Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/126/2025.20020

Report on the Elements and Composition of Emerging Contaminants in Water Bodies of China

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Abstract: In the context of rapid industrialization and urbanization in China over the past few years, the issue of water pollution has emerged as a significant concern. This article provides a comprehensive literature review on the research conducted on water body conditions in China over the past few decades. The review encompasses various studies that have examined the pollution levels of different types of water sources across the country, as well as identified different types of pollutants present in these water bodies. The contamination level is found to be varying over the past 20 to 30 years time, with a continuing increasing focus over the polluting power of neo-pollutants, the PFAS. Continued research efforts are necessary to monitor changes in pollution levels over time accurately. In addition, implementing effective regulations and adopting sustainable practices will be vital steps towards mitigating further degradation of precious water bodies in China.

Keywords: Neo-pollutants, hydrological pollution, contamination.

1. Introduction

Water originated from ancient volcanic eruptions and has existed on Earth since its earliest times in three basic forms: solid, liquid, and gas. Currently, more than two-thirds of Earth's surface is covered with water, with 75% of Earth being composed of water—mostly seawater. However, when referring to water resources that humans rely on for daily usage, it mainly pertains to freshwater resources which are becoming increasingly scare due to pollution-induced loss of accessibility. In fact, degradation in water quality is often a result of human activities; unfortunately, the depraving rate has exceeded nature's intrinsic recovery potential, resulting in a severe shortage of already scarce resources. Water quality has various definitions and standards, which can be assessed using indexes such as pH, turbidity, dissolved oxygen content (BOD and COD), heavy metal content, organic substance content, microbial content [1]. The fundamental standard for good quality of water is to ensure the well-being of both human populations and the environment. Administrations worldwide have been actively monitoring water quality in their respective regions for centuries by enacting and polishing policies that balance national development with environmental preservation. Examples include the Water Framework Directive in Europe, the Clean Water Act in the USA, and similar legislation around the world that set environmental goals for rivers and lakes to achieve a good quality status while preventing further deterioration. In terms of China, *The Water Law of the PRC* serves as primary legislation governing activities related to water resources. It states that water resources

DOI: 10.54254/2755-2721/126/2025.20020

belong to the state while providing guidelines, principles, basic management systems, and pragmatic approaches for their development and utilization. Preserving water quality is equivalent to maintaining the reusability of fresh water in the hydrology cycle, simplified as sustainability. Recognizing conventional and modern pollutants in water bodies ensures efficient and secure approaches for assessing water quality over time. According to *the List of New Pollutants Under Key Control* (2023 version) issued by Chinese government in 2022, PFAS contaminants (PFOSs and PFOAs) were classified as the most principal among the 14 identified contaminants. This list was determined based on the environmental risk assessment, considering chemical toxicity, harmfulness, regulatory feasibility, technical feasibility, and economic and social impact. Starting from 2024 onwards, all transactions, storage, or production involving PFAS substances are strictly prohibited without exception. Enterprises using or producing PFAS substances must initiate a supervised obliteration procedure for any remaining PFAS residues once these policies become effective.

2. Water bodies and water sources in China

2.1. Usable water shortage

As the world's largest developing country, China is facing the vast water demand and great pressure caused by rapid development [2]. In 2000, the total water consumption in the country was 549.8 billion m^3: agriculture 378.4 billion m3 (68.18%); industry 113.9 billion m^3 (20.17%); domestic water consumption was 57.5 billion m^3 (10.15%) [3]. According to a study conducted in 2012, among 32 provinces in China, only 10 provinces in the south and southeast coast of China have abundant water supply, which take up less than 16% of the national land area, whereas around 60.78% of the national land area is suffering from a water shortage issue [4]. Changes in water quality and quantity are intertwining: the water contamination issue caused further threats to the current water depletion situation, and the water shortage caused the even unregulated use of scarce water resources, leading to a more critical pollution status.

2.2. Water contamination

Underground water contamination: Groundwater is responsible for one-third of domestic, agricultural, and industrial sectors across the country, and around 70% of cities in China utilize groundwater as the principal water supply [5]. Thus, confronting difficulties in the underground water system is overarching for a large section of the country. According to Jia, the status of the nationwide underground water system is assessed by five main categories, which comprise 14 sub-categories [6]. It is manifested that groundwater and its external environmental factors should be considered as a perplexing adaptive system by examining the adaptive interactions and relationships among 14 sub-categories. Moreover, underground water quality has a strong negative correlation with degree of provincial development, showing that agricultural and industrial firms lead the over-exploitation of underground water. A correlation between subcategories of groundwater quality and quantity reveals the positive coupling between groundwater depletion and deterioration in China. The extraction rate of sub-surface groundwater in the plain area is 100% [3]. Over-exploitation of groundwater has caused the water table drops, high salinity water inflow, soil erosion, and land sinking and lopsidedness.

River contamination: River fragmentation and pollution are affecting a vital resource people live upon. Nearly every river in China has multiple barriers or reservoirs where point-source pollutants are accumulated [7]. In the 1980s, 82% of 878 rivers in China have been polluted to different levels, which worsen every year [8]. In 2004, of all 745 monitored river sections, 28% fell below the Grade V standard (meaning unsafe for any uses), and only 32% met Grade IV-V standards (safe for industrial and irrigation uses exclusively) [9]. Rivers in the southwest, southeast, and northwest are

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the least polluted, while the most urbanized (northeast and coastal) regions have been polluted the most [10]. Rivers in the north, such as the Liaohe, Haihe, and Yellow Rivers, are more polluted in general than rivers in the south, such as the Yangtze and Pearl Rivers [8]. The interruption of the flow of the Yellow Rivers ("duanliu" phenomena) and the drying up of the Haihe River highlight the severe situation of water shortage in China [3&11]. Around 10% of rivers are highly polluted and have become entirely unusable, and non-point source pollution due to agriculture is a major issue affecting groundwater quality nationwide [12]. According to the Communique on the State of China's Ecology and Environment of 2023, the percentage of V-Grade rivers declined since 2016, which has already settled to less than 1%; the percentage of Grade IV-V rivers has fallen to 7.9% as well [13].

Lake contamination: There have been a large amount of lake-filling activities since the 1960s and lasting for more than half a century, leading to a surprising decline in areas of open water. Moreover, many lakes adjacent to human living areas have become reservoirs of large quantities of urban sewage and industrial discharges [8]. Water quality in lakes and reservoirs is characterized by accelerated eutrophication as a consequence of nutrient enrichment from both point and non-point sources [9&14]. Potential ecological risk coefficients of eight heavy metals with the greatest concentration in the sediments of 237 lakes in China were ranked as follows: Cd >Hg > As > Cu > Ni > Pb > Cr > Zn, with Cd and Hg causing the major lake sediments' potential ecological risks in China. Heavy metals within lake sediments and nearby soil located in the Yunnan-Guizhou Plateau Region greatly exceeded the legislation standard, and Cd concentration was the main driver [14].

3. Pollutants

3.1. Source of pollutants

Identifying pollutant sources is an effective way to prevent and treat pollution [14]. Sources of waterborne pollution were defined as either direct or indirect sources, regardless of intentional or unintentional release [15]. Direct sources refer to directly releasing effluents into the water or reservoirs; for example, a scientific lab that discharges toxic experimental waste or toxic chemicals into adjacent lake or river, making the water source inaccessible for direct contact or daily usage. Solid and gaseous waste could also contaminate water quality. Indirect water pollution refers to the introduction of contaminants that were primarily used in other places, but are carried and transferred gradually eventually depositing in water bodies. Pesticides and antibiotic pollution are representative of indirect water pollution, as they are used as treatments in agriculture, injected and partially excreted by animals and plants, or leaked into streams and underground water, then migrate to rivers or lakes, causing hydrological toxcification.

Natural sources are the only non-human mediated source of water pollution and cause the least influence on water bodies. Natural source pollution includes rainfall, atmospheric particles, volcanic eruptions, runoffs, and vegetation effluence. Among all, rainfall has the strongest effect for high frequency, coverage, and mobility (in the form of clouds). Rainwater is capable of dissolving atmospheric pollutants and carrying insoluble wastes, which then penetrate through soil and water bodies. Expansion of impermeable land surfaces as a necessary procedure of rapid urbanization in China, on the other hand, changes the leaking pathway of rainfall: it reduces the portion of pollutants penetrating through land surface but enhances the percentage of non-point runoff (roof and road runoff) as well as water source pollution [16]. A case study in Three Gorges Reservoir Area showcases that loss of soil nutritious elements like nitrogen and phosphorus renders the continuation of fertilizer usage despite eutrophication of surrounding reservoirs [12]. It is also shown that storm runoff pollution has a strong positive spatial correlation with the proportion of residential land use, a great implication of controlling methods against natural runoff pollution [17].

Domestic sewage comprises waterborne wastes of the public disseminated via a fluidic mixture containing both organic and inorganic particles. The primary problems associated with sewage wastes are the yield of unpleasant odors and the spread of enteric diseases, which leads to oxygen depletion, restricted fish populations, and algae flourishing [15]. Burgeoning economies altered the portion of agricultural pollutant sources to urban sources, resulting in an upsurge of the city sewage system dimension and an ensuing skyrocketing of drainage [18]. Another issue of stampeding urbanization is that sewage waste production switches among sectors accordingly with shifting of economic centers, making it difficult to implant efficient countering measures against sewage pollution [19]. Nationwide monitoring and supervising is crucial for advanced management over unprecedented enhancing amounts of municipal waste.

Agricultural wastes and industrial waste are both harmful byproducts of mass production. Agrochemicals and microplastic are the two major threats from agricultural production that are corrosive to human body health. Fertilizer application during crop cultivation was the main cause of phosphorus and nitrogen pollution in water bodies: 7.0%–83.9% of nitrogen applied was lost from soil and 0.6%–82.8% of P lost, accounting for around 32.5% of total nitrogen pollution and 81% of total phosphorus pollution [14&20]. The usage of the mulching film cover in China has maintained an annual growth rate of 6.5% since 1997 for two decades, reaching an approximate of 1.5 million tons [14]. Water erosion caused 0.92% of the plastic debris to migrate to nearby hydrology, meaning the residual film transferred to the river network can reach 4329 tons annually, mostly carried by the Yangtze River to the East China Sea. The regional differences are a result of dependency on primary agricultural production. Industrial wastes vary largely from industry to industry in quantity and toxicity, but heavy metals are produced by almost all industrial production in China, such as the coal mining industry, metal mining industry, light industry, energy industry, and chemical industry, with lead (Pb), chromium (T-Cr, Cr(VI)), cadmium (Cd), and mercury (Hg) leading in quantity [21]. In brief, discharged polluted water accounted for 73.4 thousand tons per billion RMB of industrial China's GDP, including 11.16 tons of chemical oxygen demand (COD), 0.93 tons ammonia, nitrogen, and other trace heavy metals (including Pb, As, and Hg) [22].

3.2. Types of pollutants

There have been many studies done on reporting the status of conventional pollutants like nutrients (nitrate and phosphate), heavy metals (also known as potentially toxic elements), microplastics, etc. Nutrient substances originated from manure and agricultural waste are one of the major types of pollutants in China. PTEs are also found in almost every river and lake in China. Various types of microfibers and microplastics in tap drinking water in cities of China are identified, and the abundance of debris is dependent on the content in raw water or water source, unaffected during the transferring processes [23-24]. Microplastic contents are also reported to be present in a decent amount in several mainstream rivers in China, like the Yellow River and the Yangtze River, which play a significant role in supporting the water supply of surrounding citizens [25-26].

Besides the downsides of microplastics, substances used during the manufacture of plastic products, as well as the manufacturing of other goods, are highly harmful to the environment as well. Some of them were being identified decades ago, and regulation and treatment measures have been established for a long time in order to restrict the utilization and production of such wastes. The others, known as the emerging pollutants, were being aware of only in recent years. These include substances that are newly formed and established in the environment or compounds that have entered in the environment long ago but were detected recently [27]. Among these ECs, the negative effects of PFAS are highly appreciated by the country's supervisors.

3.3. PFAS Overview

3.3.1. The "Forever Chemical"

Per- and polyfluoroalkyl substances (PFAS), are a large, diverse family of several thousand artificial chemicals containing multiple fluorine that have been widely utilized since these compounds were developed in the 1930s [28]. They are characterized by strong C-F bonds, which provide the chemical with thermal stability and chemical stability, and both hydrophobic and lipophobic characters, which make them nonreactive and non-sticking. Water-repellency and oil-repellency in the backbone and functional group at one end make them favored as surfactants and dispersants, which are utilized in manufacturing fire-resistant material, product lining, food packaging, and semi-conductors [28]. The most frequently accessed PFAS compounds include both long and short chain ones: perfluorononanoic acid (PFNA), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), and perfluorohexanesulfonic acid (PFHxS) are long-chained, and perfluorobutanoic acid (PFBA), perfluorobutane sulfonate (PFBS), and tetrafluoro-2-(heptafluoropropoxy) propanoic acid (GenX) are short-chained. The best studied members of this family are carboxylic and sulfonic acids with chain lengths of C4 to C14, specifically PFOA and PFOS [29-30].

Their extraordinary persistent nature is a double-bladed sword, which makes these compounds favored by factories but repelled by the environment. PFAS have been referred to as the “forever chemicals” since they are almost non-degradable under natural conditions, leaving perfluorinated residues [29]. They are also bioaccumulative, meaning they are not metabolized or assimilated by organisms as long as they are absorbed, and the possibility of bioaccumulation is positively related to the length of particles [28]. PFAS circulation without flee or elimination from the food web cycle leads to repetitive in vivo addition to every level of consumers [29&31]. PFAS could cause serious illness regardless of their concentration in the organism. They have been known to cause reproductive system illness and stimulate tumor formation and are pathogenic to many serious illnesses [28]. Its ubiquitous nature makes it easily transferred through body fluid excretion like serum and blood, especially through maternal generational linkage [29&32].

3.3.2. Environmental effects of PFAS in China

According to a study conducted on PFAS content in Huangpu River and Suzhou River during 2007 that showcases the concentration of PFAS compound in soil and water: The leading substances within sediments in rivers are TFA, PFOA, and PFOS, where the quantity of PFOS in soils outcompetes other PFAS members. Their findings show differences in the ranking of each substance by amount, implying the PFAS quantitative characters of different water sources are highly dependent on the PFAS categorical feature within entering streams. The concentration of 11 types of PFAS detectable from the Yangtze River ranged from 0.30 to 88.50 ng/L in spring and from 0 to 68.78 ng/L in autumn, hypothetically attributed to the input of certain point sources at upper stream factories near Luzhou and Chongqing [33]. Nearly all the groundwater sources of the Yangtze River comprise a significant amount of PFAS, with remarkable occurrences of PFBA and PFOA. Research in regard to 20 sites along the middle and lower reaches of the Yellow River shows a 100% detection rate of short-chained PFAS, mainly PFBA, and an 80% detection rate of long-chained ones, mainly PFOA [34].

PFAS is also recognizable in municipal wastes and urban sewage systems. The dominance of PFOA in sewage systems in China, different from studies at the same spots years ago that reported a dominance of drainage PFOS, implies the altering feature of PFA composition over time, highlighting the importance of careful examination of PFAS categories in pollutants [20&35]. Although it is not widely detected in China due to regulations, a significant amount of PFAS substance is found in the water stream and sewage of firefighting sites in many other countries, like the US and Australia [36].

DOI: 10.54254/2755-2721/126/2025.20020

These findings suggested that short-chain PFAS should be taken seriously, management and research aiming at understanding the biochemical process whereby these chemicals might be altered to more toxic forms should initiate [20]. Even with the production and import of PFAS being banned in China since 2024, the monitoring over PFAS residues in different places should take region-specific management to acquire the most ideal elimination results.

4. Conclusion

This article provides a concise overview of the current contamination levels in various water sources, shedding light on the pollutants that are currently present in both major and minor water streams. These pollutants have severe implications for the well-being of citizens who rely on these water resources. However, there is still ample potential for further research to delve into the exact influence of one of the most crucial pollutants, PFAS, on overall water conditions. It is worth noting that some of the papers reviewed in this article date back 20 to 30 years ago. While they may provide valuable insights into historical perspectives on water conditions, their contents may not be as informative or relevant when it comes to understanding recent developments. Therefore, it would be beneficial for future literature reviews to prioritize more up-to-date studies that reflect current realities. Furthermore, diversifying the selection of papers included in literature reviews can enhance the understanding by incorporating foreign research perspectives. By including a larger portion of international studies alongside domestic ones, a more comprehensive view can be obtained regarding global trends and approaches towards water contamination issues.

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