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Research Article

Bibliometric analysis of disinfection by-product research trends in Türkiye

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ABSTRACT

The goal of this study is to reveal the time dynamics of studies systematically and comprehensively on drinking water treatment and disinfection, as well as the situation in the literature, by using the bibliometric analysis method to examine scientific publications in the field of "Disinfection By-Products" between 2001 and 2022. The data gathered from the investigated articles is shown using the visual mapping approach. In this regard, the research provides for an evaluation of the disinfection by-products literature. The study's database contained 115 scientific papers retrieved from Web of Science. Istanbul Technical University is the most productive university with 23 published articles on Disinfection By-products, followed by Suleyman Demirel University with 18 published articles. Trihalomethanes, haloacetic acids are the most studied types of carbonaceous disinfection by-products in published articles, and N-nitrosodimethylamine is one of the most widely published nitrogenous disinfection by-products. The precursors of disinfection by-products or the removal of disinfection by-products are the two main focuses of the purpose of all studies. Coagulation, advanced oxidation processes and membrane processes constitute the methods used in the control of disinfection by-products. Brominated, and nitrogenous DBPs have attracted much attention due to their high toxicity. Future studies on disinfection by-products should focus on water quality standards, precursor controls, toxicity, and health effects. The necessity of bibliometric analysis of disinfection by-products is a necessity to fill the existing knowledge gaps in global and regional studies.

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INTRODUCTION

In this study, either studies involving researchers located outside of Turkey or studies from universities that support disinfection by-products research in Turkey were used. However, the aim of this study is the bibliometric compilation of disinfection by-products studies completed in Turkey's water resources, regardless of where the researchers or research institutions are in the world. As a result of Web of Science search, disinfection by-products research was detected for the first time in our country in 2001. Three developmental stages were identified throughout the research. In the first part, disinfection by-products studies between 2001 and 2005 are preliminary studies of disinfection by-products (DBPs) in the country and generally include review studies. The studies in the second part are the studies that took place between the years 2005-2008

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and in this context, the studies that include monitoring studies of carbonaceous DBPs in our country. From 2008 to the present, nitrogenous DBPs and modeling studies have gained momentum in addition to C- DBPs.

The first study on DBPs in our country was carried out in 2001 [1]. Although this study was not carried out in Turkey, for the first time, there are researchers at Gebze Technology Institute in this study. In the study, the effect of water quality parameters was investigated in order to control the bromate formation after ozonation in biological activated carbon filter processes. Another of the first studies conducted in our country is a review article on the formation of DBPs in water and the effects of chlorine disinfection on health [2]. Another important article that made a difference in the early period is a review article investigating the disinfection of different wastewater sources with peracetic acid [3]. Although this article was not prepared about drinking water sources, it is important in terms of being inspiring.

The years in which DBPs studies were most striking were between 2004 and 2008. The first seasonal DBPs monitoring study in our country was carried out by spatio-temporal monitoring of total trihalomethane (THM) concentration at 22 different points in Ankara [4]. After this study, DBPs monitoring studies gained momentum. After the DBPs studies carried out in Ankara, DBPs studies were carried out in various reservoirs and water treatment plants in Istanbul [5–7]. In the same time period, the first DBPs monitoring study was carried out in İzmir [8]. The most comprehensive DBPs monitoring study carried out in our country was completed with formation potential tests in 29 different water sources from all regions of our country [9]. In 2005 Istanbul water resources, there are studies in which HAA analysis is carried out in addition to THM [10]. Studies on the removal of natural organic substances (NOM) that cause the formation of DBPs by advanced oxidation processes (AOPs) gained momentum in the early 2000s [11]. Studies on NOM removal have become popular in these years. In this period, NOM removal with adsorbents with different surface properties was also investigated [12]. In order to reduce the effect of dissolved organic substances (DOM), the effect of advanced oxidation and PAC was investigated in Istanbul water treatment plants [13]. Studies of different researchers on the precursors of DBPs are concentrated in this period [14]. In this study, researchers focused on the removal of DOM formations in low SUVA waters by adsorption of different resins and granular active carbon. Cancer risk study in Istanbul waters [15] and model studies established between water quality parameters and DBPs formation in Istanbul waters [16–18] which created awareness between 2004-2008 and guided other studies to be carried out. The effect of bromine as a water quality parameter on DBPs formation is also among the subjects studied in this period [19]. Different model studies have been developed for the rapid and practical evaluation of bromate formation in ozonated waters [20]. Another important study in this period is the toxicity studies from disinfection by-products [21].

When disinfection studies and DBPs knowledge increased, studies in many universities gained momentum since 2008. Until this period, monitoring studies carried out in surface waters only in Istanbul, Ankara and Izmir, as of this period, the monitoring of different city networks has started. Seasonal THM and haloacetonitrile (HAN) monitoring was carried out for the first time in İzmir city mains waters during this period [22]. It can be said that N- DBPs studies started with HAN monitoring. Another comprehensive study after the Istanbul, Ankara and Izmir studies is the study carried out in different processes of the Bursa drinking water treatment plant and measuring the concentrations of disinfection by-products [23]. There are studies in which THM monitoring was carried out in the water network for 15 months at 23 different points from Antalya well waters [24]. DBPs precursors were analyzed for 3 years in 6 different reservoirs in Konya [25]. In addition, studies were carried out in which THM and HAA analyzes were carried out at Altınapa Dam in Konya [26]. DBPs precursors and DBPs formation potential (FP) tests were carried out in Porsuk Stream, which supplies water to Eskisehir, and adsorption studies were carried out with different adsorbents for precursor removal [27]. In Aksaray water source, a precursor removal study was completed in order to reduce THM formation, similar to the study conducted in Eskisehir [28]. There are also studies to reduce THM formation in the water of Ulutan Lake in Zonguldak [29]. It carried its DBPs studies to a different point and carried out DBPs concentration measurement in swimming pools for the first time in Canakkale [30]. This study on swimming pools may have inspired the swimming pool studies completed in Bitlis [31] and Eskisehir [32]. The cities where DBPs studies are carried out in our country are shown in Figure 1.

In recent studies, DBPs studies have gained a different dimension and the formation of N-Nitrosodimethylamine (NDMA) from dissolved organic nitrogen (DON) forms from N- DBPs species has been investigated [33]. As of 2008, studies on N- DBPs types tend to increase. The effects of the use of chlorine and chloramine as an alternative disinfectant in drinking water treatment plants on the formation of THM and NDMA have also started to be included in research topics [34]. It can be said that halonitromethane (HNM) measurement was made for the first time in another study, which entered the literature in our country and had a researcher(s) from Turkey in the study team [35]. Similarly, more extensive studies have been conducted on the formation of C- DBPs and C- DBPs in waters affected by DBPs precursors in water resources [36]. Tests of the measurement methods of DBPs types with different techniques have begun to be carried out. Contrary to known methods, studies aiming to measure NDMA with LC-MS/MS technique are available in the literature [37]. NDMA formation mechanisms were also tried to be understood by

Figure 1. Cities in Turkey where seasonal DBPs monitoring is carried out.

using chlorine and chloramine as disinfectants in drinking water and wastewater samples [38]. A comprehensive investigation of NDMA formation was also carried out using different disinfectants in different water sources [39]. The studies in which NDMA formation potential tests were carried out in waters with and without wastewater interaction using chlorine dioxide and chlorine after pre-oxidation aimed to measure wastewater contamination in water resources [40]. The effects on the water resources affected by natural disasters in the USA and therefore on DBPs types (two C- DBPs and two N- DBPs) were investigated [41]. One of the most comprehensive studies completed in 2022, 4 THM, 9 HAA, 6 HAN and 9 HNM species in water distribution systems using different water sources such as Isparta, Antalya-Konyaaltı, Antalya-Kumluca and the formation potential tests of 28 DBPs species in Egirdir Lake and Karaagaç Natural Water Source (Kumluca) have been tested for one year [42].

In this study, bibliometric analysis of DBPs studies between 2001-2022 was carried out. In this context, studies have evolved from laboratory-scale studies to field-scale studies and finally to model studies. As a result of the developing technology and toxicity studies, while C- DBPs studies were on the agenda in the first years, N- DBPs studies were added to C- DBPs studies in the following years and their number is increasing. DBPs precursors removal studies, DBPs laboratory studies, DBPs water network studies and DBPs modeling studies maintain their importance and up to date. The main purpose of this study is to determine the deficiencies and future demands of DBPs studies.

METHODOLOGY

The study's goal was to conduct a bibliometric analysis of works published between 2001 and 2022 that had the terms "disinfection by-products" in the abstract, keywords, and title sections. The bibliometric study was shown using the VOSviewer (1.6.19) package software. The bibliometric analysis approach entails using statistical tools to determine qualitative and quantitative changes in a certain scientific study topic, to profile past publications on the subject, and to highlight patterns within a discipline. The method's objective is to evaluate scientific papers and deliver the results to scientists or other stakeholders, which makes it beneficial. The subjects investigated using this approach, the authors working on these subjects, and their distribution by country or publishing type are statistically evaluated, allowing the overall state of a given field to be presented in accordance with the data acquired.

VOSviewer (1.6.19) was used in this study to visualize the bibliometric analysis approach. VOSviewer is a software application that allows you to create and see maps based on network data. The goal of visualization is to make it easier to interpret vast amounts of complicated data by showing significant characteristics of the data. Furthermore, the data gathered with VOSviewer is displayed, giving researchers with more accurate information as well as visual metadata.

The bibliometric analysis procedure is divided into three major stages: search criteria determination, database selection, and data analysis [43]. The first stage involves determining the search criteria. At this point, the researchers were identified by scanning the database for disinfection by products topics. The gathered data were then classified based on the subject's significance, the features of the scientific papers, and the publication time. The second stage is to calculate the number of articles by picking scientific papers based on the search parameters in the databases. The data analysis and visualization step are the third and final stage. The stages of the bibliometric analysis process is shown in Table 1.

Table 1. Stages of the bibliometric analysis process

Stages of the process	Selection criteria	Result
Search criteria	Research and analysis of terms used by researchers in databases on disinfection by-products Characteristics of selected scientific publications and determination of publication period	Title, summary, and keywords ("Documents type: Article"), ("Countries/Region: Turkey"), (Web of Science Categories: Environmental Sciences or Engineering Environmental or Water Resources) or ("Web of Science Index: Science Citation Index Expanded-SCI Expanded")
Selection of database	Determination of the number of scientific publications in the Web of Science database	Web of Science – 115 Science Citation Index Expanded
Data analysis	Visualization of bibliometric analysis	VOSviewer

PERFORMANCE OF PUBLICATIONS

Publication Output

According to the data obtained from the Web of Science database for the research on the disinfection by-product; Between 2001 and 2022, "All Fields" disinfection by-products were searched. As a result of these searches, a total of 115 scientific publications were reached. All these publications are SCI-Expanded studies.

The distribution of these scientific publications by years between the period of 2001-2022 is given in Figure 2. As seen in Figure 2, it has been observed that scientific publications about disinfection by-products have increased from time to time and have found a field of study. The year in which the most scientific publications were produced was 2007 with 12 articles, while the year in which the least publications were produced was 2001 with 1 article. As a result, it can be said that the issue of disinfection by-product as a working area has gained importance in recent years.

Subject categories, journals, and institution

The geographical examination of the researchers who contributed to the literature on disinfection by-products with scientific publications is presented in Figure 3. There are 112 institutions that have contributed to the literature, but the top 10 institutions are included in the graph. Istanbul Technical University and Suleyman Demirel University are at the top in terms of the number of scientific publications and these institutions are among the institutions that have an important place in disinfection by-products. In the research of disinfection by-products on Web of Science, 19 different subject categories were determined. The articles in the

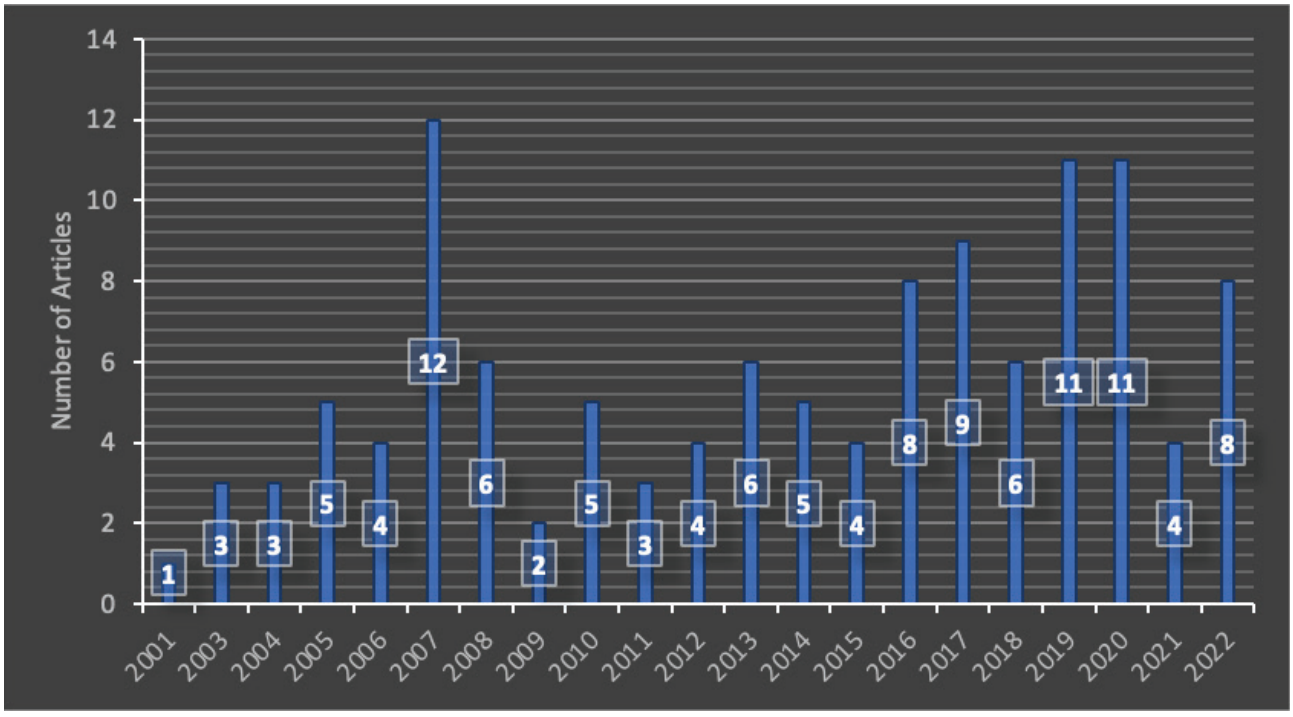

Figure 2. Distribution of scientific publications on disinfection by-products for the period 2001–2022 by year.

Figure 3. Distribution of scientific publications on disinfection by-products by institutions between 2001-2022.

Environmental Sciences category constitute 67% of the published articles. The second most common topic category is Engineering Environmental with 41 published articles, and the next topic category is Water Resources with 39 published articles. According to statistics, 115 scientific articles have been published in 42 different SCI-Expanded journal types.

Cluster sizes indicate the excess use of keywords, cluster colors mean that keywords are used together. The lines between the clusters show that the keywords are in relation to each other. As seen in Figure 4, the concepts frequently used with disinfection by-products were determined as trihalomethanes, ozonation, drinking water, humic acid, chloramination, toxicity, disinfection.

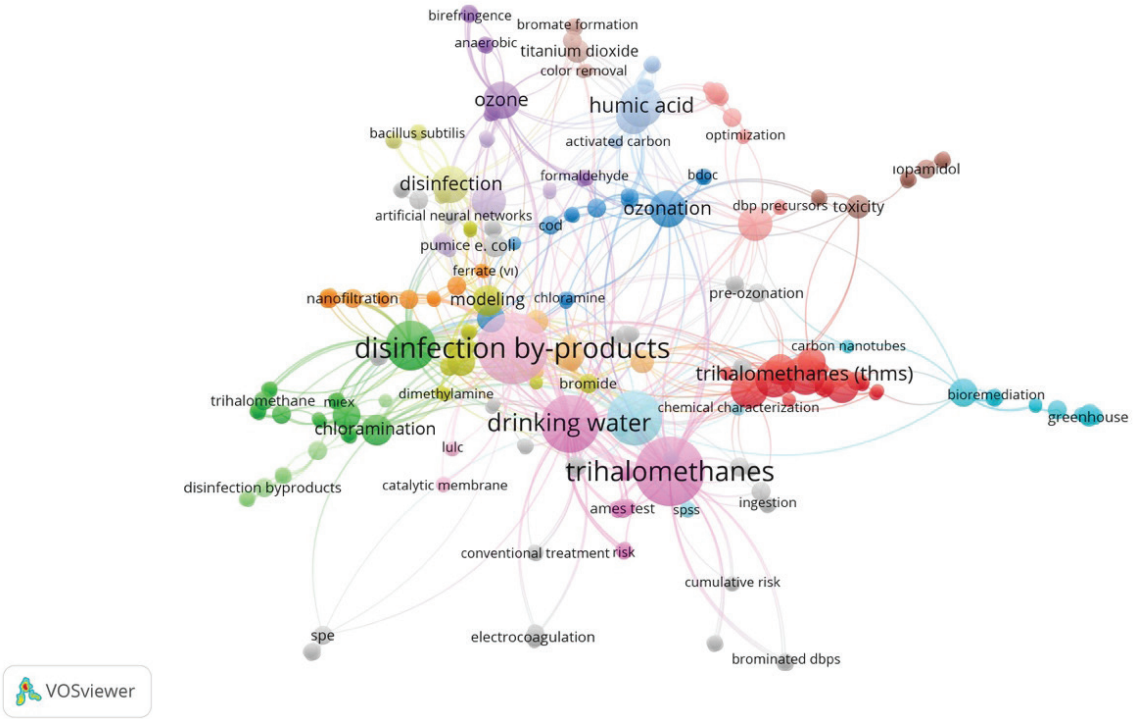

Figure 4. Bibliometric network analysis of keywords used in scientific publications on disinfection by-products for the period 2001-2022.

The bibliometric analysis conducted between 2001 and 2022 shows that Mehmet Kitis is the most productive author. Mehmet Kitis carried out his first study in the field of DBPs in 2004. The mentioned author is also the most cited author as a result of the bibliometric study with this article. Mehmet Kitis carried out his studies on DBPs in 2004 (2 articles), 2006, 2007 (5 articles), 2009, 2010 (3 articles), 2018. The scope of his work focuses on review articles and natural organic matter removal in the first years, and in the following years he focuses on the negative effects of DBPs species on human health. In addition, the related author's studies on multiple linear regression model studies between DBPs species and water quality parameters and on precursor removal using membrane processes are included. Thanks to the articles written by the mentioned author according to the needs of the period, he has made him one of the most effective researchers. The status of the authors according to the number of published articles is shown in Figure 5, and the ranking of the most cited articles is shown in Table 2.

ATTENTION-RAISING ISSUES

Although membrane processes were first used in water and wastewater treatment applications in the 1960s, a significant increase in the number of articles is observed with the beginning of the 2000s [44]. Membrane processes and water treatment DBPs have also added a different dimension to their studies. Removal of THM and HAA precursors by using nanofiltration (NF) membrane technology has started to be used in our country since 2008 [45]. Ultrafiltration (UF) membrane technology, as well as NF membrane technology, continued to be used in the subsequent years to remove the precursors of DBPs [46]. The removal of NOM, which are DBPs precursors, has been studied in UF ceramic membranes from membrane technologies [47].

With the speciation of disinfection by-products, the presence of much more cytotoxic and genotoxic DBPs species compared to THM and HAA has been detected [48]. In our country, there are studies investigating the genotoxic and carcinogenic effects of DBPs species [49]. In order to determine the health effects of DBPs through ingestion, dermal contact, and inhalation, a remarkable study was conducted [50].

Organic substances, inorganic substances, algal organic substances, and disinfectants such as chlorine, chloramine, chlorine dioxide and ozone must be present in the aquatic environment for the emergence of disinfection by-products [51] . Therefore, in DBPs control, either precursors should be reduced, or disinfectant doses should be reduced [52]. Along with the precursors of DBPs, studies for the simultaneous removal of endocrine disrupting chemicals and pharmaceutical personal care products have started [53]. In this context, it has been investigated that more than one pollutant group can be removed at the same time. Removal of algal organic matter (AOMs) that occurs as a result of eutrophication, a common problem today, has also been studied [54]. THM concentrations can be estimated in the developed multiple linear regression (MLR) models [55]. In this study, single-walled carbon nanotube and multi-walled carbon nanotube were added to the coagulation process as an innovative approach.

Figure 5. Number of articles published by the most productive authors.

Table 2. Top 10 most cited articles

Author(s)	Article Name	Journal	Citations	Year
Kitis, M	Disinfection of wastewater with peracetic acid: a review	Environment International	487	2004
Ates, N; Kitis, M and Yetis, U	Formation of chlorination by-products. in waters with low SUVA-correlations with SUVA and differential UV spectroscopy	Water Research	179	2007
Pehlivanoglu-Mantas, E and Sedlak, DL	Measurement of dissolved organic nitrogen forms in wastewater effluents: Concentrations, size distribution and NDMA formation potential	Water Research	147	2008
Selbes, M; Kim, D; Ates, N; Karanfil, T	The roles of tertiary amine structure, background organic matter and chloramine species on NDMA formation	Water Research	107	2013
Yildiz, YS; Koparal, AS and Keskinler, B	Effect of initial pH and supporting electrolyte on the treatment of water containing high concentration of humic substances by electrocoagulation	Chemical Engineering Journal	100	2008
Uyak, V and Toroz, I	Investigation of bromide ion effects on disinfection by-products formation and speciation in an Istanbul water supply	Journal Of Hazardous Materials	87	2007
Uyak, V; Yavuz, S; Toroz, I; Ozaydin, S; Genceli, EA	Disinfection by-products precursors removal by enhanced coagulation and PAC adsorption	Desalination	85	2007
Uyak, V; Koyuncu, I; Oktem, I; Cakmakci, M; Toroz, I	Removal of trihalomethanes from drinking water by nanofiltration membranes	Journal Of Hazardous Materials	84	2008
Kitis, M; Kaplan, SS; Karakaya, E; Yigit, NO; Civelekoglu, G	Adsorption of natural organic matter from waters by iron coated pumice	Chemosphere	81	2007
Kirisits, MJ; Snoeyink, VL; Inan, H; Chee-Sanford, JC; Raskin, L; Brown, JC	Water quality factors affecting bromate reduction in biologically active carbon filters	Water Research	78	2001

DBPs studies are promising for future research. The trend of DBPs studies in the world shows a continuous increase over the years. The main reason for this is that although only an upper limit for THMs has been set by legislation in Turkey, different DBPs groups have also been included in the legislation in developed countries. In addition, while articles on C-DBPs are generally published in our country, the number of articles published on nitrogenous, brominated, and iodinated DBPs is higher in developed countries. Nitrogenous, brominated, iodinated DBPs are much more cytotoxic and genotoxic for human health. Therefore, tendencies towards these types DBPs should be increased, supported, and investigated. After these research are completed, the gap between the knowledge of DBPs of developed countries and the knowledge of DBPs of Turkey will begin to close.

CONCLUSIONS

10491 studies were found by searching the disinfection by-products in the Web of Science database. After selecting the document type "Article", country/region "Turkey", the web of science category "Environmental Sciences, Environmental Engineering, Water Resources, Chemical Engineering", and the web of science index "SCI Expanded", the number of research articles decreased to 115. The 115 articles obtained were limited to 19 different subject categories and 42 different journals. Most of the articles belong to Environmental Sciences subject category. The journal of Water Research is recognized as the most productive journal with 12 published articles. 106 institutional articles were published in 42 different journals. These articles include studies carried out either by native or foreign researchers in institutions in Turkey or by local researchers working in institutions located outside the country. Among all institutions, Istanbul Technical University is the institution with the highest number of articles published, and Suleyman Demirel University is the second institution with the highest number of articles published. Mehmet Kitis from Suleyman Demirel University can be considered as the most influential person on disinfection by-products, as he is the most cited author. The most used ones according to the keyword analysis are trihalomethanes, ozonation,

drinking water, humic acid, chloramination, toxicity, disinfection. Trihalomethanes were the most analyzed disinfection by-product type between 2001-2022 in Turkey. Control of the precursors of disinfection by-products is the main objective of many articles. The coagulation process, membrane processes, and advanced oxidation processes are the main treatment methods used to control disinfection by-products. In addition, the formation of disinfection by-products in water distribution networks and their toxic effects on health should also be examined. Toxic disinfection by-products should be included in water quality regulations for drinking water safety.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest regarding the research, authorship and/or publication of this article.

DATA AVAILABILITY

The data used to support the findings of this study are included within the article.

AUTHOR'S CONTRIBUTIONS

All author is contributed equally to bring out this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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