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REVIEW ARTICLE

Water pollution and sanitation in Indonesia: a review on water quality, health and environmental impacts, management, and future challenges

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Abstract

As an archipelagic tropical developing country, Indonesia is characterized by vast expanses of rural and isolated areas. This review aims to discuss water pollution and sanitation's existing condition, health, and environmental impacts, alongside its management and challenges in Indonesia. The systematic review approach was utilized to ensure transparency and replicability, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria. Many water sources in Indonesia are contaminated by various pollutants such as heavy metals, microplastics, pesticides, and endocrine-disrupting chemicals (EDCs). Moreover, the existing water and wastewater treatment plants cannot completely remove pollutants, including bacteria that cause waterborne diseases. The lack of proper sanitation facilities, including toilets and latrines, is not only reported in rural areas but also in peri-urban regions of Indonesia. This situation forces many to rely on unimproved water sources, such as river water, for their daily use and engage in open defecation, which may increase the risk of direct exposure to waterborne contaminants. Insufficient sanitation has been linked to significant public health issues in Indonesia, including maternal health complications, childhood stunting, and an increased incidence of waterborne diseases such as diarrhea. Based on the findings of this review, Indonesia still needs to improve its sanitation and water treatment facilities, as well as reduce pollution of the aquatic environment. This condition not only illustrates the condition of water and sanitation in Indonesia but can also be used as an illustration of how developing countries face various pollution and sanitation problems during the massive development and industry.

Keywords Water pollution · Sanitation · Health impact · Environmental health · Indonesia

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Introduction

Water and sanitation are fundamental to the well-being of any nation, impacting both public health and environmental sustainability (Shaw et al. 2022; Shukla et al. 2023; Zyoud and Zyoud 2023; Anthonj et al. 2024). In the archipelagic nation of Indonesia, characterized by its diverse landscapes, cultural richness, and growing population, the challenges and complexities of water and sanitation management are manifold (Daniel et al. 2023). As Indonesia continues to evolve and grow, the nation faces a series of pressing future challenges in water and sanitation management (Karon et al. 2017; Odagiri et al. 2020). Indonesia's water resources are abundant, yet access to clean water remains a critical issue (Karon et al. 2017; Odagiri et al. 2020; Utami et al. 2023a). While significant progress has been made in urban areas, peri-urban, rural, and remote regions often face challenges in securing safe drinking water sources and sanitation facilities (Cameron et al. 2021a; Utami et al. 2023a). Rapid urbanization, population growth, and climate change are reshaping the landscape of water resource management (Fan et al. 2016; Chen et al. 2022; Pham and Lin 2023). Urbanization demands increased focus on wastewater management, sewage systems, and sanitation services to accommodate the growing population and prevent contamination of water bodies. (Sun et al. 2023; Gao et al. 2023; Warsame 2023).

Water source pollution and inadequate sanitation facilities may impact both public health and aquatic ecosystems (Ekumah et al. 2020; Kikuchi 2023; Narwal et al. 2023; Zyoud and Zyoud 2023; Thanigaivel et al. 2024). Figure 1 illustrates that the contamination of water sources originates from various anthropogenic activities such as industrial discharge, agricultural runoff, and improper waste disposal. The chemical contaminations may result in acute and chronic toxicity to the exposed population (Chandana and Rao 2022; Lin et al. 2022; Jessieleena et al. 2023; Utami et al. 2023b; Qadafi et al. 2023b, d; Lei et al. 2024). Besides, open defecation as a consequence of limited access to proper toilets and sewage systems can lead to the spread of waterborne diseases such as cholera, dysentery, and hepatitis continue to pose health risks to communities (Irda Sari et al. 2018; Siddiqua et al. 2022; Cameron et al. 2022; Priya et al. 2023).

Indonesia is an archipelagic country located in Southeast Asia with numerous rural and isolated areas (Blum et al. 2013), which experience problems related to insufficient water supply and sanitation facilities (WHO/UNICEF 2021; Cameron et al. 2021a). Due to those problems, fecal-borne illnesses of diarrhea and typhoid were reported as two of the four leading causes of death for children in Indonesia in 2018 (Cameron et al. 2019). Since 2000, Indonesia has achieved notable progress in enhancing water and sanitation conditions. Access to at least basic sanitation increased from 38 to 86%, and access to at least basic drinking water increased from 75 to 92% from 2000 to 2020. However, there are still 38 million Indonesians who lack basic sanitation and 22 million who lack basic drinking water (WHO/UNICEF 2021; Cameron et al. 2021a). Efforts to address water and sanitation challenges in Indonesia encompass a range of strategies, from government initiatives and regulatory measures to community engagement and international collaborations (Odagiri et al. 2020). Programs like the "National Sanitation Movement" underscore

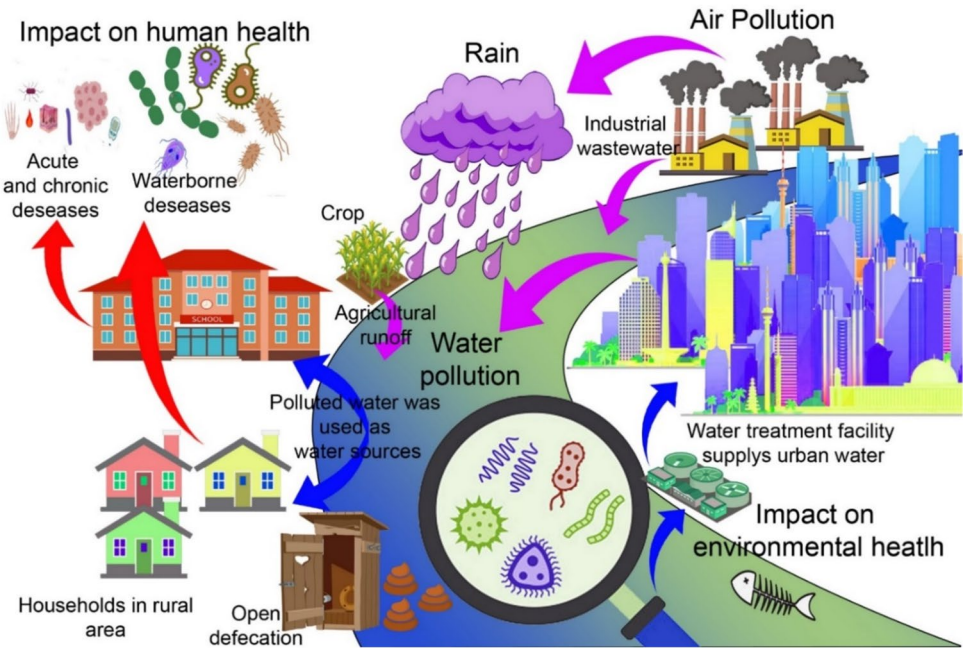

Fig. 1 Water pollution and inadequate sanitation impact on human and environmental health

the government's commitment to improving sanitation practices, while partnerships with international organizations provide vital support for infrastructure development and capacity building (Cameron et al. 2019). As Indonesia looks ahead, it confronts a series of pressing challenges in the realm of water and sanitation. Rapid urbanization, population expansion, and the impacts of climate change are disrupting water supply and sanitation services, potentially altering the landscape of water resources (Chen et al. 2022; Pham and Lin 2023; Ansari et al. 2023; Novitasari et al. 2023; Widiyanti and Dittmann 2014). Consequently, the demand for sustainable and equitable solutions in water resource management becomes paramount (Li et al. 2022; Ekmekcioğlu et al. 2022).

Numerous studies have been conducted regarding the impact of inadequate water quality due to environmental pollution (Irda Sari et al. 2018; Rozirwan et al. 2021; Jayanto et al. 2021; Astuti et al. 2022a; Fadlillah et al. 2023; Rahmawati and Lumbantobing 2023; Budi Prakoso et al. 2023; Alexakis et al. 2023) and sanitation facilities (Komarulzaman et al. 2016; Nur et al. 2020; Mukhlasin et al. 2020; Odagiri et al. 2020; Al Djono and Daniel 2022; Mudadu Silva et al. 2023) in Indonesia on both human and environmental health. However, there is still a lack of comprehensive reviews on the topic. Many recent review articles have explored water and sanitation in various countries and regions, including Pakistan (Qamar et al. 2022), China (Wang et al. 2021), Brazil (Marchesi et al. 2023), Iran (Noori et al. 2019), Europe (Anthonj et al. 2020), as well as Western Pacific and Southeast Asia (Nasim et al. 2022). Unfortunately, there is still a limited number of comprehensive reviews addressing water and sanitation problems and facilities in Indonesia, the largest archipelagic country in Southeast Asia. Furthermore, despite the abundance of reviews on water and sanitation and its impact on water quality and human health worldwide, none have delved into the impact of water quality—whether raw, seawater, estuary water, freshwater, or treated water on the environment, as well as human health in Indonesia. This review aims to provide a comprehensive overview of the current situation, health and environmental implications, management efforts, and the formidable future challenges that Indonesia faces in its journey towards achieving equitable access to clean water and improved sanitation. Indonesia's quest for equitable access to clean water and improved sanitation for all citizens is an endeavor of paramount importance, and this review provides valuable insights into the path ahead.

Methods

Data collection, retrieval strategies, and identification

In this study, a systematic review of the literature related to water and sanitation conditions in Indonesia was conducted. The systematic review method was applied to ensure transparency and replicability. This process includes defining the scope, establishing selection criteria, extracting data, synthesizing results, developing a framework, and providing recommendations for future implications. This research adopts a domain-based synthesis approach, which is particularly useful when the topic under investigation is diverse and scattered, facilitating the identification of existing gaps. This approach also highlights commonalities from various theoretical, methodological, and thematic perspectives. This is crucial as the primary objective of this study is to identify comprehensive factors related to water quality and sanitation. The authors adhered to the clear guidelines set forth by PRISMA 2020. PRISMA includes the process of searching for relevant articles for content analysis related to the issue and has been recognized across various disciplines. Subsequently, the authors will present detailed steps taken, as visualized in Fig. 2.

During the identification stage of this study, the researchers considered four key factors to encompass all relevant literature: databases, keywords, source types, and publication periods. This search aimed to identify literature related to water and sanitation conditions in Indonesia, including health and environmental impacts, management, and anticipated future challenges. Initial searches were conducted in two primary electronic databases, Scopus and Web of Science (WoS), as well as Google Scholar as an additional source, recognizing that several articles from local journals could provide valuable insights for the analysis.

This study only included publications that had undergone peer review in English, while other types of literature such as editorial notes, book chapters, and conference proceedings were excluded to maintain methodological and conceptual integrity. The keywords used in the search included "Water quality in Indonesia," "Water pollution in Indonesia," and "Sea water pollution in Indonesia" to find articles related to water quality. Additionally, the keywords "Sanitation in Indonesia" and "Sanitation management in Indonesia" were employed to locate studies regarding sanitation and its management in Indonesia. Furthermore, keywords such as "Environmental impacts of water quality in Indonesia," "Health impacts of water quality in Indonesia," "Environmental impacts of sanitation in Indonesia," and "Health impacts of sanitation in Indonesia" were utilized to search for studies on the environmental and health impacts of water quality and sanitation in Indonesia. Articles published between 2000 and 2023 were selected to ensure relevant and ongoing discourse regarding water and sanitation conditions. This approach aimed to ensure that only pertinent and high-quality articles were included, following PRISMA guidelines. Following the

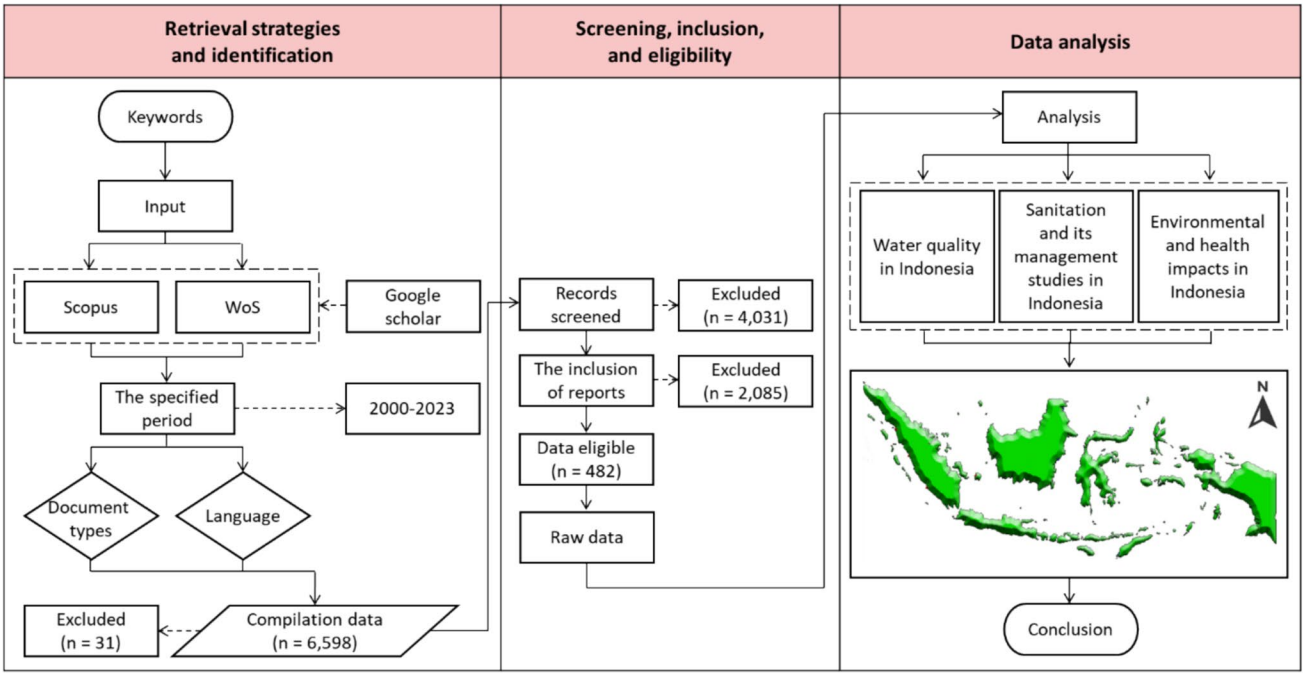

Fig. 2 Schematic representation of the procedure in this review based on PRISMA 2020 guidelines

identification process, a total of 31 articles were eliminated due to duplication across both databases, leaving 6,567 articles retained for further processing as a compiled dataset (see Fig. 2).

Screening, inclusion criteria, and eligibility

During the screening stage, the researchers conducted an initial evaluation of the information available in the titles, abstracts, and keywords of each published paper to determine its relevance to the research topic. This process aimed to identify suitable articles while excluding those that were not relevant, ensuring that only articles with significant potential contributions to the study would be considered for the next steps. During the inclusion stage, each full paper was systematically reviewed to confirm its alignment with the topics of "water," "sanitation," and/or "water and sanitation in Indonesia." The following inclusion criteria were employed to select eligible articles for analysis: (1) Studies on water quality and pollution (including drinking water, freshwater, and seawater); (2) Reports on the current sanitation conditions in Indonesia; (3) Reports on the health and environmental impacts of inadequate water quality and sanitation facilities in Indonesia. Articles written in languages other than English, as well as those that did not empirically address the three topics, were excluded. In this study, to address the risk of bias, we distributed copies of all original articles sourced from the database to all authors, ensuring that everyone had equal access to the information. Subsequently, the authors collaboratively created a shortlist by applying the established inclusion criteria, which allowed for a systematic and transparent selection process, thereby enhancing the reliability of the final list of articles used for further analysis and in-depth review. Consequently, all articles identified during the screening and inclusion phases resulted in an eligible sample consisting of 482 articles.

Data processing

Data from existing studies on water quality, sanitation, and environmental and health impact of inadequate water quality and sanitation facilities in Indonesia were collected and analyzed using descriptive statistics. The data from the selected articles were manually extracted into Microsoft Excel. The water quality data from existing studies were converted into SI units and displayed as a range (minimum to maximum) or mean. In cases where a study provided multiple values, such as distinct points, ranges, or multiple measurements over time or origins, the mean value was used. All of the data from the acquired studies were characterized and quantitatively summarized.

All study locations were identified using Google Maps and subsequently plotted on an Indonesian map to create a distribution map of available research. Due to the maps being provided at wide scales and with low accuracy,

research locations were identified based on cities or other nearby areas.

Available research in water quality, sanitation, and its environmental/health impact

Figure 3 illustrates the distribution of studies of water quality, including treated water, freshwater sources, sea/estuary water sources, sanitation, as well as the impacts on the environment and human health. The studies primarily focus on the Island of Java, with a noticeable gap in coverage for other islands, particularly those located in East Indonesia. The research predominantly focuses on the quality of freshwater sources such as rivers and lakes, with a limited theme of drinking/treated water. Since Indonesia is a huge country with diverse natural characteristics, the characteristics of water may be different in each region and need different treatment processes (Qadafi et al. 2023a). In Indonesia, fresh water was not only used as drinking water sources but also used for daily use without any treatment, especially in peri-urban and rural areas due to the scarce of water treatment facilities (Zevi et al. 2022; Utami et al. 2023a). Nevertheless, communities living in estuary areas use sea or estuary water for daily needs (Cordova and Nurhati 2019; Purwiyanto et al. 2022). The quality of the water source is a crucial factor in household sanitation.

Similar to water quality studies, research on sanitation and its impact on human and environmental health has also been predominantly focused on Java, the most dense island. Overall, studies on sanitation only reach Sumatra, Java, Bali, and Nusa Tenggara Island. Meanwhile, studies on the environmental and human health impact of sanitation and water quality barely reach Sumatra, Kalimantan, and Papua Islands. This situation poses a challenge for researchers to extend their studies to other islands, providing insights into rural Indonesia as a preliminary step in addressing water quality and sanitation issues.

Studies on water quality, sanitation, and the environmental/health impact in Indonesia are insufficient considering the vast area and population. The growth pattern of studies in Indonesia is depicted in Fig. 4. Studies on water quality have been predominant, while studies on sanitation and the impact of sanitation and water quality on human and environmental aspects are relatively comparable (Fig. 4a). The total number of studies on water quality, sanitation, and environmental/health impact in 2022 is slightly lower than 2021 but rising again in 2023 (Fig. 4b). This condition may occur due to the COVID-19 pandemic that strikes the world at the beginning of 2020 including in Indonesia. Research on water quality and sanitation often requires a significant amount of time, especially when dealing with spatial–temporal data. (Shen et al. 2023). Additionally, studies on sanitation and the environmental/health impact require rigorous fieldwork, and the efficiency of conducting such studies may be compromised during the COVID-19 pandemic. There is a need for more research to fill and update the missing data and address the gaps in the field of water quality, sanitation, and its impact on human and environmental health.

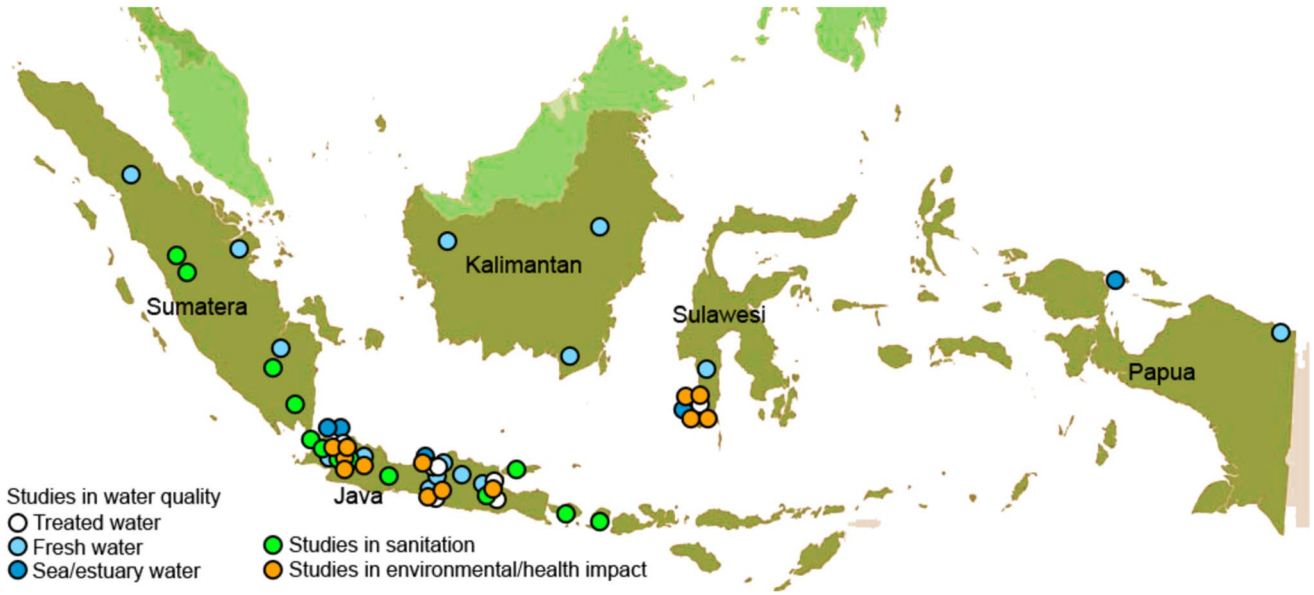

Fig. 3 Distribution of research in water quality, sanitation, and its environmental/health impact in Indonesia

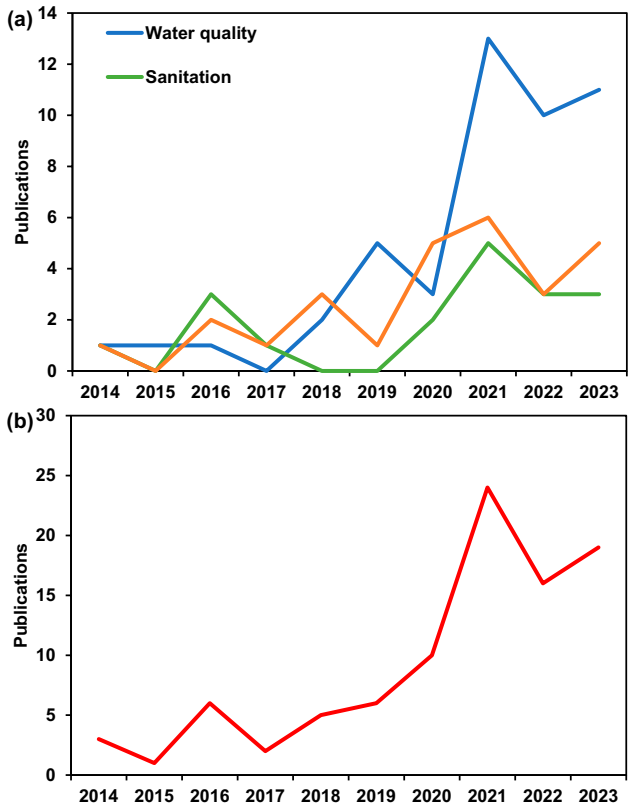

Fig. 4 Available research (**a**), and total studies (**b**) in water quality, sanitation, and environmental/health impact in Indonesia

Existing condition

Water resources

Water resources play a crucial role in the overall growth of a country (Jothivel et al. 2023). Indonesia is endowed with abundant water resources, owing to its extensive archipelagic geography and tropical climate. As a tropical country, Indonesia boasts extensive fresh water sources from both surface and ground water. Numerous rivers, lakes, and dams are distributed across its islands, providing fresh surface water sources (Pawitan and Haryani 2011). These abundant water resources make Indonesia one of the most water-rich nations in the world. The river systems, such as the Kapuas, Mahakam, and Musi, contribute to agricultural irrigation, hydroelectric power generation, and sustaining diverse ecosystems (Tang et al. 2019). Additionally, the extensive network of lakes, including Lake Toba, the world's largest volcanic lake, plays a vital role in regulating water supply and supporting local livelihoods (Sterner et al. 2020).

Rainfall plays a significant role in determining water availability in tropical countries, such as Indonesia. Indonesia has two seasons wet and dry and also two types of climate zones including monsoon and equatorial climate zone. Rainfall in the monsoon zone has two peaks that are focused on the rainy season (October to May) and rainfall in the dry season (June to September) (Jayanti et al. 2023). The average precipitation in the monsoon area is usually greater than 2000 mm/year, indicating that the rainy season is dominating in this area (Jayanti et al. 2020). According to The Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG), the peak of the rainy season occurred in March 2023 while the peak of the dry season occurred in August 2023 (BMKG 2023). Figure 5 shows the rainfall pattern in Indonesia in March 2023 (Fig. 5a) and August 2023 (Fig. 5b). In march 2023, the monthly rainfall reached > 500 mm/month in several areas of Indonesia including West of Sumatra, Central of Kalimatan, Sulawesi, and West New Guinea Islands. Although several areas of Sumatera Island still had high rainfall patterns, the rainfall in August 2023, reached the lowest level at < 20 mm/month, especially in Java Island and other southern areas.

The Malaysian-Australian monsoon, characterized by winds from the southeast and northwest, influences Southeast Asia and Australia, leading to distinct wet and dry seasonal fluctuations on Java Island (Lee 2015). The annual rainfall pattern depicts the features of the rainy season, with the greatest rainfall (2200–2400 mm) occurring and dominated by the Central Java region, and the pattern appears to proceed to the east and west of the smaller rainfall (Avia 2019). However, Other islands experience a different rainfall pattern (Aldrian and Dwi Susanto 2003). In Kalimantan, the average annual rainfall recorded in the new Indonesian planned Capital City (IKN) was 2762.9 ± 84.65 mm/year (Ramadhan et al. 2022). For Sumatra, the extreme rainfall threshold is 60 to 130 mm per day (Supriyadi et al. 2017). In Maluku and Papua islands, there are fewer drought disasters compared to other islands, where drought occurs in practically every location (Faradiba 2021).

Water pollution

Fresh water quality

Table 1 presents the water quality of various water sources in Indonesia. Most studies on freshwater are primarily conducted in Java Island and are lacking in other islands. It also showed that the quality of source water in Indonesia varied according to its location. Some water sources had poor quality when the area was surrounded by peatland (Elma et al. 2021; Qadafi et al. 2023a). The organic matter content in the peatland-influenced river and peat water located in Sumatera and Kalimantan Islands are very high depicted with high concentrations of COD and DOC (Qadafi et al. 2023c). The peat water contains a high concentration or natural organic matter (NOM) indicated by a brownish color and acidic pH (Qadafi et al. 2021). The community in the rural area used

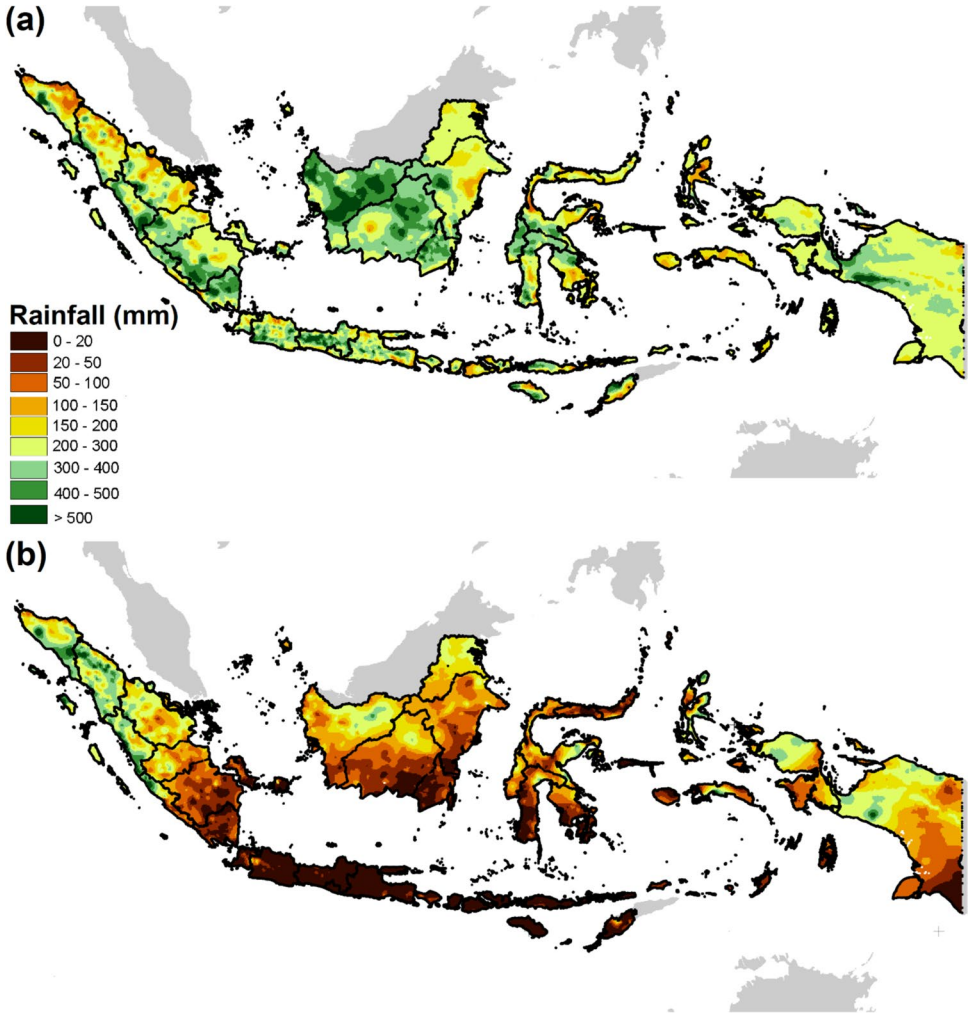

Fig. 5 The rainfall pattern in Indonesia: **a** March 2023 and **b** August 2023 (BMKG 2023)

peat water as their daily water source, including for drinking water, since there were no other options in the peatland area (Zevi et al. 2022). They usually use chlorine directly to peat water to remove the color (Qadafi et al. 2020). The use of peat water as a daily water source should be a concern, as peat water contains a high concentration of NOM in the form of humic acid. The reaction of NOM and chlorine could form disinfection by-products (DBPs) such as trihalomethanes (THM) and haloacetic acid (HAA) which can pose a cancer risk when present in extremely high concentrations. The USEPA set the maximum contamination level (MCL) for THM4 containing chloroform (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM), and bromoform (TBM) at 80 g/L and 60 g/L for HAA5 containing monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA) and dibromoacetic acid (DBAA) (USEPA 1998). Meanwhile, the Indonesia Ministry of Health sets higher standards for THM4 (560 g/L) and chlorinated-HAA5 (70 g/L) (Menteri Kesehatan Republik Indonesia 2010).

Non-peatland-influenced rivers located in Java have lower COD and BOD concentrations compared to rivers in Sumatera and Kalimantan. However, rivers in Java have been reported to be highly polluted by anthropogenic organic matter (AOM) such as pesticides (Rahmawati et al. 2013; Utami et al. 2020; Oginawati et al. 2022a, b), microplastics (Alam et al. 2019; Cordova et al. 2020, 2022a, b; Buwono et al. 2021a, b, 2022; Fajaruddin Natsir et al. 2021; Radityaningrum et al. 2021; Riani and Cordova 2022; Sulistyowati et al. 2022; Babel et al. 2022), EDC (Ismanto et al. 2022; Qadafi et al. 2023b), and pharmaceuticals (Utami et al. 2022), and heavy metals (Budiyono et al. 2015; Duvert et al. 2019; Harjupa et al. 2022; Puspitasari et al. 2023).

Water sources located in rural areas commonly have better quality compared to urban areas, indicating lower anthropogenic pollution characterized by low concentrations of DO, COD, and BOD (Jayanto et al. 2021). The AOM in water pollution refers to the introduction of organic materials into water bodies as a result of human activities. These materials can include a wide range of pollutants such as

Table 1 Water qualities in Indonesia

Source	Quality							References
	TSS (mg/L)	TDS (mg/L)	pH	COD (mg/L)	DO (mg/L)	BOD (mg/L)	Spotted contaminants	
Fresh water								
Citarum River	14.50 – 22.50[a]	83.30–439.00[b]	6.98 – 7.96[a]	12.92 – 29.54[a]	2.53 – 7.62[a]	40.00–50.10[b]	Pyrethroid: 0–0.01 mg/L[c] microplastic: 3.35 particles/m^{3}[d] Organochlorine: 0.09 µg/L[e] UV_{254} 0.22–0.27 cm^{-1}[f] THMFP 5.72–244.70 µg/L[f]	(Muntalif et al. 2023)[a] (Alexakis et al. 2023)[b] (Ariyani et al. 2023)[c] (Cordova et al. 2022a)[d] (Oginawati and Pratama 2016)[e] (Qadafi et al. 2023a)[f]
Pesanggrahan-Grogol River	N.A	N.A	N.A	N.A	N.A	N.A	Plastic waste 1.7–7.4 m^{3}/day	(Sari et al. 2022)
Cikapayang River	7.00 – 66.00	144.00 – 4090.00	5.60 – 9.80	26.00 – 179.00	0.50 – 5.00	N.A		(Prayogo et al. 2020, 2023)
Brantas River	39.0–750.1[a]	195.3 – 375	6.80 – 7.60[a]	N.A	3.60 – 7.60[a]	6.0 – 19.7[a]	Microplastic: 133 – 5467 3.35 particles/m^{3}[a] Bisphenol A: 556 ng/L[b]	(Buwono et al. 2021b)[a] (Ismanto et al. 2022)[b]
Garang River	N.A	148–266	8–8.9	11.9–61.93		4. –7.9	Cr 0.001–0.014 mg/	(Ujianti et al. 2018)
Bengawan Solo River	67.11[a]	244.21[a]	7.21[a]	N.A	5.02[a]	11.54[a]	Bisphenol A: 1070 ng/L[a]	(Ismanto et al. 2022)[a]
Ciliwung River	6.65–6.79[a]	N.A	N.A	N.A	3.00–7.90[b]	N.A	Cd: 0.3–6.3 mg/L[a] Hg: 0.6–2 mg/L[a] 59.9–73.8 mg/L[a]	(Elfidasari et al. 2023)[a] (Duvert et al. 2019)[b]
Mahakam River	N.A	200–300	6.35–6.80	N.A	2.00–3.00	N.A	TOM 40–50 Fe 0.4–0.5 Mn 0.3–0.4	(Sutapa et al. 2022)
Kapuas River	N.A	10.00–10000.00	6.00–7.80	10.00–350.00	N.A	10.00–50.00		(Purnaini et al. 2018)
Musi River	N.A	N.A	7.60–8.10	N.A	3.20–12.50	N.A		(Rozirwan et al. 2021)
Winongo River	N.A	N.A	N.A	N.A	N.A	N.A	Pb 0.01–0.69 mg/L Cu 0.00–0.06 mg/ Cr 0.01–0.05 mg/ Cd 0.00–0.01 mg/ Fe 0.20–1.68 mg/ Al 0.62–1.31 mg/	(Fadlillah et al. 2023)
Grenjeng River	N.A	N.A	N.A	49–510.5	N.A	53–5.7	Total coliforms 540–2,400,000 mL	(Widodo et al. 2019)
Jayapura Rivers	55.50–133.32	34.00–58.0	6.55–7.62	12.50–25.00	6.34–7.19	1.70–3.34		(Tanjung et al. 2022)
Sumatera peat water		82.5–2186.5	3.6–5.6	147.00–275.00			DOC 21.1–54.6 mg.C/L THMFP 1545.80–1088.59 µg/L HAAFP 557.6–727.52 µg/L	(Qadafi et al. 2020, 2021; Zevi et al. 2022)

Table 1 (continued)

Source	Quality							References
	TSS (mg/L)	TDS (mg/L)	pH	COD (mg/L)	DO (mg/L)	BOD (mg/L)	Spotted contaminants	
Kalimantan peat water	1.00–54.00	N.A	3.03–3.84	0.00–17.00	1.99–8.05	0.50–9.80	Color 888.17 PtCo Fe 2.48 mg/L Coliform 1068.00 colonies/100 mL	(Khayan et al. 2021)
Saguling reservoir	N.A	40–50[a]	N.A	18–20[a]	1.5–2.0[a]	N.A	DOC 5.08 mg/L[b] Bromide 3.31 mg/L[b] THMFP 24.98 µg/L[b] Nonylphenol 0.066 mg/L[b] Aldrin 2–37 µg/L[c] DDT 1–0 µg/L[c] Endosulfan 1–11 µg/L[c] Lindan 2–5 µg/L[c] Heptachlor 2–16 µg/L[c]	(Sutapa et al. 2022)[a] (Qadafi et al. 2023b)[b] (Oginawati et al. 2022b)[c]
Jatiluhur reservoir	N.A	N.A	N.A	28.00–59.00[a]	1.00–3.99[a]	3.10–17.0[a]	chlorophyl 2.23–43.37[b]	(Wardhani and Sugiarti 2021)[a] (Arwin et al. 2014)[b]
Jastaigede reservoir	4.00–17.00[a]	110.00–142.00[a]	6.84–7.72[a]		4.30–5.80[a]	3.24–16.22[a]	Phosphate 0.054–0.137 mg/L[b]	(Sami et al. 2021)[a] (Syifa Septiningsih et al. 2021)[b]
Lake Toba		0.00–0.07	7.94–8.85	24.27–72.31	2.67–11.26	N.A		(Lukman et al. 2019)
Well water surrounds watershed area of Pangkajene	N.A	11–8900	5.60–8.30	N.A	N.A	N.A	Cr VI 0.0005–0.0031 mg/L	(Astuti et al. 2021)
Drinking/treated water								
Surabaya WTP	N.A	N.A	N.A	N.A	N.A	N.A	Microplastics: 8500–123 00 particles/m^3	(Radityaningrum et al. 2021)
Groundwater based drinking water in Bekasi	N.A	126.82	7.10	N.A	N.A	N.A	Coliform: 88.56 MPN/L	(Dianty et al. 2022)
Malang piped water supply	N.A	N.A	N.A	N.A	N.A	N.A	Chlorine residue: 0.5–0.9 mg/L Coliform: 30–60 MPN/L	(Rofida et al. 2019)
Drinking water refill in South Bekasi	N.A	N.A	N.A	N.A	N.A	N.A	Contaminated by E. Coli and Pseudomonas, Sp	(Rahmawati and Lumbantobing 2023)
Gunungkidul drinking water pipeline	N.A	57.11–383.00	7.23–8.11	N.A	N.A	N.A	Coliform: > 20 CFU/L	(Safitri et al. 2022)

Table 1 (continued)

Source	Quality							References
	TSS (mg/L)	TDS (mg/L)	pH	COD (mg/L)	DO (mg/L)	BOD (mg/L)	Spotted contaminants	
Drinking water from village wells in Semarang	N.A	N.A	N.A	N.A	N.A	N.A	Nitrate: 0.01–84 mg/L	(Sadler et al. 2016)
Drinking water supply tidal inundation area of Semarang	N.A	N.A	7.00	N.A	N.A	N.A	Coliform > 10	(Budiyono et al. 2015)
Maros well drinking water	N.A	N.A	5.20–7.74	N.A	N.A	N.A	Cr (IV) 0.0004–0.0022 mg/L SiO_2 5.52–20.90 mg.L	(Rauf et al. 2021)
Bandung WTP	N.A	N.A	N.A	N.A	N.A	N.A	DOC 0.87–5.23 mg/L Chloroform 110–170 µg/L	(Sururi et al. 2019)
Sea/estuary water								
Jakarta Bay	1.00–9.00[a]	N.A	7.41–7.77[b]	N.A	3.61–6.14[b]	N.A	Paracetamol 420–610 ng/L[a] Pb 0.81–1.69 mg/kg[b] Cr 2.14–5.31 mg/kg[b] in suspended particulate matter[b] Microplastic 4.29–23.49 particles/m^3[c] Plastic debris 780 items/day[d]	(Koagouw et al. 2021)[a] (Puspitasari et al. 2023)[b] (Cordova et al. 2022b)[c] (Cordova et al. 2021)[d]
Wonorejo River estuary	N.A	N.A	N.A	N.A	N.A	N.A	Plastic debris 126.07–1162.37 g/m^2	(Kurniawan and Imron 2019)
Ciliwung Estuary-coast	N.A	N.A	N.A	N.A	N.A	N.A	Microplastic 8.48–9.37 particles/m^3	(Cordova et al. 2020)
Makassar Coast	N.A	N.A	5.08–7.06	N.A	N.A	N.A	Mercury 1.0013–1.0012	(Mallongi et al. 2020b)
Doreri Gulf	N.A	N.A	7.14–7.72	N.A	5.88 6.61	N.A		(Sembel et al. 2021)

Table 2 Recent available researches on sanitation in Indonesia

Location	Topic	Highlights	References
Indonesia	Functionality of community-based rural water supply and sanitation	Public tap connections are rarely work contrasting to household connections	(Daniel et al. 2023)
South Sumatra	Community-financed sanitation program	The effects of messages and solicitations are revealed by an orthogonal randomization scheme	(Yokoo and Harada 2023)
Indonesia	Relationship between water and sanitation and maternal health	Access to at least basic water has no systematic relationship with maternal and neonatal outcomes	(Cameron et al. 2021a)
Indonesia	Achieving the Sustainable Development Goals for water and sanitation	Sanitation outcomes can be improved by strengthening government processes	(Odagiri et al. 2020)
Banten	Sanitation of Ro-Ro vessel at the port of ferry branch Merak Banten	Ro-Ro ship sanitation conditions do not meet the requirements of 53%	(Mukhlasin et al. 2020)
Indonesia	Childhood stunting and cognitive effects of water and sanitation	Open defecation has a negative impact on cognitive test scores	(Cameron et al. 2021b)
Indonesia	Improving water, sanitation, and hygiene in schools	Students who learned hygiene skills from their teachers were less likely to defecate openly	(Karon et al. 2017)
Payakumbuh, Sawahlunto, Lampung	Strengthening local governance arrangements for sanitation	A motivated sanitation committee required the participation and support of local decision-makers	(Chong et al. 2016)
East Java, West Java	Public service provision under conditions of insufficient citizen demand	Increasing educational initiatives will raise citizen pressure on the government	(Winters et al. 2014)
Java, Madura	Approach to nationwide sanitation planning for developing countries	The budget needed to achieve universal access by 2019 has been estimated to be 25 billion US dollars spread over five years	(Kerstens et al. 2016)
East Java	The effect of village sanitation on child height	When village sanitation coverage approaches 50–75%, improvements in child health are realized	(Cameron et al. 2022)
Tangerang	Effect of community-based total sanitation program with diarrhoea	Toddlers in households with poor wastewater treatment were 5,2 times more likely to have diarrhoea	(Purnama Sari Indah et al. 2022)
Indonesia	The effect of community contribution on the functionality of rural water supply and sanitation	Health promotion positively influences the sustainability of rural water supply	(Al Djono and Daniel 2022)
Bali, Lombok	Opportunities for inclusive water, sanitation and hygiene in tourism	Integrated approach to Inclusive WASH will contribute to tourism recovery	(Loehr et al. 2021)
Indonesia	Clean water, sanitation and diarrhoea in Indonesia	having piped water in the dwellings reduces the odds of childhood diarrhoea by 24%	(Komarulzaman et al. 2016)

pesticides, fertilizers, industrial effluents, and sewage discharge (Qadafi et al. 2023a). The presence of AOM poses a significant threat to aquatic ecosystems, as it can lead to a variety of adverse effects (A. K et al. 2023; Tu et al. 2023). Decomposition of anthropogenic organic matter (AOM) consumes oxygen, leading to oxygen depletion in water bodies. This process, known as eutrophication can harm aquatic organisms that rely on oxygen for survival (Cui et al. 2021). Other AOMs, such as pesticides and fertilizers, can enter the water system through the runoff process, affecting not only aquatic life but also posing risks to human health when the contaminated water is used (Elfikrie et al. 2020; Utami et al. 2020; Larrea Murrell et al. 2024).

Water sources in urban areas are contaminated not just by AOM, but also by inorganic contaminants such as nutrients and heavy metals, particularly in areas with high industrial activity. The influx of nutrients, primarily nitrogen and phosphorus, can trigger eutrophication (Marselina and Burhanudin 2017; Syafei et al. 2020; Astuti et al. 2022a), fostering the excessive growth of algae and depleting oxygen levels in the water bodies. Concurrently, heavy metals derived from industrial activities pose a significant threat to aquatic ecosystems and human health (Astuti et al. 2021). These metals, including lead (Budiyono et al. 2015; Duvert et al. 2019; Harjupa et al. 2022; Puspitasari et al. 2023), mercury (Mallongi et al. 2020b, 2023; Nandiyanto et al. 2023), cadmium

(Ujianti et al. 2018; Mallongi et al. 2020a; Puspitasari et al. 2023), and chromium (Ujianti et al. 2018; Rauf et al. 2021; Astuti et al. 2022b; Puspitasari et al. 2023) do not undergo natural degradation and can accumulate in water, leading to a cascade of detrimental effects on aquatic organisms and potentially entering the human food chain. Tackling water pollution in Indonesia requires a holistic approach, encompassing stringent regulations, sustainable anthropogenic practices along the basin, and effective waste management strategies to preserve the quality and usability of freshwater resources for both the aquatic ecosystems and the communities relying on them.

Treated/drinking water quality

Inadequate fresh water source quality has an impact on the quality of treated/drinking water in Indonesia. The majority of WTP in Indonesia still uses conventional water treatment processes using coagulation/flocculation process followed by sedimentation, filtration, and chlorination (Sururi et al. 2019, 2020; Bagastyo et al. 2023). This conventional process could not completely remove pollutants from water. Studies on drinking/treated water have indicated that parameters such as Total Dissolved Solids (TDS) (Safitri et al. 2022; Dianty et al. 2022) and pH (Budiyono et al. 2015; Rauf et al. 2021; Safitri et al. 2022; Dianty et al. 2022) have met the standard requirements. However, some studies showed that drinking water is still contaminated by various pollutants, including microplastics (Radityaningrum et al. 2021), heavy metals (Rauf et al. 2021), and bacteria. The high microbiological activity was indicated by the presence of bacteria such as *E. coli* (including coliform) (Budiyono et al. 2015; Rofida et al. 2019; Safitri et al. 2022; Dianty et al. 2022; Rahmawati and Lumbantobing 2023) and *Pseudomonas*, SP (Rahmawati and Lumbantobing 2023). This condition can cause many health problems such as waterborne diseases (Andrade et al. 2018) such as diarrhea, leptospirosis cholera, and dysentery.

The conventional WTP approach proved unable to remove not just bacteria and heavy metals from water, but also natural organic matter (NOM). This condition triggers the formation of carcinogenic disinfection by-products (DBPs) such as trihalomethanes (THMs) during the final chlorination process (Sururi et al. 2020). The formation of DBPs was not only caused by the presence of NOM as a primary precursor, but also by the presence of anthropogenic organic matter (AOM) such as pesticides, pharmaceuticals, and microplastics that could not be completely removed by conventional treatments (Qadafi et al. 2023a). A high abundance of microplastics has been reported to have passed the WTP system in Surabaya City (Radityaningrum et al. 2021), the second-largest city in Indonesia and the capital of East Java Province.

The presence of pollutants in treated water was not only caused by an improper water treatment system but also by the condition of the water treatment facility. The sedimentation tank of Bandung WTP has been reported to be nurtured by moss, algae, and other low-water plants on the water surface of the gutters, settlers, and filter media (Sururi et al. 2020). This condition contributed to the presence of NOM and DBP formations during the final chlorination process.

Sea/estuary water quality

The same as freshwater studies, reports on sea/estuary water in Indonesia mostly focused on Java, with very little reported on other islands. Some studies reported that

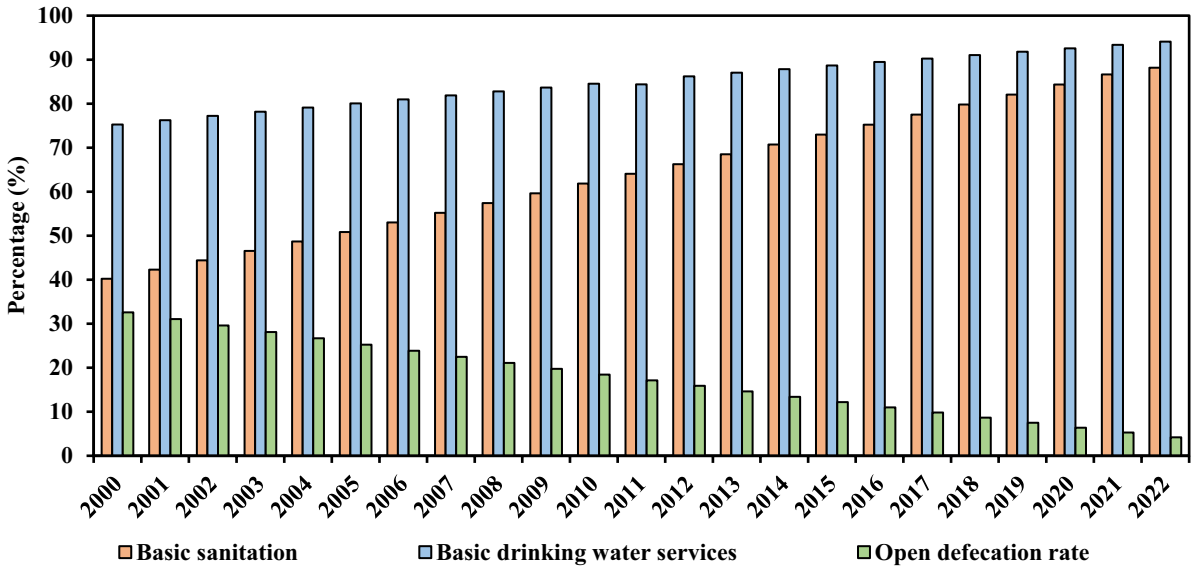

Fig. 6 Access to basic sanitation, basic drinking water, and open defecation percentage in Indonesia (World Bank 2023)

Table 3 Impacts of sanitation and water pollution on human health and environment

Object	Issue	Health impact	Environmental impact	Reference
Drinking water and sanitation facilities	Clean water and sanitation	diarrhoea prevalence among children under five	N.A	(Komarulzaman et al. 2016)
Drinking water quality	Primary school enrolment and absenteeism	water-related diseases such as diarrhoea	N.A	(Komarulzaman et al. 2019)
Polluted river water used as bathing and associated sanitary practices	Trash disposal	Diarrhoea-related deaths	N.A	(Garg et al. 2018)
Groundwater facilities	Microbial contamination (E-coli)	Diarrheal death	N.A	(Sodha et al. 2011)
Drinking water	Microbial contamination (Aeromonas sp)	Gastrointestinal infection	N.A	(Pablos et al. 2011)
Household water and sanitation	Open defaecation	Health during pregnancy: • Haemoglobin • Diarrhoea • Body mass index Complication during pregnancy: • Pre-labour term • Bleeding • Fever	N.A	(Cameron et al. 2021a)
Ciliwung River water	Microbial contamination (Cryptosporidium sp.)	cryptosporidiosis infection, diarrhea	N.A	(Mahardianti et al. 2020)
Well water	Microbial contamination (fecal coliform and E-coli)	Non-specific diarrhea	N.A	(Irda Sari et al. 2018)
Drinking water	Nitrate	Risk for birth defects	N.A	(Sadler et al. 2016)
Yogyakarta streams	NO_3-N NO_2-N NH_4-N PO_4-P		low invertebrate diversity	(Budi Prakoso et al. 2023)
Drinking water	Nitrate	birth defects, colorectal cancer, and thyroid conditions	N.A	(Lowe et al. 2021)
Drinking water	Nitrate	Colorectal cancer	N.A	(Fathmawati et al. 2017)
Saguling Dam water	Pesticide (Organochlorine) contamination	Accumulation in human' tissues	Damage aquatic biota and their habitats	(Oginawati et al. 2022b)
Brantas River water	Microplastics	N.A	Increasing water temperature, turbidity, total suspended solid, and biological oxygen demand	(Buwono et al. 2021b)
Citarum River	Microplastics	Potentially accumulate in human body through food chain	Accumulation of microplastic in Chanos chanos Sp	(Agustian Fareza and Sembiring, 2020; Sembiring et al. 2020)
Bone River Water	Heavy metals (As, Hg, Pb)	Damage to central nervous systems, skin disease, gastrointestinal diseases	N.A	(Gafur et al. 2018)
Pangkajene River, South Sulawesi	Heavy metals (Cd, Cr, Pb, Hg)	Carcinogenic and non-carcinogenic risk	Accumulation in aquatic biota (shellfish, milkfish)	(Astuti et al. 2022a)

Table 3 (continued)

Object	Issue	Health impact	Environmental impact	Reference
Well water surrounds watershed area of Pangkajene	Heavy metal	N.A	Ecological risk	(Astuti et al. 2021)
Makassar coastal area	Mercury	potentially harmful effects on the health	potentially harmful effects on ecosystem of marine organisms	(Mallongi et al. 2020b, 2023)
Makassar drinking water	Lead and cadmium	Increased blood pressure	N.A	(Mallongi et al. 2020a)
Maros well drinking water	Hexavalent chromium and silicon dioxide	Drinking water in this area are unacceptable	N.A	(Rauf et al. 2021)
Winongo River	Heavy metal	N.A	Potential ecological risk	(Fadlillah et al. 2023)
Citarum River	DBPs formation	Potential formation of cytotoxic and genotoxic DBPs when treated with chlorine	N.A	(Qadafi et al. 2023a; Qadafi et al. 2023b)
Jatiluhur reservoir	Phytoplankton and Chlorophyl	N.A	Eutrophication damage to freshwater ecosystems	(Arwin et al. 2014; Astuti et al. 2022a)
Jatigede researvoir	Phosphate pollution	N.A	Eutrophication/fertile	(Syifa Septiningsih et al. 2021)

several parameters for sea and estuary water in Indonesia such as pH (Koagouw et al. 2021), TSS (Koagouw et al. 2021), and DO (Puspitasari et al. 2023) were in normal condition. However, many other toxic pollutants such as heavy metals, pharmaceuticals, and microplastics have been reported to pollute the estuary and seawater (Mallongi et al. 2020b; Cordova et al. 2022b, 2020). This might be because some massive industries in Indonesia still dispose of their waste directly into the sea (Koagouw et al. 2021). These conditions increased seawater pollution especially the present of heavy metals such as mercury (Mallongi et al. 2020b), lead (Puspitasari et al. 2023), and chromium (Puspitasari et al. 2023). Meanwhile, the sea and estuary located on Java Island have been extensively polluted by microplastics (Cordova et al. 2020, 2022b) and plastic debris (Kurniawan and Imron 2019; Cordova et al. 2021) due to the daily disposal of tons of plastic waste (Cordova et al. 2021). Besides that, the use of personal care products that contain scrub also contributes to microplastic pollution (Qi et al. 2022; Deng et al. 2022; Thacharodi et al. 2024). For pharmaceutical pollution, it has been reported that Jakarta Bay is contaminated by paracetamol due to the presence of numerous pharmaceutical industries located near the north coastline of Java Island, especially in Jakarta Bay (Koagouw et al. 2021). Pharmaceutical pollution is also associated with the widespread use of drugs during the COVID-19 pandemic, contributing to pharmaceutical pollution in the sea/estuary water (Koagouw et al. 2021; Giné-Garriga et al. 2021).

Sanitation

Sanitation in Indonesia is a crucial aspect of public health and environmental sustainability. It encompasses a wide range of services and infrastructure aimed at ensuring access to safe drinking water, proper wastewater management, and hygiene practices. Indonesia, as a vast archipelagic nation with diverse geographical and demographic characteristics, faces various challenges in providing adequate sanitation services to its population. Access to proper sanitation facilities and clean water is fundamental for public health and environmental sustainability (Jakariya et al. 2022; van Puijenbroek et al. 2023). Even though there has been significant progress in sanitation facilities improvement and access to clean water, there is a significant disparity in access to basic water services between urban and rural areas. While 95% of urban households have access to basic water services, only 82% of rural households do (WHO/UNICEF 2019). This evidence highlights that rural and remote areas in Indonesia continue to face significant challenges in terms of access to basic water services. Table 2 displays recent studies on sanitation in Indonesia, primarily conducted in Java Island.

Household sanitation

Poor household water supply and sanitation can impact maternal and newborn health outcomes through various mechanisms (Fate et al. 2021; Cameron et al. 2021a). These include the quality of drinking water ingested by pregnant women and exposure to harmful fecal pathogens in the environment due to inadequate sanitation (Cameron et al. 2021a). Pathogens present in feces can spread to humans through water and soil, leading to illnesses such as anemia, malnutrition, and impaired physical and cognitive development (Cameron et al. 2021a). Indonesia has made substantial progress in enhancing water and sanitation conditions. Between 2000 and 2020, access to at least basic sanitation increased from 38 to 86%, and access to at least basic drinking water increased from 75 to 92%. However, there were still 38 million Indonesians who lack basic sanitation and 22 million who lack basic drinking water (WHO/UNICEF 2019). The WHO estimated 13.7 neonatal deaths per 1,000 live births in Indonesia, compared to 12.6 in the Philippines and 4.4 in Malaysia. The inadequate sanitation and water conditions in Indonesia may contribute to the elevated rates of maternal and newborn mortality (Cameron et al. 2021a). Despite continued government focus, progress in lowering maternal mortality has stalled in recent years, underlining the need to better investigate potential underlying variables and develop effective interventions (Belton et al. 2014; Soedarmono 2017).

A lack of water services impedes safe basic water, sanitation, and hygiene (WASH) (Daniel et al. 2023), impacting human health. According to a prior study, 60% of worldwide diarrhea deaths to WASH issues (Prüss-Ustün et al. 2019). The disease burden from inadequate WASH has been well-established in past decades (GBD 2015 Risk Factors Collaborators 2016; Prüss-Ustün et al. 2019). Recent evidence has highlighted additional benefits of clean sanitation in reducing diarrheal diseases, especially in communities with high sanitation coverage (Fuller and Eisenberg 2016; Jung et al. 2017). Consequently, the counterfactual exposure scenario involves using basic sanitation services in a community where more than 75% of people have access to such services.

Figure 6 shows Household access to basic sanitation, basic water, and open defecation rate in Indonesia (Cameron et al. 2021a). Open defecation, which refers to the practice of people defecating in the open, without using proper toilet facilities (Kouassi et al. 2023a), is still a significant issue in some parts of Indonesia, particularly in rural and remote areas (Odagiri et al. 2020; Cameron et al. 2021b, 2022; Lowe et al. 2021). In these areas, the construction of proper sanitation facilities, such as toilets and sewage systems, can be challenging due to geographical and economic constraints (Cameron et al. 2021b, 2022). The reasons behind open defecation in Indonesia are multifaceted and include factors such as infrastructure limitations, lack of access to sanitation facilities, cultural practices, and also poverty(Cameron et al. 2021b; Roy et al. 2023; Kouassi et al. 2023a; Nguyen 2023). The limited infrastructure and access to sanitation facilities often lead to the practice of open defecation, as there are no available alternatives (Kouassi et al. 2023a). Besides, in some communities, traditional or cultural beliefs may influence people's preferences for open defecation (Roy et al. 2023; Kouassi et al. 2023a, b). Moreover, poverty also plays a significant role in the prevalence of open defecation, as families with limited financial resources may prioritize other essential needs over building and maintaining sanitation facilities (Kouassi et al. 2023a, b). Open defecation poses serious health risks, as it can lead to the contamination of water sources and the spread of waterborne diseases that can lead to illness and death, particularly among children (Ali et al. 2022; Rahman et al. 2020; White et al. 2023; Bowman 2021; Nienie et al. 2017; Cameron et al. 2021b). A study reported that open defecation has a negative impact on cognitive test scores and childhood stunting in Indonesia (Cameron et al. 2021b).

Efforts to reduce open defecation, especially in rural and remote areas, involve a combination of strategies (Daniel et al. 2023). The construction of toilets, sewage systems, and waste treatment facilities can be challenging in these regions due to geographical constraints, limited resources, and traditional practices. It's essential to develop and implement innovative and cost-effective sanitation solutions to address these challenges and ensure proper waste disposal and management. Community education and awareness campaigns aim to change behaviors and encourage the use of toilets. These campaigns often address cultural and traditional beliefs that may hinder toilet adoption (Cameron et al. 2021b).

The Indonesian government has implemented programs and policies to address open defecation, including the Total Sanitation Movement (Gerakan Sanitasi Total Berbasis Masyarakat) to promote improved sanitation and hygiene practices (Cameron et al. 2019). Indonesia collaborates with international organizations and agencies to access funding and expertise to tackle open defecation challenges. Government initiatives play a crucial role in addressing sanitation challenges. Improving sanitation in Indonesia is a complex and ongoing process that requires investments in infrastructure, technology, education, and community engagement. The government, along with various stakeholders, is working to address these challenges and ensure that all Indonesians have access to safe and sustainable sanitation services to improve public health and environmental conditions.

Community and public facility

Providing clean and accessible public toilets in both urban and rural areas is essential to address the sanitation needs

of the population, particularly in places like markets, transportation hubs, and public institutions (Nasim et al. 2022). Studies reported that sanitation facilities in Indonesia's public transportation were lacking (Mukhlasin et al. 2020; Rajagukguk 2021). Whereas, access to clean and safe sanitation facilities is essential to prevent the spread of diseases, protect the environment, and improve the overall well-being of the population (Prüss-Ustün et al. 2019). Therefore, encouraging the construction and use of household toilets is a fundamental aspect of community sanitation. Community-Led Total Sanitation (CLTS) is an approach that empowers communities to assess their sanitation conditions, take collective action, and make their villages open-defecation-free. This community-based approach has been implemented in many parts of Indonesia (Cameron et al. 2022). The CLTS activities were varied, from promoting proper hygiene practices, such as handwashing with soap to conducting educational campaigns to raise awareness about the importance of sanitation and hygiene, as well as to change behaviors related to open defecation and unhygienic practices (Karon et al. 2017). These kinds of programs play an important role in community awareness (Yokoo and Harada 2023). Rural areas, in particular, often not only lack access to adequate sanitation infrastructure but also lack community awareness of environmental hygiene (Yokoo and Harada 2023). A study by Chong et al. (2016) also found that a motivated sanitation committee required the participation and support of local decision-makers.

In addition, government processes also play critical roles in improving sanitation facilities including waste management (Odagiri et al. 2020). The government should provide proper wastewater treatment facilities and solid waste management in public buildings, institutions, and industrial areas necessary to reduce environmental pollution and ensure clean and safe surroundings. In conclusion, the efforts to enhance sanitation in communities and public facilities in Indonesia demand collaboration among government agencies, non-governmental organizations, local communities, and international partners. Investment in infrastructure, capacity building, and behavior change initiatives is essential to ensure that all Indonesians have access to clean and safe water and sanitation facilities, leading to improved public health and environmental conditions.

Health and environmental impacts

The provision of water that is safe, economical, and easily obtainable is vital for the promotion of health, advancement, and preservation of human dignity (United Nations 2023). Even though the global WASH field has witnessed substantial advancements in recent decades, a recent analysis has determined that approximately 1.4 million deaths were attributed to diarrhea in 2016 (Prüss-Ustün et al. 2019). Among these deaths, inadequate access to safe water was found to be responsible for nearly half a million (485,000) fatalities (Prüss-Ustün et al. 2019). Furthermore, Indonesia also confronts tremendous issues in providing good water quality and sanitation due to its high population density and limited access to clean water sources. These difficulties lead to contamination of drinking water sources, which can have serious effects on human health. Waterborne infections such as diarrhea, cholera, and typhoid are common in places with poor water quality, causing illness and even mortality in the affected population (Sodha et al. 2011; Singh et al. 2014; Aslam et al. 2022; Parida et al. 2022). The presence of contaminants and chemicals in contaminated water offers long-term health hazards, including an increased risk of chronic diseases including cancer, birth defects, skin disease, and gastrointestinal and neurological problems (Fathmawati et al. 2017; Gafur et al. 2018; Astuti and Mallongi 2020; Mallongi et al. 2020b; Astuti et al. 2021, 2022b; Lowe et al. 2021).

Table 3 presents two primary categories of contaminants that have the potential to significantly affect both biota and human health in Indonesia: 1) biological agents, and 2) chemical agents. Drinking and well water in Indonesia were majorly contaminated by microbial agents such as *Escherichia coli*, *Cryptosporidium Sp,* and *Aeromonas spp* (Pablos et al. 2011; Sodha et al. 2011; Irda Sari et al. 2018; Mahardianti et al. 2020; Muurinen et al. 2022). As indicated by a previous study, the presence of piped water at the household level was strongly correlated with the occurrence of diarrhea (OR = 0.797,95% CI: 0.692–0.918; Komarulzaman et al. 2016). It might be caused by the fact that piped water was contaminated with fecal coliform and was unsafe to ingest without proper processing steps (Tong et al. 2016). The high incidence of diarrhea cases in Indonesia due to poor water quality was also associated with school absenteeism (Komarulzaman et al. 2019). The study revealed a negative correlation between the prevalence of diarrhea and school enrolment (B: 0.202, sig $p < 0.01$) in several districts in Indonesia. In addition to *Escherichia coli*, the presence of *Aeromonas Sp* in the water column also had a substantial impact on causing gastrointestinal diseases in humans (Pablos et al. 2011). Poor water quality and sanitation were connected not only with the health of children but also with the health of mothers. According to research (Cameron et al. 2021a), having access to basic household sanitation was closely linked to a significant reduction in overall risk during pregnancy and childbirth. The presence of basic sanitation in a family was strongly and significantly linked to a reduced likelihood of miscarriage and served as a reliable signal of the occurrence of high fever during labor, which was indicative of infection.

Contamination of microbes was also occurred in surface water such as in the Ciliwung River (Mahardianti et al. 2020) which contaminated by *Cryptosporidium sp.* This contamination might cause several health problems such as cryptosporidiosis infection and diarrhea.

Table 3 also shows studies about the chemical compounds contamination in drinking water and surface water including Nitrate (NO_3-N), Nitrite (NO_2-N), Ammonium (NH_4-N), Phosphate (PO_4-P), pesticides, disinfection by-products (DBPs), heavy metals, and microplastics. The health consequences of chemical compounds, such as nitrate, pesticides, silicon dioxide, DBPs, and heavy metals, include non-carcinogenic effects such as birth defects, thyroid problems, central nervous system disorders, skin illness, and kidney and gastrointestinal disorders. Additionally, these substances proved to have carcinogenic effects, including increasing the risk of colorectal cancer (Mallongi et al. 2020b; Rauf et al. 2021; Lowe et al. 2021; Astuti et al. 2022b, c; Li et al. 2023). A study by Mallongi et al. (2020b) reported that the contaminants may transport and accumulate from one-to-one environmental media such as air, water, and soil. It might also accumulate in the food chain. Thus, biota and humans living surround the contamination area might be impacted by those pollutants. The impact of pollutants did not only cause detrimental effects on human health but also on ecosystem health. The accumulation of chemical substances in water ecosystems might cause eutrophication, a decrease in water quality (increasing turbidity, total suspended solid, and biological oxygen demand), and physical and metabolic changes in aquatic biota. Another study found that when chlorine was used as a disinfectant in water environments, it reacted with organic substances to produce DBPs such as trihalomethanes-4 (THM4) and haloacetic acids-5 (HAA5) (Qadafi et al. 2023b). The contamination of DBPs into the water caused many issues for both humans and aquatic organisms due to their carcinogenic, cytotoxic, genotoxic, and mutagenic properties.

Water and sanitation management

Water and sanitation management in Indonesia presents a complex challenge due to the country's vast archipelagic nature, diverse ecosystems, and rapid urbanization. With over 17,000 islands, providing access to clean water and adequate sanitation facilities becomes a logistical and infrastructural undertaking. Urban areas, in particular, face increased pressure on water resources as populations grow, leading to challenges in waste disposal and water treatment. While the government has made strides in improving water and sanitation infrastructure, rural areas often lag, struggling with limited access to clean water and proper sanitation facilities.

Water pollution concerns in Indonesia are severe due to inadequate WWTP capacity. For example, the WWTP of Jakarta only covered 4% of dwellings (Luo et al. 2019). It means 96% or over 9.2 million people do not have access to wastewater management or treatment systems (Ardhianie et al. 2021). The Jakarta Provincial Government manages two septic tank waste treatment units with capacities of 300 m^3 (DKI Jakarta Province Government 2013). Over 90% of domestic wastewater is managed via on-site systems (septic tank and septage treatment) with low treatment quality. Existing facilities often fail due to the high cost of investment, operations, and maintenance (Kurian et al. 2013). According to best practices, improving water quality requires wastewater collection and connection to a sewerage system, ultimately leading to the wastewater treatment plant (WWTP). The construction of a comprehensive sewage system that is connected to WWTP is essential to address water pollution issues.

Water pollution control and water quality management are governed by Indonesian Government Regulation No. 22 of 2021. The regulation requires the national government to identify and carry out pollutant load capacity, water quality monitoring, and wastewater discharge determination. The provincial and municipal governments are responsible for cross-city and cross-district water pollution problems, and they must submit an annual report to the Ministry of Environment on water pollution situations based on parameters from the regulation. Water pollution controls must be adopted following comprehensive urban development plans to reduce overexploitation of ground water, prevent flood disasters, and employ ecological measures to clean urban waters.

Another significant issue is the inadequate sanitation facilities that contribute to waterborne diseases, posing a public health risk (Irda Sari et al. 2018; Siddiqua et al. 2022). Efforts to address this challenge include enhancing water treatment capabilities, expanding sanitation infrastructure, and promoting proper waste management practices. As Indonesia continues to develop, a comprehensive and inclusive approach to water and sanitation management is crucial to ensure the well-being of its people and the preservation of its environmental resources (Irda Sari et al. 2018; Daniel et al. 2023). Innovations in technology, such as the implementation of water purification technologies and eco-friendly sanitation solutions, can contribute to more effective and sustainable water and sanitation management in Indonesia (Lasut et al. 2008; Sutapa et al. 2020). Community engagement can also help raise awareness about proper hygiene practices, promote responsible water usage, and encourage the sustainable management of water resources (Loehr et al. 2021). Collaborative approaches involving the government, non-governmental organizations, and local communities are

crucial for the success of water and sanitation management initiatives (Daniel et al. 2023).

Future challenges

Indonesia faces several future challenges related to water and sanitation that need to be addressed to ensure sustainable access to clean water and proper sanitation facilities for its growing population. Indonesia is experiencing rapid urbanization, with more people moving to cities in search of better opportunities (Henriques and Louis 2011; Budi Prakoso et al. 2023). Managing the water and sanitation needs of a growing urban population presents significant challenges. Many areas, especially in rural and remote regions, still lack access to proper sanitation facilities and safe drinking water (Cameron et al. 2021a). Both, expanding and maintaining the necessary facilities are pressing challenges. Besides, achieving equitable access to water and sanitation services across all demographic groups and geographic areas is another challenge. Rural and remote regions, along with vulnerable populations, frequently face more limited access to clean water and sanitation facilities compared to urban populations (Moreira and Dias 2020; Daniel et al. 2023). Eliminating open defecation, particularly in remote and underprivileged areas, remains a challenge (Cameron et al. 2019; Odagiri et al. 2020; Lowe et al. 2021). Promoting proper hygiene practices, including handwashing, is essential for disease prevention. Behavior change communication and education initiatives are needed.

Water pollution from industrial discharge, agriculture, and household waste is also a significant concern. Maintaining and improving water quality is essential for ensuring access to clean and safe water sources (Beltrán et al. 2021; Tao et al. 2021; Qadafi et al. 2021; Dianty et al. 2022). Adequate wastewater management is essential to manage sewage effectively and reduce water pollution (Long et al. 2018). Ensuring proper collection, treatment, and disposal of wastewater presents challenges in many areas across Indonesia. Inadequate wastewater treatment can result in environmental pollution and pose risks to community health (Widyarani et al. 2022; Silori et al. 2023; Ngeno et al. 2023).

Indonesia is also vulnerable to the impacts of climate change, including more frequent and severe droughts and floods (Widiyanti and Dittmann 2014; Arifah et al. 2022). To address all of these challenges, Indonesia will need a combination of infrastructure development, policy reforms, community engagement, and international collaboration (Hermawan et al. 2023). The government, in partnership with non-governmental organizations and international agencies, is working to develop and implement strategies to improve water and sanitation access while ensuring sustainability and equity.

Conclusion and perspectives

Indonesia is a huge archipelagic tropical country with enormous water and sanitation issues. As a developing country, Indonesia has massive industries that dispose the waste to the environment, especially to the water body. Indonesia's water sources have been contaminated by many pollutants such as microplastics, pesticides, heavy metals, pharmaceuticals EDC, and even microbiological agents. Inadequate clean water and sanitation facilities force the community, especially in rural areas to do open defecation and use the raw water for daily used water. On the other hand, the water and wastewater treatment facility could not completely remove the pollutants, especially the micropollutants and bacteria. Direct exposure to water pollutants and fecal-containing drinking water contributes to many health issues such as maternal health, child stunting, child height, and waterborne diseases. Also, water pollution damages the water body and water ecosystem. Water pollution has many ecological risks and causes water eutrophication and impacts the water biota such as fish, vertebrata, and plankton. Water pollution must be addressed in Indonesia, which includes implementing effective water treatment systems, promoting correct sanitation practices, and creating awareness about the value of clean water and its influence on human and ecosystem health. To limit the occurrence of water-related diseases and maintain a healthier population, it is critical to prioritize investments in water quality monitoring and treatment infrastructure.

Although many studies on water pollution and sanitation in Indonesia have been conducted. The number of studies regarding this field is still inadequate, especially studies outside Java Island. Indonesia is a huge country with varies water and sanitation characteristics. More research should be conducted to assess the health and environmental impacts of water pollution and poor sanitation facilities. The data in this research field could provide important information to improve water treatment facilities and assist the government in providing better sanitation facilities, especially in rural and isolated areas in Indonesia.

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Formal analysis, Data Curation. Gerry Andhikaputra: Formal analysis, Data Curation.

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Declarations

Competing interests The authors declare no competing interests.

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