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Assessment of socioeconomic inequality based on virus-contaminated water usage in developing countries: A review

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ABSTRACT

Water is an essential resource required for various human activities such as drinking, cooking, and other recreational activities. While developed nations have made significant improvement in providing adequate quality water and sanitation devoid of virus contaminations to a significant percentage of the residences, many of the developing countries are still lacking in these regards, leading to many death cases among the vulnerable due to ingestion of virus-contaminated water and other waterborne pathogens. However, the recent global pandemic of COVID-19 seems to have changed the paradigm by reawakening the importance of water quality and sanitation, and focusing more attention on the pervasive effect of the use of virus-contaminated water as it can be a potential driver for the spread of the virus and other waterborne diseases, especially in developing nations that are characterized by low socioeconomic development. Therefore, this review assessed the socioeconomic inequalities related to the usage of virus-contaminated water and other waterborne pathogens in developing countries. The socioeconomic factors attributed to the various waterborne diseases due to the use of virus-contaminated water in many developing countries are poverty, the standard of living, access to health care facilities, age, gender, and level of education. Some mitigation strategies to address the viral contamination of water sources are therefore proposed, while future scope and recommendations on tackling the essential issues related to socioeconomic inequality in developing nations are highlighted.

1. Introduction

Water is regarded as the epicenter of human activities as it is required for drinking, irrigation of crops, recreational activities and industrial use. Protecting this essential natural resource against any contaminants is critical to forestalling its potential avenue for outbreaks of diseases. Unfortunately, water quality and sanitation remain elusive, with conspicuous occurrences in the developing countries (Célia da Silva Lanna et al., 2019; Montgomery and Elimelech, 2007). Available data indicate that more than 30% of the developing and less developed countries have no access to quality drinking water sources (WHO and UNICEF, 2015). Consequently, leading to an upsurge in the use of any

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available water resources including reclamation and reuse of treated wastewater for domestic activities and irrigation purpose, considering the rapid population growth, climate change, and increased water demand (Morrison et al., 2020; Bougnom et al., 2019; Santos et al., 2017). An estimate of 663 million people is reportedly consuming untreated water obtained from different sources including groundwater and surface water (WHO and UNICEF, 2015). While the current treatment procedures have achieved excellent results in treating physical, chemical and selected microbiological contaminants (Adelodun et al., 2019; Tandukar et al., 2020), the removal of human enteric viruses in the wastewater remains unsatisfactory, with less attention giving to virus contaminations in water sources and their health impact (Gall et al., 2015). Moreover, there is no regulatory standard procedures for the treatment of virus-contaminated water and wastewater at the moment (Gerba et al., 2018; Qiu et al., 2015). The ability of some of the viruses to travel a much greater distance than bacteria in the soil and eventually to groundwater source due to their sizes and their persistence for a more considerable period making their removal difficult and high risk of waterborne gastroenteritis virus infections (Gerba, 1984; Schwab, 2007). A recent global review of groundwater-related enteric disease outbreaks identified 649 events within the published literature from 1948 to 2015 with an alarming increase in groundwater-related Acute Gastrointestinal Infections (AGI) (Murphy et al., 2017).

The impact of using unsafe water on public health is of great universal concern with the frequent detection of pathogens in various water bodies. The ingestion of contaminated water, which is most often caused by poor sanitation and hygiene often results in various waterborne diseases (Adelodun et al., 2020b; Pooi and Ng, 2018; Nasser, 1994). Yang et al. (2020) found an association between drinking water and poor sanitation and the risk of disease infections among children (under five years of age) with the poor socioeconomic condition in sub-Saharan Africa. In 2012, 1.8 billion people which is almost 25% of the world population were estimated to consume contaminated water containing viruses, protozoa, and bacteria (WHO and UNICEF, 2015), that have led to various kind of diseases in human especially gastroenteritis (Bosch et al., 2008). One of the significant reoccurring waterborne diseases is diarrhea with 1.7 billion reported cases annually (WHO, 2017a), resulting in the death of 525,000 children below the age of 5 years annually (Pooi and Ng, 2018). UNICEF (2012) documented that about 90% of diarrhea death globally is a result of poor hygiene, inadequate sanitation and unsafe water. The general knowledge is that microbes are the primary organisms leading to the spread of diarrhea. Some of the contracted viruses through drinking water and their impact on human health is often neglected (Mantovani et al., 2015a). Based on the guidelines on drinking water, WHO classified water transmitted virus-related pathogens as exhibiting an average and to a great health significance on human health, and these viruses include enteroviruses, adenovirus, rotavirus, norovirus and other caliciviruses, astrovirus, hepatitis A, polioviruses and coxsackieviruses (WHO, 2017b). Besides, other viruses like cytomegalovirus and polyomaviruses can also be proliferated via water (WHO, 2017a,b; Cannon et al., 2011), as well as coronaviruses and influenza that have been alluded to spread through potable water with inconclusive evidence (WHO, 2017b). Unfortunately, some of the viruses may result in acute illnesses such as hepatitis (hepatitis A and E viruses), cancer (polyomavirus), meningitis, encephalitis, and myocarditis (enteroviruses) (WHO, 2017b).

While developed nations have made significant progress in water treatment systems to address viruses and pathogens contaminations in water and wastewater, the majority of people have access to improved drinking water, thereby averting waterborne related diseases. However, the use of contaminated water for various human activities continues by many people living in developing and less developed nations due to the wide differential inequality in socioeconomic development. So, the importance of accessibility to potable water cannot be overemphasized as it plays a vital role in the present global efforts to address the prevalent poverty and poor health, specifically in developing countries. Previous studies proved that those living below $1.25 per day (those living in abject poverty) correspond almost with those lacking access to potable water (Sambu, 2016; Rijsberman, 2006). In order to prevent and contain diseases, accessibility to water and sanitation is essential to combating the virus and maintaining the good health and well-being as contained in the Sustainable Development Goal 3. Thus, to attain the United Nations (UN) sustainable development goal 6 “Clean Water and Sanitation” by 2030, a substantial attempt in the creation and management of wastewater treatment plants (WWTPs) should be put into operation in these less developed countries in the subsequent years (Gallego-Schmid and Tarpani, 2019; Nhamo et al., 2019; UN-Water, 2017). Considering the current global pandemic caused by the novel coronavirus (SARS-CoV-2) with several studies indicating its possible persistence and potential risk in water environment coupled with the existing endemic of waterborne related infections and diseases, especially those resulting from the ingestion of virus-contaminated water, a review focusing on the assessment of differential inequality of virus-contaminated water use in developing countries is essential.

In an attempt to provide an outline of the status quo of socioeconomic disparities on the basis of virus-contaminated water use in developing nations, the paper is structured as follows. Firstly, there is a review of the water pollution status in developing countries. Also, virus associated with water pollution and their human health impacts are expatiated. More importantly, this paper assessed the socioeconomic inequality factors relating to virus-contaminated water usage in developing countries. Further, some possible mitigation strategies were proffered based on the existing literature that can be adopted for the developing countries, especially those characterized by low level social and economic development. Finally, this review concludes with future research needs to curb the viral contamination in water in developing countries and put forward recommended policies.

We employed three-stage procedures in order to address the objectives of this study adequately. Firstly, the peer-reviewed articles published only in the English language were searched for and retrieved from the Scopus database (www.scopus.com), which has the most extensive abstract and citation of peer-reviewed literature. The relevant keywords corresponding to the topic and objectives of this study including “contamination”, “water”, “socioeconomic”, “drinking water”, “virus”, which were combined with the Boolean search words of ‘AND’, ‘OR’ were used. The selected articles include original and review articles published within the last 20 years (1999–2019). The articles that mainly on water pollution without pathogenic contaminations and attributed waterborne diseases were not considered. Secondly, to avoid the omission of important key papers that capture the objectives of this study, relevant articles from the references of the retrieved papers were manually screened for relevance, after which they were retrieved. Lastly, all the retrieved articles were thoroughly reviewed, synthesized, and included in this study.

2. Status of water pollution in developing countries

Water quality indicators of an area are usually defined based on physical, chemical and biological parameters and the choice of which is dependent on water use. The physicochemical properties of water have been reported to influence the development of biological life in water, thereby affecting water quality (Adelodun et al., 2020b; Soja and Wiejaczka, 2014). Thresholds are allocated to each indicator, and when such permissible limits are exceeded, there is a high risk of threat to human health (Mukate et al., 2019). Recent studies on analyses of river water pollution in Ethiopia considered some physicochemical water quality parameters (pH, dissolved oxygen, biochemical oxygen demand, total nitrogen, total phosphorus, and electrical conductivity) and bio-indicators (macroinvertebrate and diatom indices) by obtaining water samples from agriculture, forest, and urban landscapes within the Nile, Omo-Gibe, Tekeze and Awash River basins (Awoke et al., 2016).

Water policy frameworks and interviews were also employed to

ascertain the effectiveness of the study. The study concluded that there was a significant water quality deterioration in the study areas in all the four basins. It was concluded that the river water pollution poses a great challenge to human health and immediate solutions should be proffered to prevent future health deterioration. A good look at available literature centered on water pollution in the South Asian region, predominantly in Bangladesh, Nepal, and India, showed that high pollution loads discharged in rivers as a result of industrial wastes, population growth, pesticides, fertilizers, domestic sewage, domestic effluent and urban activities had offered more severe and adverse effects on the health of inhabitants. Karn and Harada (2001) performed regression analysis on their study data to evaluate annual pollution trends in average biochemical oxygen demand (BOD) and dissolved oxygen (DO) at Bagmati, Yamuna and Buriganga rivers and discovered that the BOD increase rate in Bagmati was highest and most rapid than the others. Average annual BOD was found to be at least five times higher than standards in the rivers of Dhaka and Delhi and as much as 15 times higher in the Bagmati if the standards for Nepal were on the same scale as those in India and Bangladesh.

As a continent, Africa is endowed with substantial water resources, including a huge interconnected river water network (Fig. 1), which are often serve as a reservoir for domestic, industrial, and agricultural wastes, thereby leading to significant economic scarcity of the water resources in the region. Some studies have assessed and confirmed the viral contamination of river systems in selected countries in Africa. Marie and Lin (2017) evaluated the presence of viral causing waterborne in the Umhlangane River of South Africa, which serves as the main drinking water catchment as well as reservoir for domestic, industrial and agricultural wastes. Some infectious viral groups, including human adenovirus, polyomavirus and hepatitis A and C virus were identified, which may pose a significant health risk to the many populations using the water from the River source for various domestic and agricultural uses. Also, the section of Nile River up to 300 km south of Egypt was reported to contain enteroviruses and (coxsackieviruses) with a frequency of 60% (Rabeh, 2009), which indicates potential health risk for the rural communities who majorly use the River water for domestic consumption and recreational purposes. Likewise, Virus-like particles were reported in the Umgeni River water samples in South Africa, indicating potential health risk implications for human consumption (Ganesh et al., 2014). Similarly, the high prevalence of Human astrovirus was identified from both Rivers Mboone and Mbagathi in Kenya (Kiulia et al., 2010). Further, the enteric viruses like adenoviruses and enteroviruses were also confirmed from the water samples taken from the Lake Victoria in Kenya (Opere et al., 2020). Although some of the tested samples only confirmed the genetic materials of the viruses with no possible viability, the reported viral infections associated with drinking water supplies cannot be entirely ignored (Verheyen et al., 2009; Sekwadi et al., 2018).

Developing countries, mainly in Africa, are currently faced with adoption, implementation and valuation of water for ecosystem conservation and water quality management practices are still in the juvenile stage. This situation has strengthened the consumption of untreated water and enhanced untreated water discharged into rivers. Similar reported cases have been documented in Ethiopia, and findings have been concluded that gross pollution of many rivers is a consequential result of rapidly increasing urban populations and intense industrial and agricultural activities (Beyene et al., 2012). The ultimate goal of drinking water supply as declared by water resources engineers in developing countries is to provide good water quality, not only on the verge of leaving the treatment plant but at the customer's tap and point of discharge. However, most researches have failed to assess water pollution in the course of distribution. According to Prest et al. (2016), treated drinking water enters a distribution system containing physical particles, microbial loads (cells) and nutrient loads (organic and



Fig. 1. Topographic map of African River network.

inorganic nutrients). When treated water moves through contaminated distribution lines and it's retained with an extensive 'water age', especially at the dead-end nodes, available physicochemical and microbiological contaminants can result in the deterioration of the quality of water that reaches customer's tap compared to the original water produced at the treatment plant (Proctor and Hammes, 2015).

Liu et al. (2016) identified four essential elements involved in water pollution during its distribution through pipes:

1. The bulk water that flows through the pipe networks;
2. The suspended solids which are particulate matter that is suspended in the water and transported through the network;
3. The pipe surface with the associated material, e.g., biofilm, extracellular polymeric substance (EPS), scaling; and
4. The loose deposits which are particulate matter that has accumulated and is retained in the pipes. During water distribution, suspended particles may be transported or deposited as loose deposits and then re-suspended due to flow hydraulic turbulence resulting from flow conditions and characteristics. Pipe geometry and material play a greater part in water pollution and quality with respect to energy efficiency as submitted by (Broo et al., 2001). Rabin (2008) further investigated Broo et al. (2001) submission and concluded that the release of lead in pipes poses health risks to consumers and that pipes manufactured with rubber materials promote microbial synthesis in water distribution networks, thereby increasing the microbial load of the water. Yu et al. (2004) also attributed a faulty plumbing system to the spread of SARS coronavirus in some apartment buildings in Hong Kong in 2003. It is noteworthy that materials accumulated in pipes such as biofilm, scaling and loose deposits develop over time and the significance of such an effect may not be manifested in the preliminary stage. The age of use of such a conveyance system plays a vital role in the accumulation of material in the form of pipe scales, loose deposits and biofilm material (Makris et al., 2014). Magnetic treatment of water has been reported to reduce scale formation and carbonate deposits in pipes (Lipus and Dobersek, 2007). However, it is still not a universally-proven approach to water treatment as it is marred with several controversies and divided opinions. However, human health is of global, paramount importance and a good knowledge of contaminants' effect on human health is essential, be it on the microscopic or macroscopic scale.

3. Viruses associated with water pollution

Viruses are intracellular organisms with a genome within a protein capsid and are possibly the most lethal pathogens amongst those discovered in wastewater (O'Brien et al., 2017). According to Flint et al. (2004), viruses are classified as single-stranded DNA (ssDNA), single-stranded RNA (ssRNA), double-stranded DNA (dsDNA), and double-stranded RNA (dsRNA), depending on their genome kind. Bosch et al. (2008) reported that over 100 known kinds of viruses are defecated in human feces. In contrast, about 200 high diversity of human viral pathogens are found in the environment (O'Brien et al., 2017). They are also raised in samples affected by pollution with more species discovered (Bibby, 2013). Moreover, human viral pathogens such as bacteriophages might have a severe impact on the natural watercourses that receive treated effluent containing these viruses which are specifically resistant to wastewater treatment and difficult to detect in environmental media despite the recent advances in water and wastewater treatment technologies (Shapiro et al., 2010).

Water has been recognized as a common medium for the proliferation of viruses which may allow their continued existence (Pinon and Vialette, 2019). Surface water resources like oceans, rivers, lakes, estuary, groundwater, marine water are concerned with viral pollution (Shoham et al., 2012). This is because the sewage treated effluents are not efficiently removed, containing certain amounts of viruses that are subsequently discharged into the water environment (Okoh et al., 2010). The receiving water bodies further convey these viruses downstream, where it is utilized for various purposes like irrigation of crops, recreational activities, and other anthropogenic uses. This clearly explained how humans are exposed to fecally contaminated water via different exposure routes like direct ingestion of water during recreation, improperly treated drinking water and feeding on contaminated food products (Lodder et al., 2015; Ehlers et al., 2005). Some viruses such as coxsackieviruses, echoviruses, adenoviruses, noroviruses, and hepatitis A viruses are portrayed as recreationally related waterborne microorganisms (Sinclair et al., 2009).

Pathogenic germs such as protozoa and bacteria are also transmitted via the water route and stayed in the gastrointestinal tract of their host (humans and animals) and subsequently released into the environment via feces from where surface and ground waters are polluted (Paleologos et al., 2020). It may also be released into the host's environment through urine and respiratory secretions (Ghernaout, 2020). The most common human enteric viruses include enterovirus, Hepatitis A virus, Adenoviruses, Torovirus, Hepatitis E virus, Bocaviruses and coronaviruses, which may be released into water supplies, recreational waters and crops through sewage, runoffs, solid waste landfills and septic tanks (Ghernaout, 2020). Instances are prevalent with swimming pool water where outbreaks of norovirus, hepatitis A virus and adenoviruses were recorded.

Other human viruses such as adenovirus type 40 and noroviruses genogroup I and genogroup II are widely found in wastewater through fecal excretion. Aichi virus 1 and adenovirus are likely major human enteric viruses regularly detected throughout the year (Rachmadi et al., 2016; Kitajima et al., 2014). Adenoviruses are among the most abundant human viruses in wastewater treatment plant effluent (La Rosa et al., 2010) and were previously identified in wastewater through conventional techniques (Bofill-Mas et al., 2010). Wastewater is remediated microbiologically and physicochemically in wastewater treatment plants to eliminate pollutants before the discharge of environmentally safe water. Fecal pollution of environmental water is the main health concern, given that environmental waters are utilized for the production of food and drinking water supply (Masclaux et al., 2013). Besides, viruses from the released environmental water might reach diverse food items such as vegetables, fruits and raw shellfish (Bosch et al., 2008). Moreover, a virus infecting pepper plant called pepper mild mottle virus was suggested as a new indicator for human fecal contamination in a water environment because of its moderately high occurrence in treated sewage (Kitajima et al., 2014; Hamza et al., 2011).

At the moment, the newly discovered strain from the coronavirus family has unquestionably attracted the attention of the world as some studies have reported its detection in wastewater in Netherlands, Australia, USA and Greece (Paleologos et al., 2020; Medema et al., 2020; Ahmed et al., 2020; Lodder and de Roda Husman, 2020). Meanwhile, few reports indicate whether the SARS-CoV-2 can be transmitted via contaminated water (Adelodun et al., 2020a; Arslan et al., 2020a). However, supporting evidence to monitor the dynamics of SARS-CoV-2 closely has emerged as Arslan et al. (2020a,b) posited that the virus could stay longer in the digestive tract than the respiratory tract with infected patients excreting viral nucleic acid despite testing negative after 6 and 14 days from respiratory sampling specimen. Also, the close similarity of SARS-CoV-1 and SARS-CoV-2 in chemical structures and morphological characteristics needs full-fledged attention as the outbreak of the former in 2003 was traced to a failed water seal system and poor sanitation procedures.

4. Socioeconomic inequality due to virus-associated water pollution

One of the 21st century's challenges is the continuous gap in educational and socioeconomic inequalities that have ravaged different countries around the world and consequently rendered the world economic growth and development at high risk (Anlimachie and Avoada,

2020). Generally, it has been established that there exists a wide margin of inequalities between the rich and the poor; an average rich man's income is 57 times the poorest (Katiyatiya, 2020). Socioeconomic inequality has distinctively shown the varied level of access to basic social amenities within most developing nations' homes, including essential facilities such as access to potable water and sanitation (Akoteyon, 2019; Gbemiga and Deborah, 2019; Gasana et al., 2002); . Part of the United Nations sustainable development goals (SDG) (Goal 6) stressed on the need to provide adequate and sustainable water and environmental sanitation for all (United Nations, 2018). However, adequate water supply, proper sanitation and improved hygiene are devoid of a particular location and time – it is a primary need for human survival. These are mostly not adequately provided, especially in developing nations (World Bank Group, 2017a; Gasana et al., 2002).

The lack of access to potable water, proper sanitation and proper waste management conspicuously exists in many parts of the developing nations. For instance, Nigeria recorded a decline in access to potable water from 32% to 7% from 1990 to 2015, while 90% of rural dwellers in Niger republic practices open defecation and 51% do not have access to potable water (World Bank Group, 2017b). Similarly, lower-income households in Haiti have high susceptibility factors of 2.4 in contracting enteric diseases than high-income household children; 41% of water supply sources in Bangladesh is contaminated with *E. coli* and 56% of the top 20% in India has access to treated water compared to 6% of the bottom 20% (World Bank Group, 2017b). Developing nations have been ravaged with high death rates due to the use of contaminated water from complications from enteric diseases, with a larger percentage of these populations from rural dwellers (Gomez et al., 2019). The socioeconomic imbalance of water supply and sanitation have rendered the low-income earners to wait for options provided by the government, which sometimes are irregular. In contrast, the high-income earners sought after personal provisions, such as borehole and premium sanitation services. Improved access to water and sanitation services will increase people's hygiene, increase work productivity, reduce susceptibility to diseases and malnourishment (Morales-Novelo et al., 2018).

Though socioeconomic indicators are crucial for assessing and mitigating the impact of waterborne viral diseases, only in the past decade or so have efforts been made to understand better their role (Ajibade et al., 2020; Beltran et al., 2011). The advent of current novel coronavirus (SARS-CoV-2) and the possible persistence in a water environment (Carducci et al., 2020) has further created more apprehension on potential socioeconomic implications of virus-associated water pollution, especially in less developed countries with a wide-gap of socioeconomic inequality (Arslan et al., 2020a,b; Adelodun et al., 2020). Waterborne viral pathogens have huge socioeconomic impacts in both developed and developing nations; however, the magnitude of the impact and the burden of viral diseases including severity and prevalence are more severe in regions of the world with highly polluted environments, majority of which are developing nations (Rodríguez-Díaz et al., 2009). There have been global reports on viral pathogens resulting from exposure to contaminated drinking and recreational waters, especially as it concerns human socioeconomic factors. This section, therefore, examines some of the socioeconomic factors and their linkage with waterborne viral diseases.

4.1. Poverty

The poor are more susceptible to waterborne diseases than the well-off (WHO and UNICEF, 2015). This is because they lack adequate supplies of safe water and proper methods of disposing of their wastes. The lack of quality water and sanitation creates ideal conditions under which viral pathogens thrive. Further, the lack of good quality and reliable water sources may drive the poor to extract water from unsafe alternative sources, thereby exposing them to waterborne viral diseases and putting their health at risk. Several studies have established linkages between poverty and virus-associated water pollution. El Zanfaly (2015) reported a clear link between poverty and water pollution, implying an association between poverty and dirtiness, and dirtiness with microbial polluted water. The author further reported that children in rural households were more prone to contaminated water sources than children who live in urban households and that effects of polluted water were compounded by the tendency of rural women to reuse the household water drawn from pumps or wells, further buttressing the significance of poverty on the use of microbially contaminated water. Also, Blaise and Dovie (2007) in their study on diarrheal diseases in the history of public health reported that poverty and environmental filth (hygiene level) were leading risk factors associated with water pollution and consequently waterborne diseases. Similarly, Parvez et al. (2019) reported a direct relationship between poverty and waterborne diseases, implying that extreme poverty levels resulted in increased waterborne diseases, especially in developing countries. Furthermore, research conducted in Latin America by Saback et al. (2001) and Struchiner et al. (1999) found waterborne viral diseases to be higher in low-income populations than high-income populations implying that poverty was a major cause of waterborne illnesses.

4.2. Standard of living

A decent standard of living entails that people are able to comfortably provide health or medical facilities for the well-being of their families. Thus, the prevalence of waterborne diseases could be used as an index for measuring the level of development in a given country. Studies have shown that waterborne diseases vary widely due to a country's standard of living. Polimeni et al. (2016) reported varying degree of macro-level socioeconomic factors such as the standard of living; the unbalanced split of rural/urban population; regional inequality; the level of trade (imports of goods and services) and access to health care with an increased risk for viral waterborne illnesses and death. Also, Yongsi and Ntetu (2008) and Pande et al. (2008), whose study areas were developing countries (Cameroun and Benin Republic, respectively), reported that households with the low standard of living recorded a higher prevalence of waterborne illnesses and vice versa; implying that waterborne illnesses could be inhibited or encouraged by households standard of living. Kunasol et al. (1998), whose study was conducted in Southeast Asia, also documented that exposure to waterborne viral pathogens decreased with an improvement in living standards. Similar results were also reported by Osundare et al. (2020), Salman (2017), and Potgieter et al. (2010), who observed an increase in waterborne viral infections between populations with the low standard of living, thus recommending that prompt actions should be taken to improve the living standards in the study areas.

4.3. Level of education

Several findings show a clear inverse correlation between the level of education of a people and the rate of viral waterborne illnesses. The more people know about waterborne viral diseases, the greater the tendency to manage the diseases, and hence the lower the disease occurrence. Nearly one-third of the global population lives in developing South Asia, where waterborne diseases are high, especially in rural areas due to the inadequate awareness about these diseases (Malik et al., 2012). Arora et al. (2013) also reported that an increase in the household level of education would decrease viral waterborne disease prevalence. Martins et al. (2015) also confirmed these reports in their study on environmental sanitation and mortality associated with waterborne diseases in Brazilian children, concluding that the most significant health hazards related to water pollution were found in the rural communities characterized by a high concentration of low-income population with limited education. Furthermore, similar studies conducted in Algeria and Bangladesh by Guenifi et al. (2017) and Parvez et al. (2019), respectively, also reported a lower seroprevalence rate within households with a higher educational level, further confirming the

significance of educational level to the degree of waterborne disease prevalence.

4.4. Access to healthcare

The risk of infection with waterborne viral diseases can be influenced by the level of access to healthcare, reflecting a factor of households' socioeconomic status. The tendency to easily access healthcare facilities can decrease susceptibility to waterborne viral disease complications by providing early detection and required medication to curb morbidity (Dickin and Schuster-Wallace, 2014). As reported by Polimeni et al. (2016), the level of access to healthcare would influence the risk level of waterborne viral infections. Households with low access to health facilities were at a greater risk of waterborne illnesses than households with high access, implying a negative correlation between access to healthcare and waterborne diseases. Saback et al. (2001) also gave an account of similar findings in their study on waterborne viral infections and socioeconomic status in a developing country. They observed that exposure to waterborne infections among residents decreased with an improvement in the country's healthcare status. Similarly, WHO (2009) and Hughes et al. (2014) reported that poor access to healthcare facilities was a measure of the high waterborne disease burden in developing countries of Africa and Asia.

4.5. Age

The most glaring implication of not preventing waterborne diseases is a possible high morbidity and mortality rates among children (Gleick, 2002). Waterborne viral pathogens can cause serious health challenges in children and the elderly alike. Even though several viral waterborne diseases are not age-specific, many cases of infections occur early in life, affecting mainly children between the ages of 5 and 9 (Mantovani et al., 2015b). Globally, unsafe water due to microbial contamination kills at least 1.6 million children under the age of five years, of which 84% of them live in rural areas characterized by poor socioeconomic status (Olowe et al., 2016). Hau et al. (1999) investigated a potential outbreak of enteric Hepatitis A and E viruses as a function of the vulnerable population group in the Mekong River Delta region of Vietnam, where the high risk of infection was found to be among the occupational and age-dependent group. McMichael (2019) and Rana (2010) also observed that children under the age of five were more likely to get seriously ill from waterborne pathogens compared to their adult counterparts. Similarly, Alian et al. (2011) also affirmed that viral waterborne disease infections increased with age, with the majority of infections coming from children living in rural areas. This is not surprising since rural settlements, especially developing countries, face huge sanitation problems and acute poverty, thus rendering the children from these areas vulnerable to waterborne disease infections. As El Zanfaly (2015) stated, lack of access to safe water and proper sanitation leads to the spread of waterborne diseases and has a significant impact, especially on the health of vulnerable age groups (5 years and below).

4.6. Gender

Gender differences exist in the social determinants of waterborne diseases due to the different household roles borne by each gender, which is a determining factor of waterborne infections. There is a significant contribution of women in fetching water, especially within rural household labor division in developing countries (Kher et al., 2015). The domination of women involved in fetching water invariably means that they have the most contact with water and less access to unpolluted alternatives and are thus more prone to waterborne infections than their male counterparts (World Bank Group, 2012). Similar findings were reported by Siddiqui et al. (2012), who attributed the high level of waterborne disease vulnerability of the female gender to the fact that the activities of women involve water usage in many ways, such as washing, cooking, etc. Furthermore, Pouramin et al. (2020) also affirmed that the female gender is more prone to waterborne infections.

The prevention of waterborne viral diseases is of great importance wordwide, especially in developing countries characterized by low and middle-income inhabitants. This is because the majority of the casualties from waterborne viral diseases have been reported among low and middle-income countries. Therefore to develop appropriate policies to reduce virus-associated water pollution, a complex approach to social structures and economic systems is required. In terms of socioeconomics, the literature on waterborne viral diseases finds the sources of infection to include poverty (low income and hygiene level), low level of education, low standard of living, inadequate access to healthcare, age, and gender (Fig. 2).

5. Human health risk of virus-associated water pollution

Viral agents are being recognized as the leading cause of epidemic as relates to water pollution and contamination. The ingestion of virus-contaminated water or any other contaminants of such have a considerable health risk to human life. Many human viruses have been identified to cause gastroenteritis, a communicable disease that is mainly transmitted through water (Schwab, 2007). Gastroenteritis can lead to other illnesses, including headache, fever, and diarrhea, which could result in significant causes of mortality in developing nations due to its dehydration effect on infected individuals coupled with the existence of inadequate measures on rehydration therapy (Cheng et al., 2005). Some of these viruses are highly infectious and can persist, ranging from weeks to months in the water environment (Seitz et al., 2011; Shoham et al., 2012). Notably, among these viruses is the rotavirus that causes diarrhea and responsible for the majority of childhood morbidity and mortality in developing nations (Schwab, 2007). Diarrhea is singly responsible for the death of the world's youngest children (525,000 cases annually) within the bracket age of 5 years and below, with the majority of the cases occurring among the disadvantaged children in sub-Saharan Africa and South Asia (Pooi and Ng, 2018; UNICEF, 2012). Other waterborne viruses such as adenoviruses, enterovirus, hepatitis A and norovirus have also been reported to transmit various forms of infections and diseases including respiratory, ocular and urinary tract, muscle pain, pharyngitis, meningitis, conjunctivitis, paralysis, cardiomyopathy, gastroenteritis, and diarrhea which resulted in epidemics (Bonadonna and La Rosa, 2019); hence making the emergence of SARS-CoV-2 and its potential risk of COVID-19 spread through water, a serious of concern. Table 1 shows the presence of selected viruses in water environment across different countries, which indicate the potential risk of the virus transmission through this medium.

Developing nations with inadequate water and sanitation system are at high risk receiving end when the possible pathways of SARS-CoV-2 maybe from wastewater from hospitals and isolations centers and indiscriminate infected materials disposals with possible runoffs and underground water contamination of the nearby communities that relied mostly on wells and rivers (Adelodun et al., 2020a). The risk of exposing the vulnerable sections of the communities is a determining factor in combating the pandemic to a standstill. However, negligence of their basic needs (such as adequate wastewater treatment, provision of clean and drinkable water, and good sanitation management) will affect the fight against COVID-19.

This is evident as some of these countries lacked a working wastewater treatment plant and had to rely on discharging effluents into rivers, streams, and canals with little or no treatment (Arslan et al., 2020b). For instance, enterovirus of detectable level was confirmed in about 19% of the drinking water samples in South Africa (Ehlers et al., 2005). To curb the possibility of widespread COVID-19 amongst the vulnerable part of the community, Adelodun et al. (2020a,b) posited the following sustainable preventive measures – special treatment of hospital and isolation waste from public waste, proper monitoring within the community and frequent testing of SARS-CoV-2 in effluent water,

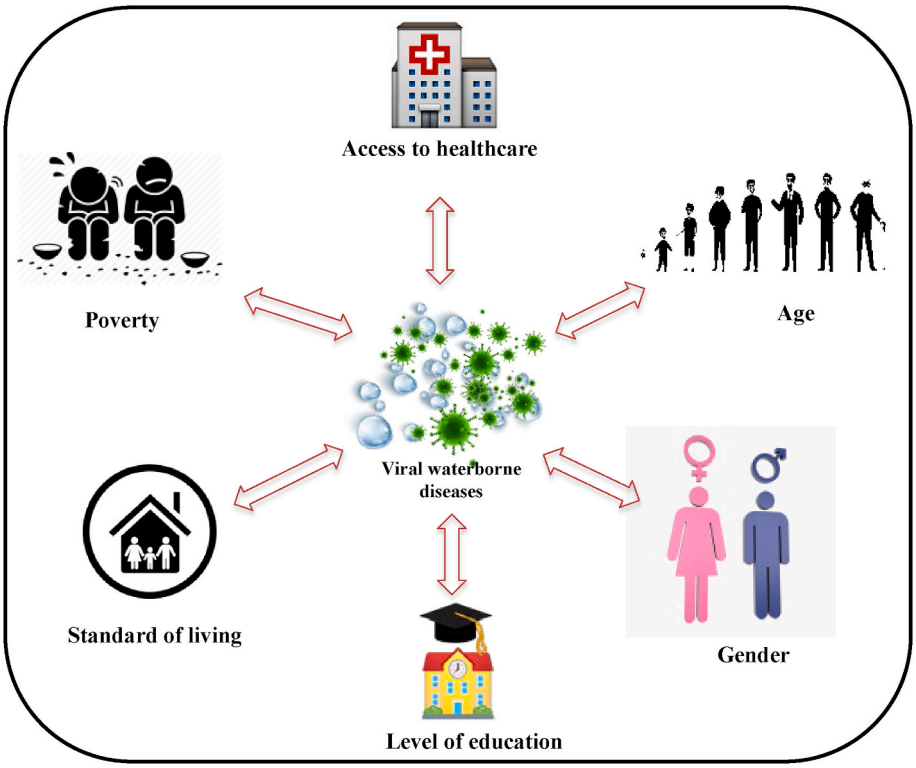


Fig. 2. Socioeconomic factors influencing the occurrence of viral waterborne diseases.

practicing best sanitation procedure and improved water quality, provision of adequate decontaminants (such as point-of-use device) and government policy intervention.

Globally, the human health risk due to the socioeconomic inequality experienced in developing nations and felt mainly by women and girls due to exposure to contaminated water and soil has increased as against the SDG's goal 6 agenda (Pouramin et al., 2020). In the face of this coronavirus pandemic, the inadequate resources available has dramatically opened up a lot of loopholes in crisis management and decision making, inadequate and underpaid medical personnel, lack of investment in research and development for new product and services; these factors are results of decades of negligence in socioeconomic provisions for the citizens (UNDP, 2020).

In a report by Rosa et al. (2020), it was opined that SARS-CoV-2 has low stability in the environment and sensitive to chlorine, the virus survival at a temperature around 23 °C–25 °C declines and non-availability of data to claim the transmission via drinking water route. However, there is a need for continuous research on the survival of the virus in water, recovery method for Covid-19 polluted water, and capacity to provide tests for the populace and detection of the virus in waterways. The most vulnerable population will be badly hit if none of the above measures are put in place.

6. Management and mitigation strategies

The sustainable management of viral contaminated water in developing countries is paramount in preventing environmental degradation and reducing human infection (Lim et al., 2015). In this section, the issues around sustainable management in this domain are discussed, and possible mitigation strategies proffered. Improperly conducted waste management and pollution prevention practices can have negative consequences on human health and the environment (Girones et al., 2014). This risk is quite high in developing countries where water quality monitoring is not efficient, and water reuse is done for resource conservation (Toze, 2006).

Even in very low concentrations, the presence of viruses is an indicator of overall poor water quality (Lin and Ganesh, 2013). Viruses in the environment and drinking water treatment plants were previously confirmed (Albinana-Gimenez et al., 2006; Verbyla and Mihelcic, 2015; Ehlers et al., 2005). In the environment, it has been identified in rivers (Phanuwan et al., 2006), source water dams (Chigor et al., 2014), water basins (De Paula et al., 2007) and groundwater (Hunt et al., 2010). These viruses include polyomaviruses (Albinana-Gimenez et al., 2006), adenoviruses (Rames et al., 2016), hepatitis virus (De Paula et al., 2007), *acanthamoeba polyphaga* mimivirus (Ashbolt, 2015), rotavirus (Sano et al., 2016), enterovirus (Chigor et al., 2014), norovirus (Seitz et al., 2011), pepper mild mottle virus (Kitajima et al., 2018; Haramoto et al., 2013), human picobirnaviruses, torque teno virus (Hamza et al., 2011), poliovirus (Robeck et al., 1962) and caliciviruses (Xagoraraki et al., 2014).

These viruses bear grave consequences on human health in the case of infection. Besides the risk to humans (Masclaux et al., 2013), virus contamination also bears significant cost implications from its mitigation (Adelman et al., 1998). For the conventional treatment of polluted water by treatment plants, virus removal efficiency can be affected by meteorological and physicochemical factors (Carducci and Verani, 2013). This suggests that more intricate and integrated processes are needed to treat virus-contaminated water to achieve sustainable management. Processes generally used for the mitigation of viral pollution in water is membrane processes (Antony et al., 2012; Madaeni et al., 1995), reverse osmosis (Pype et al., 2016), activated sludge (Sano et al., 2016) and chlorination (Yang et al., 2011).

Researchers have investigated a variety of novel techniques for the mitigation of virus contamination of water in recent times. Asami et al. (2016) compared coagulation-sedimentation and rapid sand filtration to mitigate the spread of pepper mild mottle virus and JC polyomavirus through water. Coagulation-sedimentation was observed to be less efficient for pepper mild mottle virus in comparison to JC polyomavirus. The study furthermore observed that the reverse was the case for rapid sand filtration. Chlorination is effective for the mitigation of

Table 1
Detection of viruses in water environment.

Virus type	Water Matrix	Concentration in genome (copies/L)	Country	Reference
Rotavirus	Wastewater treatment plant (influent and effluent)	10^3 to 10^5	South Africa	Osuolale and Okoh (2017)
Adenovirus,	Treated wastewater	4.6×10^4 to 1.2×10^6	Brazil	Schlindwein et al. (2010)
Pepper mild mottle	Municipal pond	1.0×10^3 to 1.0×10^6	Bolivia	Symonds et al. (2014)
Hepatitis E	Wastewater treatment plant (influent and effluent)	6.1×10^2 to 5.8×10^5	Italy	Di Profio et al. (2019)
SARS-CoV-2	Sewage	Low of detection to 5.6×10^4	Italy	La Rosa et al. (2021)
SARS-CoV-2	River	2.1×10^3 to 3.2×10^4	Ecuador	Guerrero-Latorre et al. (2020)
SARS-CoV-2	Wastewater (treated and untreated)	10^5 to $10^{6.5}$	France	Wurtzer et al. (2020)
SARS-CoV-2	Untreated wastewater	2.6×10^3 to 2.2×10^6	The Netherlands	Medema et al. (2020)
SARS-CoV-2	Wastewater (treated and untreated)	3.1×10^3 to 7.5×10^3	USA	Sherchan et al. (2020)
SARS-CoV-2	Untreated wastewater	1.9×10^1 to 1.2×10^2	Australia	Ahmed et al. (2020)
SARS-CoV-2	Wastewater (Untreated and Secondary treated wastewater)	1.4×10^5 to 3.4×10^5	Spain	Randazzo et al. (2020)
SARS-CoV-2	Secondary treated wastewater (before chlorination)	2.4×10^3	Japan	Haramoto et al. (2020)

noroviruses, rotaviruses, and hepatitis E virus contamination of water (El-Senousy et al., 2014a, 2014b; Nasser, 1994). At a 4 mg/L dosage of chlorine, Log 10 reduction value of $\geq$6 was achieved for all three viruses. Positive results have also been achieved using a similar process, albeit for adenovirus (Girones et al., 2014). Cold atmospheric-pressure plasma (in argon) mixed with air and plasma-activated water have also been evaluated as potential techniques for the mitigation of viral contamination of water (Guo et al., 2018). The key focus of Guo et al. (2018) investigation was to elucidate how singlet oxygen inactivated the bacteriophages T4, ϕ174, and MS2 by damaging their nucleic acid.

The mechanism of virus inactivation by the iron electro-coagulation process has been recently investigated (Heffron et al., 2019a). For adenovirus, echovirus, and feline calicivirus and bacteriophage surrogates, coagulation is quite efficient in de-contaminating the water. However, the performance of ferrous ions in deactivating the virus was observed to depend on the electrostatic interactions between the ions and the viruses (Heffron et al., 2019a). These, in turn, are controlled by the solution chemistry of the process. Having established the suitability of electro-coagulation, it has also been shown that adding a secondary electro-oxidation stage does not give a significant performance advantage, especially in light of the added costs (Heffron et al., 2019b). A hybrid process of ozonation, coagulation, and ceramic membrane separation has been shown to reduce bacteriophage MS2 in water effectively (Im et al., 2018). The utilization of ozonation in the process was observed to reduce both reversible and irreversible fouling of the experimental apparatus, which enhanced overall performance. However, this came at the cost of a slight reduction in the coagulation of MS2, especially at high ozone input.

These are but a few of the studies considered in recent times. Table 2 presents a more detailed catalog of mitigation strategies for virus contamination of water conducted in recent times alongside the key findings. Most studies implement a hybrid technique where two or more processes are integrated to improve performance and efficiency. Besides those already discussed, other recent mitigation techniques studied for virus decontamination include ceramic water filter (Farrow et al., 2014; Van der Laan et al., 2014), coagulation – microfiltration (Matsushita et al., 2013a; Zhu et al., 2005) and solar and UV irradiation (Mayer et al., 2015; Polo et al., 2015). Furthermore, it is also observed that the most common target species investigated in recent times was Bacteriophage MS2. Most of these studies indicated positive findings for virus removal. This bodes well for the general environmental sustainability effort and affords more options for tackling the problem.

Based on the discussions in this section, several recommendations are herein presented in light of the need for the mitigation of viral contamination of water sources in developing countries. Most of the studies have implemented hybrid processes using a combination of two or more techniques for virus mitigation. Such techniques can be employed in treatment at the plant scale. These are only relevant to larger cities where such treatment plants are in place. Though studies have shown that the utilization of silver in the virus de-contamination of water is of advantage like for photocatalytic degradation (Liga et al., 2011), adsorption column (Shimabuku et al., 2017) and ceramic pot filtration (Van der Laan et al., 2014), these would be rather expensive solutions for developing countries especially when implementation is on a large scale.

There are other quite simple technologies for virus decontamination like the ceramic water filter (Farrow et al., 2014; Van der Laan et al., 2014) shown in Fig. 3. The ceramic water filter shown in Fig. 3 Was used in the removal of human enteric viruses from water (using MS2 ad a surrogate phage). The device was able to achieve optimum removal efficiency values of 1.5–2.5 log using 100 NTU turbid influent water and no cleaning between trials. Though the process was efficient, increasing the turbidity of the influent water using bentonite helped to improve the viral decontamination efficiency. This specific system is elaborated due to its simplicity, ease-of-use, low-cost and usability even in rural areas. Such simple techniques can be re-designed and improved for domestic and local applications in developing countries (albeit at low cost). Putting all these into consideration, the onus is on the government agencies to develop regulations for the water co-operations to ensure the viral decontamination of water being processed for commercial use. Furthermore, entrepreneurial insight is needed to develop low-cost technologies for virus decontamination that would be amenable to remote and rural locations in developing countries.

7. Future scope and recommended policies

In line with the observations of this review, interesting areas of work are hereby discussed that could form the foundations of novel investigations. As observed by Ighalo and Adeniyi (2020), water quality monitoring and assessment in developing countries have been more focused on the conventional physico-chemical parameters. There is a need for future studies to direct their efforts towards the analysis of viral contamination too. In light of these, policy adjustments would also be needed to develop guideline limits of viral contamination in water sources. The COVID-19 pandemic has changed so many areas in contemporary societies and important adjustments will need to be made in line with the prevailing peculiarities. IoT-enables systems will also be an interesting technology for water monitoring systems and mitigation technologies. These are fast, reliable and can produce results in real-time. In the area of mitigation, entrepreneurial insight is needed to develop low-cost technologies for virus decontamination that would be amenable to remote and rural locations in developing countries. The following specific recommendation policies are therefore proposed.

i. The regulatory guidelines for pathogen removal in water for various reuse calls for thorough evaluation for stricter requirements with the recent detection of the SARS-CoV-2 in wastewater.
ii. In water distribution systems, appropriate chlorine residual should be applied in the piping system to decontaminate any

Table 2
Summary of mitigation strategies for virus contamination of water.

Process	Target viruses	Key findings	Reference
Coagulation-sedimentation	Pepper mild mottle virus and JC polyomavirus	The process was able to achieve a Log 10 reduction value of 0.41 and 1.91 for Pepper mild mottle virus and JC polyomavirus (wet season).	Asami et al. (2016)
Rapid sand filtration	Pepper mild mottle virus and JC polyomavirus	The process was able to achieve a Log 10 reduction value of 1.26 and 0.49 for Pepper mild mottle virus and JC polyomavirus (wet season).	Asami et al. (2016)
Chlorination	Noroviruses, rotaviruses and hepatitis E virus	At a 4 mg/L dosage of chlorine, Log 10 reduction value of ≥6 was achieved for all three viruses.	El-Senousy et al. (2014a, 2014b)
Ceramic water filter	Enteric virus	Though the process was efficient, increasing the turbidity of the influent water using bentonite helped to improve the viral decontamination efficiency.	Farrow et al. (2014)
Chlorination	Hepatitis E virus and human adenovirus 2	A Log reduction of value of 0.41 was achieved.	Girones et al. (2014)
Cold atmospheric-pressure plasma and plasma-activated water	Bacteriophages T4, ϕ174 and MS2	The mechanism of virus deactivation was a singlet oxygen attack on the nucleic acid and other proteins.	Guo et al. (2018)
Iron electrocoagulation	Adenovirus, echovirus, and feline calicivirus and bacteriophage surrogates (Fr, MS2, P22 and ϕ174)	The viruses were effectively removed by the physical coagulation process but less susceptible to iron inactivation.	Heffron et al. (2019a)
Sequential electrocoagulation-electrooxidation by boron-doped diamond electrodes	Bacteriophages ϕ174 and MS2	The results were not that positive as the sequential process alone did not give any major advantage in comparison with using the only electrocoagulation.	Heffron et al. (2019b)
Combined ozonation, coagulation and ceramic membrane	Bacteriophage MS2	Introducing ozonation to the process improves the performance of the process.	Im et al. (2018)
Ceramic pot filter with silver	Bacteriophage MS2	Pot characteristics were observed not to affect the virus decontamination process nor the contact time in the filtration phase. The important effect of silver came at contact time with silver during storage.	Van der Laan et al. (2014)
Silver-doped titanium oxide photocatalytic degradation	Bacteriophage MS2	The higher silver content in the photocatalytic adsorbent improved the inactivation efficiency of the virus.	Liga et al. (2011)
Silica-modified titanium oxide photocatalytic degradation	Bacteriophage MS2	Modification improved viral deactivation by about 270%.	Liga et al. (2013)
Micro-filtration membrane	Foot-and-mouth disease (type O) and Infectious bovine respiratory disease	The fuzzy inference system was successfully used to model the experimental data to predict virus removal based on operational parameters.	Madaeni and Kurdian (2011)
Aluminum-based coagulation	Bacteriophages T4, Qβ and MS2	The viruses were effectively decontaminated due to interactions with the coagulant.	Matsushita et al. (2011)
Adsorption by super-powdered activated carbon	Bacteriophages Qβ and MS2	In contrast with the ordinary activated carbon (AC), the super-powdered AC was more effective in virus removal due to its higher hydrophobicity, the greater portion of nano-pores and lesser electrophoretic repulsion.	Matsushita et al. (2013b)
Microfiltration	Norovirus	It was unsuitable for virus removal (pore size 0.1 μm).	Matsushita et al. (2013a)
Ultrafiltration	Norovirus	The process was able to achieve a virus reduction value in the Log 4 region.	Matsushita et al. (2013a)
Hybrid pre-coagulation – microfiltration process	Norovirus	A first-stage coagulation process helped to improve the efficiency of the microfiltration.	Matsushita et al. (2013a)
Ultraviolet (UV) irradiation	Adenovirus, feline calicivirus, coxsackievirus, echovirus, poliovirus and bacteriophage	The process was more efficient in the decontamination of adenoviruses than for the others.	Mayer et al. (2015)
Titanium oxide photocatalytic degradation	Adenovirus, feline calicivirus, coxsackievirus, echovirus, poliovirus and bacteriophage	The process was more efficient in the decontamination of bacteriophages than for the others.	Mayer et al. (2015)
Ferric chloride coagulation	Adenovirus, feline calicivirus, coxsackievirus, echovirus, poliovirus and bacteriophage	The process was more efficient in the decontamination of coxsackievirus, bacteriophage MS2 and adenovirus than for the others.	Mayer et al. (2015)
Nano-filtration by carbon nanotubes	Bacteriophage MS2	At an 8–11 bar pressure, virus removal was effectively achieved.	Mostafavi et al. (2009)
Solar water disinfection	Hepatitis A virus, norovirus surrogate and murine norovirus	UV from solar irradiation was effective for virus inactivation albeit to a greater extent than the temperature of the process.	Polo et al. (2015)
Polysulfone membrane coated with magnetite	Bacteriophage MS2	Coating with magnetite improves treatment performance up to 99.99% in the Log 4 region.	Raciny et al. (2011)
Advanced bardenpho as a secondary treatment in a water plant	Pepper mild mottle virus, Aichi virus, noroviruses, enterovirus, sapovirus, rotavirus, adenovirus and polyomaviruses	When the advanced bardenpho was used as a secondary treatment in a water treatment plant, most pathogenic viruses were removed and it compared better to the conventional process.	Schmitz et al. (2016)
Activated carbon modified with silver and copper oxide nanoparticles	Bacteriophage T4	The modified porous media was able to achieve virus reduction in the region of Log 3.	Shimabuku et al. (2017)
Iron electrocoagulation – microfiltration	Bacteriophage MS2	The primary mechanism was by sweep flocculation which was assisted by charge neutralization.	Tanneru and Chellam (2012)
Nano-Titanium oxide membrane adsorption	Bacteriophage F2	PAN (0.05 μm) membrane had higher removal efficiency than PVDF (0.20 μm) membrane.	Zheng et al. (2013)
Photocatalytic membrane separation process	Bacteriophage F2	At an optimum condition of 40 L/(m^2h) intermittent suction mode, virus removal of over 5 log was achieved in 24 h.	Zheng et al. (2015)
Iron coagulation – microfiltration	Bacteriophage MS2	The process was able to achieve over 4-log virus removal at optimum conditions.	Zhu et al. (2005)

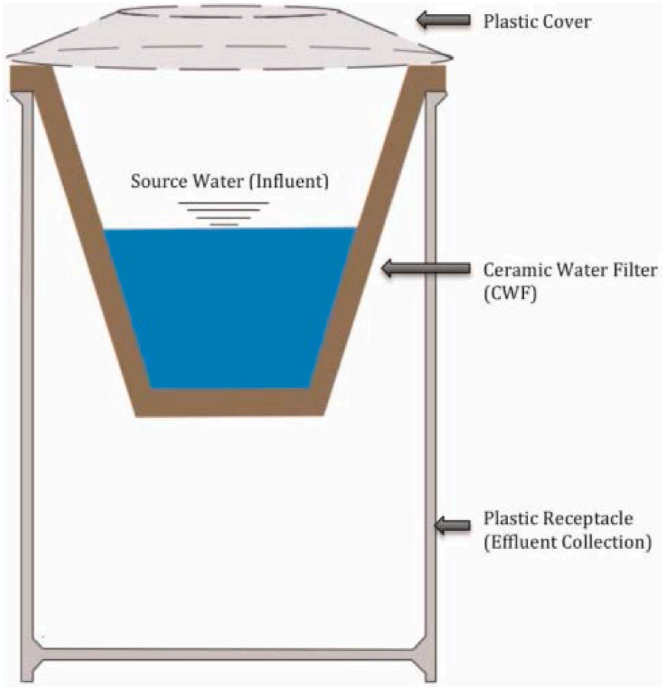


Fig. 3. Schematic of a ceramic water filter (Farrow et al., 2014).

viruses that can easily recolonize or provide protection from entry of pollution to the pipes during the process of unintended cross-connection between non-potable and potable lines.

iii. A comprehensive understanding of the efficiency of evolving disinfection treatment techniques (Ozonation, activated carbon, UV based advanced oxidation processes) for virus and other pathogenic organisms deactivation specifically procedural steps that are incorporated into safe water reuse is a vital research necessity.

iv. The development of new or improved existing water and wastewater treatment facilities for critical areas that receives coronavirus from hospitals, isolation centers, clinics and swine pen should be the focal point of all researchers.

v. At the point of use, specifically for drinking purpose in homes, handy disinfection devices should be provided to reduce the waterborne viral diseases and secondary transmission

vi. Detailed appraisal and usage of new and promising sustainable methodologies for viral and other pathogenic/infectious disease surveillance.

vii. An enhanced understanding of the fate and behavior of these viruses in water environment will pave way for routine implementation for water quality monitoring and for viral risk evaluation. There is therefore, a need for the synergy between the public health experts, scientists (Chemists, virologist, and Microbiologist), engineers to team up and proffer pragmatic solutions for potable water and healthy environs to address this issue of virus and other pathogen contamination in water especially developing a simple operating process for the detection of viruses in water.

8. Conclusion

In this review, socioeconomic inequality based on virus-contaminated water usage in developing countries was assessed and discussed. Possible mitigation strategies were proffered based on the existing literature that can be adopted for the developing countries, especially those characterized by low level social and economic development. The recent global COVID-19 pandemic has changed the paradigm by reawakening the importance of water quality and sanitation and focusing more attention on the deleterious effect of contaminated water. As discussed in the review, the socioeconomic factors attributed to the various waterborne diseases due to the use of virus-contaminated water in many developing countries are poverty, the standard of living, access to health care facilities, age, gender, and level of education. Some mitigation strategies to address the viral contamination of water sources are therefore proposed, while future scope and recommendations on tackling the essential issues related to socioeconomic inequality in developing nations are highlighted.

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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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