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Global water shortage and potable water safety; Today's concern and tomorrow's crisis

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ABSTRACT

Climate change, severe droughts, population growth, demand increase, and poor management during the recent decades have further stressed the scarce freshwater resources worldwide and resulted in severe water shortages in many regions. The water utilities address the water shortage by providing alternative source of water, augment the supplied water, supply intermittently, and even bulk water delivery under severe water shortage conditions. On the other hand, many households store water in building storage tanks to cope with insufficient delivery of potable water due to frequent interruptions. All these practices could pose crucial risks to the chemical and microbiological quality of the water. However, consistent monitoring and implementation of mitigation strategies could lower the potential risks associated with these practices. It is critical to identify the potential hazards resulting from the alternative water supplies and distribution practices to develop temporary and long-term monitoring and mitigation plans and reduce the microbial and chemical contamination of potable water delivered to the consumers. This paper provides a holistic review of the significant hazards associated with the practices employed by the water utilities and water consumers to alleviate the potable water shortage and discusses the required monitoring and mitigation practices.

1. Introduction

Global sustainability will not be reached without ensuring the availability of safe water for all consumers. Despite being one of the major goals (SDG6) of the UN2030 agenda for sustainable global development (UN, 2015), the current water shortage is rapidly growing and impacting an increasing number of residential, commercial, industrial, and agricultural water consumers worldwide (Faramarzi et al., 2010; Vollmer and Harrison, 2021; Mishra et al., 2021). The global water demand is expected to rise by 55%, while currently, around 25% of large cities are experiencing some levels of water stress (Lund Schlamovitz and Becker, 2021). The climate change, severe droughts, population growth, demand increase, and poor management during the recent decades further stressed the scarce freshwater resources around the world and resulted in a severe water shortage for around 4 billion people, at least one month annually (Shalamzari and Zhang, 2018; Procházka et al., 2018; Khatibi and Arjjumend, 2019; Orimoloye et al., 2021). Worldwide, about 2.2 billion people do not have access to safe drinking water (UNICEF and WHO, 2019). The water scarcity literature predominately focused on the quantity of water. However, the quality of the water delivered to the consumers during the water scarcity could be threatened if the safety measures were not in place. The regional hot spots for water shortage could also represent the regions under stress regarding water quality (van Vliet et al., 2021). With global warming-induced drought increasing, planning for effective water management and distribution is vital to ensure reliable access to sufficient, safe water.

The rapidly declining freshwater resources and aging water infrastructure in numerous urban and rural regions created hardship for many water utilities addressing the regular water demand. The solutions employed by the water utilities to cope with the water shortage are mainly focusing on providing alternative source of water (e.g., reuse, rainwater harvesting) (Angelakis et al., 2018; Hashim and Sayl, 2021), augmenting the supplied water (e.g., blending) (Campbell et al., 2002), and reducing water consumption (e.g., intermittent water supply) (Kumpel and Nelson, 2016; Zhou et al., 2021). Moreover, under severe water shortage conditions, the bulk water is delivered using tanker trucks to the consumers to address their vital potable water needs. On the other hand, the water consumers are asked to decrease their water consumption to drop the demand. Nonetheless, many households store some water in buildings storage tanks to cope with insufficient delivery of potable water caused by frequent interruptions. The potential risks associated with these practices could be reduced

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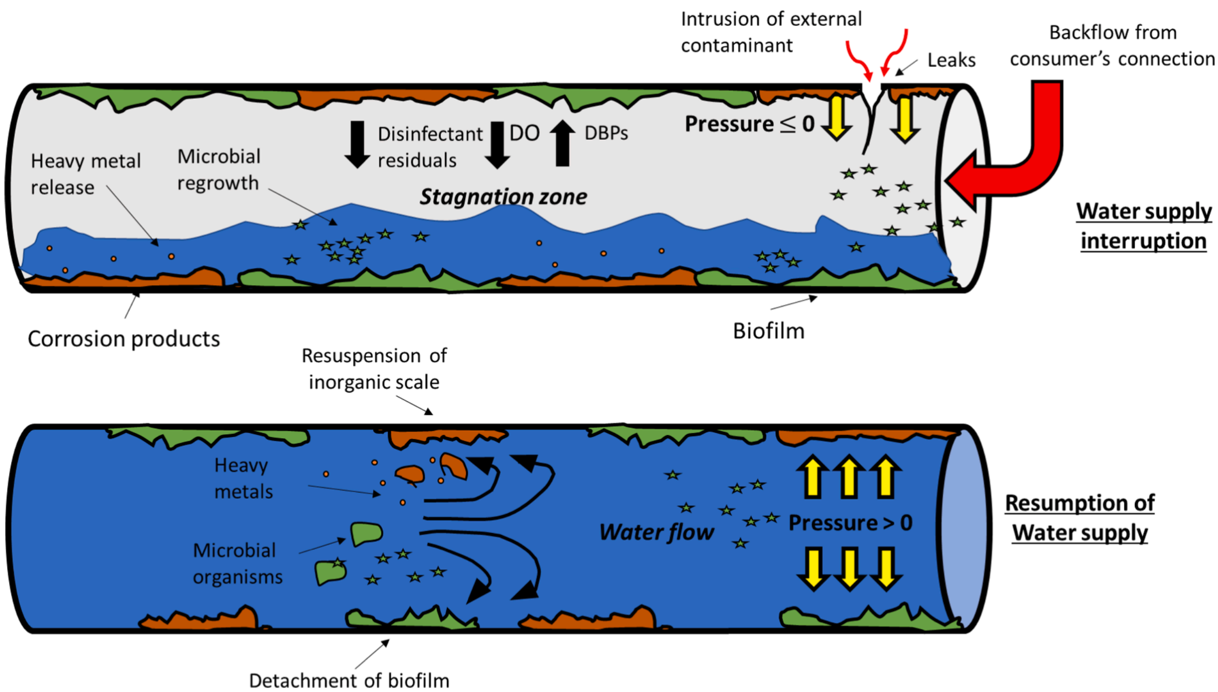

Fig. 1. The schematic demonstrating main pathways for water contamination within the IWS.

with consistent monitoring and proper implementation of mitigation actions. This paper provides a holistic review of the significant hazards associated with the practices employed by the water utilities and households to alleviate the potable water shortage and discusses the required monitoring and mitigation practices to reduce the potential risks toward the water consumers' health.

2. Water utilities' response to water shortage and potential hazards toward potable water quality

2.1. *Intermittent water supply (IWS)*

In response to the water resources constraints, the continuous supplement of water by many utilities in water-stressed regions has been transitioned to the intermittent water supply (IWS) (Simukonda et al., 2018; Ellawala and Priyankara, 2016). More than 309 million people, mostly in developing countries around Africa, South America, and Asia, are experiencing the IWS (Li et al., 2020; Loubser et al., 2021; Erickson et al., 2017; Kumpel and Nelson, 2016). In an intermittent water supply that may occur daily, weekly, or seasonally, the drinking water is provided for less than 24 h per day to the consumers within the distribution network (Farmani et al., 2021). The pressure transient events created by stopping and resuming the water supply could damage the water mains and decline the water chemical, microbiological, and aesthetic quality. The major reasons for water quality deterioration via IWS are (1) intrusion of microbial contaminant to the underground pipes from the surrounding environment via leaks, (2) contaminant backflow from consumers connections during the low or negative pressure events, (3) microbial growth in bulk water, pipes wall in stagnation zones, and (4) scouring off the biofilm, scales, and corrosion products from the pipe surfaces due to the shear forces created by the sudden increase in water velocity by resuming the supply (Kumpel and Nelson, 2016; Mohammadi et al., 2020; Klingel, 2012). The schematic demonstrating the main pathways for water quality contamination within the IWS is shown in Fig. 1.

Disturbance of biofilm accumulated onto the pipe during the intermittent water supply deteriorates the microbial quality of water (Calero Preciado et al., 2021). Absence or low level of disinfectant residuals within the IWS network is associated with the long water stagnation and elevated chlorine demand by the distribution network (Sakomoto et al., 2020; Ecura et al., 2011). Reduced dissolved oxygen (DO), and disinfectant residuals levels as water stagnants in low pressure zones introduce changes in microbial community and promote their proliferation as reported by increased cell counts, fecal coliforms, and heterotrophic plate count (HPC). Furthermore, biofilm exposure to air by draining the pipes impacts their attachment to the pipe wall and reduces their stability toward the shear forces applied by resuming the water supply. Duration and frequency of IWS events influence the degree of water quality deterioration. The shorter interruption durations have resulted in a greater concentration of aromatic organic compounds which, promoted the disinfectant byproducts (DBPs) formations. However, the alteration of microbial community compositions has occurred to a more significant extent during the more prolonged interruptions, in which the fungal communities changed less than bacterial communities (Calero Preciado et al., 2021). The literature reported more frequent and greater concentrations of *E. coli* in water samples supplied by IWS than those supplied by continuous water supply (CWS) (Kumpel and Nelson, 2013; Andey and Kelkar, 2007). The greater levels of fecal coliforms and heterotrophic plate counts (HPC) were found in the water samples collected from IWS network and tap water in Peru, Gaza, and Mozambique than their supplied reservoirs and source water (Abu Amr and Yassin, 2008; Mermin et al., 1997; Swerdlow et al., 1992; Tokajian and Hashwa, 2003). The frequent microbial contaminations that were reported for the intermittent water supplies were directly linked to waterborne diseases (e.g., diarrhea, typhoid, cholera, and hepatitis) (Mermin et al., 1997; Bivins et al., 2017). The first flush water samples that represent the first water samples collected from the taps after resuming the water supply had more indicator bacteria and turbidity (Erickson et al., 2017). Discolorations (e.g., red and black), taste, and odor problems were reported for water that was supplied intermittently (Cerrato et al., 2006; Rubino et al., 2019). Reducing the duration of IWS incidents could decrease the potential impacts on microbial communities (Calero Preciado et al., 2021). Maintaining a sufficient level of disinfectant residuals is necessary to reduce the microbial contamination and inactivate the pathogens that intruded into the network through the leaks (Sakomoto et al., 2020). Furthermore, the continuous pressure monitoring through the distribution system to identify the negative pressures events could assist the water utilities to better plan their water supply schedule, identify the water main breaks, and reduce the intrusion of external contaminants into the water (Erickson et al., 2017). Although, this could be challenging for under-resourced utilities in low income countries which barely can maintain the integrity of their infrastructure. The water consumers could avoid consuming the first flush to reduce their exposure to the tap water contaminant after resuming the water supply. However, systematic investigations should be conducted to identify the appropriate volume of water to be flushed after the resumption of water supply to prevent the households from exposure to the tap contaminant. Reduced duration of water outages and increased level of disinfectant residuals were reported to reduce the microbial contamination of water within the intermittent supply system (Erickson et al., 2017; van den Berg et al., 2021). However, extended storage of finished water by water utilities should be avoided to prevent disinfectant residuals loss (Angelakis et al., 2018).

2.2. Water blending

Rapid depletion of groundwater resources has prompted many water utilities that historically relied on groundwater to consider blending the treated groundwater with the finished surface water to augment their supplied water. However, the irregular changes of water chemistry caused by blending different sources of water may result in more aggressive water and consequently destabilization of inorganic scale and microbial biofilm that was accumulated over the decades onto the water main and building plumbing (Liu et al., 2017; Taylor et al., 2006; Liu et al., 2010). Greater iron release was reported from aged water pipes after exposure to the water quality, different from the historical groundwater that was contacted them for many years (Tang et al., 2006). Iron water mains are prone to corrosion; however, the extent of corrosion varies by water pH, alkalinity, buffering capacity, and dissolved oxygen (DO) concentration (Tang et al., 2006; McNeill and Edwards, 2001; Sarin et al., 2001). Blending different sources of water could alter the water chemistry and consequently destabilize the iron-bearing scale, release iron, and other contaminants such as arsenic (As) that are accumulated onto the iron scale (Tang et al., 2021). Furthermore, the dissolution of heavy metals such as arsenic, iron, lead, and cadmium from the inorganic scale accumulated onto the other types of water mains such as steel, polyvinyl chloride (PVC), polyethylene (PE), and glass-reinforced pipes (GRP), along with a detachment of bacterial community accumulated onto these pipes could create the negative health consequences and aesthetic problems (taste, odor, and color) (Dashtizadeh et al., 2019; Mirzabeygi et al., 2017; Fakhri et al., 2018; Salehi et al., 2017; Salehi et al., 2018). Comprehensive investigations should be conducted to evaluate the corrosivity of blended water to identify the required water chemistry adjustments before to the water distribution (Zhang et al., 2018). Furthermore, the water utilities are recommended to consistently monitor the water quality within the distribution system following the implementation of blending practices to identify the possible destabilization of biofilm or resuspension of inorganic scales and apply the essential mitigation practices. For instance, real-time particle counting could be a feasible practice to identify the potential destabilization within the distribution system (Liu et al., 2017). Limited information is available regarding the water quality impacts caused by water blending. Future research is needed to develop facile real-time monitoring techniques to identify the water quality variations due to the water blending.

2.3. Bulk water distribution

The bulk water delivery generally occurs for isolated rural regions lacking water distribution networks in developing countries, in the arctic regions where water cannot be conveyed through the piped network because of permafrost, and during emergencies such as earthquakes and wildfire in developed countries (Gora et al., 2020; Abdullah, 1999). Moreover, under severe water shortage conditions, the water utilities may fail to deliver sufficient drinking water to the consumers via the distribution network. Consequently, the water providers are obligated to deliver the bulk water using the water tanker trucks to fulfill the consumers' vital potable water needs (Paper, 2017; Pike, 1996; Raina et al., 2019). Overlooking the sanitary practices during water filling, transporting, storage, and final distribution could result in microbial contamination of delivered water and health hazard toward the water consumers. Tankers have been identified as a major source of total coliforms for water contamination due to the operators' hygiene practices and/or improper tanker materials (Constantine et al., 2017). Insufficient levels of disinfectant residuals, extended water storage, and elevated outdoor temperature could promote bacterial proliferation and biofilm formation within these tankers. Using the non-potable water tankers to transport the potable water under limited resources poses a severe hazard to the consumers' health (Sule et al., 2014). Lack or improper disinfection of tankers could contribute to the microbial contamination of stored water (Halim, 2021). The tankers that were used to haul other food products should be cleaned and disinfected before transporting the potable water. A sufficient level of disinfectant residuals should be present in water before transportation.

Table 1
The select studies investigated the bulk water delivery (TDS: total dissolved solids, TC: total coliform, FC: fecal coliform, HPC: heterotrophic plate counts).

Country	Region/City	Reason	Studied aspect	Ref
Lebanon	Beirut	Water shortage	Water quality [pH, conductivity, TDS, calcium hardness, total hardness, alkalinity, chloride, nitrate, sulfates, bromide, potassium, sodium, TC, FC], economic burden, management framework	(Constantine et al., 2017)
Zimbabwe	Harare		Policy and governance	(Manzungu et al., 2016)
Mexico	Mexico City		Truck water service delivery	(Pike, 1996)
Jordan	Amman		Market analysis	(Paper, 2017)
Nepal	Kathmandu		Market analysis	(Raina et al., 2019)
Kenya	Nairobi		Water use and cost analysis	(Ochungo et al., 2019)
Pakistan	Karachi		Socioeconomic aspects and policy implications	(Abdullah, 1999)
Yemen	Dhamar	Lack of distribution system	Water quality [*E. coli*, antibiotic resistance index]	(Halim, 2021)
Nigeria	Agba Dam, Ilorin, Kwara State		Water quality [pH, residual chlorine, suspended solids and total hardness, TC, FC]	(Sule et al., 2014)
South Africa	Mtamuntengayo		Water quality [pH, residual chlorine, turbidity, conductivity, *E. coli*, TC, HPC]	(Singh et al., 2013)
	Durban		Water quality [pH, turbidity, residual chlorine, TC, *E. coli*]	(Singh et al., 2013)
India	Bangalore		Governance, political economy	(Ranganathan, 2014)
Sri Lanka	Eastern Province	Tsunami disaster	Challenges providing water and sanitation after the disaster	(Fernando et al., 2009)

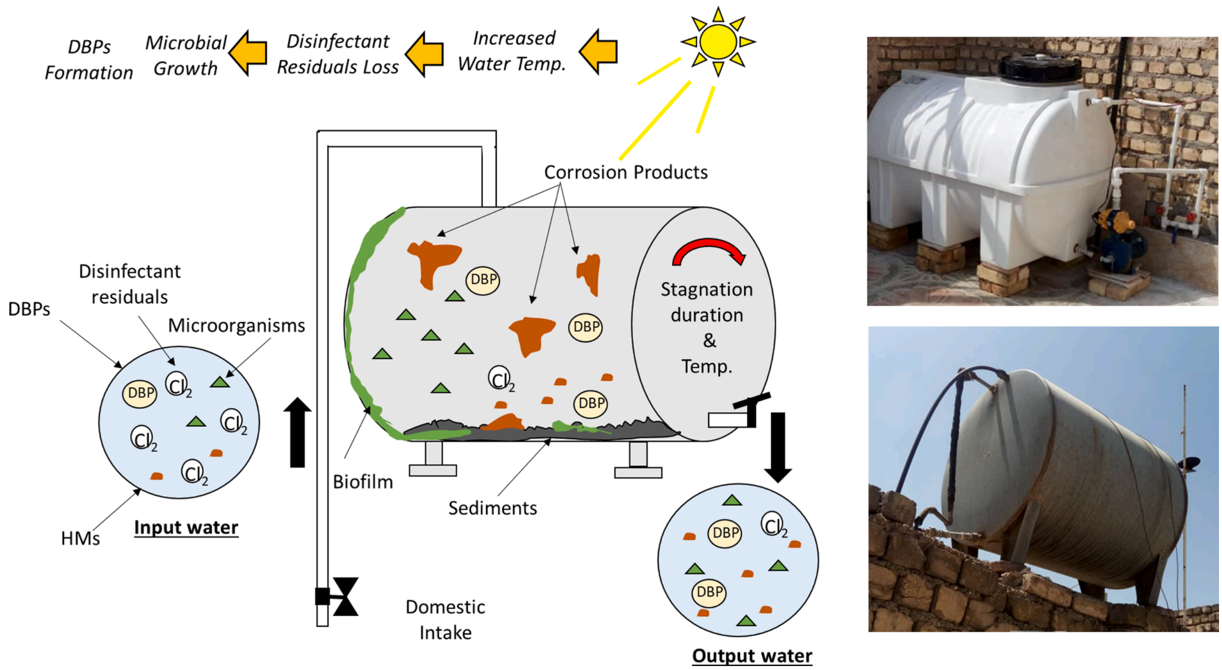

Fig. 2. Schematic demonstrating the water quality deterioration in storage tanks, plastic and galvanized iron storage tanks used in Iran.

Moreover, for longer expected storage durations, a greater level of disinfectant residuals (within the allowable range) should be added to the water (Florida Department of Health, 2019). The routine monitoring of water quality at the filling stations and trucks is required to ensure water safety. Table 1 lists the select studies associated with bulk delivery of potable water. The literature mainly focused on the economic and social aspects of bulk water delivery (Constantine et al., 2017; Ochungo et al., 2019) and the potential hazards threatening the quality of delivered water are significantly overlooked. However, this understanding is essential to develop efficient sanitary practices and protect public health.

3. Households' response to unreliable water supply

Due to the unreliability of water supplies in some regions (e.g., Middle East, South America, Africa), many water consumers use in-house storage tanks to have some backup water for periods of low water pressure or interruption of water supplies, specifically in summer (Negharchi and Shafaghat, 2020). The water consumers are not supposed to pump the water out of the connecting distribution line directly. Instead, the water should initially be conveyed from the building point of entry (POE) to the storage tank and then fed to the building plumbing using a pressure booster system or by gravity. However, improper design and locating the pressure booster system before the storage tank may result in direct suction of water out of the distribution line. The negative pressure events created under this circumstance could enhance the risk of backflow, and contaminate the water main by surrounding buildings that do not have the pressure booster systems (WHO, 2006).

The storage tanks are mainly constructed from galvanized iron, polyethylene, reinforced concrete, and fiberglass. They are located on the roof of the building, which feeds the building plumbing system by gravity, or most recently inside the buildings, and water is pumped to the plumbing system (Fig. 2). The tanks' materials, plumbing configurations, and surrounding environment (ambient temperature) could influence the proliferation of pathogens such as *Legionella* in water stored in the storage tanks (Peter and Routledge, 2018). The chemical leached from plastic storage tanks, mineral and sediments originated from source water, and corrosion products released from metallic storage tanks could act as the nutrients to encourage *Legionella* proliferation (Peter and Routledge, 2018). The drinking water stagnation in these tanks and elevated temperature due to the exposure to the sunlight or ambient environment could accelerate the disinfectant decay in water and promote the disinfectant by-products (DBPs) and biofilm formation (Fig. 2) (Peter and Routledge, 2018; Mohamed and Gad, 2011). Increased water temperature in tanks promotes microbial growth; thus, the light penetration into the storage tank should be prevented by selecting the appropriate materials for the tanks. Shading could avoid the direct sunlight exposure of tanks and potentially reduce microbial proliferations (Slavik et al., 2020; Miyagi et al., 2017). The sediments accumulated in tanks provide an environment for microbial growth within the tank. The duration of water stagnation within the tank and temperature are significant factors influencing microbial growth (Evison and Sunna, 2001). Sometimes, these storage tanks are oversized in relation to the households' demand resulting in a long turnover for water and consequently a prolonged stagnation of water in tanks, resulting in the lower disinfectant residuals, increased water temperature, presence of corrosion products in these tanks (Proctor et al., 2020). This condition promotes microbial growth, including opportunistic pathogens, and creates hazards toward water consumer health (Slavik et al., 2020). Furthermore, the absence or low level of disinfectant residuals in drinking water fed by storage tanks to the buildings' plumbing promotes the microbial regrowth within the plumbing system and enhances the dissolution of the heavy metal into the water (Salehi et al., 2021). The microbiological contaminant such as *Legionella pneumophila, Pseudomonas,* and *Naegleria fowleri* originated from in-home storage tanks could result in crucial human health impacts (Peter and Routledge, 2018; Ghanchi et al., 2016). To prevent water quality deterioration, regular cleaning of storage tanks is necessary. The deposits, sediments, and biofilm that provide the habitat for microbial growth and increase the chlorine demand are removed from the storage tanks by cleaning. Studying the water quality in storage tanks cleaned at least three times a year illustrated lower turbidity and *E. Coli* counts compared to the less frequently cleaned tanks (Schafer, 2010). Moreover, disinfection of storage tanks for a sufficient duration of time is also recommended to reduce microbial growth (Artiola et al., 2012). Table 2 summarizes the select studies that investigated the water chemical and microbial deterioration due to the stagnation in cold water storage tanks.

Table 2
The summary of select studies investigated the water chemical quality deteriorations in cold water storage tanks (PE: polyethylene, nr: not reported, TDS: total dissolved solids, DO: dissolved oxygen, TOC: total organic carbon, HPC: heterotrophic plate counts, THMs: total trihalomethanes).

Location	Water quality parameters	Tank material	Major results	Ref.
Bolivia	Temp, conductivity, TDS, DO, pH, turbidity, total coliform, *E.coli*, chlorine residuals	PE, fiberglass, cement	No difference in physical and chemical water quality between different materials of storage tanks. Increased temperature in the black PE tank promoted microbial growth. The cleaning frequency could impact the microbial quality of water.	(Schafer, 2010)
Jordan	Residual chlorine, HPC, temp, pH, turbidity, TOC	PE, fiberglass, cast iron	No difference was found between total bacterial counts in the water and sediment samples. The tanks' sediments provided an environment for insect larvae, bacteria, and protozoa. The tank material did not influence the HPC level.	(Evison and Sunna, 2001)
	TOC, bromide ion, THMs, temp, pH, fecal and total coliform counts, total HPC, and *Pseudomonas Aeruginosa*	Steel, nr	The cleaning did not reduce the chlorine decay in tanks. THMs concentrations in 63% of sampled tanks followed the decreasing, increasing, and then decreasing trend over time. A strong correlation was found between total HPC levels and chlorine residual for each tank.	(Al-Omari et al., 2008)
Egypt	pH, chlorine residual, algae concentration	Reinforced concrete	The oversized storage resulted in elevated water age, lower disinfectant residuals, and a greater level of DBPs. A significant portion of chlorine residual decays in the storage tank, before it enters the building plumbing.	(Mohamed and Gad, 2011)
U.K.	*E. coli*, Coliforms, *Legionella pneumophila*	Galvanized iron, Metal with internal butyl lining, Fiberglass, Plastic, Glass-reinforced plastic	Significant differences were found between the microbiological quality of water samples collected under the ball valve (where samples are routinely taken for monitoring) and the far end of the tank that feeds the water to buildings.	(Peter and Routledge, 2018)
Japan	Temp, chlorine residuals, total viable count *Aeromonas spp*, fecal coliform,	Stainless steel, reinforced concrete, fiberglass plastic	The total viable count and fecal coliforms were not greater than the required quality levels. Elevated water temperature, oversized tanks, and low water demand resulted in the loss of residual chlorine in tap water.	(Miyagi et al., 2017)
Ethiopia	pH, turbidity, total coliform, and fecal coliform	Plastic	The water samples collected from all storage tanks were contaminated with coliform. The microbial contamination of water increased as it entered the storage tanks.	(Chalchisa et al., 2018)

4. Conclusion and future outlook

Although implementing alternative practices such as water blending and intermittent water supply temporarily addresses the consumers' need for potable water, water providers should conduct a careful investigation and monitoring practices prior to and during the implementation of these practices to avoid contamination of delivered water. Furthermore, the water consumers should be informed regarding the possible risks associated with the consumption of first flush water provided after water supply resumptions and guided appropriately to reduce their exposure to chemical and microbial contaminants in tap water. The tanker trucks intended for potable water delivery should be carefully inspected and disinfected before use. The disinfectant residuals and microbial contaminants in the water transported by tanker trucks should be monitored regularly to maintain water safety. Future studies are needed to better understand the potential hazards threatening the quality of water delivered using the tanker trucks to develop efficient sanitary practices. The disinfectant residuals loss, microbial proliferation, and DBPs formation in buildings' storage tanks varied by water stagnation duration, tank materials, and surrounding environment (ambient temperature). The outreach programs should be conducted to educate the households regarding the required maintenance practices and safety considerations for cold water storage tanks to decrease the water quality deterioration.

CRediT authorship contribution statement

Maryam Salehi: Conceptualization, Investigation, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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