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Bibliometric Profile of Global Scientific Research on Monitoring and Assessment of Aquatic Toxicology (2015-2019)

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Abstract

In recent decades, extensive research has been conducted to explore toxicity in the aquatic environment. In spite of the extensive research conducted on toxicity in the aquatic environment, there is a need for a comprehensive analysis that integrates various aspects of the research landscape. This study focused on: i) providing characteristics of research areas of publications, ii) assessing productive countries and institutions, iii) identifying research topics based on certain keywords and defining research hotspots, and iv) assisting in the perspective of current hot topics, future trends, and challenges. A systematic review and analysis of studies on natural water and wastewater toxicology from the Scopus database were conducted, covering the period from 2015 to 2019. This study presents a temporal distribution of publications considering several factors, such as materials, types of toxicity, test organisms, journals, and country. By conducting a comprehensive search on Scopus, our study identified a total of 7,043 articles on acute (62%) and chronic toxicity (38%). Freshwater environments accounted for the majority of acute and chronic toxicity studies, while studies on wastewater environments were relatively scarce. *Daphnia magna* emerged as the most used organism, representing 41% of acute toxicity studies and 27% of chronic toxicity studies. The results show that China is the most productive country with 330 articles. The study has made it possible to visualise an effective contribution to science by filling the existing gaps. It has provided some perspectives and insights for the development of further research on this topic.

Keywords: Ecotoxicity, acute, chronic, aquatic systems, bibliometric analysis

1. INTRODUCTION

Examining the studies of each branch of science shows the stages of development in the field. It is also important to determine which topics have been the focus over time [1]. Bibliometric analyses are important tools to assess and measure the growth of the literature on a particular topic. Recently, the bibliometric method has been used in various contexts to identify research gaps for future studies and to show trends in research activity [2-7]. Therefore, bibliometric analysis is nowadays a promising alternative approach for assessing research on water and wastewater toxicity.

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Aquatic toxicology is the scientific field that examines the impact of substances and physicochemical conditions on plants and animals residing in water ecosystems. It encompasses the investigation of mechanisms through which alterations in water quality or food availability influence the growth, reproduction, behavior, and survival of aquatic organisms. The discipline of aquatic toxicology delves into the effects of both synthetic chemicals and naturally occurring substances, as well as human-induced and natural activities, on aquatic organisms at various levels of organization. These levels range from subcellular and individual organisms to communities and ecosystems [5].

The most effective way to protect aquatic ecosystems is to measure and monitor changes in the area of concern [8]. Toxicity testing is important for monitoring water quality and discharge areas, protecting organisms in the food chain and determining the stimulatory effects of toxic substances on organisms [9-11]. Toxicity tests conducted for this purpose attempt to determine the toxic effect on the selected organism (acute/chronic) based on exposure [12]. Factors such as organism types, trophic levels (producers, primary and secondary consumers, decomposers), taxonomic groups, organism species and strains, age, sex, temperature, body mass index, maturity, and experimental environmental conditions affecting the quality of life of the organism are effective in determining the endpoint of toxicity [13]. By conducting bioanalysis studies, ecotoxicity can be demonstrated in environmental risk assessment and water quality/pollution control [14]. Pollutants originating from industrial, domestic and agricultural activities first flow into rivers and enter lakes and oceans through them. Pollution of water bodies not only affects the creatures they harbour, but also reaches humans through the food chain [15-18].

Zooplankton are frequently utilized in ecotoxicological tests due to their high sensitivity to toxic chemicals and their crucial role in the lentic food chain. These organisms can provide valuable insights into their responses to toxicity and the overall effects on the ecosystem [19-20]. However, not every organism that meets the requirements of a toxicity test may be suitable. For instance, in environments with lower toxicity, such as surface waters, it is more appropriate to employ more sensitive test organisms.

Despite the considerable research efforts dedicated to the study of toxicity in the aquatic environment, there remains a need for a comprehensive analysis encompassing the various facets of the research landscape [5]. The aim of this study is, therefore, to evaluate the studies on toxicity in water and wastewater from the Scopus database (Elsevier), in order to address the existing research gaps comprehensively. This study focuses on several objectives: i) providing characteristics of the research areas covered in the publications, ii) assessing productive countries and institutions, iii) identifying research topics based on specific keywords and defining research hotspots, and iv) offering insights into current hot topics, future trends, and challenges.

2. MATERIALS AND METHODS

2.1. Keywords Used in Literature Search

This study utilized the Scopus search engine to identify acute and chronic toxicity studies in the field of environmental sciences conducted between 2015 and 2019. The identification of toxicity studies was performed in two steps using predefined keywords, encompassing research on both acute and chronic toxicity. In the first step, a general search was conducted using keywords such as "toxicity," "acute/chronic," "journal," "environmental science," "article," and "years" to identify relevant publications. The second step involved a focused search using the keywords "toxicity" and "acute" or "chronic" or "freshwater (FW)" for freshwater environments, "marine water (MW)/seawater (SW)" for seawater environments, and "wastewater (WW)" for wastewater

environments. Additionally, the years "2015," "2016," "2017," "2018," and "2019" were selected to assess changes over time, applying the restriction to both the first and second search criteria.

2.2. Limitations of the Study

The identified search was limited to the research field of environmental science. In this way, study areas such as medicine, chemistry and pharmacology, or any other departments of toxicology were excluded.

Publications were searched for the words "article" or "original research" to identify original studies. Articles published in book chapters, reviews, opinion pieces and conference papers were excluded from the analysis for reasons of scientific acceptability. In addition, publications that did not contain multiple research informants such as organism, environment and/or substance were not included in this study. These studies were included in the group "Other".

2.3. Analysis and Visualization of Data in the Study

Microsoft Excel® and VOSviewer® (version 1.6.16) were used for the visual representation of the data. The data obtained on organisms, countries and journals were transferred to the VOSviewer® programme and displayed visually, as the VOS analysis tool shows the best performance among the other techniques [21]. VOSviewer® supports the visual representation and verification of bibliometric networks by providing easy access to the VOS mapping method [21]. The interpretation of the images, the size of the circles on the map, the font used, and the number of classes are indicated by colour clusters. The interpretation of the similarity and relationship between the circles is indicated by the distance between the circles [22].

3. RESULTS AND DISCUSSION

To interpret the results of the study, each article identified in the Scopus search tool between 2015 and 2019 was categorised by research environment (freshwater, seawater, and wastewater), toxicity (acute/chronic), authors, organism, article title, journal name and years. The data are presented and interpreted in subheadings by toxicity exposure, research setting, years, test organism, countries, and published journals.

3.1. Distrubution by Exposure

Based on the Scopus search, 7043 articles were found on acute and chronic toxicity between 2015 and 2019 in the first search. Of these, 62% were acute, while 38% of them were chronic studies. The second search revealed 1162 articles on acute toxicity and 613 articles on chronic toxicity. 5268 articles identified out of 7043 products are included in the "others" category (see subtitle 2.2). Of the articles in the "Others" category, 3186 of them were related to acute toxicity and 2082 to chronic toxicity (Figure 1).

The first search found a large number of articles because there was no restriction of "FW, WW, SW and MW" in the search field. In the second search, the keywords "FW, WW, SW and MW" were used to restrict the research environment in aquatic areas. However, despite the use of keywords to restrict the research environment, it was found that there are also studies where the search field is not aquatic areas. The present study is based on literature searches where samples were taken from aquatic environments for toxicity testing.

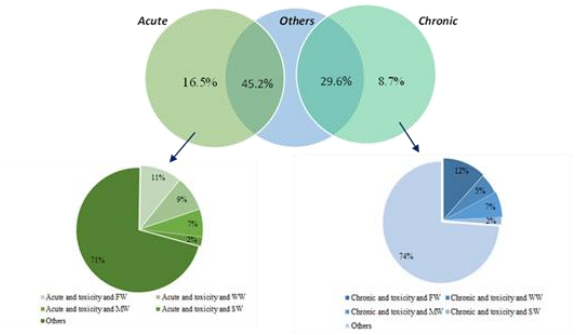

Figure 1 Distribution by exposure ("Others" category considered)

No search criteria were used to identify studies involving organisms. For this reason, each of the articles was examined individually, and the articles that did not contain organism species were excluded. In this way, the types of organisms were determined. However, the limitation of the search field is not the only factor here. Although the keywords "toxicity, acute, chronic, FW, WW, SW and MW" and the limiting criteria "journal, article, environmental science, 2015, 2016, 2017, 2018 and 2019" were used, it was found that some studies did not meet these criteria. When the articles found in the second search were examined individually, studies that were not related to environmental science were excluded to ensure that publications from different disciplines were not encountered as science. For this reason, the importance of examining the content of the articles became apparent. All these identified studies were included in the category "Other".

The results indicated a higher number of acute toxicity studies compared to chronic toxicity studies. This difference can be attributed to the fact that acute toxicity tests provide faster results for researchers compared to chronic toxicity tests. Furthermore, chronic toxicity studies tend to be more costly and time-consuming [23]. Acute toxicity tests are often preferred in emergency situations or when there is a need for a quicker assessment of chemicals, wastewater, or water samples. However, combining acute toxicity studies with chronic toxicity studies enables a more comprehensive toxicological evaluation, allowing for the consideration of various risk scenarios.

3.2. Distrubution by Environment

The second search, limited to the research setting, found 1775 articles, of which 682 were in FW, 596 in SW and 497 on WW. Most studies on acute toxicity were found in FW with a rate of 36% and the fewest in WW environments with a rate of 31%. On the other hand, most chronic toxicity studies were in FW (46%) and the fewest in WW (22%) (Figure 2).

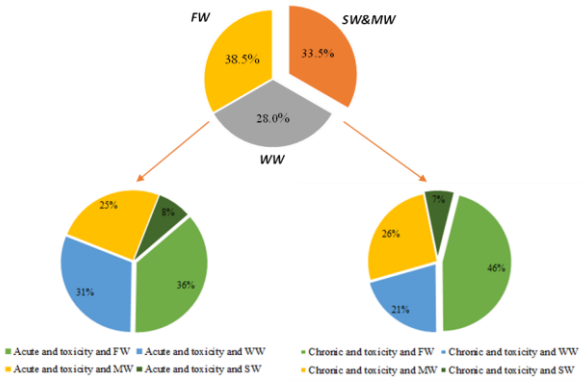

Figure 2 Intersection of acute and chronic toxicity studies across different research environments (2015-2019)

In some studies, both acute and chronic cues were included together. In total, there are 311 articles containing both acute and chronic toxicity studies. The overlap of acute and chronic toxicity studies included 147 FW, 87 SW and 69 WW studies.

Given the geographical locations of countries, freshwater ecosystems tend to be more widespread and accessible compared to seawater ecosystems. Freshwater resources encompass a variety of water bodies, including lakes, rivers, and streams, whereas seawater ecosystems are limited to seas and oceans. Considering that freshwater ecosystems play a crucial role in sectors such as agriculture, drinking water supply, energy production, and industry, addressing water resource conservation and human health becomes of greater importance. Consequently, researchers may be inclined to

focus more on understanding the toxic effects within freshwater ecosystems. However, it is important to acknowledge that the choice of test organisms used can also be considered as another contributing factor. *Daphnia magna*, a small planktonic crustacean, is commonly used for toxicity tests that provide rapid results. For this reason, "freshwater" was the most commonly studied medium in both acute and chronic toxicity studies, while seawater was the least studied environment.

3.3. Distrubiton by Years

Studies on acute and chronic toxicity were categorized as FW, WW, and MW-SW to analyze their distribution over the years. In terms of acute toxicity, there were 232 studies, while chronic toxicity studies numbered 122, as depicted in Figure 3. The figure clearly illustrates the numerical dominance of acute toxicity studies over chronic toxicity studies. In the case of acute toxicity, the highest number of studies (102 articles) was observed in FW in 2018, whereas the lowest number (48 articles) was recorded in SW in 2015. Regarding chronic toxicity, the most studies were conducted in FW, totaling 70 articles in 2018, whereas the fewest studies (22 articles) were carried out in WW between 2015 and 2017.

In Figure 3, a regression line was added to the graph to better observe the changes in the acute and chronic toxicity studies. The regression analysis resulted in R^2 values of 0.825 for acute toxicity studies and 0.705 for chronic toxicity studies, indicating a moderately strong fit between the regression line and the data. Although an R^2 value approaching 1 would indicate a closer fit, the obtained values still suggest a significant relationship between the variables. From 2015 to 2019, there was a general increase in acute toxicity studies, with relatively small increases observed in 2017 and 2019. On the other hand, no definite increase was observed in the chronic toxicity studies. The growing importance of environmental awareness and management in recent years has contributed to the increasing number of studies in the field of ecotoxicology, highlighting the need for further investigation.

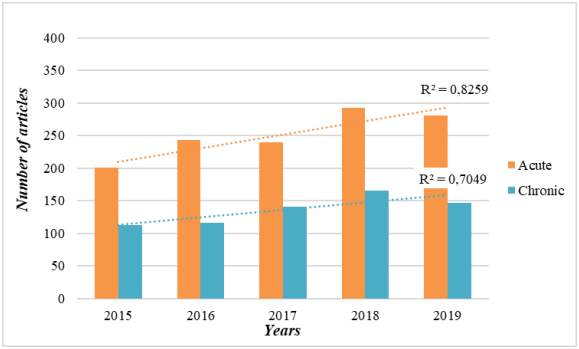

Figure 3 Change in acute and chronic toxicity studies over the years

3.4. Distribution By Test Organisms

Daphnia magna emerges as the predominant organism, accounting for 41% in acute toxicity studies and 27% in chronic toxicity studies. Among the standardized test protocols, toxicology tests involving *Daphnia magna* take precedence due to its easy availability, low cost, ease of cultivation and maintenance, reproducibility, and extensive scientific data available for this organism.

In addition to *Daphnia magna*, other frequently employed organisms in acute toxicity studies include *Aliivibrio fischeri*, *Danio rerio*, and *Artemia salina*, while chronic toxicity studies commonly utilize *Ceriodaphnia dubia*, *Aliivibrio fischeri*, and *Hyalella azteca* (Figure 4). *Aliivibrio fischeri* has gained popularity in recent years among laboratories and researchers due to its heightened sensitivity and significantly faster testing durations (5, 15, and 30-minute exposures) compared to toxicity tests conducted with *Daphnia magna* [24, 25].

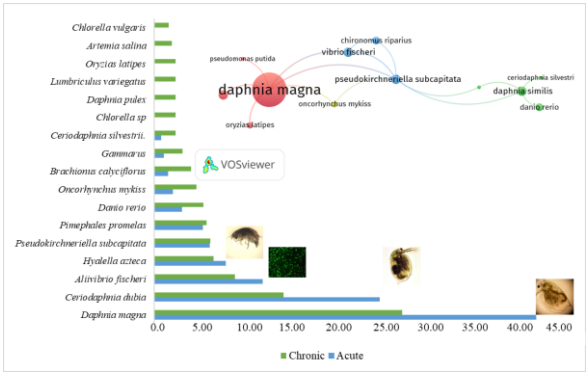

Figure 4 Representation of the organisms most commonly used in acute and chronic toxicity studies

3.5. Distribution By Country

When examining the distribution and collaborations among countries regarding acute and chronic toxicity, it becomes evident that 64 countries were identified for acute toxicity and 54 countries for chronic toxicity between 2015 and 2019 (Figure 5-a). Notably, there are distinct clusters represented by nine different colors. However, the presence of Japan (14 publications) and Sweden (15 publications) in relatively smaller clusters suggests a comparatively lower emphasis on toxicity studies in these countries compared to the USA and China, among others.

Figure 5-b and Figure 5-c provide a more detailed analysis of acute toxicity and chronic toxicity, respectively. In the realm of acute toxicity studies, China takes the lead with 243 articles, followed by Brazil with 122 articles and the USA with 111 articles. When assessing the aquatic areas where these studies were conducted in China, it is observed that 60 articles focused on freshwater (FW), 77 articles on seawater (SW), and 106 articles on wastewater (WW).

Regarding chronic toxicity studies, the USA tops the list with 93 articles, closely followed by China with 87 articles. Other countries with a notable number of studies include Brazil (51 articles) and Australia (42 articles) (Figure 5-c). In terms of specific aquatic areas, the number of published studies in FW, SW, and WW were 43, 40, and 17, respectively. Overall, China, the USA, and Brazil emerge as the top three countries in both acute and chronic toxicity studies. These findings highlight that the focus of scientific research may vary depending on factors such as a country's level of development, proximity to the sea, or abundance of water resources.

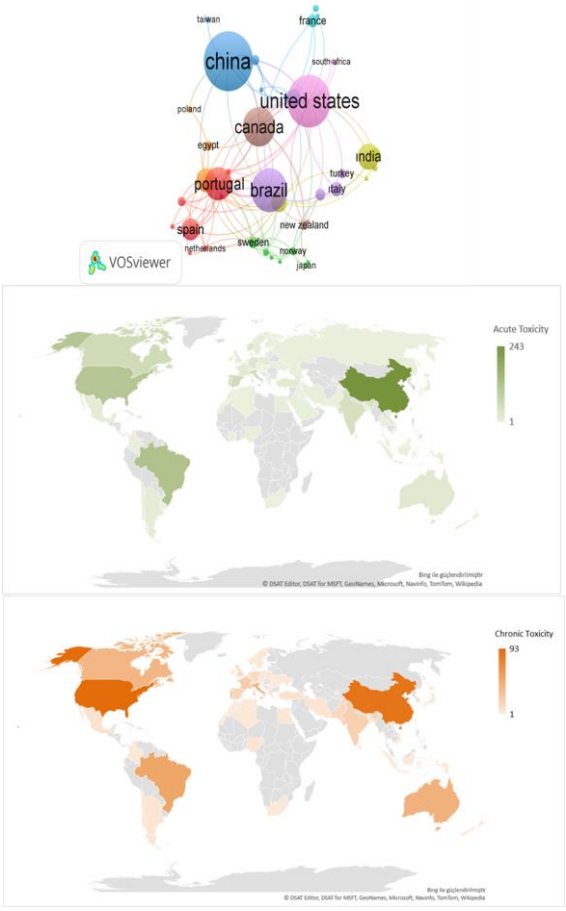

Figure 5 a) Network analysis of the publishing density of countries. b) Countries studying on acute toxicity c) countries studying on chronic toxicity

3.6. Distribution of Studies By Journals Published

Figure 6 presents a visual representation of the prominent journals in the field of acute and chronic toxicity studies. The journals are grouped based on their publication frequency, resulting in multiple clusters. The larger red circles in the center indicate the journals with the highest number of published studies. Among these leading journals, Environmental Toxicology and Chemistry stands out as the largest circle. Other influential journals in this field include Ecotoxicology and

Environmental Safety, Chemosphere, Environmental Science and Pollution Research, and Science of the Total Environment.

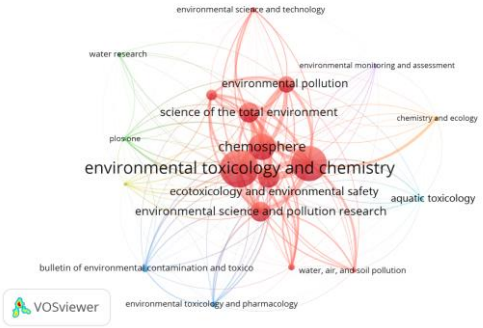

Figure 6 Network analysis of journals in which most acute and chronic toxicity studies were published

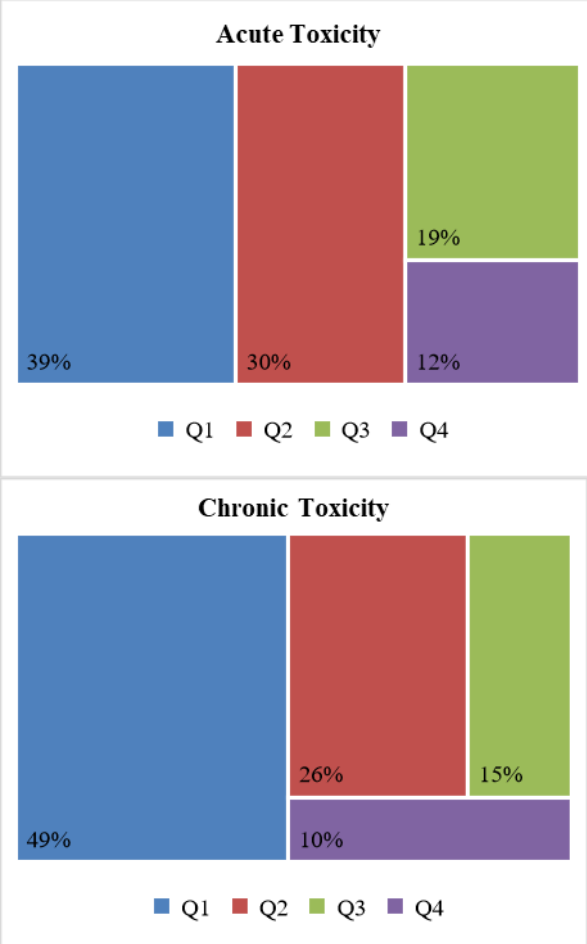

Figure 7 Q factor of journals in which acute and chronic toxicity studies were published

Figure 7 illustrates the classification of journals that published acute and chronic toxicity studies based on their Q-factors. Among the 155 journals publishing acute toxicity studies, the majority (Q1 category) accounted for 78 journals. Similarly, 78 journals in the chronic toxicity studies category fell into the Q1 category. Consequently, there is a linear increase in the number of journals from the Q4 category to the Q1 category. It is notable that the majority of publications in both acute and chronic toxicity studies appear in Q1 category journals, while the fewest publications are found in Q4 category journals.

4. CONCLUSIONS

This study presents a comprehensive bibliometric analysis of acute and chronic toxicity studies in water and wastewater, utilizing data from the Scopus database. The analysis provides valuable insights into research trends, key characteristics, knowledge structures, and hotspots in this field.

The findings of the performance analysis indicate a consistent upward trend in the number of publications addressing acute and chronic toxicity. Among the total studies, 62% focused on acute toxicity, with a significant portion of these studies conducted in freshwater environments. *Daphnia magna* emerged as the most commonly used organism, accounting for 41% of acute toxicity studies and 27% of chronic toxicity studies. Notably, China, the USA, and Brazil emerge as the top three countries contributing to both acute and chronic toxicity research.

To safeguard the ecological balance in water ecosystems, it is crucial to enhance studies that focus on the characterization of water areas, examine the relationship between pollution levels and toxicity, implement robust toxicity monitoring methods, and promote scientific research in these domains. Among the countries engaged in environmental toxicology, Turkey demonstrates a commendable research output, surpassing the efforts of many other nations. This emphasizes the importance for

countries to prioritize acute and chronic toxicity studies as a means to protect and preserve the ecosystem.

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Authors' Contribution
ANB: Data collection, literature research, writing - analysis - original draft; VZS: Writing - original draft, visualization; CA: Writing - original draft, comprehensive analysis; NS: Writing - original draft, supervision.

The Declaration of Conflict of Interest/ Common Interest
No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics
The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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