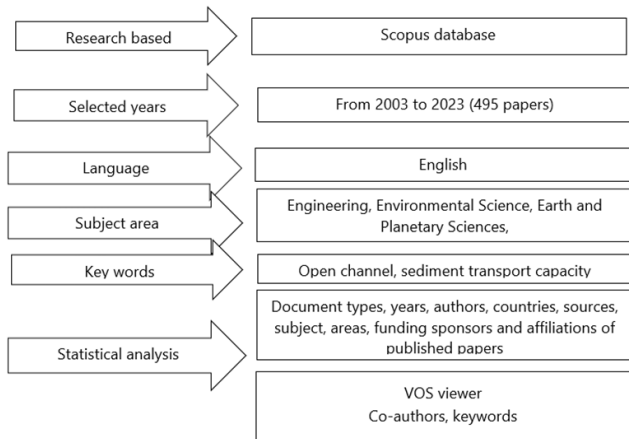


Figure 1: Methodology flow chart for the research

3. RESULTS

3.1 Publications on open channel and sediment transport capacity

In order to understand the development of sediment transport capacity in open channels publication and citation trends were analysed as shown in Figure 2. In the last 20 years, there has been a significant surge in the total amount of research conducted on open channel and sediment transport, with a total of 495 studies being published from 2003 to 2023. The diagram gives information about how many papers published on open channel and sediment transport capacity for 20 years from 2003. Examining the graph closely, it becomes evident that a number of papers were produced in this field over the years; the minimum number of papers was seven, in the year 2003. There was a four-fold increase in the figure of number of papers before plummeted to 14 in 2014. Interestingly, half of these publications were produced after 2017 and witnessed the highest number in 2019 (43 publications), before decreasing slightly to 38 at the end of the period.

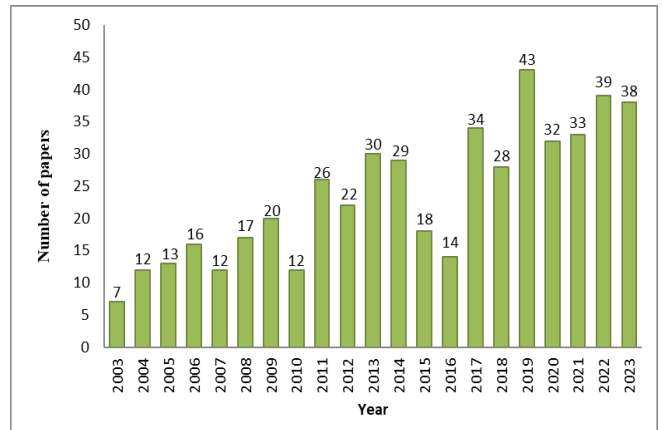


Figure 2: Number of papers on open channel and sediment transport capacity by year

3.2 Journals on open channel and sediment transport capacity

A wide variety of journals are used by scholars to publish their research. The investigation indicates that the total output was distributed across 117 journals published in 64 countries. Ten journals published 87 (17.5%) papers and remaining 82.4% papers were published in other journals. Table 1 lists name of the 20 journals which published a minimum of three papers during the above-mentioned period.

Table 1: Number of papers on open channel and sediment transport capacity by the year of publication			
Scopus Source title	Number of papers	Scopus Source title	Number of papers
Journal of Hydraulic Engineering	15	AIP Conference Proceedings	4
Flow Measurement and Instrumentation	12	ISH Journal of Hydraulic Engineering	4
Journal of Hydrology	10	Journal of Geophysical Research Earth Surface	4
Water Switzerland	10	Lecture Notes in Civil Engineering	4
Journal of Hydraulic Research	8	Physics of Fluids	4
Journal of Irrigation and Drainage Engineering	8	Wit Transactions on Ecology and The Environment	4
Water Resources Research	8	Applied Energy	3
Applied Mechanics and Materials	6	Arabian Journal of Geosciences	3
IOP Conference Series Materials Science and Engineering	5	Earth Surface Processes and Landforms	3
Journal of Hydrodynamics	5	Environmental Fluid Mechanics	3

The second analysis criteria are the name of publishing country and impact factor of the top 15 journals (Table 2). Of these seven journals were published from the USA, four from UK and only one from the Netherlands, Germany, France, Switzerland. The average impact factor of

the journals with the greatest number of articles was 5.42. Among the 15 journals, the IEEE International Conference on Communications had the highest impact factor and the Journal of Hydraulic Engineering had the highest number of publications with 15 articles.

Table 2. Distribution of research output in prolific journals

Journal	TNP (%)	Publishing country	IF
Journal of Hydraulic Engineering	5.6 %	USA	2.7
Journal of Hydrology	4.5%	Netherland	6.4
IEEE International Conference on Communications	3.8%	USA	14.9
Flow Measurement and Instrumentation	3.8%	USA	2.2
Hydrology and Earth System Sciences	3%	Germany	6.9
Journal of Hydraulic Research	3%	UK	2.2
Earth Surface Processes and Landforms	3%	UK	3.3
Journal of Irrigation and Drainage Engineering	2.3%	USA	2.6
Water Resources Research	1.9%	USA	5.4
Applied Energy	1.9%	UK	11.2
Journal of Geophysical Research: Earth Surface	1.5%	USA	3.9
Reviews of Environmental Contamination and Toxicology	1.5%	USA	7.1
International Journal of Thermal Sciences	1.5%	France	4.5
Advances in Water Resources	1.5%	UK	4.7
Water (Switzerland)	1.5%	Switzerland	3.4
Total	40.3%		

3.3 Top authors on open channel and sediment transport capacity

There is no doubt that authors play an important role in the development of a particular field of research in any region of the world. By analyzing authors with the most publications, this section provides insight into the research contributions of individuals. Table 3 illustrates total of 15

different top authors on the open channel and sediment transport capacity during the last two decades. According to statistical information, Constantinescu G is the top contributing author with 10 publications from University of Lova (USA), moreover he and Blanckaert, K. are the most cited researchers. Riviere, N, Mignot, E and Franca, M.J have the highest H-index, which extends their position as leading experts.

Table 3: List of top productive authors in research on open channel and sediment transport capacity issue in the world

Author	TP(R)	H- index	Country
Constantinescu, G.	10	49	USA
Mignot, E.	7	25	France
Emiroglu, M.E.	6	13	Turkey
Khatua, K.K.	5	17	India
Riviere, N.	5	26	France
Agah, M.	4	2	Iran
Blanckaert, K.	4	31	Austria
Devi, K.	4	1	India
Franca, M.J.	4	28	Germany
Kaya, N.	4	1	Turkey
Schleiss, A.J.	4	44	Germany
Tang, X.	4	1	China
Uijtewaal, W.S.J.	4	36	Netherlands
Ahmad, Z.	3	5	Indonesia
Haghiabi, A.H.	3	25	Iran

During 2003-2023, one hundred fifty-nine different funding sponsors worked in cooperation to publish 283 papers on open channel and sediment transport capacity. Based on our analysis of the top 10 funding sponsors of open channel and sediment transport capacity, we were able to identify the most influential and productive institutions in the field. As indicated in Figure 3, of the 10 funding sponsors, three were from China, two from United States, while Australia, the UK, the European Union, Japan and Canada each have one representation.

3.4 Top countries on open channel and sediment transport capacity

Geographic regions can be measured by the number of countries participating in research activities on a particular topic. A total 64

countries worked together on open channel and sediment transport capacity from 2003- 2023. Figure 3 highlights the top 10 countries that published at least 18 publications. The USA holds a dominant position with 116 research documents representing 23.4% of the research body, followed by China 79 (16%), India 40 (8%), and Iran and Turkey both with 19 (3.8%). Researchers from these top three countries participated in produced nearly 47.4% of all manuscripts.

3.5 Top institutions on open channel and sediment transport capacity

Generally, institutions are ranked as a result of the quality of the papers published by their researchers. 160 different institutions published 495

papers on open channel and sediment transport capacity over the period 2003-2023. In order to identify the most influential and productive institutions on open channel and sediment transport capacity, we have analyzed the top 15 institutions. As indicated in Figure 4, of the 15 institutions, four were from China, three each were from the USA and France, one each from India, Turkey, Switzerland, the Netherlands and Iran. These prolific institutions contributed around 27.7% of the total output. Among these, CNRS Centre National de la Recherche occupies the 1st position (19 records), followed by China and Switzerland (11 records).

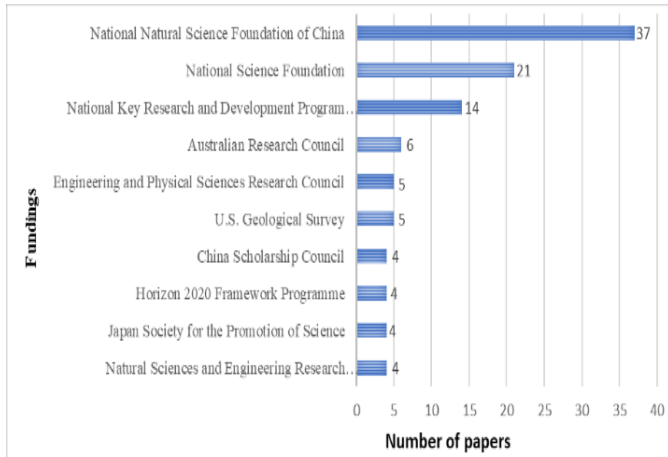


Figure 3: List of top 10 funding sponsors on open channel and sediment transport capacity

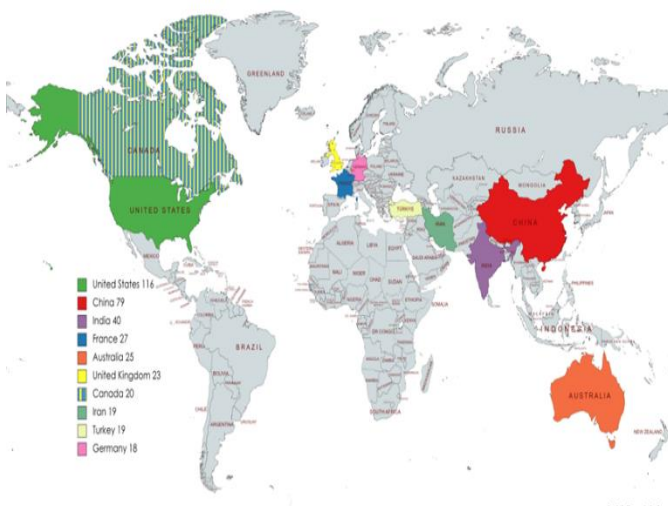


Figure 4: Top 10 countries on open channel and sediment transport capacity research

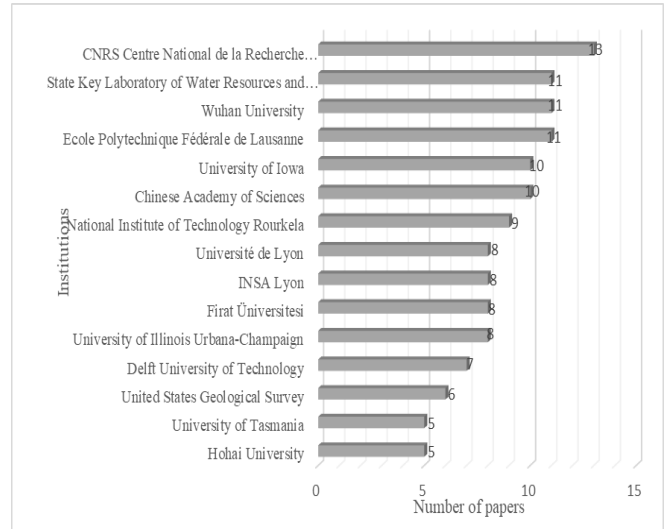


Figure 5: List of top institutions on open channel and sediment transport capacity.

3.6 Top cited papers on open channel and sediment transport capacity

A large number of citations indicates a quality and novelty of research. The Fourteen most cited papers on open channel and sediment transport capacity are listed in Table 4. A total of 6237 citations given to 495 publications on open channel and sediment transport capacity exist for the given period. Almost 46.2 % of citations given to 14 papers from the Table 4. The initial 14 papers with the highest citation count include one review and 13 research articles. Among these highly cited papers, the United States has five entries, the Netherlands has two, while China, the United Kingdom, Denmark, Austria, Belgium, South Korea, and Turkey each have one representation.

3.7 Top cited journals open channel and sediment transport capacity

A minority of scientific journals publish the majority of scientific papers and receives the majority of citations (Ioannidis, 2006). In sub-section 3.2 we analyzed the top journals which published the greatest number of papers. Taking into consideration this factor we decided to investigate top-cited journals on open channel and sediment transport capacity in the water management branch. Initially, we sorted source names alphabetically. Then each paper’s citations were summarized for each journal. Initially 10 journals selected as shown in Figure 5. Almost 35.1 % (2996 citations) of all citations appeared in these 10 journals. Four journals: Journal of Hydraulic Engineering, Flow Measurement and Instrumentation, Journal of Hydrology and Water Switzerland were the most dominant figures in terms of number of papers, accounting for 15, 12, 10 and 10 respectively. The Journal of Hydraulic Engineering, Angewandte Chemie- International Edition, and the Journal of Hydrology are ranked as top cited journals on open channel and sediment transport capacity.

Table 4: Papers with the highest citations					
No.	Title	Journal	Corresponding author	PY	TC
1	Two-dimensional covalent organic frameworks for carbon dioxide capture through channel-wall functionalization	Angewandte Chemie - International Edition	Huang N	2015	549
2	Wet but not slippery: Boundary friction in tree frog adhesive toe pads	Journal of the Royal Society Interface	Federle W.	2006	301
3	Depth-averaged two-dimensional numerical modeling of unsteady flow and nonuniform sediment transport in open channels	Journal of Hydraulic Engineering	Weiming Wu	2004	198
4	Momentum exchange in straight uniform compound channel flow	Journal of Hydraulic Engineering	van Prooijen, B.C.	2005	147
5	One-Dimensional numerical model for nonuniform sediment transport under unsteady Flows in channel networks	Journal of Hydraulic Engineering	Weiming Wu	2004	140
6	Cyanide hazards to plants and animals from gold mining and related water issues	Reviews of Environmental Contamination and Toxicolog	Eisler, R	2004	119

items each), clusters 5 and 6 (9 items each), cluster 7 (8 items), clusters 8-10 (7 items each), cluster 11 (5 items), clusters 12-16 (3 items each), clusters 17-27 (2 items each), clusters 28-41 (1 item each).

4. DISCUSSION

The purpose of this study was to examine the current understanding of open channel and sediment transport capacity at a broad scale. Through a systematic review, the goal was to identify the scientific articles and research domains that have made the most significant contributions to this subject. This scientific review revealed which articles published during two decades have had the most significant impact on studies related to open channel and sediment transport capacity within the last seven years. The yearly output of articles in open channel and sediment transport capacity from 2003 to 2023 depicts three distinct developmental phases: a gradual increase from 2003 to 2013. To estimate flow carrying capacity of compound open channels many engineers use Computational fluid dynamic (CFD). Both two-dimensional (2D) and three-dimensional (3D) methods have been utilized for predicting discharge in compound channels (Yang et al., 2012). Typically, traditional methods for estimating discharge rely on straight channel flow. Regarding the utilized techniques, the studies conducted in this

timeframe primarily focused on forecasting the sections of the channel susceptible to erosion.

4.1 Role of Computational Fluid Dynamic on predicting sedimentation

Computational Fluid Dynamics (CFD) plays an important role in simulating sediment movement and bed formation in channels that provide a comprehensive framework for predicting any process in irrigation system. It captures the physical processes thought to be relevant and consequently each is a conjecture about the dynamical behavior of the geomorphic system. Over the recent years, the advancement in computing power has led to the creation of long-term morphodynamic models. These models are being increasingly utilized in the research of open channel dynamics. 3D models have been created and evaluated. These models have enabled the simulation of both suspended and bed-load transport, along with the corresponding bed deformation in natural rivers.

Table 5 provides information on the performance capabilities of some of the models, including simulation of unsteady flows, sediment exchange, bottom sediments, suspended sediments, cohesive and non-cohesive sediments.

Table 5: Information on the performance capabilities of some of the models

Models	Used equation	Flow conditions	Bed sediments	Suspended sediments	Mixed sediments	cohesive	References
RSM: Reynolds stress turbulence model	Navier-Stooks	unsteady	Yes	Yes	No	Yes	(Tariq et al., 2022)
FVCOM (Finite Volume Community Ocean Model)	three-dimensional primitive equations	unsteady	Yes	Yes	No	Yes	(Garcia Novo and Kyozyuka, 2020)
EPANET2: Environmental Protection Agency's Network	Saint-Venant	unsteady	Yes	Yes	Yes	No	(Nyende-Byakika et al., 2013)
SIC (Simulation of Irrigation Canals)	Saint-Venant	unsteady	Yes	Yes	Yes	No	(Bouisse et al., 2011)
FSS (Fluvial Stream Separation)	Saint-Venant	unsteady	Yes	Yes	Yes	Yes	(Voevodin et al., 2008)
RNG (Re-Normalization Group)	Navier-Stokes	steady	Yes	Yes	Yes	No	(Dehrashid et al., 2023)
SJD-PTM_LR (stochastic jump diffusion particle tracking)	Stochastic differential equation	unsteady	Yes	Yes	No	Yes	(Tsai et al., 2016)
Telemac 3D	Reynolds-averaged Navier-Stoke equations (RANS)	unsteady	Yes	Yes	No	No	(Clark et al., 2020)
HEC-RAS (Hydrologic Engineering Center's River Analysis System)	Saint-Venant	unsteady	Yes	Yes	No	Yes	(Ghosh, 2023)
FLOW 3D; Flow Science (2000)	Navier-Stooks	unsteady	Yes	Yes	Yes	Yes	(Kim et al., 2022)

However, these approaches are fundamentally flawed when applied to meandering channels (Khatua et al., 2011; Karamisheva et al., 2006). A notable decline occurred in 2016 with 14 while a surge in 2019 at 34. In second phase soil erosion is a serious problem worldwide which causes problems such as erosion of side walls of the canals, turbidity of the water, and reduced reservoir storage. Numerical modeling of erosion and sedimentation has been organized by (Wang et al., 2019; Sawadogo et al., 2019). A two-dimensional (2D) morpho-dynamic model was set up, to simulate both cohesive non-cohesive suspended sediment transport (Xie et al., 2019; Lepesqueur et al., 2019). Third phase was followed by a period of steady growth with high number of papers from 2020 to 2023 (37 articles per year on average). Change of climate in some places, the increase in precipitation is also causing the water in the channels to become turbid (Hosseinzadeh Asl et al., 2020). This factor is one of the most important directions for future water and sediment environment research (Guo et al., 2021; Daneshfaraz et al., 2021).

Many studies have focused on flood prevention and flood impact assessment (Yang et al., 2022b). To identify and resolve such issues the

rise of network applications and computer systems, the advancement of desktop Geographic Information Systems (GIS), and the extensive use of Satellite Remote Sensing (RS) and Global Positioning System (GPS) data have all fueled this surge in research. This is largely due to their ability to address problems on a broad scale (Ke and Zhang, 2024). Upon analyzing global trends in open channel and sediment transport capacity, France emerges as a frontrunner among top countries and France takes the second position in terms of authors contributing to water resource research. The National Center for Scientific Research occupies the first position in with 13 articles. As far as authors are concerned, France is second only to the USA. The Journal of Hydraulic Engineering, Flow Measurement and Instrumentation, and Journal of Hydrology are dominant in the number of published articles, according to top cited journals, the Journal of Hydraulic Engineering, Angewandte Chemie - International Edition, and Journal of Physiology and Pharmacology are top among others. Surprisingly, Journal of Hydraulic Engineering ranks first in terms of both number of published articles and citations.

5. CONCLUSIONS

In general, there has been a notable uptick in the quantity of articles published on open channels and the flow capacity. This suggests a heightened focus on water resource studies over the last two decades. These bibliometric findings indicate that sediment transport is a multifaceted and interdisciplinary subject that has been thoroughly studied using a variety of approaches by researchers from 64 countries beginning in 2003. All articles were published in English, with the highest publication numbers coming from USA, China, India, France, Australia, United Kingdom, Canada, Iran, Turkey and Germany. Most publications were from countries with large areas irrigated with open channel networks and with major pressure to overcome problems induced by sediment transport capacity. It is recommended that more efficient global cooperation for improving future worldwide sustainability should concentrate on underdeveloped and developing countries with significant potential for soil and water loss and immediate conservation requirements. This is particularly relevant for countries in central Asia, Africa and South America experiencing agricultural growth. Despite two decades of study, sediment transport continues to face numerous obstacles and unresolved issues.

It is likely that the primary causes for the interruption in research stems from the limited duration of funding for research projects. Consequently, there is a deficiency in sustained, long-term studies and the seamless incorporation of open channel and sediment transport capacity research into agricultural and water resource management frameworks. These problems should be addressed in the future. Furthermore, international research on irrigation and improvement of parameters of open channels would benefit from expanding the scientific exchange on this topic, in particular between emerging and industrial countries, between the agricultural and technological communities as well as between stakeholders and scientists.

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DATA AVAILABILITY

All data generated or analyzed for this study will be made available upon request.

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CONFLICT OF INTEREST

The authors must declare if there is a conflict of interest.

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