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A bibliometric analysis of research on arsenic in drinking water during the 1992–2012 period: An outlook to treatment alternatives for arsenic removal

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ABSTRACT

A bibliometric analysis based on the Web of Science database was carried out to identify the global research related to arsenic in the drinking water field from 1992 to 2012 and to improve the understanding of the research trends in the same period. The results from the analysis reveal a linearly increasing number of annual publications and a high effort to find effective technical solutions to the problems caused by the presence of arsenic in water. The most relevant research aspects of the four main technologies applied to arsenic removal from drinking water (coagulation, flocculation and precipitation followed by filtration; adsorption and ion exchange; membrane-based processes and biological treatments) were summarized in this paper, with adsorption appearing to be the alternative that has received most attention according to the research trends during the studied period.

1. Introduction

Arsenic (As) is a metalloid that is very abundant and can be easily found in soils, water and biota (specifically in marine organisms), being the twentieth most common element in the earth's crust, the fourteenth one in the seawater and the twelfth one in the human body [299]. It can be considered as a dangerous environmental pollutant, especially in the aquatic medium. The two common oxidation states of arsenic in water are As^{+3} and As^{+5} as part of the dissolved oxyanions arsenite ($AsO_3{}^{-3}$) and arsenate ($AsO_4{}^{-3}$), respectively [54,151]. Both species can be present in different protonated forms as a function of the pH: the As^{+3} system includes H_3AsO_3 and the corresponding deprotonated derivatives $H_2AsO_3{}^{-}$, $HAsO_3{}^{-2}$ and $AsO_3{}^{-3}$ with dissociation constant values of 9.2, 12.7 and 13.4 for pK_{a1}, pK_{a2} and pK_{a3} [228], while the As^{+5} system includes H_3AsO_4 and the corresponding protolitic derivatives $H_2AsO_4{}^{-}$, $HAsO_4{}^{-2}$ and $AsO_4{}^{-3}$ with dissociation constant values of 2.3, 6.8 and 11.6 for pK_{a1}, pK_{a2} and pK_{a3} [3]. According to these data, the prevalent species around neutral conditions (typical pH range for natural surface waters and groundwaters from 6.5 to 8.5) are H_3AsO_3 for As^{+3} and $H_2AsO_4{}^{-}$ and $HAsO_4{}^{-2}$ for As^{+5}. This fact implies that arsenate remains as anion while arsenite appears as a non-charged molecule and it only converts to anion when the pH value is higher than 9.2.

Besides pH, the redox potential plays an important role in the control of the mobility of the arsenic species. A complete speciation diagram for arsenic in aqueous systems as a function of pH and redox potential can be found in bibliography [32]. On one hand, under oxidant conditions, the As^{+5} state becomes clearly dominant over the As^{+3} one but, on the other hand, the As^{+3} species are prevalent under reducing conditions. Therefore, the arsenate system is thermodynamically more stable for surface waters. The case of groundwaters is a bit more complex as both oxidation states are going to coexist and the incidence of each one depends on the arsenic input to the system, the chemical conditions and the biological activity [35].

The presence of arsenic in the environment can be mainly justified by the natural sources because of weathering of rocks and sediments, mineral ores formation processes with hydrothermal origin, volcanic eruptions and geothermal activity [97]. However, anthropogenic activities account for a widespread arsenic contamination as a result of some industrial activities such as mineral ores processing, combustion of arsenic-enriched coals, and manufacturing of semiconductors, glass and some pharmaceuticals [47,172,145].

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Although arsenic is suspected to be an essential trace element in living organisms, where as far as 15 mg of As can be present in an adult human body and it could be related to the synthesis of some aminoacids and the metabolism of zinc [246,171], this metalloid must nevertheless be considered as a high priority toxic pollutant. Arsenic can cause acute, chronic and lethal intoxications. The lethal dose of inorganic arsenic for an adult human is estimated in the range 1–3 mg As/kg [74]. The probability of acute intoxication by ingestion of arsenic-enriched water is minimal and most cases of acute arsenic poisoning occur from accidental ingestion of arsenic compounds or less commonly from attempted suicide [225]. Long-term exposure to arsenic induces chronic intoxication called arsenicosis [65]. It has been reported in people living in endemic zones suffering high levels of arsenic in drinking water [126,21] or burning arsenic-enriched coals indoors [318,153]. It is additionally necessary to mention the health consequences attributable to the genotoxic, mutagenetic and carcinogenic properties of arsenic, since it is classified as a Group I carcinogen, that is, human carcinogen [122].

The presence of arsenic in drinking water is one of the most alarming challenges to be solved in order to assure the human right to safe access to potable water [277]. The contamination of drinking water by arsenic has been reported in more than 70 countries where above 150 million habitants are under high health risk. More than 100 million of these persons live in Southeastern Asian countries like Bangladesh [114], Cambodia [9], China [110], India [257], Laos [53], Myanmar [22], Nepal [305], Pakistan [30], Taiwan [158] and Vietnam [217]. In Latin America, especially in Argentina [229], Bolivia [88], Chile [263] and Peru [76], the same problem has also been reported since several decades ago, affecting mainly urban and rural poor populations. High arsenic concentrations in natural groundwaters or surface waters polluted from industrial sources and the resulting arsenic poisoning episodes have been reported in other countries all over the world [259]. To avoid these toxic conditions, standards for arsenic in drinking water have become stringent. World Health Organization (WHO) produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting [297]. For the particular case of arsenic, the standard limit is fixed at 10 ppb (10 μg/L).

The amount of published papers about arsenic and drinking water that can be found in bibliography is huge, so basic managing tools are very useful to handle all this information. Bibliometrics refers to the research methodology employed in library and information sciences that applies quantitative analysis and statistics methods to describe the distribution patterns of publications according to some given categories such as topic, field, source, author or country. The term bibliometrics was first introduced by Pritchard, who explained that the term "deals with relationships among numbers of scientific papers, numbers of patents, amounts of exports and other quantities" [220]. It is a powerful tool that helps to explore, organize and analyze large amounts of information in a quantitative manner [72] and it has became a common method to analyze the trends in research, including multiple knowledge areas: medicine [93,190], social sciences [121,139], computer sciences [219,193], psychology [41,288], economics [58,237], agricultural sciences [28,59], environmental sciences [85], mathematics, physics and chemistry [216,179,147], arts and humanities [69,45] or engineering [77,176]

The purpose of this study is to bibliometrically analyze the literature published in Web of Science from 1992 to 2012 related to the research on arsenic removal from drinking water. These documents were analyzed and evaluated according to several criteria and were employed to determine the quantitative characteristics of the research on arsenic in drinking water worldwide and find the most relevant present and future trends related to this topic.

2. Data sources and methodology

The data source was Web of Science, the scientific citation indexing service maintained by Thomson Reuters. This searchable platform of publications gives access to several databases and other sources of technical information that can be relevant for the diffusion and evaluation of the scientific research. After the disappearance of Web of Knowledge in 2014, Web of Science has remained as a unique noun and a new denomination for the global database has been created: Web of Science Core Collection. The citation databases provide authoritative, multidisciplinary coverage from more than 12,000 high impact research journals worldwide, including Open Access journals. Cover-to-cover indexing of content is provided by Science Citation Index Expanded, Social Sciences Citation Index Expanded, Conference Proceedings Citation Index, and Arts & Humanities Citation Index [276].

For this bibliometric analysis, the online search within Web of Science was carried out by the insertion of "drinking water" and "arsenic" as keywords in the topic field of the search-engine in order to compile a complete bibliography with all the articles related to the research on arsenic in drinking water published during the period from 1992 to 2012. The final number of articles that were found was 4143.

All the compiled articles were assessed with the following aspects: publication year, document type and language of publications, distribution of output in subject categories and journals and publication outputs of countries and institutes.

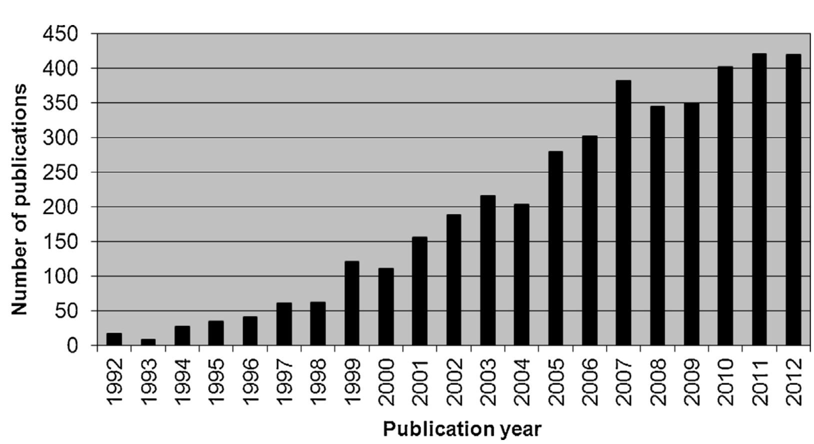

Fig. 1. Annual publication output.