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Review

Environmental Hydraulics in the New Millennium: Historical Evolution and Recent Research Trends

Xianglai Zeng [1], Carlo Gualtieri [2], Haifei Liu [1] and Dongdong Shao [1,3,*]

[1] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China; zengxl@mail.bnu.edu.cn (X.Z.); haifei.liu@bnu.edu.cn (H.L.)
[2] Department of Civil, Architectural and Environmental Engineering, University of Napoli Federico II, Via Claudio 21, 80125 Napoli, Italy; carlo.gualtieri@unina.it
[3] Tang Scholar, Beijing Normal University, Beijing 100875, China
* Correspondence: ddshao@bnu.edu.cn; Tel.: +86-10-5880-5053

Abstract: Environmental Hydraulics (EH) is the scientific study of environmental water flows and their related transport and transformation processes in natural water systems. This review provides some remarks about the historical development of EH throughout three different paradigms or ages, namely, the Public Health Age, the Water Quality Age, and finally the Integrated Environmental Hydraulics Age. We further evaluate how EH research has changed in the last 20 years through a bibliometric analysis of the proceedings of the International Symposium on Environmental Hydraulics (ISEH) and Environmental Fluid Mechanics (EFMC) journal articles conducted using Citespace and Leximancer. Authors and affiliations are analyzed to identify patterns of collaboration, followed by an analysis of the temporal evolution of the EFMC impact index as well as its highly-cited articles. Finally, the major EH topics are identified with a comparison between the topics extracted from the two different sources. As the EH field is becoming rapidly global, some topics were confirmed to have attracted more interest in EH such as Flow Condition, Numerical Modelling, Experimental Measurements. It is hoped that our findings could provide a reference for students, academics, and policy-makers related to EH.

Keywords: Environmental Hydraulics (EH); historical development; bibliometric analysis; research topics; Citespace; Leximancer

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1. Introduction

Environmental Hydraulics (EH) is the scientific study of environmental water flows and their related transport and transformation processes affecting the environmental quality of natural water systems, such as rivers, lakes, and aquifers, on our planet Earth [1]. Hence EH constitutes a subset of the Environmental Fluid Mechanics (EFM), which includes both water and airflow in natural systems [1]. These water flows and processes can be tackled by using theoretical analyses, field studies, laboratory measurements on physical models, and numerical simulations. In this broad sense, EH studies the motion of water at several different scales, from millimeters to kilometers, and from seconds to years the fate and transport of species, dissolved and suspended, carried along by this fluid, and the interactions among those flows and geological, biological, and eventually engineered systems. Interestingly, as EH flows are ultimately investigated to achieve an acceptable quality of the aquatic ecosystem, the above definition of EH is not in contrast with that of environmental flow as the hydrological regime required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them [2]. While classical Hydraulics deals with the design and operation of water supply and urban and rural drainage networks, EH is mostly aimed at predicting and decision about water quality in natural channels. Hence, EH integrates the traditional analyses of classical Hydraulics in terms of discharge, velocity, water level, and pressure with that carried out in terms of mass

loading rate, flux, and concentration. With the exception of groundwater flows, EH flows are ubiquitously turbulent, because of the large scales that they typically occupy in natural water systems [1]. Turbulence and stratification, that is related to density differences due to heat, salinity, or suspended matter, are the main ingredients of EH [1].

EH involves several substances (Table 1). They may be gases, solutes, or solids, and they can be naturally present or be produced by human activities. They can be reactive and non-reactive substances. These substances may be discharged into natural waters through *point sources*, which have a well-defined point of discharge, such as a pipeline, and are typically continuous, and *non-point* or *diffuse sources*, which are not confined to a specific location but can enter a given river or lake via overland runoff or through the land and water surface.

Table 1. Substances studied in Environmental Hydraulics, listed from less to most hazardous.

Material Types	Description
Natural inorganic salts and sediments	These materials are not toxic, only become possible pollutants in excessive doses, such as an increase in turbidity.
Waste heat	This is usually related to electric generating plants.
Organic wastes	Domestic sewage containing organic matter can cause damage to the ecosystem, but if adequately treated and dispersed, these materials can be safely assimilated into large water bodies.
Trace metals	Examples are lead, mercury, and cadmium which are naturally present in the environment in very small amounts, but wastewater often has much higher concentrations which can be toxic.
Synthetic organic chemicals	These substances are slow to degrade in the environment and are often bioaccumulated in the food chain, which is capable in some instances of multiplying the concentration by a factor of 10^5.
Radioactive materials	They need a long-term storage without leakage or contamination of natural waters.

Several processes are analyzed in the natural aquatic systems considered in EH. They can be categorized into two broad groups:

- Transport processes are those moving a substance from a point to another within the bulk water and across its surrounding boundaries, such as advection, molecular and turbulent diffusion, gas-transfer, sediment transport, hyporheic exchange.
- Transformation processes are those changing a substance into another substance or the same substance in another form. There are physical, chemical, and biological transformations.

Since its foundation, the EH field has experienced a deep evolution, which was subjected to a rapid shift in the last two decades. This large shift in terms of problems and methods was the main reason for the present study. The question is: which are the most widely investigated EH topics and approaches emerging from a bibliometric analysis of papers published in the last 15 years at the *International Symposium on Environmental Hydraulics* (ISEH), which is a conferences series specialized in EH, and since its launch (i.e., 2001) in the journal *Environmental Fluid Mechanics* (EFMC)?

The study first presents the historical evolution of EH during three different *paradigms* or *ages*: *Public Health Age*, when the unique focus was on microbiological pollution and its impact on human communities, *Water Quality Age*, when the focus was on water quality of aquatic systems, *Integrated Environmental Hydraulics Age* when the traditional problems are integrated with advanced treatment of turbulence and full consideration of the exchanges processes involving any natural water system. Second, the applied methodology of the bibliometric analysis, the tools Citespace and Leximancer, is introduced. Third, the results in terms of nationality and affiliations are presented to identify patterns of collaboration among scientific institutions (universities and research institutes) and authors, which is followed by an analysis of the temporal evolution of the EFMC impact index as well as its

highly-cited articles. Finally, the major EH topics are presented with a comparison between the topics extracted from the two different sources.

2. Historical Development and Future Challenges of Environmental Hydraulics

The close relationship between humans and water goes back to the origin of mankind. Hence, the concerns about the quality of water in aquatic systems, and particularly in those used for drinking water and irrigation, date back to the earliest human communities. In this sense, the first interest in EH flows and processes originate from those communities. However, until people lived by hunting, fishing, and gathering in small groups constantly on the move, waterborne health risks were very limited, except for parasites.

Since approximately 10,000 years ago, most people on Earth became sedentary farmers starting to live concentrated around wells, lakes, rivers, and other sources of water in growing urban centers acting as sources of wastewater discharges [3]. The management of urban wastewater discharge to minimize the risk of microbiological pollution with the associated impacts on human communities represents the original focus of EH, which was unique or largely predominant until the 20th century. Hence, we can propose calling such a long period of time as the *Public Health Age* of EH. The oldest sewerage systems are documented in Mesopotamia and Persia (ca. 4000–2500 BC), Minoan Civilization (ca. 3200–1100 BC), Indus or Harappan Civilization (ca. 3200–1900 BC), and Egypt and China (ca. 2000–500 BC) [4–6] (Figure 1). Alcmaeon of Croton (ca. 470 B.C.) is known to be the first Greek doctor to state that the quality of water may influence the health of people, while later Hippocrates of Kos, (ca.460–ca.370 BC), who is considered the Father of Medicine, presented in detail in the treatise "*Air, waters, places*" (Figure 1) the different sources, qualities, and health effects of water [7]. Greeks and Romans used different methods to improve the quality of the water if it did not satisfy their quality requirements, such as settling tanks (even in series), sieves, filters through sands to remove sediments and the boiling of water [7]. Furthermore, it is believed that Romans used dropshafts for a vertical drop in invert elevation, kinetic energy dissipation, and also flow aeration, to improve water quality [8,9]. If the Romans are commonly celebrated for their aqueducts, which brought vast amounts of water to towns, their sewer systems are quite poorly known. In large towns sewerage systems were vast, but in many other cases they were partially or totally lacking, and streets and rivers worked as sewers. Hence, streets were constantly flushed for cleaning by the waters of aqueducts [4,7]. On the other hand, another EH process, i.e., sediment transport, was present in Antiquity and relevant to irrigation and drainage channels in Mesopotamia and Egypt [5], and the Dujiangyan city system (ca. 300 BC) for controlling silt deposition and flooding in Sichuan province of China (Figure 1) [10].

In Europe, after the fall of the Roman Empire, water supply and sewage systems experienced a decline in maintenance and extension being limited to castles, monasteries, and large towns. The lack of proper sanitation increased the effects of epidemics during the Middle Age and the Renaissance Age in Europe (Black Death, Great Plague of London, etc.). Interestingly, it was just during the Renaissance Age that the Italian word *turbolenza* (turbulence) appears, both as a noun and in its adjectival forms, for the first time just throughout the writings of Leonardo [11,12]. He used that term both in the context of a furious battle, to depict the rapid movement of the soldiers, and of water motion, where he extensively referenced a range of scales of eddies and their random nature at small scales). He wrote: "*The small eddies are almost innumerable, and large things are only turned round by large eddies and not by small ones, small things revolve both in small eddies and large.*" [13] (Figure 1). Such and other descriptions have led Gad-el-Hak et al. [14] and others to conclude that they presage the concept of coherent structures and the Richardson–Kolmogorov cascade [12]. It was argued that he brought to his scientific work the background of a formal artistic apprenticeship and a profound consideration of what was beautiful at the time [12]. In the end, this close relationship between his mathematical and mechanical studies with his work as an artist suggests that Leonardo's vision of Nature lies at the border between

the Hermetic-Cabalist Philosophy of the Renaissance and the Mechanical Philosophy of Nature of the Modern Age [15].

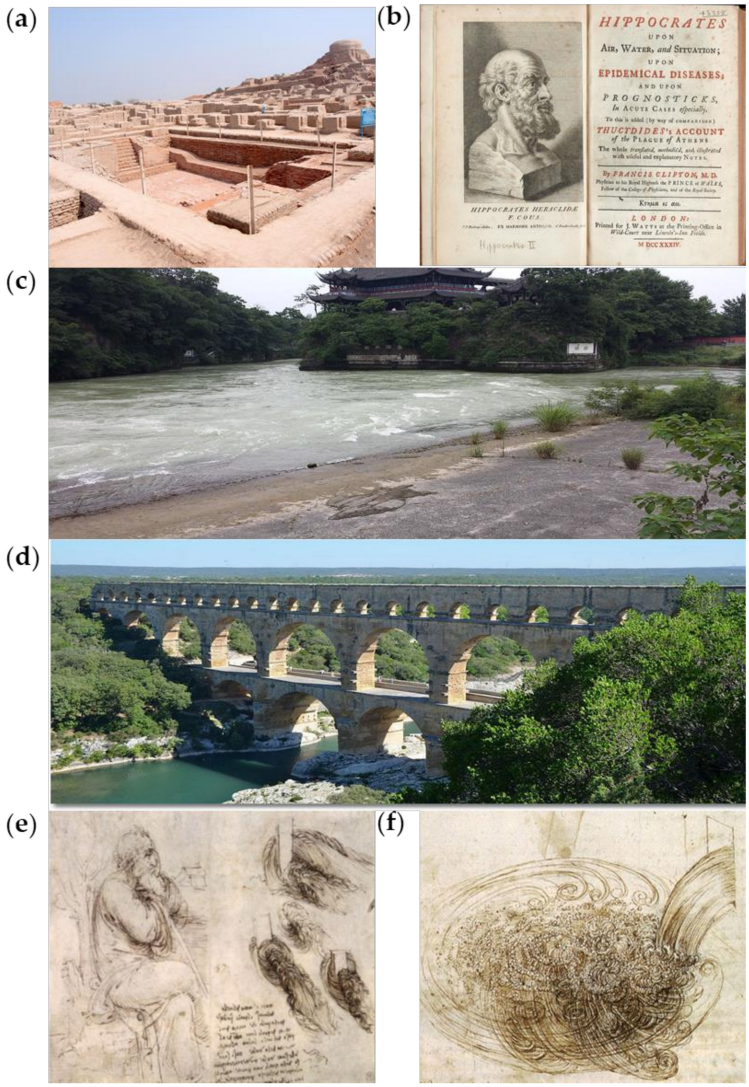


Figure 1. Public Health Age of Environmental Hydraulics. (**a**) Great Bath, Mohenjo-Daro, Pakistan (3000 BC) (Wikimedia, Saqib Qayyum) (**b**) Hippocrates (ca.460–ca.370 BC) (Wikimedia) (**c**) Dujiangyan city system, China (ca. 300 BC) (Photo by C. Gualtieri) (**d**) Roman aqueduct at Pont du Gard, France (1st Century) (Wikimedia) (**e**) Leonardo da Vinci. Seated old man, studying a water current (ca 1500) (Windsor Castle, The Royal Collection, RL 12579) (**f**) Leonardo da Vinci. Sketches of a plunging water jet into a pool, with the resultant turbulent flow (ca 1500) (Windsor Castle, The Royal Collection, RCIN 91266).

Initiation of sediment motion was first described by Albert Brahams (1692–1758), who suggested that initiation of sediment motion takes place if the near-bed velocity is proportional to the submerged bed material weight to the one-sixth power, using an empirically based proportionality coefficient [16].

Since the 18th Century, the industrialization and urbanization of the Western World made more urgent the need to properly manage public health, and the governments started to develop water supply and sanitation. In the meantime, in the 19th, the role of water in the transmission of several important diseases was identified, and filtering of the entire water supply of a town was introduced, while the systematic chlorination of drinking water started in the early 20th century [7]. However, new challenges related to the impact

of wastewater discharges on dissolved oxygen and nutrient levels emerged in the early 20th century. This created the first shift in EH focus from human health only to the water quality of surface and groundwaters. Hence, we may suggest that EH moved from *Public Health Age* to the *Water Quality Age*, starting from the 1920s (Figure 2).

The historical development of the *Water Quality Age* of EH was well outlined by Chapra [17] with emphasis on theoretical analysis and numerical modeling. The first, seminal EH study in the modern sense was that about river water quality from Streeter and Phelps (1925) [18], who developed a model to address the dissolved oxygen cycle in the Ohio River that was impaired by wastewater discharges. Subsequent investigations provided a means to evaluate dissolved oxygen levels in streams and estuaries [19–22]. In addition, bacteria models were also developed [23]. Because of the non-availability of computers, model solutions were closed-form and limited to simple geometries and linear kinetics in steady-state conditions. Since the 1960s, the number of studies related to the EH processes increased rapidly, even because in the 1970s, the rising ecological consciousness drew attention within society on environmental problems, and eutrophication and, later, in the 1980s toxic pollution came under investigation. The first textbooks related to EH were published in those years, i.e., Fischer et al. [24], Thomann and Mueller [25], and later, Chapra [17].

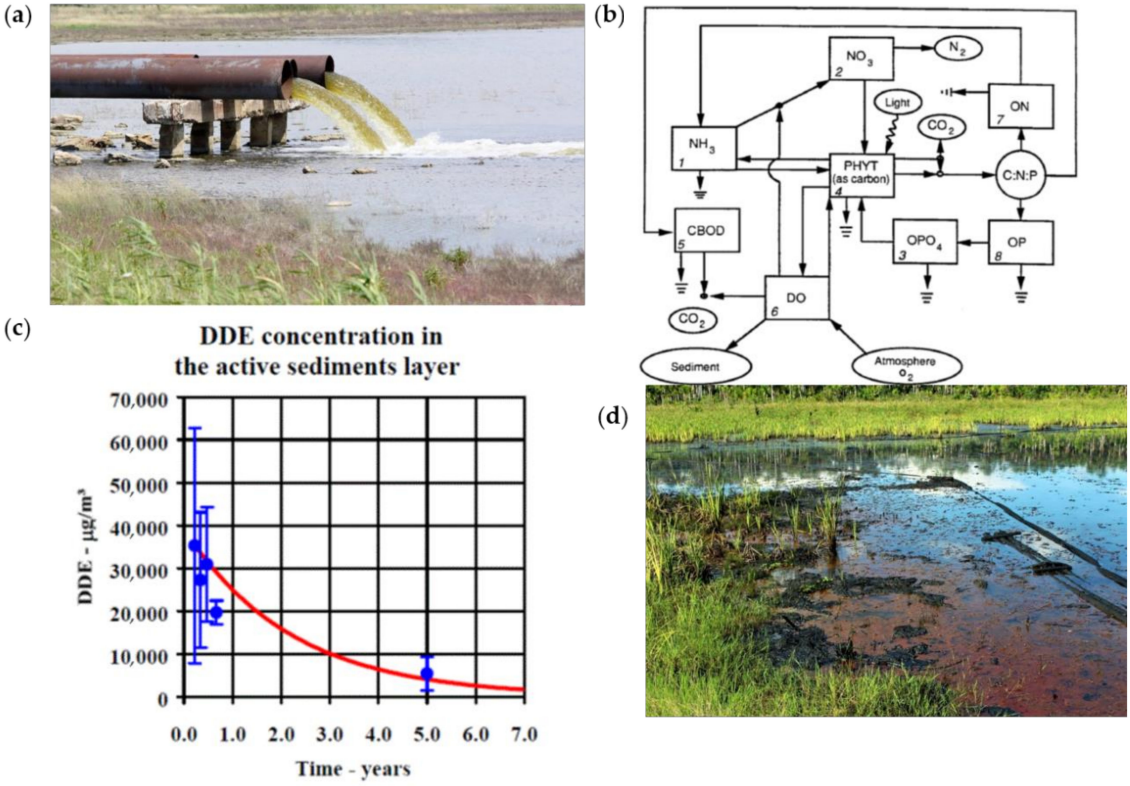


Figure 2. Water Quality Age of Environmental Hydraulics. (**a**) Point-source of pollutants (https://reason.org/commentary/why-are-sewage-spills-just-accepted/ accessed on November 2020), (**b**) Eutrophication kinetic model for WASP versions 3–6 (Wool et al., 2020) [26], (**c**) DDE concentration in the active sediments layer (Gualtieri, 1999) [27], (**d**) Toxic pollution in the Amazon River Basin (https://phys.org/news/2018-04-toxic-arsenic-amazon-basin.html accessed on 1 November 2020).

Since the new millennium, the scientific focus of EH was oriented to the integration of classical water quality-based approaches with (1) the large body of new knowledge about fluid turbulence, (2) the impressive advancements in river morphodynamics, and (3) the full consideration of the connections between physical, chemical and biotic components of a natural water system around the concept of *environmental interface* [28]. This originates the *Integrated Environmental Hydraulics Age* (Figure 3).

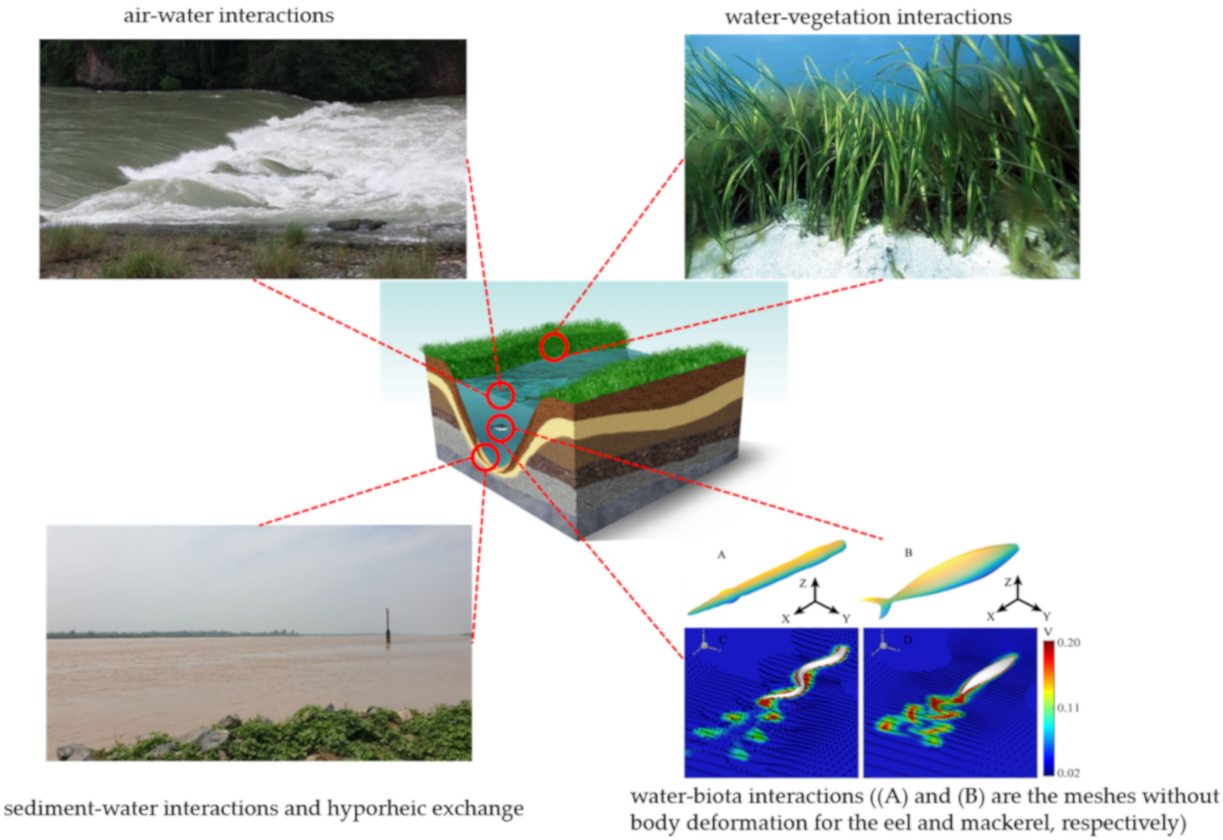


Figure 3. Integrated age of Environmental Hydraulics.

Despite the recent progress, the treatment of turbulence is still a difficult task. Turbulent flows are complex, three-dimensional, intrinsically irregular, and chaotic and are characterized by intense mixing and dissipation at a large range of spatio-temporal scales, and by the coexistence of coherent structures and random fluctuations [29]. Turbulence strongly controls several EH transport processes and their equations [29].

An *environmental interface* can be defined as a surface between two either abiotic or biotic systems that are in relative motion and exchange mass, heat, and momentum through biophysical and/or chemical processes. These processes are fluctuating temporally and spatially. These interfaces in the EH realm are: air-water [30], water-sediment [10], water-aquatic organisms [31], water-vegetation [32], and water-porous medium [33] interfaces (Figure 3). The concept of environmental interface is also consistent with Professor Nikora's remark on the need for integration among Aquatic Ecology, Biomechanics and Environmental Fluid Mechanics into the Hydrodynamics of Aquatic Ecosystems that deals with two key interconnected issues, i.e., physical interactions between flow and organism and ecologically relevant mass-transfer-uptake processes [34]. Further studies are also needed to improve our current knowledge about exchange processes at the environmental interfaces.

In the end, during the last two decades in the *Integrated Environmental Hydraulics Age*, the analysis of EH processes found great benefit from the continuous advancement in the power of computational resources and accuracy/resolution of field/laboratory instrumentation as well as from the rapid advancements of both experimental and numerical studies about turbulence in environmental flows, sediment transport and morphodynamics [10,29,35–37]. EH is currently a vast and broad subject dealing with a large number of complex and interdisciplinary problems in natural water systems using a fully 3D approach and cutting-edge methodologies and technologies.

3. Materials and Methods

3.1. Data Collation

Environmental Hydraulics is an interdisciplinary subject and a journal specialized in EH is still unavailable. Results acquired by retrieving as a keyword the term "Environmental Hydraulics" through Clarivate Analytics Web of Science and Elsevier Scopus cannot completely encompass the field of Environmental Hydraulics. As such, we attempted to explore the research done in EH through the lenses of the proceedings of *the International Symposium on Environmental Hydraulics* (ISEH) and the papers published in the international journal *Environmental Fluid Mechanics* (EFMC) published by Springer Nature [38].

The International Symposium on Environmental Hydraulics (ISEH) is a biennial event specialized in EH that has been organized since 1991. Following the success of the 1st Symposium hosted in Hong Kong, 8 ISEH meetings were held in five different cities across four countries between 1991 and 2018 (Table 2). ISEH has become a major event bringing together scientists and researchers working in the field of EH. ISEH features demonstration and discussion about the main topics and methodologies related to EH. Hence, ISEH can be considered as a representative conference in the field of environmental hydraulics, and the ISEH conference proceedings can provide a potential source to identify the main developments in the field. However, the number of papers published in ISEH Proceedings was not large and the length of each paper was limited to 8–10 pages, suggesting that some other sources such as an international journal should be considered in addition to ISEH Proceedings to achieve a more comprehensive sampling of EH research. As EH constitutes a subset of the Environmental Fluid Mechanics, the journal Environmental Fluid Mechanics (EFMC), which is the unique international journal specialized in that field, was selected to complement ISEH proceedings in our analysis. Generally, EFMC is devoted to the publication of basic and applied studies broadly related to natural fluid systems, particularly as agents for the transport and dispersion of environmental contamination, but a good number of papers are focused on EH themes [38]. It should be acknowledged that there are a number of other journals that publish EH-related works, including more established journals such as the Journal of Hydraulic Research, Journal of Hydraulic Engineering, Water Resources Research, as well as relatively young journals such as Water, Journal of Ecohydraulics, to name just a few. However, these journals all have their specific scopes and are not targeted exclusively on EH publication as Environmental Fluid Mechanics (EFMC). Besides, its volume of the publication since its establishment in 2001 provides a sufficient sample size for our analysis. In addition, there are other conferences and professional events that are occasionally with EH-related themes, such as the serial International School of Hydraulics, whose themes in 2006 and 2019 are "Environmental Hydraulics" and "Recent trends in Environmental Hydraulics" [39], respectively. Likewise, as the title of the conference indicates, ISEH is dedicated to the field of Environmental Hydraulics. It has also been continuously running as a conference series since 1991, and thus provide both the historical perspective and sample size for our analysis. As ISEH and EFMC have different author groups, a combined analysis of the two can play a complementary role and lead to a more comprehensive analysis of the trend of EH. Although the selected ISEH conference proceedings and EFMC journal articles were by no means an exhaustive coverage of EH research, we believe that our dataset is both representative of the field and best suited to the type of bibliometric analysis conducted.

Table 2. List of all ISEH conferences by year, city, and country.

Year	City	Country
1991	Hong Kong	China
1998	Hong Kong	China
2001	Tempe Arizona	USA
2004	Hong Kong	China
2007	Tempe Arizona	USA
2010	Athens	Greece
2014	Singapore	Singapore
2018	South Bend	USA

The subsequent analysis was based upon the abstract of each paper. We collated the papers from ISEH proceedings from 2004 to 2018 (ISEH 2004, ISEH 2010, ISEH 2014, ISEH 2018) as they were the available ones to the authors. In total, 637 conference papers or extended abstracts in PDF format were converted to text files for information extraction and content analysis (Figure 4). For EFMC journal, all the articles published since its launch (2001) were considered, i.e., a total of 852 papers. As some articles do not have abstracts, 826 abstracts were eventually used in the analysis.

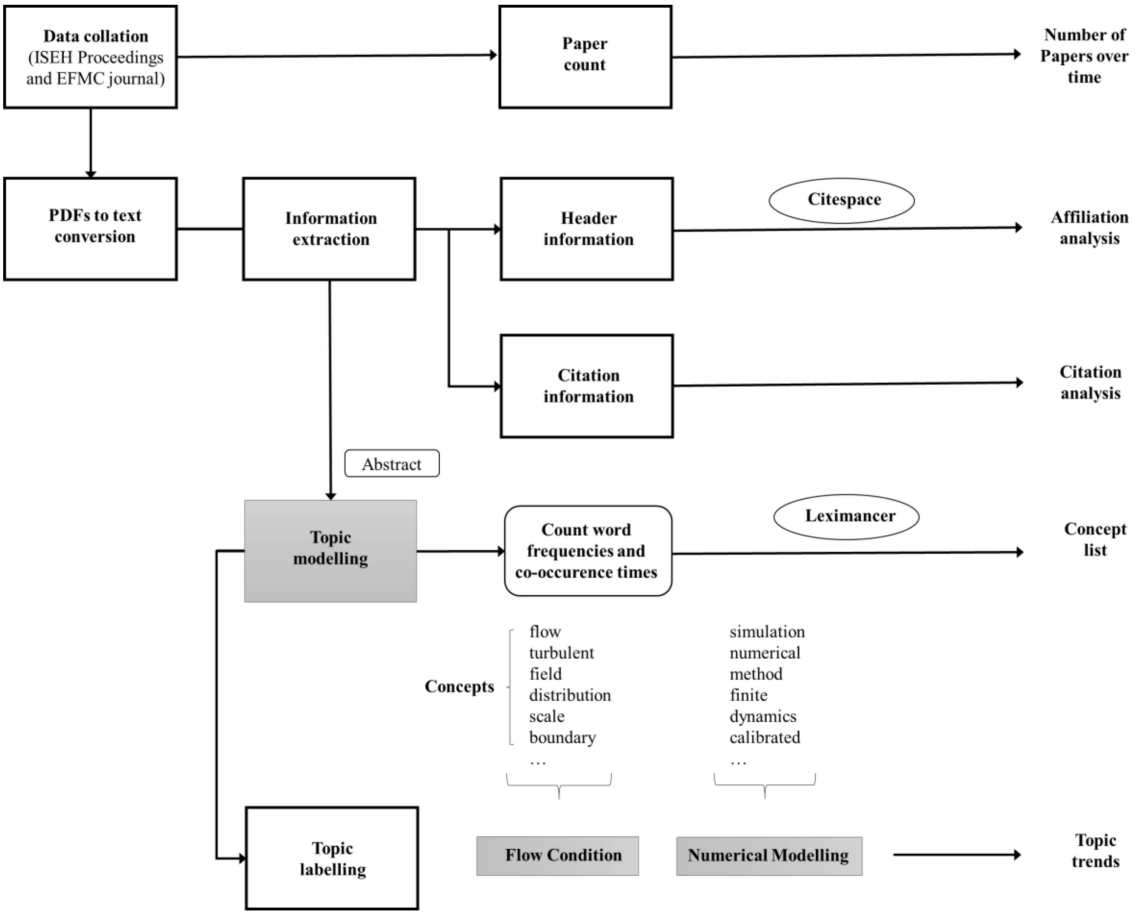


Figure 4. Methodological flowchart for data collation and analysis.

3.2. Information Extraction and Analysis

We chose Grobid for information extraction for its accuracy and user-friendliness [40], and names of authors, affiliation information, and abstracts were extracted from the converted text documents. We collected all affiliation information for subsequent analysis

of the author affiliation network. The author and affiliation information were extracted into a format required by Citespace.

The extracted author and affiliation information were then fed into Citespace to map authors, institutions, and countries, and analyze their interrelationships [41–43]. The contribution of different research-related organizations (universities and research institutes) was estimated by summing up the number of publications in which at least one author of the publication is affiliated with the affiliation in question and irrespective of the author order. Based on author affiliations, an analysis of country information was carried out to show the distribution of countries conducting studies on EH. We also evaluated the degree of collaboration in scientific publication among the authors and institutions (universities and research institutes), as well as the average number of authors and institutions per paper in the ISEH proceedings and EFMC journal and their change over time, etc. The abstracts were used for subsequent content analysis.

3.3. Content Analysis

3.3.1. Topic Modelling

Abstracts are generally regarded as highly condensed content of the articles [44]. The text which contains the abstract but no other information (e.g., authors' names, journal title, article title, etc.) is suitable for automated content analysis (ACA) [45]. ACA is an innovative text-mining and machine learning approach for qualitative and quantitative synthesis of literature. It uses a group of algorithms and probabilistic models to discover the underlying topics within a body of literature in the form of "concepts", or families of words that appear together and are strongly correlated [46].

ACA was applied to implement Leximancer 4.5 software [47], whereby concepts were automatically extracted from the abstracts using unsupervised seeding where the starting point of each concept (a word or concept seed) was identified based on the frequency of its occurrences in each text. Then visual concepts would be created by Leximancer after identifying meanings of text by running its own algorithms, and Leximancer takes text segment as the basic identification unit [48]. Each concept will form a thesaurus of terms by adding terms to each concept seed. If the cumulative weight of thesaurus words exceeds the predefined threshold, the text segment will be recorded as containing a particular concept. In Leximancer, we could specify the number of sentences that comprised each text segment, and the optimal value for this parameter depends on the nature of the data. Because the abstracts are highly condensed text, the text segment size was set to one sentence [47,49]. We made a concept list based on the Leximancer results (see Table S1 in Supplementary Material for additional details) and found that most of these concepts were relevant to EH.

3.3.2. Identification of Topics

A group of concepts that occurred in the dataset most frequently and connected with other recognized concepts within the group very closely was defined as a "topic". When identifying a topic, it was usually represented by the top n words in the group with the highest occurrence [47]. Therefore, based on the occurrence and connections between concepts afforded by Leximancer and our subjective judgment, Labelled Topics (LT) were formed, which could reflect the focused topics in the research field of EH. Finally, we compared the LTs from ISEH and EFMC. It is worth noting that function words (e.g., of, and, the), which did not carry semantic information themselves, were excluded throughout our analysis (see Table S2 in Supplementary Material).

3.4. Temporal Trends

We modeled the corpus for the four conference proceedings separately. We analyzed the average number of authors and institutions per paper for ISEH and EFMC as well as their change over time. For the EFMC journal, we examined its Institute for Scientific Information (ISI) Impact Factor and Scopus SCImago Journal Rank (SJR) variation trends and analyzed the highly cited articles published by the journal. Impact Factor (IF) is a

statistic provided in the JCR (Journal Citation Report) of the ISI. This metric is defined as the total number of citations of the papers published in the previous two years of a journal divided by the total number of papers published in the previous two years of the journal, which is the internationally accepted journal evaluation index. The SJR is a size-independent prestige indicator that ranks journals by their "average prestige per article", which expresses how central to the global scientific discussion an average article of the journal is [50]. To identify high-impact papers in the EFMC journal, we selected articles with a total citation count of at least 50 from the inception of the journal for analysis. The total number of citations from publication to the end of the year in question was defined as TC_{year}. Thus, the highly cited articles were selected based on criterion $TC_{2020} \geq 50$, and the citation information was retrieved from Web of Science.

4. Results and Discussion

4.1. Affiliation and Author Analyses

We analyzed the number of papers for each edition of the ISEH and each year of the EFMC (Figure 5). The number of papers of ISEH proceedings fluctuated from around 150 to above 300, whereas the annual publication volume of EFMC journal showed an overall increasing trend throughout the time.

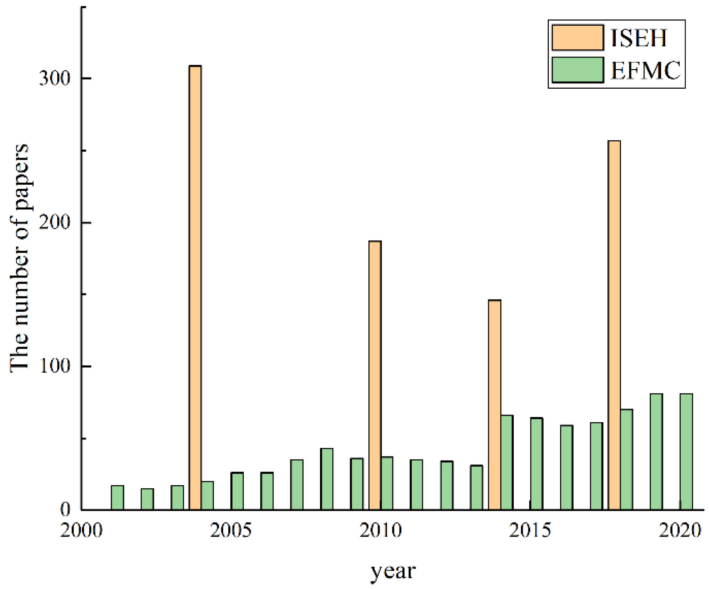


Figure 5. The number of papers for each edition of the ISEH and each year of the EFMC.

The proportion distribution of publications by research-related organizations (universities and research institutes) and by geographical areas is illustrated in Figure 6 for all years. For ISEH, Japan and China stand out with far more papers than other countries, which are followed by the United States and Greece. Among the institutions, Hohai University, Kyoto University and Tohoku University are far ahead in the number of publications. For EFMC, the United States appears to be the main publishing force, followed by Australia and China, and the University of Queensland is the leading institution. Regarding the collaboration pattern, it appears that the most productive institutions tend to cooperate, generating several major clusters of institutions, each of which usually has one or more core institutions. In general, more clusters are formed in ISEH than in EFMC.

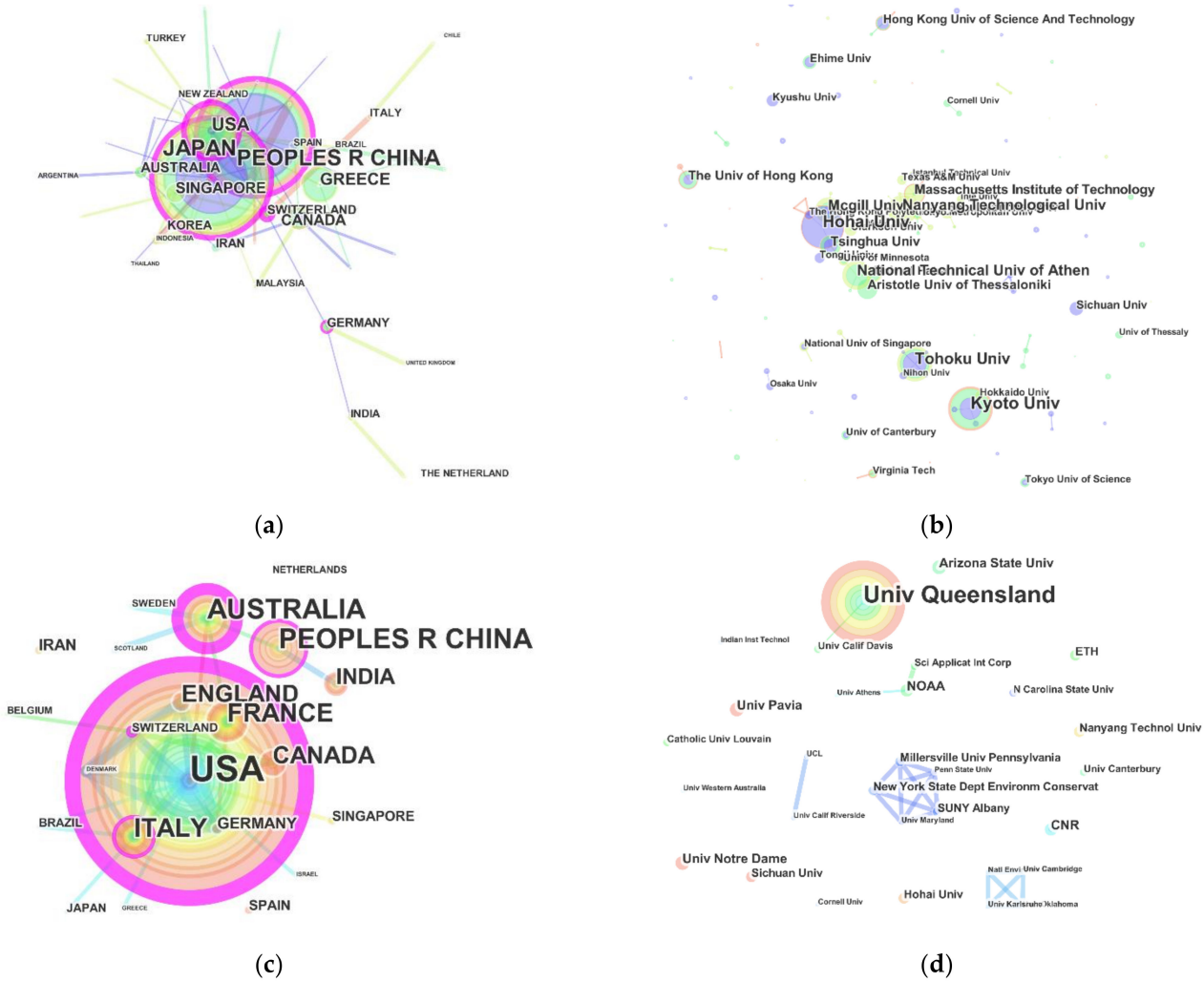
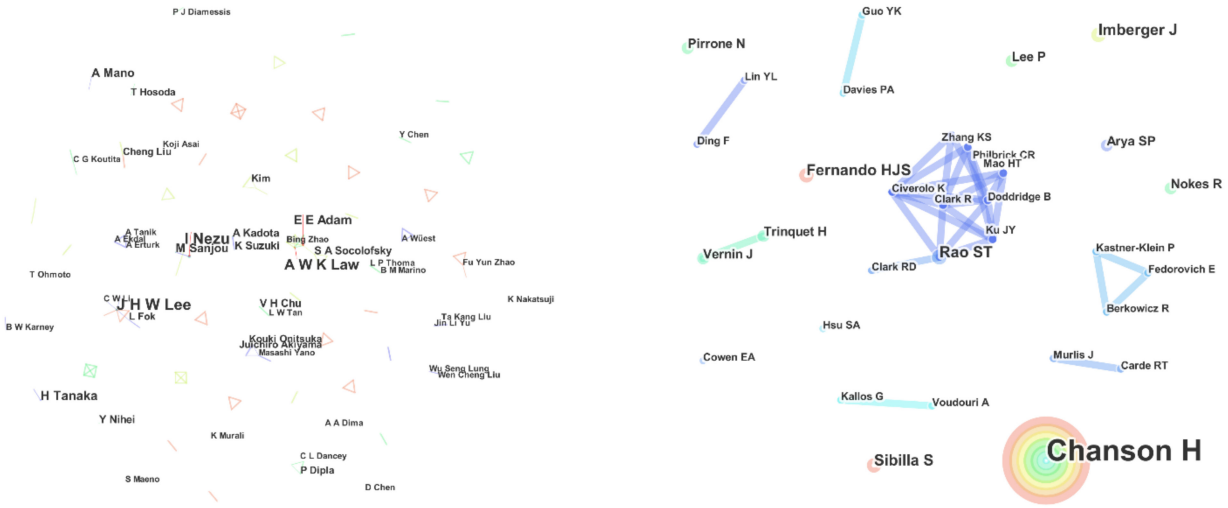


Figure 6. Visualization map of the distribution of papers among research-related organizations (universities and research institutes) and geographical areas. Note: The higher the frequency of occurrence, the larger the font displayed in the figures. (**a**) Country distribution of ISEH proceedings (**b**) Institution distribution of ISEH proceedings (**c**) Country distribution of EFMC articles (**d**) Institution distribution of EFMC articles.

The author distribution of the papers is illustrated in Figure 7. A similar collaboration pattern among the most productive authors as that among the institutions can be observed. Numerous small clusters are formed in the ISEH proceedings, whereas a smaller number of larger clusters are formed in the EFMC journal. Notably, however, it was found that Prof. Hubert Chanson from the University of Queensland, Australia, who authored/co-authored a very large number (45 of 854) of papers published in EFMC journal, tended to publish independently.



(**a**) (**b**)

Figure 7. Visualization map of the author of papers. (**a**) Author distribution of ISEH proceedings (**b**) Author distribution of EFMC articles.

Figure 8 shows the department to which authors are affiliated for EFMC journal articles. The results indicate that the majority are from Civil Engineering (443), Environmental Engineering/Sciences (359), and Water Engineering (115) with some overlapping among each other. The changes of the departmental affiliation throughout the time are shown in Figure 9. According to the result of the linear fitting, the ratios of the number of articles published by each departmental category to the total number of articles in each year increased persistently for all three departmental categories.

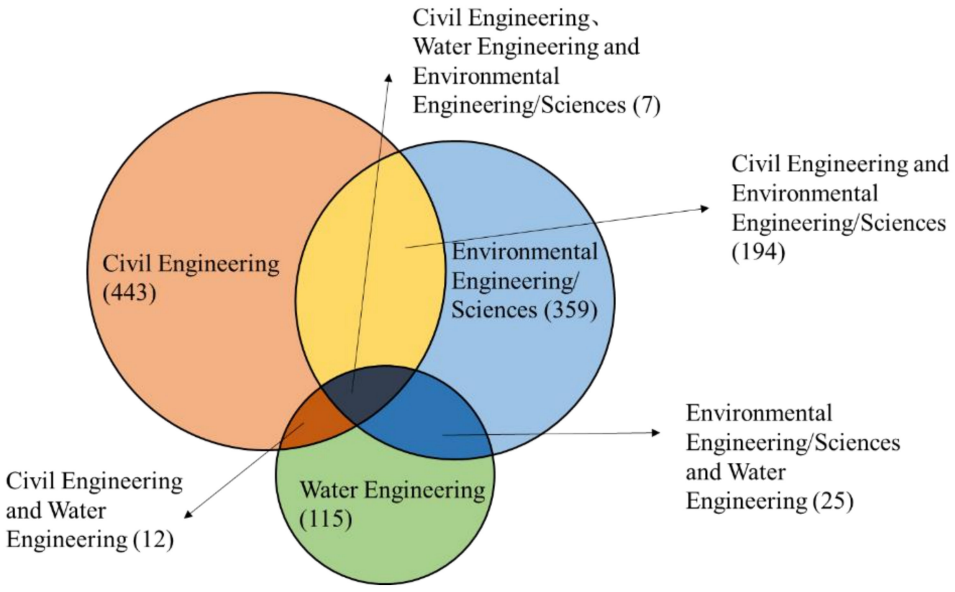


Figure 8. Venn diagram of the author's departmental affiliation.

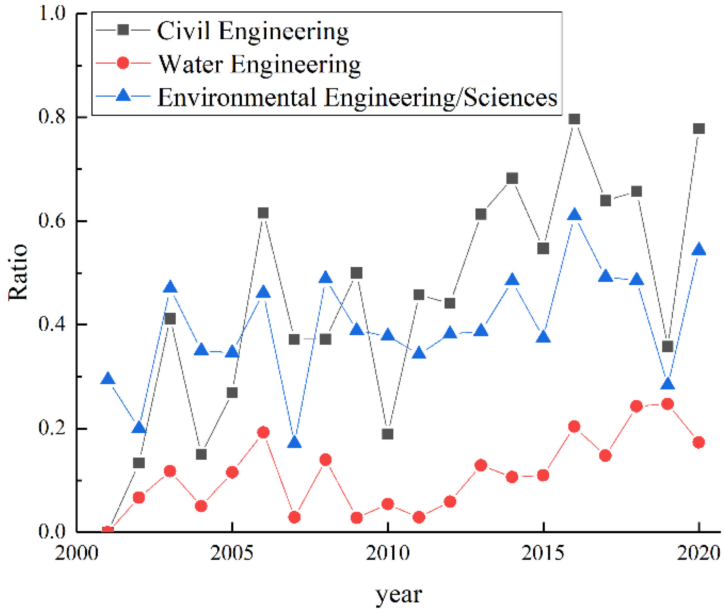


Figure 9. Temporal trend of the ratio of the number of articles published by each departmental category to the total number of articles published in EFMC each year.

We also analyzed the average number of authors and institutions per paper for each ISEH meeting and EFMC journal in each year. Figure 10 shows that the average number remains stable and does not fluctuate greatly, except for the average number of institutions for ISEH proceedings that show a slight persistent growth over the years. For the gross average, it was found that both the average number of authors (3.25 versus 2.95) and institutions (2.13 versus 1.29) per paper are greater in EFMC journal than in ISEH proceedings, suggesting a stronger level of collaboration among EFMC authors.

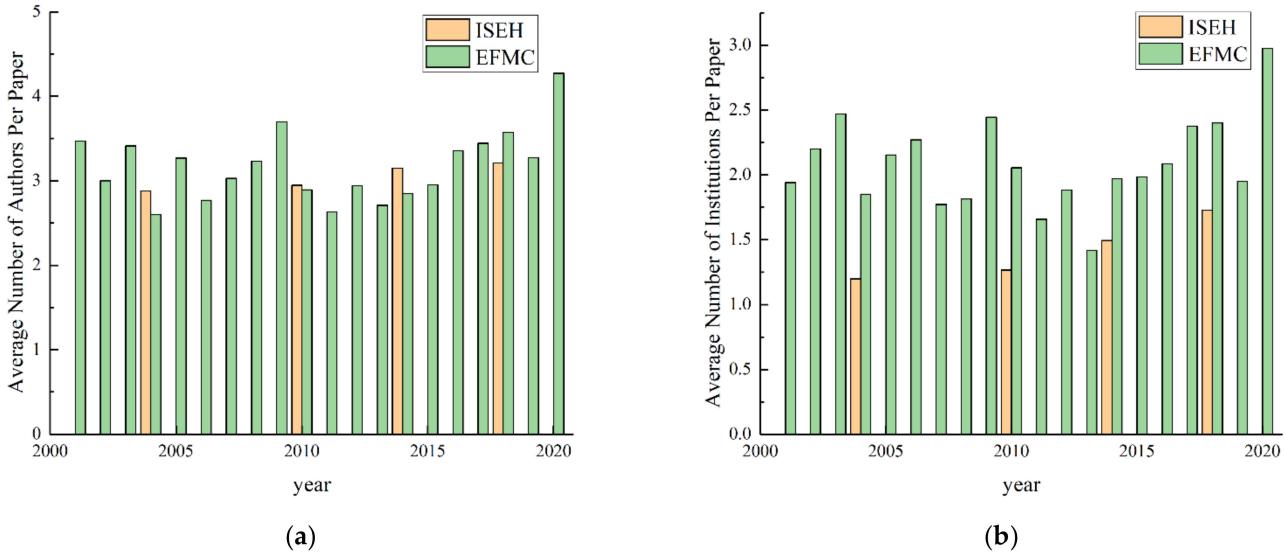


Figure 10. (**a**) Change in the average number of authors per paper. (**b**) Change in the average number of institutions for four proceedings of ISEH (2004, 2010, 2014, and 2018), respectively, and journals of EFMC in each year.

4.2. EFMC Impact Indices and Highly Cited Articles

Figure 11 presents the variation of the ISI Impact Factor and Scopus SJR for EFMC journal over the years. Significant fluctuation can be observed for both metrics, and they both peaked in 2012.

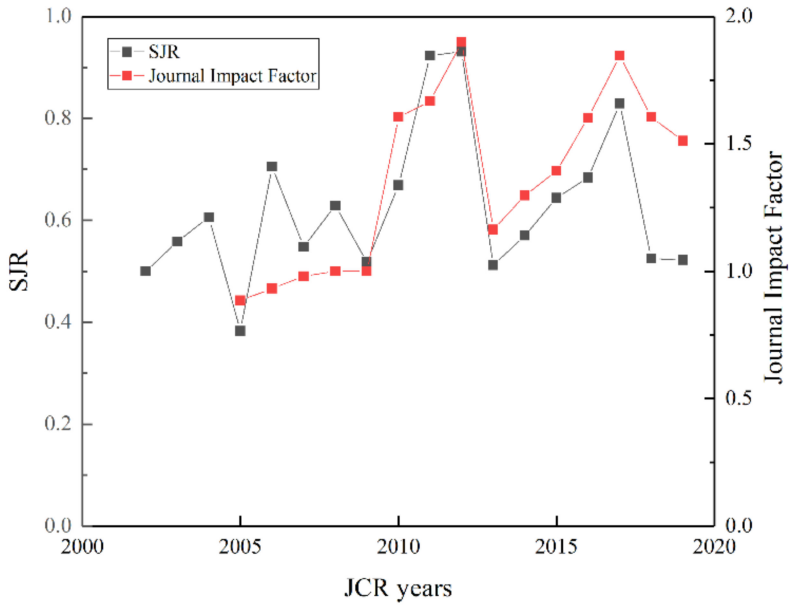


Figure 11. ISI Impact Factor and Scopus SJR variation trend for EFMC journal.

Among all papers published in EFMC since its launch, a total of 31 articles satisfied the selection criterion of highly cited articles ($TC_{2020} \geq 50$). However, some of the articles dealt with air and other topics that were deemed irrelevant. We removed those articles and retained 20 articles related to EH for further analysis (Table 3). The maximum and average values of TC_{2020} were 209 and 83, respectively. Among the 20 articles, the majority were published between 2006 and 2010 (13 articles), followed by 4 articles between 2001 and 2005, and 3 articles between 2011 and 2015, and no articles published between 2016 and 2020 are currently highly cited, which might be because citation takes time to accumulate. The main topics covered in the highly-cited articles can be categorized as follows: (1) Flow-vegetation interaction: flow-vegetation interactions and their impacts on mass transport (paper 1, 3, 4, 9 and 15) [51–55]; (2) Canonical flows: such as buoyant jets (paper 2, 8 and 18) [56–58], multiphase flows (paper 6) [59], gravity currents (paper 11) [60], and shallow flows (paper 14) [61]; (3) Geophysical flows: such as landslide-induced waves (paper 7) [62], estuarine plumes (paper 13) [63]; (4) Engineering issues: such as free-surface aeration (paper 5) [64], ship-generated waves (paper 10) [65], spillway (paper 12) [66], and scouring (paper 16) [67]; (5) Pollutant transport: such as river dispersion (paper 17) [68].

Table 3. The most cited articles in EFMC journal.

Rank (TC_{2020})	Rank (C_{2020})	Citation/Year	Article Title	References
1 (209)	1 (20)	13.93	The structure of the shear layer inflows over rigid and flexible canopies	Ghisalberti, M. and Nepf, H.M. (2006)
2 (161)	4 (12)	9.47	Integral model for turbulent buoyant jets in unbounded stratified flows. Part I: Single round jet	Jirka, G.H. (2004)
3 (148)	3 (14)	11.38	Interaction between flow, transport, and vegetation spatial structure	Luhar, M. et al. (2009)

Table 3. *Cont.*

Rank (TC_{2020})	Rank (C_{2020})	Citation/Year	Article Title	References
4 (106)	5 (10)	6.63	Mass transport in vegetated shear flows	Ghisalberti, M. and Nepf, H.M. (2005)
5 (89)	6 (10)	7.42	Turbulent air-water flows in hydraulic structures: dynamic similarity and scale effects	Chanson, H. (2009)
6 (75)	2 (16)	6.25	An equation of motion for particles of finite Reynolds number and size	Loth, E. and Dorgan, A.J. (2009)
7 (73)	8 (7)	5.62	Impulsive waves caused by subaerial landslides	Ataie-Ashtiani, B. et al. (2008)
8 (65)	12 (6)	5.91	Mixing and boundary interactions of 30A degrees and 45A degrees inclined dense jets	Shao, D and Law, A. W. (2010)
9 (61)	17 (1)	4.07	Prediction of near-field shear dispersion in an emergent canopy with heterogeneous morphology	Lightbody, A. F. and Nepf, H. M. (2006)
10 (61)	16 (2)	3.81	Fast ferry traffic as a qualitatively new forcing factor of environmental processes in non-tidal sea areas: A case study in Tallinn Bay, Baltic Sea	Soomere, T. (2005)
11 (60)	9 (7)	8.57	Dynamics of the head of gravity currents	Nogueira, H. I. S. et al. (2014)
12 (58)	7 (9)	5.8	Laboratory measurements and multi-block numerical simulations of the mean flow and turbulence in the non-aerated skimming flow region of steep stepped spillways	Bombardelli, F. A. et al. (2011)
13 (57)	10 (7)	4.75	Dynamics of the buoyant plume off the Pearl River Estuary in summer	Ou, S. et al. (2009)
14 (54)	18 (1)	4.15	Experimental and numerical analysis of flow instabilities in rectangular shallow basins	Dewals, B. J. et al. (2008)
15 (53)	14 (5)	5.3	Flow regimes in gaps within stands of flexible vegetation: laboratory flume simulations	Folkard, A. M. (2011)
16 (53)	15 (4)	3.79	Numerical simulation of scour around pipelines using an Euler-Euler coupled two-phase model	Zhao, Z. and Fernando, H. J. S. (2007)
17 (52)	11 (7)	3.47	Parameter estimation for fractional dispersion model for rivers	Deng, Z. et al. (2006)
18 (51)	13 (6)	3.4	Integral model for turbulent buoyant jets in unbounded stratified flows. Part 2: Plane jet dynamics resulting from multiport diffuser jets	Jirka, G. H. (2006)

TC_{2020} number of citations till 2020, C_{2020} number of citations in 2020.

4.3. Major Topics in Environmental Hydraulics

A co-occurrence matrix of concepts from the conference proceedings of the four ISEH meetings and EFMC journal was produced using Leximancer, and 8 labeled topics of ISEH proceedings and 6 labeled topics of EFMC journal articles were formed based on their interconnected concepts (Table 4). They represent the topics of focus in Environmental Hydraulics in recent years. We mapped the labeled topic map of Environmental Hydraulics (Figure 12) to analyze the relationship among the hot topics of Environmental Hydraulics in recent years. As shown in Figure 12, the size of the gray area reflects the frequency of the concepts appearing together with other words on the map, and the larger grey dots represent the concept having stronger associations with other concepts. Spanning trees (gray lines) indicate connections between specific concepts. Closely related concepts were grouped together and clustered into labeled topics, and the larger and colored circles depict dominant labeled topics, the overlaps between which are meaningless. The heat-mapping

of labeled topics indicates the frequencies of their uses [48,69], with the hottest or most important labelled topic appearing in red, and the next hottest in orange, and so forth.

For ISEH proceedings, studies on Flow Condition (32.8%) appear to be the most prominent subject, followed by Numerical Modelling (21.1%). Additional major topics include Sediment Transport (19.6%), Experimental Measurement (9.0%), Hydrologic Monitoring (7.5%), etc. For EFMC articles, studies on Flow Condition (41.7%) appear to be the most prominent subject, followed by Experimental Measurements (13.1%). Additional major topics include Turbulent Evolution (12.7%), Air-water flow (11.9%), Numerical Modelling (11.8%), etc.

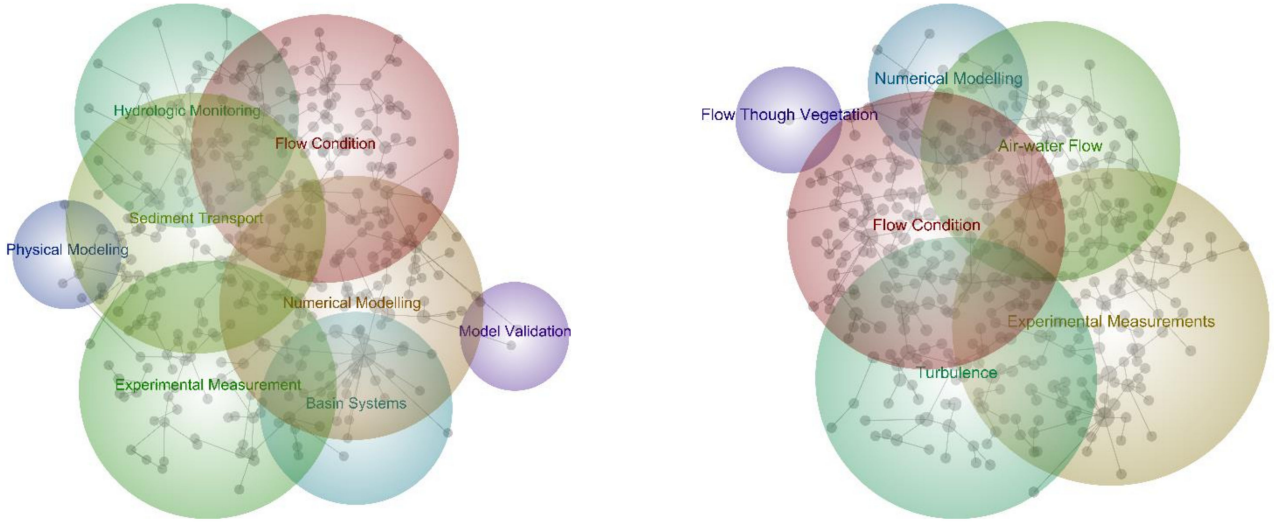


Figure 12. Labeled topic map of Environmental Hydraulics. (**a**) ISEH conference proceeding (**b**) EFMC journal.

Table 4. List of labeled individual topics.

	Hits	Labeled Topic	Concepts				
ISEH proceedings	4806	Flow Condition	flow momentum evolution supercritical	turbulent intensity interaction subcritical	distribution channel shear stress	scale spatial critical	boundary pressure vortices
	3091	Numerical Modelling	simulation ANN grid	finite computational LES	dynamics 2D k-ε	calibrated 3D RANS	mathematical depth-averaged DNS
	2868	Sediment Transport	bed floodplain erosion	slope downstream reclamation	densimetric upstream bankfull	suspended load	column aquatic
	1325	Experimental Measurement	velocity wake	vertical velocimetry	horizontal ADV	Reynolds ADCP	particle
	1107	Hydrologic Monitoring	systems hydrological	hydrodynamic inundation	monitoring	watershed	drainage
	1063	Basin Systems	basin lake	rivers capacity	reservoir dam	groundwater rainfall	runoff shoreline
	250	Physical Modeling	diffusion LIF	bubble PLIF	phase ADV	tracer LDV	trajectory PIV
	156	Model Validation	validated discretized	accuracy calibrated	analytical data	verified comparison	intervals

Table 4. *Cont.*

	Hits	Labeled Topic	Concepts				
EFMC articles	10,157	Flow Condition	flow distribution shear stress	velocity plume wake	mixing jet	vertical fluctuations	parameter laboratory
	3191	Experimental Measurements	measurements temperature	data spatial	field theory	experimental tunnel	concentrations
	3099	Turbulence	conditions free	experiments eddy	momentum	evolution	pressure
	2889	Air-water Flow	transport 3D	particles diffusion	dynamics buoyant	air hydrodynamic	shallow
	2864	Numerical Modelling	simulations approaches	equations sources	dispersion computational	methods	performance
	2172	Flow Though Vegetation	current vortex	channel slopes	bed propagation	vegetation coherent	gravity dense

5. Conclusions

Environmental Hydraulics (EH) is the scientific study of transport and transformation processes affecting the environmental quality of natural water systems. EH problems accompany human communities since their establishment. In the *Public Health Age*, EH problems focused on microbiological pollution and on the need to have safe drinking water. With industrialization and urbanization, the challenges related to the impact of wastewater discharges on dissolved oxygen and nutrient levels on the surface and groundwater quality emerged as the main EH focus leading to the *Water Quality Age* of EH. Finally, since the new Millennium, EH experienced a new shift as it became imperative to integrate classical water quality-based approaches with new knowledge about fluid turbulence, the impressive advancements in river morphodynamics, and the full consideration of the exchange processes across the *environmental interfaces* existing in any natural water systems. This is the current *Integrated Environmental Hydraulics Age*.

This study aimed at identifying and discussing the recent research trends of EH in the last two decades. By analyzing the papers from the conference proceedings for the 4 ISEH meetings from 2004 to 2018 and the EFMC journal from 2001 to 2020, it was found that many research-related organizations (universities and research institutes) and authors preferred a collaborative research approach, generating several major clusters of institutions and authors, and this was especially true in core institutions and authors. While the average number of authors and institutions per paper remained stable in the last two decades, researchers tended to engage more collaboration when it came to formal publication work in journals such as EFMC than preparing to attend academic conferences such as ISEH. In terms of departmental affiliation, the majority of the authors were from Civil Engineering and Environmental Engineering/Sciences. ISI Impact Factor and Scopus SJR for EFMC journal both peaked in 2012 and showed significant fluctuation throughout the year, and the highly-cited articles of the journal were mostly published between 2001 to 2010. Through topic analysis, it was found that Flow Condition, Numerical Modeling, and Experimental Measurements represent the most popular topics in EH in the last two decades.

Although the data were limited, our study was based on the results of topic modeling, which enhances the objectivity and repeatability of the analysis results. It is hoped that our findings could provide a reference for students, academics, and policy-makers related to EH.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w13081021/s1, Table S1: ISEH Concept List; Table S2. EFMC Concept List.

Author Contributions: Conceptualization, D.S. and C.G.; methodology, X.Z.; software, X.Z.; validation, X.Z., D.S., H.L., and C.G.; formal analysis, X.Z.; investigation, X.Z.; resources, D.S.; data curation, X.Z. and D.S.; writing—original draft preparation, X.Z. and C.G.; writing—review and editing, X.Z., D.S., and C.G.; visualization, X.Z.; supervision, D.S. and C.G.; project administration, D.S.; funding acquisition, D.S. All authors have read and agreed to the published version of the manuscript.

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