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Viruses as Indicators of Fecal Pollution in Aquatic Environment

Mohammed K. Rashed [1], Waled M. El-Senousy [1], ElSayed T. Abd ElSalam [2], Maha M. AlKhazindar [2*]

[1]Environmental Virology Lab, Water Pollution Research Department, Environmental and Climate Change Research Institute and Food born Viruses group, Center of Excellence for Advanced Sciences, National Research Centre NRC, Dokki, Giza, Egypt.

[2] Botany and Microbiology Department, Faculty of Science, Cairo University, Egypt.

*** Corresponding author: malkhazi@aucegypt.edu**

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ABSTRACT

This review was presented to suggest if viruses could be used as fecal indicators for drinking water and treated sewage pollution. The failure of bacterial indicators in a lot of cases to indicate viral pollution in drinking water and treated sewage indicates that bacterial indicators may fail to express fecal pollution in drinking water and treated sewage. We could explain this statement as viruses, especially enteric viruses are generally secreted in the feces of infected or carrier persons. Thus, it always expresses the fecal contamination in sewage and consequently water. Hence, the defect of bacterial indicators to indicate the enteric virus's presence in a lot of cases may indicate failure in expressing the fecal pollution, which is the cause of viral contamination of sewage and water. Adding at least one viral indicator besides bacterial indicators can help supply more perfect water quality results and greater assurance of water quality safety. Adenoviruses and bacteriophages may represent suitable candidates as indices of viral and fecal pollution indicators in drinking water and treated sewage samples.

INTRODUCTION

Water is necessary for life; however, till now a huge number of people can't attain safe, clean, and healthy drinking water, and many cases of death are caused by the contamination of water by pathogenic organisms. Over fifty severe illnesses can be caused by contaminated water, including infectious diseases, skin diseases, digestive sickness, respiratory diseases and cancer **(Wen *et al*., 2020)**. Drinking water safety is a significant public health hazard; as of 2022, approximately two billion people live in countries with extreme water deficiency, as the result of population expansion and climate change. The drinking water sources of over two billion people were contaminated with waste, and 829 000 people annually die from diarrheal diseases caused by unhealthy drinking water, deficiency of sanitation, and poor hand hygiene **(WHO, 2022)**. Hospitals, industries considered, decontamination stations, outlets of wastewater treatment plants, and storm drains are considered the most common sources of pollution from natural water

sources. Some studies show the relation between urban activities and pathogens concentrations **(Marsalek & Rochfort, 2004; Selvakumar & Borst, 2006)**. There are two sources of fecal contamination; the first source is related to human activities such as non-collective sewage systems, water sewage treatment plants, and combined sewage overflow. The second source is manure spreading by wild and domestic animals **(Jung *et al*., 2014)**. Most studies have found that gastroenteritis diseases occur at higher rates than other diseases **(EPA, 2012).** Enteric viruses and enteric bacteria have been the most causes of waterborne gastroenteritis diseases **(Said *et al*., 2003; Kay *et al*., 2007)**. Because of the difficulties of methodology, enumeration of pathogens (viruses, bacteria, parasites), and a low dose of infectivity to occur the infection, the environmental and health authorities have been used as micro-bioindicators to assess the water's quality and the performance of treatment process **(Bartram *et al*., 2001)**.

Indicator term can be used to refer to the index and the indicator function **(Bartram *et al*., 2001)**, in which the index is linked to the presence of microorganism surrogate or material (pathogens, age, fecal remnants); on the other hand, the function of indicator includes features such as stability under the environmental conditions and treatment processes resistance **(García- Aljaro *et al*., 2019)**. Fecal indicators bacteria (FIB) were first introduced in the 1880s to determine the quality of water when bacteriological media were used to show the microbial presence in food and water **(Ashbolt *et al*., 2001)**. FIB covers all the roles of indicators, but now viruses are the most resistant to treatment operation and more survival in the environment than the FIB **(Grabow, 2001; García- Aljaro *et al*., 2019)**; in addition, FIB fails to detect fecal contamination sources **(Malakoff, 2002)**. There is no common indicator, only a wide range of indicators with certain features **(Ashbolt *et al*., 2001)**.

This review aimed to suggest if viruses could be used as fecal pollution indicators in drinking and treated sewage water samples.

1. Enteric viruses in the aquatic environment

Many groups of enteric viruses, enteric bacteria, and protozoa are transferred by water **(Liste *et al*., 2000)**. About 150 several serological types of viruses including, adenoviruses (AVs), noroviruses (NoVs), rotaviruses (RVs), enteroviruses (EVs), and polyomaviruses (PVs) cause a variety of diseases. **(Hamza *et al*., 2009; Rodriguez-Lazaro *et al*., 2012; Tran *et al*., 2015; Adriaenssens *et al*., 2019)**. Enteric viruses replicate in the human and animal intestinal tract; they can tolerate the gut acidic pH, the alkaline activity, and the duodenum proteolytic activity **(Greening & Cannon, 2016; Katayama & Vinjé, 2017)**. Moreover, enteric viruses have high resistance to environmental conditions (temperature, light, salinity), water, and wastewater treatment processes **(Gibson, 2014; Kauppinen *et al*., 2018; Sekwadi *et al*., 2018)**. Enteric viruses are host-specific and can be used to distinguish between human and animal sources of fecal contamination **(Jiang *et al*., 2007; Silva *et al*., 2011)**. Fecal-oral route is the main

route for the transmission of the enteric virus by contaminated food or water, in addition, to the direct contact with infected individuals **(Koopmans & Duizer, 2004; Katayama & Vinjé, 2017)**. Many diseases are caused by enteric viruses such as conjunctivitis, respiratory infection, non-bacterial gastroenteritis and hepatitis **(Lenaerts *et al*., 2008; Okoh *et al*., 2010; Fewtrell & Kay, 2015; Graciaa *et al*., 2018)**. Some enteric viruses can excrete in infected individuals' feces with a range of up to 10^{11} viral particles per gram of stool **(Bosch, 1998)**, as well as very low infectious dose (1-10) viral units **(Leclerc *et al*., 2002)**. Rivers, seawater, and soil can be contaminated by enteric viruses through defects in the wastewater treatment process **(La Rosa *et al*., 2012)**.

Rotaviruses are the main causative agent of gastroenteritis in kids under the age of five years, with 258 million diarrhea cases **(Crawford *et al*., 2017)**. There are 111 million diarrheal cases, and about 2 million children hospitalized during the year **(Wang *et al*., 2016; Badur *et al*., 2019)**. Rotaviruses are the most RNA enteric viruses detected in rivers and raw sewage water. They are the most resistant RNA enteric viruses to treatment operations in water and wastewater treatment plants **(Kukkula *et al*., 1999; Borchardt *et al*., 2004; Verheyen *et al*., 2009; El-Senousy *et al*., 2013a, 2015; El-Senousy & Abou-Elela, 2017)**. Adenoviruses are the main cause of many diseases, including conjunctivitis, respiratory disease and gastroenteritis **(Chitambar *et al*., 2012)**. Fever, vomiting, and diarrhea are all symptoms of pediatric gastroenteritis caused by the adenovirus F 40 and 41 serotypes, which is considered the second major causative agent of gastroenteritis in kids after rotaviruses **(El-Senousy *et al*., 2013a; Ogorzaly *et al*., 2013)**. In addition, adenoviruses are the main pathogens associated with severe childhood pneumonia **(Jonnalagadda *et al*., 2017)**. Adenoviruses were detected in drinking water and sewage samples worldwide **(Lee & Kim, 2002; He & Jiang, 2005; Verheyen *et al*., 2009; El-Senousy *et al*., 2013a; Quintão *et al*., 2021)**. Astrovirus is also one of the causes of gastroenteritis **(Gofti-Laroche *et al*., 2003)**. They follow rotavirus as a major cause of diarrhea in both young and adults **(Liste *et al*., 2000; Macdonald *et al*., 2015)**. Astroviruses were also found in sewage and drinking water samples **(Abad *et al*., 1997; Kukkula *et al*., 1999; El-Senousy *et al*., 2007; Meleg *et al*., 2008)**. Noroviruses are the causative agent of gastroenteritis infections, with 200,000 deaths and 685 million diarrheal cases **(Katayama & Vinjé, 2017)**. Noroviruses were detected in different water types such as treated sewage and drinking water **(Kukkula *et al*., 1999; Borchardt *et al*., 2004; Meleg *et al*., 2008; El-Senousy *et al*., 2013b, 2014)**. Papillomaviruses and human polyomaviruses have been detected in infected individuals' feces and urine **(Rachmadi *et al*., 2016)**. Certain polyomaviruses have been detected in seawater, wastewater, river and sediment **(Fratini *et al*., 2014; Di Bonito *et al*., 2015; Hamza & Hamza, 2018; Samir *et al*., 2020)**. Some enteric viruses were detected in water and sewage samples, such as the hepatitis A virus **(Borchardt *et al*., 2004; El-Senousy *et al*., 2004; Ouardani *et al*., 2016; Rachida & Taylor, 2020)**. Enteroviruses **(Donaldson *et al*., 2002; Lee and Kim, 2002; Borchardt *et al*., 2004; El-Senousy *et al*., 2004; Ehlers *et al*., 2005; Tiwari and**

Dhole, 2018) were also detected. Other enteric viruses that are considered accusative agents of gastroenteritis have been detected in contaminated rivers and wastewater, with lower titer such as bocaviruses, torque teno virus, and human picobirna viruses **(Haramoto *et al*., 2008; Symonds *et al*., 2009; Hamza *et al*., 2011; Adriaenssens *et al*., 2018)**.

2. Microbial indicators for water quality

Observing all pathogenic microorganisms in aquatic environments needs a great effort because of the large variety of pathogens that present (bacteria, viruses, and protozoa), the methods required for concentration, analysis, culturing of many pathogens, and the difficulty of identifying, besides the existence in low titer in aquatic environments. On the other hand, detecting only one pathogen can give a false impression if another pathogen not tested is present **(Scott *et al*., 2005; Stoeckel & Harwood, 2007)**. The water quality microbiological indicator selection is the process to select one species or group of microorganisms transferred to water through the feces of infected individuals but can be easily detected to measure than other harmful pathogens that pose to risk human health **(Berg, 1978; Bosch, 2007)**. The perfect indicators are detected whenever a pathogen is present **(Payment *et al*., 2003)**. The destruction and removal of indicators against the target pathogen have an important role in the selection of any indicator system **(Berg, 1978)**. There is no unique indicator, but a variety of indicators with a specific characteristic. The difference between these indicators is controlled by a wide range of factors that affect their ability to be stable and transport through the environment, such as the size, tolerance to environmental factors, abundance in feces, and the nature of the hydrological process **(Anderson *et al*., 2005; Yates, 2007)**. The ideal indicator should include the following characteristics: **(i)** should be completely related to the origin of the pathogen (specific to a host species) and must be absent in non-contaminated areas, **(ii)** detected with concentration higher than pathogens concentration, **(iii)** very simple for detection and quantification (easy, cheap, rapid methods), **(iv)** does not replicate outside the host, **(v)** related with human diseases, **(vi)** high abundant in feces of host individuals, **(vii)** more resistant than pathogen to environmental factors (persistence, survival, fate, transport, temp, pH, salinity, light) and disinfection processes in water and wastewater treatment, **(viii)** must not be pathogenic (safe for those who are monitoring) **(Bosch, 1998; Walker *et al*., 2020)**.

2.1 Fecal indicator bacteria (FIB)

FIBs are used to determine the fecal pollution in different aquatic environments which are related to other pathogenic intestinal bacteria. Total coliform, fecal streptococcus, fecal coliform, and *E. coli* are used to assess contamination since they are easy and low-cost to detect **(Bitton, 2005; Fong & Lipp, 2005; Fong *et al*., 2010; Tawfik *et al*., 2012; El-Senousy *et al*., 2013a; Ogorzaly *et al*., 2013)**. The first time that fecal coliform was

recommended as FIB by the **EPA (1976)**, it was used to detect pathogens in recreational waters **(Cabelli *et al*., 1983; Dufour, 1984)**. The coliform group includes *E. coli* and *E. aerogenes* which are found in contaminated water by infected individuals' feces. *E. coli* provides a good indicator for fecal pollution **(Messner *et al*., 2017)**. The correlation between the pathogens and FIB can be changed in an aquatic environment due to a wide range of parameters such as the environmental survival of pathogens, dilution, and water flow characteristics **(Devane *et al*., 2014; Boehm *et al*., 2015; Ahmed *et al*., 2018; Nelson *et al*., 2018)**. According to WHO, the acceptable levels of *E. coli* and coliform bacteria must be null for 100 ml of water and about 126 CFU/100 ml for recreational and domestic water **(Gunda & Mitra, 2016)**.

2.2 Correlation between FIB and enteric viruses

Globally, *E. coli* and Enterococci are the most common fecal indicators used; when compared with viruses, they are less tolerant to environmental conditions, like UV irradiation, sun irradiation, pH and temperature **(Gerba *et al*., 1979; Wyer *et al*., 1995; Borchardt *et al*., 2004; Harwood *et al*., 2005)**. Enteric viruses have been detected during the drinking water and wastewater treatment processes, with higher incidence rates than bacterial indicators; furthermore, they are also greater persistent in the aquatic environment **(Kim *et al*., 2009; Staley *et al*., 2012; Lin & Ganesh, 2013; Prez *et al*., 2015; Sidhu *et al*., 2017)**. Many environmental studies reported that, there is no relationship between FIB and human enteric viruses **(Baggi *et al*., 2001; Kageyama *et al*., 2003; Haramoto *et al*., 2007; Espinosa *et al*., 2009; Kitajima *et al*., 2009; Jurzik *et al*., 2010; Kuo *et al*., 2010; Simmons *et al*., 2011; Wu *et al*., 2011; Flannery *et al*., 2012)**. The defect of FIB in a lot of cases to detect viral contamination in drinking water and treated sewage samples indicates that the bacterial indicators may fail to express fecal pollution in treated sewage and drinking water. We could explain this statement as viruses, especially that enteric viruses are usually excreted in infected or carrier persons' feces, thus it always expresses the fecal contamination in sewage and subsequently water. Consequently, the failure of FIBs to indicate the enteric virus's presence in a lot of cases may indicate failure in expressing the fecal pollution which is the cause of viral contamination of sewage and water. The addition of at least one viral indicator besides bacterial indicators can help providing more adequate water quality results and more trust in the safety of water quality **(Toribio-Avedillo *et al*., 2021)**. The drinking water quality standard, which was issued by WHO includes twenty-eight microbiological indicators; it contains eight kinds of viruses, twelve kinds of bacteria, six kinds of protozoa, and two kinds of parasites **(WHO, 2011)**. It is agreeable that, FIB concentration above the level of detection is supposed to detect fecal contamination. However, the detection of FIB to evaluate the effect of pathogenic contamination in natural waters is difficult because this FIB may multiply in the natural aquatic environment under suitable conditions **(Ishii *et al*., 2006; Vogel *et al*., 2007)**. Moreover, it's not easy to distinguish between the source of

fecal pollution origin as human or animal-infected individuals by using bacterial indicators. Additionally, the incidence of some pathogens, such as adenoviruses, human enteroviruses, *Giardia* spp., Salmonella spp., *Cryptosporidium*, and coliphages are more stable than FIB in aquatic environments; thus, the detection of FIB in different types of waters does not indicate the incidence of pathogens **(Bonadonna *et al*., 2002; Payment & Locas, 2011; Sidhu & Toze, 2012)**. One of the most important tasks is to identify the fecal contamination source markers **(Tran *et al*., 2015)**.

3. Viral indicators for water quality

The optimal viral indicator must have similar stability, and higher resistance to environmental conditions or treatment processes than the pathogen, and it must be detected throughout the year in aquatic contaminated environments. Furthermore, during a viral outbreak or pandemic, the viral indicator can determine the ratio of infected people **(Xagoraraki & O'Brien, 2020)**. Adenoviruses are used as viral indicators for contamination to monitor water quality due to their higher persistance in the environment compared to the FIB **(Simmons *et al*., 2011; Rachmadi *et al*., 2016; Messner *et al*., 2017; El-Senousy, 2021; Rashed *et al*., 2022)**. Norovirus can be used also as a viral indicator because of its higher resistance to treatment processes **(Duizer *et al*., 2004; Jimenez & Chiang, 2006)**, high persistance in the environment, long-term stability **(Wu *et al*., 2005; D'Souza *et al*., 2006)** and a low dose of infection **(Teunis *et al*., 2008)**. NoV has also been reported in recreational water **(Maunula *et al*., 2004; Sartorius *et al*., 2007)** and in many outbreaks of contaminated drinking water **(Maunula *et al*., 2005; Hewitt *et al*., 2007)**. The viral indicators for water quality can be classified into two types:

3.1 Viral indicators used as fecal pollution indicators

Enteric viruses are considered a promising fecal pollution indicator due to their host specificity and prevalence in host feces **(Sidhu & Toze, 2009; Payment & Locas, 2011; Tran *et al*., 2015)**. In addition, they can differentiate between human or animal fecal pollution sources by identifying the sequence of common genes in the genus **(Fong *et al*., 2005; Ahmed *et al*., 2010)**. Human adenovirus and polyomavirus (JC and BK) have been suggested as fecal indicators and targets for microbial source monitoring markers based on their distribution in the population ($10^3 - 10^7$ gc/l), high resistance to environmental factors, and human host specificity **(Pina *et al*., 1998; Albinana-Gimenez *et al*., 2009; Ahmed *et al*., 2010; Wolf *et al*., 2010; Wyn-Jones *et al*., 2011; McQuaig *et al*., 2012; Hewitt *et al*., 2013; Liang *et al*., 2015)**. **De Giglio *et al*. (2017)** detected enterovirus, rotavirus, and norovirus (fecal pollution indicators) in groundwater. On the other hand, FIBs were poor to indicate the presence of viruses in groundwater. Many studies suggested coliphages as an adequate fecal indicator in several types of water according to their characteristics, occurrence, fate, and epidemiological relationship in the

environment **(Blanch *et al*., 2006; Lee *et al*., 2011)**. F-specific RNA coliphages (F - RNA) were suggested to express fecal pollution in groundwater and surface water. Moreover, by using their genotyping or serotyping groups, it is easy to identify the source of fecal contamination **(Havelaar *et al*., 1993)**. In addition to the results of some studies subgroups I and IV of F - RNA are typically related to animal feces and subgroups II and III are correlated with human fecal pollution **(Ibarluzea *et al*., 2007; Lee *et al*., 2011)**.

3.2 Viral indicators used as surrogates for viral pollution

Aichi virus (AiV1) has been found at a higher concentration in wastewater and the environment, compared to NoVs due to the morphological and prevalence similarity **(Hata *et al*., 2013; Kitajima *et al*., 2014)**. AiV can be used as a viral indicator to detect viral contamination in different types of waters **(Kitajima & Gerba, 2015)**. **Garcia *et al*. (2022)** suggested that adenovirus, pepper mild mottle virus (PMMoV), and crAssphage may be used as viral indicators. Some studies showed that many groups of coliphages have similarities in structure, morphology, size, persistence, and survivability in the environment to enteric viruses when compared to FIB **(Cole *et al*., 2003; Love *et al*., 2008)**. The removal of somatic coliphages is still regarded as a reflection of the elimination of human viruses, while the use of F-specific coliphages as human viruses index is restricted **(Ottoson *et al*., 2006)**. **Havelaar *et al*. (1993)** suggested that F- RNA coliphages are a suitable microbial marker for human viral pollution in the aquatic environment. PMMoV was suggested as a viral indicator that was detected with high concentrations to evaluate enteric viruses' detection in different types of water. **(Hamza *et al*., 2011; Kitajima *et al*., 2018; Garcia *et al*., 2022)**.

4. Survival of viral indicators in the environment

Viruses are obligatory host-specific and cannot multiply outside their hosts, thus the viral particles may survive or be damaged when they are suspended in the environment; this means that the viral concentration will be the same or decreased **(Pinon & Vialette, 2018)**. The effect of these factors changed according to the type of environment **(Rzeżutka and Cook, 2004; Pinon and Vialette, 2018)**. Enteric viruses in the soil can persist for more than 100 days at 20 to 30°C, up to 120 days in fresh water and sewage, and up to 130 days in seawater **(Wetz *et al*., 2004)**. **Kocwa-Haluch (2001)** showed that with a wide range of pH (3 to 10) and low degrees of temperatures enteric viruses can persist for a long time. Rotavirus is one of the more persistent viruses in aquatic environments; it can survive for 16 days with a 2-$\log_{10}$ reduction in the initial count, using cell-based techniques for the detection of the virus in unpolluted lake water **(Pancorbo *et al*., 1987)**. **Espinosa *et al*. (2008)** reported that, the survival of rotavirus by using quantitative polymerase chain reaction in surface water and groundwater samples may reach 4-$\log_{10}$ and 3-$\log_{10}$ reduction, respectively, in periods ranging between 150 to 180 days. Many environmental conditions such as temperature, sunlight, and salinity

have an impact on viruses' survival in the environment **(Rzeżutka & Cook, 2004; Pinon & Vialette, 2018).**

a. Temperature

The biological processes such as occurrence, penetration, attachment, viability, and multiplication depend on the degree of environmental temperatures **(Sobsey & Meschke, 2003; Jończyk *et al*., 2011)**. High temperatures may destroy nucleic acids, and the viral capsid protein, or inactivate the enzymes of replication **(Bitton, 1980)**. The effect of temperature can increase the activity of viral cells at ambient temperature, but decay occurred rapidly at higher temperatures while at a low temperature above freezing **(Shahid *et al*., 2009; Paluszak *et al*., 2012)**. Several studies reported that enteric viruses and coliphages have been surviving for long periods in natural environments at low-temperature degrees and rapid inactivation at higher temperature degrees **(Long and Sobsey, 2004; Fong & Lipp, 2005)**. **Abad *et al*. (1997)** noted that, the logarithmic reduction of astroviruses in drinking water can reach 2 $\log_{10}$ for 30 days at 20°C and 60 days at 4°C. Adenovirus can be persisted in groundwater for 132 days at 4°C, when the temperature increases to 20°C, the decay occurred more rapidly in 36 days with the same reduction (1 $\log_{10}$) **(Ogorzaly *et al*., 2010)**. Porcine rotavirus and MS2 coliphage have low inactivation rates constant at temperatures ranging from 14 to 42°C, the inactivation rates increased 10-fold when the temperature increased to 50°C **(Romero *et al*., 2011)**. **Seo *et al*. (2012)** examined the $\log_{10}$ of MS2 coliphage and murine NoV at a range of temperatures between 24 to 85°C. The result showed that the reduction of MS2 coliphage was lower than murine NoV at the range of 24°C and 60°C, while both viruses inactivated rapidly at temperatures higher than 60°C.

b. Sunlight

In addition, sunlight is the most common factor in virus inactivation. In dark conditions, coliphages and enteric viruses have lower reduction than in sunlight conditions **(Sobsey & Meschke, 2003; Fong & Lipp, 2005; Jończyk *et al*., 2011)**. The main composition of sunlight, besides the visible light is UV light that is responsible for the damage of the genetic materials of the viral cell by forming pyrimidine dimers or other photo products **(Lytle & Sagripanti, 2005; Love *et al*., 2010; Silverman *et al*., 2013)**. **Johnson *et al*. (1997)** observed that, the inactivation of polioviruses increased to 3$\log_{10}$ when exposed to sunlight than dark after 24 h incubation in the marine environment. **Sinton *et al*. (2002)** reported that, the reduction rates of bacteriophages are ten times higher in sunlight conditions than in dark conditions. Under sunlight conditions, the reduction rates of somatic coliphages, poliovirus type 3, and F-DNA phages were equal to or higher than the reduction rates of F-RNA phages and adenovirus type 2 in seawater **(Love *et al*., 2010)**. **Silverman *et al*. (2013)** observed that, the GI of F-RNA phage reduction rates were equal to or less than adenovirus type 2 and significantly below poliovirus type 3 in

all examined waters under sunlight and dark conditions. This study emphasized that the reduction rates of dark conditions were less than the reduction rates of sunlight conditions.

c. Salinity

Salinity has an impact factor on the reduction rates of enteric viruses by increasing or decreasing, according to the salt concentration, the salt type, temperature, and the specific viruses found **(Nguyen *et al.*, 2011; Seo *et al.*, 2012)**. The salinity effect depends on monovalent salts that provide strong steric and electrostatic stabilization that have a strong inactivation effect by aggregating all the particles of viruses **(Mylon *et al.*, 2010; Nguyen *et al.*, 2011)**. **Hurst and Gerba (1980)** showed that, the results of reduced rates of simian rotavirus, coxsackievirus, poliovirus, and echovirus, in fresh and estuarine water for two different years were more rapid in estuarine water than in fresh water in one year, and become similar in the second year. **Seo *et al.* (2012)** observed that, MS2 RNA coliphage was more resistant to NaCl than murine NoV under different concentrations of NaCl at several temperatures ranging between 24°C to 50°C.

5. Correlation between viral indicator and pathogen

The correlations between the indicator and pathogen detection are controlled by some factors, such as detection methods, sample size, number of positive samples of pathogens, and pathogen sources. Furthermore, it might be difficult to assess the health hazards of decisions based on the results of indicators **(Wu *et al.*, 2011)**. The fundamental objective of the viral indicator is to serve as a monitoring system for detecting pathogens. The indicator should be detected at an equal or greater number than the pathogen. Many studies' results have been used to help find the suitable viral indicator correlated with the pathogen. **Payment and Franco (1993)** reported a significant correlation between enteric viruses and *Cryptosporidium* oocysts, *Giardia* cysts, and *C. perfringens* counts. Also, the study showed that somatic coliphages and *C. perfringens* can be used to assess the virological and parasitological quality of treated drinking water. Detection of enteric viruses' genomes has been easy than the isolation by cell culture such as the detection of the enterovirus genomes Furthermore, the results of detecting viral contamination in surface water showed that somatic coliphages were not suitable for the detection of viral contamination and pathogens **(Hot *et al.*, 2003)**. Another study done by **Ottoson *et al.* (2006)** represents the significant relation between coliphages, enterococci, and *E. coli* in untreated wastewater and no correlation between pathogens reductions and indicators (P>0.05). Total coliphages can be used as a viral index indicator rather than using F-specific phages. This study agrees with other studies that suggested using viral indicators for pollution detection, for example, polyomaviruses **(Bofill-Mas *et al.*, 2000)**, adenoviruses **(Pina *et al.*, 1998)**, and enteroviruses **(Hot *et al.*, 2003)**. **Tonani *et al.* (2013)** found that no statistical significance in *Cryptosporidium* count decreases with

pathogens; besides, there is a significant decrease in the count of adenovirus, rotavirus, and *giardia* (P<0.05). Additionally, there was no significant seasonal detection observed in protozoa (oo) cysts distribution in the collected sewage samples. **Tian *et al*. (2017)** reported that, the human NoV rate was detected in all positive and negative bacterial pathogens samples without any positive relationship between the incidence of human NoV and pathogenic bacteria (Listeria, Salmonella, O157 *E. coli* STEC and non-O157 STEC).

As a result, the study of **Tandukar *et al*. (2018)** on 8 viruses (human adenoviruses, rotavirus A, Aichi virus 1, human cosaviruses, enteroviruses, caliciviruses, and noroviruses GI and GII) found a positive relationship between human enteric viruses and theses viruses (P < 0.05); no positive correlation was detected between FIB and *Cryptosporidium* or *Giardia* (P > 0.05). Furthermore, the detection ratio of fecal markers was lower than the human *bacteroidales*, besides that these fecal markers have a significant relationship with human enteric viruses. Finally, this study suggested that the use of the viral index, bacterial indicators, and human *bacteroidales* could be used as good indicators for human fecal contamination detection in rivers.

Another study in 2020, compared four water-borne enteric viruses (enterovirus, astroviruses, hepatitis A virus, and rotaviruses) with fecal bacterial and bacteriophages indicators of fecal pollution in wastewater treatment plants. The incidence rates in influent samples of EV, AV, HAV, and RV were 100%, 75%, 12.5%, and 12.5%, respectively; however, enteroviruses RNA was detected in half of all the outlet samples. The positive samples of the enteric virus had a high concentration of bacteriophages in inlet and outlet samples. The most abundant phages in the samples were *E. coli* phages, which had titer ranging between (7-8) log pfu/ml. The fecal bacteriological indicators were detected in high concentrations in all outlet samples: 1.92×10^3 cfu/ml, 1.32×10^3 cfu/ml, and 3.20×10^3 cfu/ml for shigella spp., salmonella spp., and *E. coli*, respectively. According to these results, a positive relation was recorded between the detection and cultivation of pathogenic bacteria (salmonella, fecal coliform, and *E. coli*), and the detection of EV and their specific bacteriophages. Thus, the study introduced the non-pathogenic coliphages as a good indicator for viral pollution to assess water quality **(Janahi *et al*., 2020)**.

Bailey *et al*. (2021) found that *cryptosporidium*, adenoviruses, and *giardia* were found in 100%, 81%, and 41%, respectively, of all samples; furthermore, the incidence of total coliphage, somatic coliphages, and F+ coliphages were detected in 77%,77%, and 32%, respectively, of all samples. *E. coli* was detected in half of the samples, while total coliforms and enterococcus were found in 95%, and 64%, respectively, of all samples. This study investigated that, the presence or absence of an indicator is not always accurate in predicting the presence of pathogens in the samples, and these results noted that many cases of false-positive or negative results used only one indicator for the

detection of pathogens. Consequently, in the prediction of pathogen presence or survival in surface water, no one signal indicator was perfect in detection. This study suggested that enteric pathogens, including salmonella spp., adenoviruses, *cryptosporidium*, and *giardia* may be used as indicators for drinking water sources. From previous studies, we try to answer one question to help in determining the viral indicator that can suit for viral detection.

6. Which viral indicators are suitable?

Most viruses don't have the complete requirements to be a universal indicator. Thus, it is necessary to select the suitable indicator according to the distribution in the aquatic environment, seasonal variation, stability to environmental conditions, and resistance to the treatment process. The suitable viral indicators should have the ability for long-term detection of viral pollution in aquatic environments throughout the year **(Walker *et al*., 2020)**. Papillomaviruses, coronaviruses, and influenza viruses have been detected in wastewater with high titer but not or less detected in a contaminated environment; this is due to the rapid damage of these viruses **(Bosch *et al*., 2016)**. Other viruses have clear peaks during the seasons of the year, such as rotavirus peaks in autumn and winter **(Villena *et al*., 2003; El-Senousy *et al*., 2004, 2013a, 2014)**, AiV peaks during spring and winter in wastewater **(Kitajima *et al*., 2014)**, the peaks of sapoviruses and noroviruses in winter, and the enteroviruses peaks in summer **(Prevost *et al*., 2015; Cooper *et al*., 2018)**. The suitable indicator must be able to distinguish between human and animal sources of contamination **(Scott *et al*., 2002)**, such as zoonotic enteric viruses (hepatitis E virus, torque teno virus, rotavirus, and astrovirus), which are present due to the activities of agriculture contaminated with human wastes in the aquatic environment **(Bosch *et al*., 2016)**. Human AdVs are found in polluted environments without any seasonal variation which is detected all over the year, many studies have suggested human adenovirus as an effective indicator **(Kitajima and Gerba, 2015; Rachmadi *et al*., 2016)**. PMMoV has been proposed as useful viral pollution for wastewater pollution **(Kitajima *et al*., 2018; Symonds *et al*., 2018)**. It is detected with a high concentration in wastewater samples before and after the treatment process over the year **(Myrmel *et al*., 2015; Schmitz *et al*., 2016)**. Coliphages are usually found in high titer in several types of water and used proposed as a viral indicator to detect enteric viruses in contaminated water **(McMinn *et al*., 2017)**. A result of the previous studies that suggested different viral candidates as a viral indicator for viral pollution of water and wastewater discussed the following topics:

I. Bacteriophages

Viruses that infect bacteria are called bacteriophages (phages). Phages were discovered in the early 1900s and originated from the intestinal tract of humans **(d'Herelle & Smith, 1926; Ashbolt *et al*., 2001)**. These phages may be detected in several environments

where the bacteria can grow, like in different types of water, soil, and can detect inside other higher individuals **(Clokie *et al*., 2011; Dutilh *et al*., 2014; Dorevitch, 2016)**. Bacteriophages are divided into three taxonomic groups: somatic coliphages, F-specific (DNA, RNA) coliphages, and bacteriophages that can infect *Bacteroides* spp. **(Jofre *et al*., 2016; Jebri *et al*., 2017)**. Bacteriophages are suggested as fecal and viral indicators for fecal contamination in several aquatic environments and assessing the viral pollution. Coliphages are phages that infect *Escherichia coli*; they have been suggested as alternatives to FIB and as a surrogate to enteric viruses to detect viral contamination. Bacteriophages infect intestinal bacteria in a similar way to enteric viruses **(Hilton & Stotzky, 1973; Gerba, 1987; Sobsey *et al*., 1995; Chung *et al*., 1998; Contreras-Coll *et al*., 2002; Skraber *et al*., 2004; Mocé-Llivina *et al*., 2005; McMinn *et al*., 2017; Toribio-Avedillo *et al*., 2019)**. Bacteriophages have the most ideal features of viral indicators such as being excreted in feces and not replicating in the environment till the presence of their hosts, being stable against the environmental conditions, more distributed in the environment,giving high accuracy results **(Tufenkji and Emelko, 2011)**.

Somatic coliphage can infect *E. coli* and coliform bacteria by adhesion to specific receptors on the cell wall of bacteria **(Muniesa *et al*., 2003)**. Several trials, laboratory experiments, and validation testing suggested that somatic coliphages such as PRD-1, phix174, T-4, and T-7 can be used as viral surrogates to enteric viruses to detect viral pollutions **(Lucena & Jofre, 2010)**. **Hot *et al*. (2003)** showed no positive relationship between somatic coliphages and HAdVs, EVs, Norwalk I and II viruses.

F coliphage is another new approach to detect and quantify pathogens and fecal pollution in the aquatic environment **(Griffith *et al*., 2016)**. They are recommended for use as a fecal and viral indicator of water contamination because of the similarity in shape and size to enteric viruses, detection in sewage contamination, and the difficulty to multiply outside the host in the environment **(Duran *et al*., 2003)**. Many studies detected these phages in recreation water, groundwater, surface water, rivers, harbors and wastewater **(Yamahara *et al*., 2012; Vijayavel *et al*., 2014; Rashed *et al*., 2022)**. **Stewart- Pullaro *et al*. (2006)** reported that, somatic coliphages have been found at high concentrations than male-specific phages in raw water sources and wastewater. Especially, F-RNA phages, and somatic coliphages have been demonstrated as excellent fecal viral indicators **(Jofre *et al*., 2016; Jebri *et al*., 2017)**. HSP 40 phage can infect the *bacteroides fragilis*. *Bacteroides fragilis*, the anaerobic bacteria found with high titer in the human intestinal tract, execrated through the feces of infected individuals, and die rapidly when released into the environment. HSP 40 phage is represented as a unique indicator for fecal pollution in polluted water **(Duran *et al*., 2003)**.

There are some disadvantages of bacteriophages that prevent them to be viral indicators such as some coliphages present in low numbers than bacterial indicators **(Payment &**

Locas, 2011). To differentiate between the origin of fecal pollution as an animal or human fecal contamination was recorded a failure **(Hot *et al*., 2003; Jiang & Chu, 2004)**. Some types of bacteriophages are present in contaminated water with high concentrations than other types like somatic coliphages detected in raw and wastewater with high titer than male-specific phages **(Stewart- Pullaro *et al*., 2006)**. In some studies, there is no relationship between viral contamination and coliphages in sewage water **(Carducci *et al*., 1999)**, surface water **(Hot *et al*., 2003)** and groundwater **(Long & Dewer, 2008)**.

II. Pepper mild mottled virus (PMMoV)

PMMoV is RNA plant virus that infects the leaves of a pepper plant. It is a member of *Tobamo* virus genus, and it is responsible for economic losses of infected pepper worldwide **(Fauquet *et al*., 2005)**. **Zhang *et al*. (2006)** was the first study that identified the PMMoV in feces by using viral metagenomics techniques. PMMoV is suggested by many studies as a fecal indicator **(Hamza *et al*., 2011; Symonds *et al*., 2018)**. It has been detected at a significantly high concentration, with a higher prevalence than enteric viruses and pathogenic viruses in human feces **(Rosario *et al*., 2009; Hamza *et al*., 2011; Haramoto *et al*., 2013; Symonds *et al*., 2018)**, It was detected in several types of water such as surface water and sewage water **(Rosario *et al*., 2009; Kitajima *et al*., 2018; Shrestha *et al*., 2018; Symonds *et al*., 2018; Tandukar *et al*., 2020)**. PMMoV is also present in wastewater in some places such as Florida, Germany, New Zealand, and Vietnam, with a range from 10^6 to 10^{10} gc/l. **(Rosario *et al*., 2009; Hamza *et al*., 2011; Kitajima *et al*., 2014; Schmitz *et al*., 2016; Gyawali *et al*., 2019)**. On the other hand, it was less prevalent with a titer range between (10^3-10^6 gc/l) in Spain, Arizona, and the UK **(Kitajima *et al*., 2014; Rusinol *et al*., 2015; Schmitz *et al*., 2016; Cooper *et al*., 2018)**. **Rashed *et al*. (2022)** detected PMMoV in four samples of drinking water, with a complete absence of the infectious units of phix174 bacteriophage virus and adenoviruses in these samples. This is due to the higher resistance of PMMoV to treatment processes (chlorine disinfection) than phix174 bacteriophage virus and adenoviruses, which can give false positive results so it cannot be used as a viral indicator for all types of waters **(Shirasaki *et al*., 2018, 2020)**.

III. Adenoviruses

Adenoviruses have been considered the second viral pathogen after rotavirus which leads gastroenteritis **(Fong *et al*., 2010)**. They infect children less than five years **(Lennon *et al*., 2007)**. Ad40 and Ad41 enteric serotypes are found under species F **(Rigotto *et al*., 2011)**, which are responsible for most cases of gastroenteritis **(Logan *et al*., 2006)**. Adenoviruses sub-species B is responsible for 5–7% of conjunctivitis and respiratory diseases in kids **(Wold & Horwitz, 2007)**. Compared to other interic viruses, adenoviruses are more resistant to environmental degradation **(Hijnen *et al*., 2006)**, and

ultraviolet disinfection **(Linden *et al*., 2007)**. In addition, they are more resistant to pH conditions **(Thurston-Enriquez *et al*., 2003)**, and chlorine in the water treatment process **(Thurston-Enriquez *et al*., 2005; Rashed *et al*., 2022)**. They are detected in several types of water, such as drinking water, wastewater, groundwater, swimming pools, recreational waters, rivers, and polluted water **(Pina *et al*., 1998; Bofill-Mas *et al*., 2006; Haramoto *et al*., 2007; Katayama *et al*., 2008; Miagostovich *et al*., 2008; Wong *et al*., 2009; Dong *et al*., 2010; El-Senousy *et al*., 2014)**. It's a human host specificity that cannot replicate outside of the host **(Fong *et al*., 2005; Wong *et al*., 2012)**. **Pina *et al*. (1998)** worked on wastewater treatment plants and found that adenoviruses were detected throughout the year. On the other hand, the concentrations of fecal coliform were below regulatory standards, thus the proposed adenoviruses as a viral indicator. Another study was done by **Jiang *et al*. (2001)** on California beaches exposed to an urban runoff in which adenoviruses genomes concentrations ranged from 0.9 to 7.5×10^3 genomes/l. AdV was more resistant to water and sewage treatment processes in treatment plants than RV **(El-Senousy *et al*., 2013a)**. it is important to detect the HAdV infectious units to know the recent contamination because HAdV infectious units persist in water less than the genomes **(Donia *et al*., 2010; El-Senousy *et al*., 2014; Prevost *et al*., 2016; Rashed *et al*., 2022)**. HAdV is suggested as a viral water quality indicator by several studies **(Puig *et al*., 1994; Pina *et al*., 1998; Albinana-Gimenez *et al*., 2006; Hundesa *et al*., 2006; Bosch *et al*., 2008; Jurzik *et al*., 2010; Okoh *et al*., 2010; El-Senousy *et al*., 2013a; Rames *et al*., 2016; Iaconelli *et al*., 2017; Lun *et al*., 2019; Ibrahim *et al*., 2021; Rashed *et al*., 2022)**.

IV. Human polyomavirus (HPyVs)

HPyVs are non-enveloped DNA viruses, are found under the family *Polyomaviridae* **(Bofill-Mas *et al*., 2001; Johne *et al*., 2011)**, consist of five serotypes JCV, BKV, KIV, MCV, and WUV **(Kean *et al*., 2009)**. HPyV is mainly excreted in the feces and urine of infected individuals **(Rachmadi *et al*., 2016)**. HPyVs were detected in different aquatic environments such as in sources of drinking water **(Albinana-Gimenez *et al*., 2006)**, in river water **(Haramoto *et al*., 2010; Hamza *et al*., 2014; Rusinol *et al*., 2015)**, in drinking water sources **(Albinana-Gimenez *et al*., 2006)**, in wastewater **(Hamza *et al*., 2014; Kitajima *et al*., 2014)**, stormwater **(Sidhu *et al*., 2012)**, swimming water **(La Rosa *et al*., 2012)** and seawater **(Moresco *et al*., 2012)**. **Fratini *et al*. (2014)** detected that the major pathway of the infection by the HPyV by inhalation or ingestion of contaminated water with HPyV. HPyVs have been concentrated in different types of water by many concentrated methods such as virus adsorption and elution **(Karim *et al*., 2009; Haramoto *et al*., 2010)**, ultrafiltration **(Liang *et al*., 2015)**, and skim milk flocculation **(Calgua *et al*., 2013)**. Also, several molecular methods detections used to detect HPyV in concentrated samples including PCR **(Sidhu *et al*., 2012)**, qPCR **(Wong *et al*., 2012;**

Liang *et al*., 2015), immunofluorescence **(Calgua *et al*., 2011)**, microarray and cell culture technique **(Schowalter *et al*., 2012)**.

JCV and BKV were detected in drinking water sources in Spain with titer ranging between (2.6×10^1 gc/l - 4.62×10^3 gc/l) and 2.1×10^1 gc/l respectively (**Albinana-Gimenez *et al*., 2006, 2009)**. While detected in Japan with titer (2.90×10^2 gc/l –1.3×10^3 gc/l) and 2.50×10^2 gc/l respectively, **(Haramoto *et al*., 2012)**.

McQuaig *et al*. (2009) suggested that HPyVs especially BKV and JCV serotypes are a good indicator of pathogenic viruses due to the high resistance to different degrees of temperature which is similar to AdV resistance. Also, several studies suggested HPyV as a viral indicator due to its high stability in environmental waters with little seasonality **(Bofill-Mas *et al*., 2001, 2006; Rachmadi *et al*., 2016)**, resistance to UV **(Nims and Plavsic, 2013; Calgua *et al*., 2014)** resistant to acidic conditions **(Bofill-Mas and Girones, 2003)** and more resistant to the treatment process in water and sewage plants than other types of viruses such as AdV type 2 and MNV-1 **(Hata *et al*., 2018)**.

CONCLUSION

From this review, we conclude some points to select the best viral indicator

- No correlation between fecal indicators bacterial and viral indicators.
- No single viral indicator can be used for the detection of pathogenic viruses in all water bodies.
- Use of one or more viruses as viral indicators according to the prevalence of these viruses in the aquatic environment for each country which can change from country to country.
- Detection of infectious units of viral indicators is necessary to determine the recent contamination than detection of genome copies which are more persistent than infectious units.
- PMMoV is more resistant to the water treatment process than other enteric viruses so it cannot be used as a viral indicator for all types of water.
- Bacteriophages can be used as viral indicators, while some studies, showed that bacteriophages do not always correlate with human enteric viruses and it is difficult to differentiate between the source of contamination (human or animal fecal contamination).
- Till now the studies suggested adenoviruses as viral indicators which are more tolerant to the water treatment process than other viruses, rapidly detecting the infectious units and easy differentiating between human and animal contamination.

- Most of the water quality criteria don't have any of the viruses to express the pollution of water and wastewater with enteric viruses so, more studies are needed to suggest one or grouped viral indicators that can be used as viral indicators.

REFERENCES

Abad, F. X.; Pintó, R. M.; Villena, C.; Gajardo, R. and Bosch, A. (1997). Astrovirus survival in drinking water. Appl. Environ. Microbiol., 63(8): 3119–3122.

Adriaenssens, E. M.; Farkas, K.; Harrison, C.; Jones, D. L.; Allison, H. E. and McCarthy, A. J. (2018). Viromic analysis of wastewater input to a river catchment reveals a diverse assemblage of RNA viruses. MSystems., 3(3): e00025-18.

Adriaenssens, E. M.; Walker, D. I.; McDonald, J. E.; Malham, S. K. and Jones, D. L. (2019). Critical evaluation of CrAssphage as a molecular marker for human-derived wastewater contamination in the aquatic environment. Food Environ. Virol., 11(2): 113–119.

Ahmed, W.; Gyawali, P.; Sidhu, J. and Toze, S. (2014). Relative inactivation of faecal indicator bacteria and sewage markers in freshwater and seawater microcosms. Lett. Appl. Microbiol., 59(3): 348–354.

Ahmed, W.; Hamilton, K. A.; Lobos, A.; Hughes, B.; Staley, C.; Sadowsky, M. J. and Harwood, V. J. (2018). Quantitative microbial risk assessment of microbial source tracking markers in recreational water contaminated with fresh untreated and secondary treated sewage. Environ. Int., 117: 243–249.

Ahmed, W.; Wan, C.; Goonetilleke, A. and Gardner, T. (2010). Evaluating sewage- associated JCV and BKV polyomaviruses for sourcing human fecal pollution in a coastal river in Southeast Queensland, Australia. J. Environ. Qual., 39(5): 1743–1750.

Albinana-Gimenez, N.; Clemente-Casares, P.; Bofill-Mas, S.; Hundesa, A.; Ribas, F. and Girones, R. (2006). Distribution of human polyoma-viruses, adenoviruses, and hepatitis E virus in the environment and in a drinking-water treatment plant. Environ. Sci. Technol., 40(23): 7416–7422.

Albinana-Gimenez, N.; Miagostovich, M. P.; Calgua, B.; Huguet, J. M.; Matia, L. and Girones, R. (2009). Analysis of adenoviruses and polyomaviruses quantified by qPCR as indicators of water quality in source and drinking-water treatment plants. Water Res., 43(7): 2011–2019.

Anderson, K. L.; Whitlock, J. E. and Harwood, V. J. (2005). Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. Appl. Environ. Microbiol., 71(6): 3041–3048.

Asami, T.; Katayama, H.; Torrey, J. R.; Visvanathan, C. and Furumai, H. (2016). Evaluation of virus removal efficiency of coagulation-sedimentation and rapid sand

filtration processes in a drinking water treatment plant in Bangkok, Thailand. Water Res., 101: 84–94.

Ashbolt, N. J.; Grabow, W. O. K. and Snozzi, M. (2001). Indicators of microbial water quality. Water Qual. Guidel. Stand. Heal., 289–316.

Badur, S.; Öztürk, S.; Pereira, P.; AbdelGhany, M.; Khalaf, M.; Lagoubi, Y.; Ozudogru, O.; Hanif, K. and Saha, D. (2019). Systematic review of the rotavirus infection burden in the WHO-EMRO region. Hum. Vaccin. Immunother.

Baggi, F.; Demarta, A. and Peduzzi, R. (2001). Persistence of viral pathogens and bacteriophages during sewage treatment: lack of correlation with indicator bacteria. Res. Microbiol., 152(8): 743–751.

Bailey, E. S.; Hopkins, M.; Casanova, L. and Sobsey, M. D. (2021). Evaluating fecal indicator and pathogen relationships in sewage impacted surface waters to blend with reclaimed water for potable reuse in North Carolina. Pathogens, 10(12): 1603.

Bartram, J.; Fewtrell, L. and Stenström, T. A. (2001). Harmonised assessment of risk and risk management for water-related infectious disease: an overview. IWA Publishing, London.

Berg, G. (1978). The indicator system. Indicators of Viruses in Water and Food, 1–13.

Bitton, G. (1980). Introduction to environmental virology. Wiley New York.

Bitton, G. (2005). Wastewater microbiology. John Wiley and Sons.

Blanch, A. R.; Belanche-Muñoz, L.; Bonjoch, X.; Ebdon, J.; Gantzer, C.; Lucena, F.; Ottoson, J.; Kourtis, C.; Iversen, A. and Kühn, I. (2006). Integrated analysis of established and novel microbial and chemical methods for microbial source tracking. Appl. Environ. Microbiol., 72(9): 5915–5926.

Boehm, A. B.; Soller, J. A. and Shanks, O. C. (2015). Human-associated fecal quantitative polymerase chain reaction measurements and simulated risk of gastrointestinal illness in recreational waters contaminated with raw sewage. Environ. Sci. Technol. Lett., 2(10): 270–275.

Bofill-Mas, Silvia, Albinana-Gimenez, N.; Clemente-Casares, P.; Hundesa, A.; Rodriguez-Manzano, J.; Allard, A.; Calvo, M. and Girones, R. (2006). Quantification and stability of human adenoviruses and polyomavirus JCPyV in wastewater matrices. Appl. Environ. Microbiol., 72(12): 7894–7896.

Bofill-Mas, Sílvia and Girones, R. (2003). Role of the environment in the transmission of JC virus. J. Neurovirol., 9(1): 54–58.

Bofill-Mas, Sílvia.; Formiga-Cruz, M.; Clemente-Casares, P.; Calafell, F. and Girones, R. (2001). Potential transmission of human polyomaviruses through the gastrointestinal tract after exposure to virions or viral DNA. J. Virol., 75(21): 10290–10299.

Bofill-Mas, Sílvia.; Pina, S. and Girones, R. (2000). Documenting the epidemiologic patterns of polyomaviruses in human populations by studying their presence in urban sewage. Appl. Environ. Microbiol., 66(1): 238–245.

Bonadonna, L.; Briancesco, R.; Ottaviani, M. and Veschetti, E. (2002). Occurrence of *Cryptosporidium* oocysts in sewage effluents and correlation with microbial, chemical and physical water variables. Environ. Monit. Assess., 75(3): 241–252.

Borchardt, M. A.; Haas, N. L. and Hunt, R. J. (2004). Vulnerability of drinking-water wells in La Crosse, Wisconsin, to enteric-virus contamination from surface water contributions. Appl. Environ. Microbiol., 70(10): 5937–5946.

Bosch, A. (1998). Human enteric viruses in the water environment: a minireview. Int Microbiol, 1(3): 191–196.

Bosch, A. (2007). Human viruses in water: Perspectives in medical virology. Elsevier.

Bosch, A.; Guix, S.; Sano, D. and Pinto, R. M. (2008). New tools for the study and direct surveillance of viral pathogens in water. Curr. Opin. Biotechnol., 19(3): 295–301.

Bosch, A.; Pintó, R. M. and Guix, S. (2016). Foodborne viruses. Curr. Opin. Food Sci., 8, 110–119.

Cabelli, V. J.; Dufour, A. P.; McCabe, L. J. and Levin, M. A. (1983). A marine recreational water quality criterion consistent with indicator concepts and risk analysis. J. Water Pollut. Control Fed., 1306–1314.

Calgua, B.; Barardi, C. R. M.; Bofill-Mas, S.; Rodriguez-Manzano, J. and Girones, R. (2011). Detection and quantitation of infectious human adenoviruses and JC polyomaviruses in water by immunofluorescence assay. J. Virol. Methods., 171(1): 1–7.

Calgua, B.; Carratala, A.; Guerrero-Latorre, L.; de Abreu Corrêa, A.; Kohn, T.; Sommer, R. and Girones, R. (2014). UVC inactivation of dsDNA and ssRNA viruses in water: UV fluences and a qPCR-based approach to evaluate decay on viral infectivity. Food Environ. Virol., 6(4): 260–268.

Calgua, B.; Rodriguez-Manzano, J.; Hundesa, A.; Suñen, E.; Calvo, M.; Bofill-Mas, S. and Girones, R. (2013). New methods for the concentration of viruses from urban sewage using quantitative PCR. J. Virol. Methods., 187(2): 215–221.

Carducci, A.; Gemelli, C.; Cantiani, L.; Casini, B. and Rovini, E. (1999). Assessment of microbial parameters as indicators of viral contamination of aerosol from urban sewage treatment plants. Lett. Appl. Microbiol. 28(3): 207–210.

Chitambar, S.; Gopalkrishna, V.; Chhabra, P.; Patil, P.; Verma, H.; Lahon, A.; Arora, R.; Tatte, V.; Ranshing, S. and Dhale, G. (2012). Diversity in the enteric viruses detected in outbreaks of gastroenteritis from Mumbai, Western India. Int. J. Environ. Res. Public Health., 9(3): 895–915.

Chung, H.; Jaykus, L.-A.; Lovelace, G. and Sobsey, M. D. (1998). Bacteriophages and bacteria as indicators of enteric viruses in oysters and their harvest waters. Water Sci. Technol., 38(12): 37–44.

Clokie, M. R. J.; Millard, A. D.; Letarov, A. V, and Heaphy, S. (2011). Phages in nature. Bacteriophage, 1(1): 31–45.

Cole, D.; Long, S. C. and Sobsey, M. D. (2003). Evaluation of F+ RNA and DNA coliphages as source-specific indicators of fecal contamination in surface waters. Appl. Environ. Microbiol., 69(11): 6507–6514.

Contreras-Coll, N.; Lucena, F.; Mooijman, K.; Havelaar, A.; Pierzo, V.; Boque, M.; Gawler, A.; Höller, C.; Lambiri, M. and Mirolo, G. (2002). Occurrence and levels of indicator bacteriophages in bathing waters throughout Europe. Water Res., 36(20): 4963–4974.

Cooper, D. M.; McDonald, J. E.; Malham, S. K.; de Rougemont, A. and Jones, D. L. (2018). Seasonal and spatial dynamics of enteric viruses in wastewater and in riverine and estuarine receiving waters. Sci. Total Environ.,634, 1174–1183.

Costán-Longares, A.; Montemayor, M.; Payan, A.; Mendez, J.; Jofre, J.; Mujeriego, R. and Lucena, F. (2008). Microbial indicators and pathogens: removal, relationships and predictive capabilities in water reclamation facilities. Water Res., 42(17): 4439–4448.

Crawford, S. E.; Ramani, S.; Tate, J. E.; Parashar, U. D.; Svensson, L.; Hagbom, M.; Franco, M. A.; Greenberg, H. B.; O'Ryan, M. and Kang, G. (2017). Rotavirus infection. Nat. Rev. Dis. Prim., 3(1): 1–16.

d'Herelle, F. and Smith, G. H. (1926). The bacteriophage and its behavior. Am Assoc Immnol.

D'Souza, D. H.; Sair, A.; Williams, K.; Papafragkou, E.; Jean, J.; Moore, C. and Jaykus, L. (2006). Persistence of caliciviruses on environmental surfaces and their transfer to food. Int. J. Food Microbiol., 108(1): 84–91.

De Giglio, O.; Caggiano, G.; Bagordo, F.; Barbuti, G.; Brigida, S.; Lugoli, F.; Grassi, T.; La Rosa, G.; Lucentini, L. and Uricchio, V. F. (2017). Enteric viruses and fecal bacteria indicators to assess groundwater quality and suitability for irrigation. Int. J. Environ. Res. Public Health., 14(6): 558.

Devane, M. L.; Moriarty, E. M.; Wood, D.; Webster-Brown, J. and Gilpin, B. J. (2014). The impact of major earthquakes and subsequent sewage discharges on the microbial quality of water and sediments in an urban river. Sci. Total Environ.,485, 666–680.

Di Bonito, P.; Della Libera, S.; Petricca, S.; Iaconelli, M.; Sanguinetti, M.; Graffeo, R.; Accardi, L. and La Rosa, G. (2015). A large spectrum of alpha and beta papillomaviruses are detected in human stool samples. J. Gen. Virol., 96(3): 607–613.

Donaldson, K. A.; Griffin, D. W. and Paul, J. H. (2002). Detection, quantitation and identification of enteroviruses from surface waters and sponge tissue from the Florida Keys using real-time RT–PCR. Water Res., 36(10): 2505–2514.

Dong, Y.; Kim, J. and Lewis, G. D. (2010). Evaluation of methodology for detection of human adenoviruses in wastewater, drinking water, stream water and recreational waters. J. Appl. Microbiol., 108(3): 800–809.

Donia, D.; Bonanni, E.; Diaco, L. and Divizia, M. (2010). Statistical correlation between enterovirus genome copy numbers and infectious viral particles in wastewater samples. Lett. Appl. Microbiol. 50(2): 237–240.

Dorevitch, S. (2016). Comments on the US EPA "Review of coliphages as possible indicators of fecal contamination for ambient water quality." University of Illinois at Chicago School of Public Health, Chicago, IL

Dufour, A. P. (1984). Health effects criteria for fresh recreational waters.

Duizer, E.; Bijkerk, P.; Rockx, B.; De Groot, A.; Twisk, F. and Koopmans, M. (2004). Inactivation of caliciviruses. Appl. Environ. Microbiol., 70(8): 4538–4543.

Duran, A. E.; Muniesa, M.; Mocé- Llivina, L.; Campos, C.; Jofre, J. and Lucena, F. (2003). Usefulness of different groups of bacteriophages as model micro- organisms for evaluating chlorination. J. Appl. Microbiol., 95(1): 29–37.

Dutilh, B. E.; Cassman, N.; McNair, K.; Sanchez, S. E.; Silva, G. G. Z.; Boling, L.; Barr, J. J.; Speth, D. R.; Seguritan, V. and Aziz, R. K. (2014). A highly abundant bacteriophage discovered in the unknown sequences of human faecal metagenomes. Nat. Commun., 5(1): 1–11.

Ehlers, M. M.; Grabow, W. O. K. and Pavlov, D. N. (2005). Detection of enteroviruses in untreated and treated drinking water supplies in South Africa. Water Res., 39(11): 2253–2258.

El-Senousy, W. M. (2021). Suitability of some viruses as indices of viral pollution of water. Egypt. J. Aquat. Biol. Fish., 25(4): 1049–1084.

El-Senousy, W. M. and Abou-Elela, S. I. (2017). Assessment and evaluation of an integrated hybrid anaerobic–aerobic sewage treatment system for the removal of enteric viruses. Food Environ. Virol., 9(3): 287–303.

El-Senousy, W. M.; Barakat, A. B.; Ghanem, H. E. and Kamel, M. A. (2013a). Molecular epidemiology of human adenoviruses and rotaviruses as candidate viral indicators in the Egyptian sewage and water samples. World Appl. Sci. J.,27(10): 1235–124.

El-Senousy, W. M.; Costafreda, M. I.; Pintó, R. M. and Bosch, A. (2013b). Method validation for norovirus detection in naturally contaminated irrigation water and fresh produce. Int. J. Food Microbiol., 167(1): 74-79.

El-Senousy, W. M.; El-Gamal, M. S.; Mousa, A. A. E.; El-Hawary, S. E.; Kamel, M. M.; Fathi, M. N. and El-Mahdy, E. M. (2014). Effect of chlorine on noroviruses, rotaviruses and Hepatitis E virus in drinking water. World Appl. Sci. J.,32(11): 2206–2212.

El-Senousy, W. M.; Guix, S.; Abid, I.; Pintó, R. M. and Bosch, A. (2007). Removal of astrovirus from water and sewage treatment plants, evaluated by a competitive reverse transcription-PCR. Appl. Environ. Microbiol., 73(1): 164–167.

El-Senousy, W. M.; Pintó, R. M. and Bosch, A. (2004). Epidemiology of human enteric viruses in the Cairo water environment. 1st International Conference of Environmental Research Division on Sustainable Development Environmental Challenges Facing Egypt. National Research Centre, Cairo, Egypt.

El-Senousy, W. M.; Ragab, A. M. E. S. and Handak, E. M. A. E. H. (2015). Prevalence of rotaviruses groups A and C in Egyptian children and aquatic environment. Food Environ. Virol., 7(2): 132–141.

EPA. Environmental Protection Agency (1976). Quality criteria for water. EPA 440-9-76-023 In US. Washington, DC: USEPA.

EPA. Environmental Protection Agency (2012). Recreational water quality criteria. EPA-820-F-12-058. In US. Washington, DC: USEPA.

Espinosa, A. C.; Arias, C. F.; Sánchez-Colón, S. and Mazari-Hiriart, M. (2009). Comparative study of enteric viruses, coliphages and indicator bacteria for evaluating water quality in a tropical high-altitude system. Environ. Heal.,8(1): 1–10.

Espinosa, A. C.; Mazari-Hiriart, M.; Espinosa, R.; Maruri-Avidal, L.; Méndez, E. and Arias, C. F. (2008). Infectivity and genome persistence of rotavirus and astrovirus in groundwater and surface water. Water Res., 42(10–11): 2618–2628.

Fauquet, C. M.; Mayo, M. A.; Maniloff, J.; Desselberger, U. and Ball, L. A. (2005). Virus taxonomy: VIIIth report of the International Committee on Taxonomy of Viruses. Academic Press.

Fewtrell, L. and Kay, D. (2015). Recreational water and infection: a review of recent findings. Curr. Environ. Heal. Reports, 2(1): 85–94.

Flannery, J.; Keaveney, S.; Rajko-Nenow, P.; O'Flaherty, V. and Doré, W. (2012). Concentration of norovirus during wastewater treatment and its impact on oyster contamination. Appl. Environ. Microbiol., 78(9): 3400–3406.

Fong, T. T. and Lipp, E. K. (2005). Enteric Viruses of Humans and Animals in Aquatic Environments: Health Risks, Detection, and Potential Water Quality Assessment Tools. Microbiol. Mol. Biol. Rev.,69(2): 357–371.

Fong, T. T.; Griffin, D. W. and Lipp, E. K. (2005). Molecular assays for targeting human and bovine enteric viruses in coastal waters and their application for library-independent source tracking. Appl. Environ. Microbiol., 71(4): 2070–2078.

Fong, T. T.; Phanikumar, M. S.; Xagoraraki, I. and Rose, J. B. (2010). Quantitative detection of human adenoviruses in wastewater and combined sewer overflows influencing a Michigan river. Appl. Environ. Microbiol., 76(3): 715–723.

Fratini, M.; Di Bonito, P. and La Rosa, G. (2014). Oncogenic papillomavirus and polyomavirus in water environments: is there a potential for waterborne transmission? Food Environ. Virol., 6(1): 1–12.

García, A. C.; Blanch, A. R.; Campos, C.; Jofre, J. and Lucena, F. (2019). Pathogens, faecal indicators and human- specific microbial source- tracking markers in sewage. J. Appl. Microbiol., 126(3): 701–717.

Garcia, A.; Le, T.; Jankowski, P.; Yanaç, K.; Yuan, Q. and Uyaguari-Diaz, M. I. (2022). Quantification of human enteric viruses as alternative indicators of fecal pollution to evaluate wastewater treatment processes. PeerJ, 10, e12957.

Gerba, C. P. (1987). Phage as indicators of fecal pollution. Phage Ecol.

Gerba, C. P.; Goyal, S. M.; LaBelle, R. L.; Cech, I. and Bodgan, G. F. (1979). Failure of indicator bacteria to reflect the occurrence of enteroviruses in marine waters. Am. J. Public Health, 69(11): 1116–1119.

Gerba, C. P.; Gramos, D. M. and Nwachuku, N. (2002). Comparative inactivation of enteroviruses and adenovirus 2 by UV light. Appl. Environ. Microbiol., 68(10): 5167–5169.

Gibson, K. E. (2014). Viral pathogens in water: occurrence, public health impact, and available control strategies. Curr. Opin. Virol.,, 4, 50–57.

Gofti-Laroche, L.; Gratacap-Cavallier, B.; Demanse, D.; Genoulaz, O.; Seigneurin, J.-M. and Zmirou, D. (2003). Are waterborne astrovirus implicated in acute digestive morbidity (E. MI. RA study)? J. Clin. Virol.27(1): 74–82.

Grabow, W. O. K. (2001). Bacteriophages: update on application as models for viruses in water. Water Sa, 27(2): 251–268.

Graciaa, D. S.; Cope, J. R.; Roberts, V. A.; Cikesh, B. L.; Kahler, A. M.; Vigar, M.; Hilborn, E. D.; Wade, T. J.; Backer, L. C. and Montgomery, S. P. (2018). Outbreaks associated with untreated recreational water—United States, 2000–2014. Am. J. Transplant., (Vol. 18, Issue 8, pp. 2083–2087). Wiley Online Library.

Greening, G. E. and Cannon, J. L. (2016). Human and animal viruses in food (including taxonomy of enteric viruses). In Viruses in foods (pp. 5–57). Springer.

Griffith, J. F.; Weisberg, S. B.; Arnold, B. F.; Cao, Y.; Schiff, K. C. and Colford Jr, J. M. (2016). Epidemiologic evaluation of multiple alternate microbial water quality monitoring indicators at three California beaches. Water Res., 94, 371–381.

Gunda, N. S. K. and Mitra, S. K. (2016). Rapid water quality monitoring for microbial contamination. Electrochem. Soc. Interface., 25(4): 73.

Gyawali, P.; Croucher, D.; Ahmed, W.; Devane, M. and Hewitt, J. (2019). Evaluation of pepper mild mottle virus as an indicator of human faecal pollution in shellfish and growing waters. Water Res., 154, 370–376.

Hamza, H. and Hamza, I. A. (2018). Oncogenic papillomavirus and polyomavirus in urban sewage in Egypt. Sci. Total Environ.,610, 1413–1420.

Hamza, I. A.; Jurzik, L. and Wilhelm, M. (2014). Development of a Luminex assay for the simultaneous detection of human enteric viruses in sewage and river water. J. Virol. Methods., 204, 65–72.

Hamza, I. A.; Jurzik, L.; Stang, A.; Sure, K.; Überla, K. and Wilhelm, M. (2009). Detection of human viruses in rivers of a densly-populated area in Germany using a virus adsorption elution method optimized for PCR analyses. Water Res., 43(10): 2657–2668.

Hamza, I. A.; Jurzik, L.; Überla, K. and Wilhelm, M. (2011). Evaluation of pepper mild mottle virus, human picobirnavirus and Torque teno virus as indicators of fecal contamination in river water. Water Res., 45(3): 1358–1368.

Haramoto, E.; Katayama, H. and Ohgaki, S. (2008). Quantification and genotyping of torque teno virus at a wastewater treatment plant in Japan. Appl. Environ. Microbiol., 74(23): 7434–7436.

Haramoto, E.; Katayama, H.; Oguma, K. and Ohgaki, S. (2007). Quantitative analysis of human enteric adenoviruses in aquatic environments. J. Appl. Microbiol., 103(6): 2153–2159.

Haramoto, E.; Kitajima, M. and Otagiri, M. (2013). Development of a reverse transcription-quantitative PCR assay for detection of salivirus/klassevirus. Appl. Environ. Microbiol., 79(11): 3529–3532.

Haramoto, E.; Kitajima, M.; Katayama, H. and Ohgaki, S. (2010). Real-time PCR detection of adenoviruses, polyomaviruses, and torque teno viruses in river water in Japan. Water Res., 44(6): 1747–1752.

Haramoto, E.; Kitajima, M.; Kishida, N.; Katayama, H.; Asami, M. and Akiba, M. (2012). Occurrence of viruses and protozoa in drinking water sources of Japan and their relationship to indicator microorganisms. Food Environ. Virol., 4(3): 93–101.

Harwood, V. J.; Levine, A. D.; Scott, T. M.; Chivukula, V.; Lukasik, J.; Farrah, S. R. and Rose, J. B. (2005). Validity of the indicator organism paradigm for pathogen reduction in reclaimed water and public health protection. Appl. Environ. Microbiol., 71(6): 3163–3170.

Hata, A.; Hanamoto, S.; Ihara, M.; Shirasaka, Y.; Yamashita, N. and Tanaka, H. (2018). Comprehensive Study on Enteric Viruses and Indicators in Surface Water in Kyoto, Japan, During 2014–2015 Season. Food Environ. Virol., 10(4): 353–364.

Hata, A.; Kitajima, M. and Katayama, H. (2013). Occurrence and reduction of human viruses, F- specific RNA coliphage genogroups and microbial indicators at a full- scale wastewater treatment plant in J apan. J. Appl. Microbiol., 114(2): 545–554.

Havelaar, A. H.; Van Olphen, M. and Drost, Y. C. (1993). F-specific RNA bacteriophages are adequate model organisms for enteric viruses in fresh water. Appl. Environ. Microbiol., 59(9): 2956–2962.

He, J. W. and Jiang, S. (2005). Quantification of enterococci and human adenoviruses in environmental samples by real-time PCR. Appl. Environ. Microbiol., 71(5): 2250–2255.

Hewitt, J.; Bell, D.; Simmons, G. C.; Rivera-Aban, M.; Wolf, S. and Greening, G. E. (2007). Gastroenteritis outbreak caused by waterborne norovirus at a New Zealand ski resort. Appl. Environ. Microbiol., 73(24): 7853–7857.

Hewitt, J.; Greening, G. E.; Leonard, M. and Lewis, G. D. (2013). Evaluation of human adenovirus and human polyomavirus as indicators of human sewage contamination in the aquatic environment. Water Res., 47(17): 6750–6761.

Hijnen, W. A. M.; Beerendonk, E. F. and Medema, G. J. (2006). Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo) cysts in water: a review. Water Res., 40(1): 3–22.

Hilton, M. C. and Stotzky, G. (1973). Use of coliphages as indicators of water pollution. Can. J. Microbiol., 19(6): 747–751.

Hot, D.; Legeay, O.; Jacques, J.; Gantzer, C.; Caudrelier, Y.; Guyard, K.; Lange, M. and Andreoletti, L. (2003). Detection of somatic phages, infectious enteroviruses and enterovirus genomes as indicators of human enteric viral pollution in surface water. Water Res., 37(19): 4703–4710.

Hundesa, A.; Maluquer de Motes, C.; Bofill-Mas, S.; Albinana-Gimenez, N. and Girones, R. (2006). Identification of human and animal adenoviruses and polyomaviruses for determination of sources of fecal contamination in the environment. Appl. Environ. Microbiol., 72(12): 7886–7893.

Hurst, C. J. and Gerba, C. P. (1980). Stability of simian rotavirus in fresh and estuarine water. Appl. Environ. Microbiol., 39(1): 1–5.

Iaconelli, M.; Muscillo, M.; Della Libera, S.; Fratini, M.; Meucci, L.; De Ceglia, M.; Giacosa, D. and La Rosa, G. (2017). One-year surveillance of human enteric viruses in raw and treated wastewaters, downstream river waters, and drinking waters. Food Environ. Virol., 9(1): 79–88.

Ibarluzea, J. M.; Moreno, B.; Serrano, E.; Larburu, K.; Maiztegi, M. J.; Yarzabal, A. and Santa Marina, L. (2007). Somatic coliphages and bacterial indicators of bathing water quality in the beaches of Gipuzkoa, Spain. J. Water Health.,5(3): 417–426.

Ibrahim, Y.; Ouda, M.; Kadadou, D.; Banat, F.; Naddeo, V.; Alsafar, H.; Yousef, A. F.; Barceló, D. and Hasan, S. W. (2021). Detection and removal of waterborne enteric viruses from wastewater: A comprehensive review. Journal of Environmental Chemical Engineering, 9(4). https://doi.org/10.1016/j.jece.2021.105613

Ishii, S.; Ksoll, W. B.; Hicks, R. E. and Sadowsky, M. J. (2006). Presence and growth of naturalized *Escherichia coli* in temperate soils from Lake Superior watersheds. Appl. Environ. Microbiol., 72(1): 612–621.

Janahi, E. M.; Mustafa, S.; Parkar, S. F. D.; Naser, H. A. and Eisa, Z. M. (2020). Detection of enteric viruses and bacterial indicators in a sewage treatment center and Shallow Water Bay. Int. J. Environ. Res. Public Health., 17(18): 6483.

Jarchow-Macdonald, A. A.; Halley, S.; Chandler, D.; Gunson, R.; Shepherd, S. J. and Parcell, B. J. (2015). First report of an astrovirus type 5 gastroenteritis outbreak in a residential elderly care home identified by sequencing. J. Clin. Virol.73, 115–119.

Jebri, S.; Muniesa, M. and Jofre, J. (2017). General and host-associated bacteriophage indicators of faecal pollution. Global Water Pathogens Project, Http://Www. Waterpathogens. Org (Farnleitner, A. **and** Blanch, A.(Eds) Part 2 Indicators and Microbial Source Tracking Markers): Http://Www. Waterpathogens. Org/Book/Coliphage Michigan State University, E. Lansing, MI, UNESCO.

Jiang, S. C. and Chu, W. (2004). PCR detection of pathogenic viruses in southern California urban rivers. J. Appl. Microbiol., 97(1): 17–28.

Jiang, S. C.; Chu, W. and He, J. W. (2007). Seasonal detection of human viruses and coliphage in Newport Bay, California. Appl. Environ. Microbiol., 73(20): 6468–6474.

Jiang, S.; Noble, R. and Chu, W. (2001). Human adenoviruses and coliphages in urban runoff-impacted coastal waters of Southern California. Appl. Environ. Microbiol., 67(1): 179–184.

Jimenez, L. and Chiang, M. (2006). Virucidal activity of a quaternary ammonium compound disinfectant against feline calicivirus: a surrogate for norovirus. Am. J. Infect. Control., 34(5): 269–273.

Jofre, J.; Lucena, F.; Blanch, A. R. and Muniesa, M. (2016). Coliphages as model organisms in the characterization and management of water resources. Water, 8(5): 199.

Johne, R.; Buck, C. B.; Allander, T.; Atwood, W. J.; Garcea, R. L.; Imperiale, M. J.; Major, E. O.; Ramqvist, T. and Norkin, L. C. (2011). Taxonomical developments in the family Polyomaviridae. Arch. Virol., 156(9): 1627–1634.

Johnson, D. C.; Enriquez, C. E.; Pepper, I. L.; Davis, T. L.; Gerba, C. P. and Rose, J. B. (1997). Survival of *Giardia*, *Cryptosporidium*, poliovirus and Salmonella in marine waters. Water Sci. Technol., 35(11–12): 261–268.

Jończyk, E.; Kłak, M.; Międzybrodzki, R. and Górski, A. (2011). The influence of external factors on bacteriophages. Folia Microbiol.,56(3): 191–200.

Jonnalagadda, S.; Rodríguez, O.; Estrella, B.; Sabin, L. L.; Sempértegui, F. and Hamer, D. H. (2017). Etiology of severe pneumonia in Ecuadorian children. PloS One, 12(2): e0171687.

Jung, A. V.; Le Cann, P.; Roig, B.; Thomas, O.; Baurès, E. and Thomas, M. F. (2014). Microbial contamination detection in water resources: interest of current optical methods, trends and needs in the context of climate change. Int. J. Environ. Res. Public Health., 11(4): 4292–4310.

Jurzik, L.; Hamza, I. A.; Puchert, W.; Überla, K. and Wilhelm, M. (2010). Chemical and microbiological parameters as possible indicators for human enteric viruses in surface water. Folia Int. J. Hyg. Environ. Health., 213(3): 210–216.

Kageyama, T.; Kojima, S.; Shinohara, M.; Uchida, K.; Fukushi, S.; Hoshino, F. B.; Takeda, N. and Katayama, K. (2003). Broadly reactive and highly sensitive assay for Norwalk-like viruses based on real-time quantitative reverse transcription-PCR. J. Clin. Microbiol., 41(4): 1548–1557.

Kapikian, A. Z. (2001). A rotavirus vaccine for prevention of severe diarrhoea of infants and young children: development, utilization and withdrawal. Novartis Foundation Symposium, 153–179.

Karim, M. R.; Rhodes, E. R.; Brinkman, N.; Wymer, L. and Fout, G. S. (2009). New electropositive filter for concentrating enteroviruses and noroviruses from large volumes of water. Appl. Environ. Microbiol., 75(8): 2393–2399.

Katayama, H. and Vinjé, J. (2017). Norovirus and other Calicivirus. Global Water Pathogens Project.

Katayama, H.; Haramoto, E.; Oguma, K.; Yamashita, H.; Tajima, A.; Nakajima, H. and Ohgaki, S. (2008). One-year monthly quantitative survey of noroviruses, enteroviruses, and adenoviruses in wastewater collected from six plants in Japan. Water Res., 42(6–7): 1441–1448.

Kauppinen, A.; Pitkänen, T. and Miettinen, I. T. (2018). Persistent norovirus contamination of groundwater supplies in two waterborne outbreaks. Food Environ. Virol., 10(1): 39–50.

Kay, D.; Wyn-Jones, A. P.; Stapleton, C. M.; Fewtrell, L.; Wyer, M. D.; Watkins, J.; Francis, C. A. and Drury, D. (2007). The microbiological quality of seven large commercial private water supplies in the United Kingdom. J. Water Health.,5(4): 523–538.

Kean, J. M.; Rao, S.; Wang, M. and Garcea, R. L. (2009). Seroepidemiology of human polyomaviruses. PLoS Pathogens, 5(3): e1000363.

Kim, W. J.; Managaki, S.; Furumai, H. and Nakajima, F. (2009). Diurnal fluctuation of indicator microorganisms and intestinal viruses in combined sewer system. Water Sci. Technol., 60(11): 2791–2801.

Kitajima, M. and Gerba, C. P. (2015). Aichi virus 1: environmental occurrence and behavior. Pathogens, 4(2): 256–268.

Kitajima, M.; Haramoto, E.; Phanuwan, C.; Katayama, H. and Ohgaki, S. (2009). Detection of genogroup IV norovirus in wastewater and river water in Japan. Lett. Appl. Microbiol. 49(5): 655–658.

Kitajima, M.; Iker, B. C.; Pepper, I. L. and Gerba, C. P. (2014). Relative abundance and treatment reduction of viruses during wastewater treatment processes—identification of potential viral indicators. Sci. Total Environ.,488, 290–296.

Kitajima, M.; Sassi, H. P. and Torrey, J. R. (2018). Pepper mild mottle virus as a water quality indicator. NPJ Clean Water, 1(1): 1–9.

Kocwa-Haluch, R. (2001). Waterborne enteroviruses as a hazard for human health. Polish J. Environ. Stud.,10(6): 485–488.

Koopmans, M. and Duizer, E. (2004). Foodborne viruses: an emerging problem. Int. J. Food Microbiol., 90(1): 23–41.

Kukkula, M.; Maunula, L.; Silvennoinen, E. and von Bonsdorff, C.-H. (1999). Outbreak of viral gastroenteritis due to drinking water contaminated by Norwalk-like viruses. J. Infect. Dis., 180(6): 1771–1776.

Kuo, D. H. W.; Simmons, F. J.; Blair, S.; Hart, E.; Rose, J. B. and Xagoraraki, I. (2010). Assessment of human adenovirus removal in a full-scale membrane bioreactor treating municipal wastewater. Water Res., 44(5): 1520–1530.

Kuroda, K.; Nakada, N.; Hanamoto, S.; Inaba, M.; Katayama, H.; Do, A. T.; Nga, T. T. V.; Oguma, K.; Hayashi, T. and Takizawa, S. (2015). Pepper mild mottle virus as an indicator and a tracer of fecal pollution in water environments: comparative evaluation with wastewater-tracer pharmaceuticals in Hanoi, Vietnam. Sci. Total Environ.,506, 287–298.

La Rosa, G.; Fratini, M.; della Libera, S.; Iaconelli, M. and Muscillo, M. (2012). Emerging and potentially emerging viruses in water environments. Ann. Ist. Super. Di Sanità, 48, 397–406.

Leclerc, H.; Schwartzbrod, L. and Dei Cas, E. (2002). Microbial agents associated with waterborne diseases. Crit. Rev. Microbiol., 28(4): 371–409.

Lee, J. E.; Lee, H.; Cho, Y. H.; Hur, H. G. and Ko, G. (2011). F+ RNA coliphage-based microbial source tracking in water resources of South Korea. Sci. Total Environ.,412, 127–131.

Lee, S. H. and Kim, S. J. (2002). Detection of infectious enteroviruses and adenoviruses in tap water in urban areas in Korea. Water Res., 36(1): 248–256.

Lenaerts, L.; De Clercq, E. and Naesens, L. (2008). Clinical features and treatment of adenovirus infections. Rev. Med. Virol., 18(6): 357–374.

Lennon, G.; Cashman, O.; Lane, K.; Cryan, B. and O'Shea, H. (2007). Prevalence and characterization of enteric adenoviruses in the South of Ireland. J. Med. Virol., 79(10): 1518–1526.

Liang, L.; Goh, S. G.; Vergara, G.; Fang, H. M.; Rezaeinejad, S.; Chang, S. Y.; Bayen, S.; Lee, W. A.; Sobsey, M. D. and Rose, J. B. (2015). Alternative fecal indicators and their empirical relationships with enteric viruses, Salmonella enterica, and Pseudomonas aeruginosa in surface waters of a tropical urban catchment. Appl. Environ. Microbiol., 81(3): 850–860.

Lin, J. and Ganesh, A. (2013). Water quality indicators: bacteria, coliphages, enteric viruses. Int. J. Environ. Health Res., 23(6): 484–506.

Linden, K. G.; Thurston, J.; Schaefer, R. and Malley Jr, J. P. (2007). Enhanced UV inactivation of adenoviruses under polychromatic UV lamps. Appl. Environ. Microbiol., 73(23): 7571–7574.

Liste, M. B.; Natera, I.; Suarez, J. A.; Pujol, F. H.; Liprandi, F. and Ludert, J. E. (2000). Enteric virus infections and diarrhea in healthy and human immunodeficiency virus-infected children. J. Clin. Microbiol., 38(8): 2873–2877.

Logan, C.; O'Leary, J. J. and O'Sullivan, N. (2006). Real-time reverse transcription-PCR for detection of rotavirus and adenovirus as causative agents of acute viral gastroenteritis in children. J. Clin. Microbiol., 44(9): 3189–3195.

Long, S. C. and Dewer, K. G. (2008). Coliform and Coliphage Monitoring for Groundwater Wells in Massachusetts. JOURNAL-NEW ENGL. WATER WORK. ASSOC. 122(1): 12.

Long, S. C. and Sobsey, M. D. (2004). A comparison of the survival of F+ RNA and F+ DNA coliphages in lake water microcosms. J. Water Health.,2(1): 15–22.

Love, D. C.; Silverman, A. and Nelson, K. L. (2010). Human virus and bacteriophage inactivation in clear water by simulated sunlight compared to bacteriophage inactivation at a southern California beach. Environ. Sci. Technol., 44(18): 6965–6970.

Love, D. C.; Vinje, J.; Khalil, S. M.; Murphy, J.; Lovelace, G. L. and Sobsey, M. D. (2008). Evaluation of RT- PCR and reverse line blot hybridization for detection and genotyping F+ RNA coliphages from estuarine waters and molluscan shellfish. J. Appl. Microbiol., 104(4): 1203–1212.

Lucena, F. and Jofre, J. (2010). Potential use of bacteriophages as indicators of water quality and wastewater treatment processes. Bacteriophages in the Control of Food- and Waterborne Pathogens, 103–118.

Lun, J. H.; Crosbie, N. D. and White, P. A. (2019). Genetic diversity and quantification of human mastadenoviruses in wastewater from Sydney and Melbourne, Australia. Sci. Total Environ.,675, 305–312.

Lytle, C. D. and Sagripanti, J.-L. (2005). Predicted inactivation of viruses of relevance to biodefense by solar radiation. J. Virol., 79(22): 14244–14252.

Malakoff, D. (2002). Microbiologists on the trail of polluting bacteria. Science, 295(5564): 2352–2353.

Marsalek, J. and Rochfort, Q. (2004). Urban wet-weather flows: sources of fecal contamination impacting on recreational waters and threatening drinking-water sources. J. Toxicol. Environ. Heal.,Part A, 67(20–22): 1765–1777.

Maunula, L.; Kalso, S.; Von Bonsdorff, C.-H. and Pönkä, A. (2004). Wading pool water contaminated with both noroviruses and astroviruses as the source of a gastroenteritis outbreak. Epidemiol. Infect.,132(4): 737–743.

Maunula, L.; Miettinen, I. T. and Von Bonsdorff, C.-H. (2005). Norovirus outbreaks from drinking water. Emerg. Infect. Dis.,11(11): 1716.

McMinn, B. R.; Ashbolt, N. J. and Korajkic, A. (2017). Bacteriophages as indicators of faecal pollution and enteric virus removal. Lett. Appl. Microbiol. 65(1): 11–26.

McQuaig, S.; Griffith, J. and Harwood, V. J. (2012). Association of fecal indicator bacteria with human viruses and microbial source tracking markers at coastal beaches impacted by nonpoint source pollution. Appl. Environ. Microbiol., 78(18): 6423–6432.

McQuaig, S. M.; Scott, T. M.; Lukasik, J. O.; Paul, J. H. and Harwood, V. J. (2009). Quantification of human polyomaviruses JC virus and BK virus by TaqMan quantitative PCR and comparison to other water quality indicators in water and fecal samples. Appl. Environ. Microbiol., 75(11): 3379–3388.

Meleg, E.; Bányai, K.; Martella, V.; Jiang, B.; Kocsis, B.; Kisfali, P.; Melegh, B. and Szűcs, G. (2008). Detection and quantification of group C rotaviruses in communal sewage. Appl. Environ. Microbiol., 74(11): 3394–3399.

Messner, M. J.; Berger, P. and Javier, J. (2017). Total coliform and *E. coli* in public water systems using undisinfected ground water in the United States. Folia Int. J. Hyg. Environ. Health.,220(4): 736–743.

Miagostovich, M. P.; Ferreira, F. F. M.; Guimarães, F. R.; Fumian, T. M.; Diniz-Mendes, L.; Luz, S. L. B.; Silva, L. A. and Leite, J. P. G. (2008). Molecular detection and characterization of gastroenteritis viruses occurring naturally in the stream waters of Manaus, central Amazonia, Brazil. Appl. Environ. Microbiol., 74(2): 375–382.

Mocé-Llivina, L.; Lucena, F. and Jofre, J. (2005). Enteroviruses and bacteriophages in bathing waters. Appl. Environ. Microbiol., 71(11): 6838–6844.

Moresco, V.; Viancelli, A.; Nascimento, M. de A. do, Souza, D. S. M.; Ramos, A. P. D.; Garcia, L. A. T.; Simões, C. M. de O. and Barardi, C. R. M. (2012). Microbiological and physicochemical analysis of the coastal waters of southern Brazil. Mar. Pollut. Bull., 64(1): 40–48.

Muniesa, M.; Mocé-Llivina, L.; Katayama, H. and Jofre, J. (2003). Bacterial host strains that support replication of somatic coliphages. Antonie Van Leeuwenhoek, 83(4): 305–315.

Mylon, S. E.; Rinciog, C. I.; Schmidt, N.; Gutierrez, L.; Wong, G. C. L. and Nguyen, T. H. (2010). Influence of salts and natural organic matter on the stability of bacteriophage MS2. Langmuir, 26(2): 1035–1042.

Myrmel, M.; Lange, H. and Rimstad, E. (2015). A 1-year quantitative survey of noro-, adeno-, human boca-, and hepatitis E viruses in raw and secondarily treated sewage from two plants in Norway. Food Environ. Virol., 7(3): 213–223.

Nelson, K. L.; Boehm, A. B.; Davies-Colley, R. J.; Dodd, M. C.; Kohn, T.; Linden, K. G.; Liu, Y.; Maraccini, P. A.; McNeill, K. and Mitch, W. A. (2018). Sunlight-mediated inactivation of health-relevant microorganisms in water: a review of mechanisms and modeling approaches. Environ. Sci. Process. Impacts, 20(8): 1089–1122.

Nguyen, L. T.; Haney, E. F. and Vogel, H. J. (2011). The expanding scope of antimicrobial peptide structures and their modes of action. Trends Biotechnol., 29(9): 464–472.

Nims, R. W. and Plavsic, M. (2013). Polyomavirus inactivation–a review. Biologicals, 41(2): 63–70.

Nygård, K.; Torvén, M.; Ancker, C.; Knauth, S. B.; Hedlund, K. O.; Giesecke, J. andersson, Y. and Svensson, L. (2003). Emerging genotype (GGIIb) of norovirus in drinking water, Sweden. Emerg. Infect. Dis.,9(12): 1548.

Ogorzaly, L.; Bertrand, I.; Paris, M.; Maul, A. and Gantzer, C. (2010). Occurrence, survival, and persistence of human adenoviruses and F-specific RNA phages in raw groundwater. Appl. Environ. Microbiol., 76(24): 8019–8025.

Ogorzaly, L.; Bonot, S.; El Moualij, B.; Zorzi, W. and Cauchie, H.-M. (2013). Development of a quantitative immunocapture real-time PCR assay for detecting structurally intact adenoviral particles in water. J. Virol. Methods., 194(1–2): 235–241.

Okoh, A. I.; Sibanda, T. and Gusha, S. S. (2010). Inadequately treated wastewater as a source of human enteric viruses in the environment. Int. J. Environ. Res. Public Health., 7(6): 2620–2637.

Ottoson, J.; Hansen, A.; Björlenius, B.; Norder, H. and Stenström, T. A. (2006). Removal of viruses, parasitic protozoa and microbial indicators in conventional and membrane processes in a wastewater pilot plant. Water Res., 40(7): 1449–1457.

Ouardani, I.; Turki, S.; Aouni, M. and Romalde, J. L. (2016). Detection and molecular characterization of hepatitis A virus from Tunisian wastewater treatment plants with different secondary treatments. Appl. Environ. Microbiol., 82(13): 3834–3845.

Paluszak, Z.; Lipowski, A. and Ligocka, A. (2012). Survival rate of Suid herpesvirus (SuHV-1, Aujeszky's disease virus, ADV) in composted sewage sludge. Pol. J. Vet. Sci.

Pancorbo, O. C.; Evanshen, B. G.; Campbell, W. F.; Lambert, S.; Curtis, S. K. and Woolley, T. W. (1987). Infectivity and antigenicity reduction rates of human rotavirus strain Wa in fresh waters. Appl. Environ. Microbiol., 53(8): 1803–1811.

Payment, P. and Locas, A. (2011). Pathogens in water: value and limits of correlation with microbial indicators. Groundwater, 49(1): 4–11.

Payment, P.; and Franco, E. (1993). *Clostridium perfringens* and somatic coliphages as indicators of the efficiency of drinking water treatment for viruses and protozoan cysts. Appl. Environ. Microbiol., 59(8): 2418–2424.

Payment, P.; Waite, M. and Dufour, A. (2003). Introducing parameters for the assessment of drinking water quality. Assess. Microb. Saf. Drink. water.,4, 47–77.

Pina, S.; Puig, M.; Lucena, F.; Jofre, J. and Girones, R. (1998). Viral pollution in the environment and in shellfish: human adenovirus detection by PCR as an index of human viruses. Appl. Environ. Microbiol., 64(9): 3376–3382.

Pinon, A. and Vialette, M. (2018). Survival of viruses in water. Intervirology, 61(5): 214–222.

Prevost, B.; Goulet, M.; Lucas, F. S.; Joyeux, M.; Moulin, L. and Wurtzer, S. (2016). Viral persistence in surface and drinking water: Suitability of PCR pre-treatment with intercalating dyes. Water Res., 91, 68–76.

Prevost, B.; Lucas, F. S.; Goncalves, A.; Richard, F.; Moulin, L. and Wurtzer, S. (2015). Large scale survey of enteric viruses in river and waste water underlines the health status of the local population. Environ. Int., 79, 42–50.

Prez, V. E.; Gil, P. I.; Temprana, C. F.; Cuadrado, P. R.; Martínez, L. C.; Giordano, M. O.; Masachessi, G.; Isa, M. B.; Ré, V. E. and Pavan, J. V. (2015). Quantification of human infection risk caused by rotavirus in surface waters from Córdoba, Argentina. Sci. Total Environ.,538, 220–229.

Puig, M.; Jofre, J.; Lucena, F.; Allard, A.; Wadell, G. and Girones, R. (1994). Detection of adenoviruses and enteroviruses in polluted waters by nested PCR amplification. Appl. Environ. Microbiol., 60(8): 2963–2970.

Quintão, T. S. C.; Silva, F. G.; Pereira, A. L.; Araújo, W. N.; Oliveira, P. M.; Souza, M.; Lamounier, T. A. and Haddad, R. (2021). Detection and molecular characterization of enteric adenovirus in treated wastewater in the Brazilian Federal District. SN Appl. Sci., 3(7): 1–11.

Rachida, S. and Taylor, M. B. (2020). Potentially infectious novel hepatitis a virus strains detected in selected treated wastewater discharge sources, South Africa. Viruses, 12(12): 1468.

Rachmadi, A. T.; Torrey, J. R. and Kitajima, M. (2016). Human polyomavirus: Advantages and limitations as a human-specific viral marker in aquatic environments. Water Res., 105, 456–469.

Rames, E.; Roiko, A.; Stratton, H. and Macdonald, J. (2016). Technical aspects of using human adenovirus as a viral water quality indicator. Water Res., 96, 308–326.

Rashed, M. K.; El-Senousy, W. M.; Sayed, E. T. A. E. and AlKhazindar, M. (2022). Infectious Pepper Mild Mottle Virus and Human Adenoviruses as Viral Indices in Sewage and Water Samples. Food Environ. Virol., 0123456789.

Rigotto, C.; Hanley, K.; Rochelle, P. A.; De Leon, R.; Barardi, C. R. M. and Yates, M. V. (2011). Survival of adenovirus types 2 and 41 in surface and ground waters measured by a plaque assay. Environ. Sci. Technol., 45(9): 4145–4150.

Rodriguez-Lazaro, D.; Cook, N.; Ruggeri, F. M.; Sellwood, J.; Nasser, A.; Nascimento, M. S. J.; D'Agostino, M.; Santos, R.; Saiz, J. C. and Rzeżutka, A. (2012). Virus hazards from food, water and other contaminated environments. FEMS Microbiol. Rev., 36(4): 786–814.

Romero, O. C.; Straub, A. P.; Kohn, T. and Nguyen, T. H. (2011). Role of temperature and Suwannee River natural organic matter on inactivation kinetics of rotavirus and bacteriophage MS2 by solar irradiation. Environ. Sci. Technol., 45(24): 10385–10393.

Rosario, K.; Symonds, E. M.; Sinigalliano, C.; Stewart, J. and Breitbart, M. (2009). Pepper mild mottle virus as an indicator of fecal pollution. Appl. Environ. Microbiol., 75(22): 7261–7267.

Rusinol, M.; Fernandez-Cassi, X.; Timoneda, N.; Carratala, A.; Abril, J. F.; Silvera, C.; Figueras, M. J.; Gelati, E.; Rodó, X. and Kay, D. (2015). Evidence of viral dissemination and seasonality in a Mediterranean river catchment: implications for water pollution management. J. Environ. Manage., 159, 58–67.

Rzeżutka, A. and Cook, N. (2004). Survival of human enteric viruses in the environment and food. FEMS Microbiol. Rev., 28(4): 441–453.

Said, B.; Wright, F.; Nichols, G. L.; Reacher, M. and Rutter, M. (2003). Outbreaks of infectious disease associated with private drinking water supplies in England and Wales 1970–2000. Epidemiol. Infect.,130(3): 469–479.

Samir, S.; Barakat, A. B.; El-Senousy, W. M.; Abou-Zeid, A. A. and Rabiee, O. A. (2020). Role of the JC Polyomavirus (JCV) and BK Polyomavirus (BKV) in the colorectal cancer of some Egyptian patients. Nov. Res. Microbiol., 4(1): 598–605.

Sartorius, B.; Andersson, Y.; Velicko, I.; De Jong, B.; Löfdahl, M.; Hedlund, K.-O.; Allestam, G.; Wångsell, C.; Bergstedt, O. and Horal, P. (2007). Outbreak of norovirus in Västra Götaland associated with recreational activities at two lakes during August 2004. Scandinavian J. Infect. Dis., 39(4): 323–331.

Schmitz, B. W.; Kitajima, M.; Campillo, M. E.; Gerba, C. P. and Pepper, I. L. (2016). Virus reduction during advanced Bardenpho and conventional wastewater treatment processes. Environ. Sci. Technol., 50(17): 9524–9532.

Schowalter, R. M.; Reinhold, W. C. and Buck, C. B. (2012). Entry tropism of BK and Merkel cell polyomaviruses in cell culture.

Scott, T. M.; Jenkins, T. M.; Lukasik, J. and Rose, J. B. (2005). Potential use of a host associated molecular marker in Enterococcus faecium as an index of human fecal pollution. Environ. Sci. Technol., 39(1): 283–287.

Scott, T. M.; Rose, J. B.; Jenkins, T. M.; Farrah, S. R. and Lukasik, J. (2002). Microbial source tracking: current methodology and future directions. Appl. Environ. Microbiol., 68(12): 5796–5803.

Sekwadi, P. G.; Ravhuhali, K. G.; Mosam, A.; Essel, V.; Ntshoe, G. M.; Shonhiwa, A. M.; McCarthy, K.; Mans, J.; Taylor, M. B. and Page, N. A. (2018). Waterborne outbreak of gastroenteritis on the KwaZulu-natal coast, South Africa, december 2016/january 2017. Epidemiol. Infect.,146(10): 1318–1325.

Selvakumar, A. and Borst, M. (2006). Variation of microorganism concentrations in urban stormwater runoff with land use and seasons. J. Water Health.,4(1): 109–124.

Seo, K.; Lee, J. E.; Lim, M. Y. and Ko, G. (2012). Effect of temperature, pH, and NaCl on the inactivation kinetics of murine norovirus. J. Food Prot., 75(3): 533–540.

Shahid, M. A.; Abubakar, M.; Hameed, S. and Hassan, S. (2009). Avian influenza virus (H5N1); effects of physico-chemical factors on its survival. Virol. J., 6(1): 1–6.

Shirasaki, N.; Matsushita, T.; Matsui, Y. and Koriki, S. (2020). Suitability of pepper mild mottle virus as a human enteric virus surrogate for assessing the efficacy of thermal or free-chlorine disinfection processes by using infectivity assays and enhanced viability PCR. Water Res., 186, 116409.

Shirasaki, N.; Matsushita, T.; Matsui, Y. and Yamashita, R. (2018). Evaluation of the suitability of a plant virus, pepper mild mottle virus, as a surrogate of human enteric viruses for assessment of the efficacy of coagulation–rapid sand filtration to remove those viruses. Water Res., 129, 460–469.

Shrestha, S.; Shrestha, S.; Shindo, J.; Sherchand, J. B. and Haramoto, E. (2018). Virological quality of irrigation water sources and pepper mild mottle virus and tobacco mosaic virus as index of pathogenic virus contamination level. Food Environ. Virol., 10(1): 107–120.

Sidhu, J. P. S.; Ahmed, W.; Palmer, A.; Smith, K.; Hodgers, L. and Toze, S. (2017). Optimization of sampling strategy to determine pathogen removal efficacy of activated sludge treatment plant. Environ. Sci. Pollut. Res., 24(23): 19001–19010.

Sidhu, J. P. S.; and Toze, S. G. (2009). Human pathogens and their indicators in biosolids: a literature review. Environ. Int., 35(1): 187–201.

Sidhu, J. P. S. and Toze, S. (2012). Assessment of pathogen survival potential during managed aquifer recharge with diffusion chambers. J. Appl. Microbiol., 113(3): 693–700.

Sidhu, J. P. S.; Hodgers, L.; Ahmed, W.; Chong, M. N. and Toze, S. (2012). Prevalence of human pathogens and indicators in stormwater runoff in Brisbane, Australia. Water Res., 46(20): 6652–6660.

Silva, H. D.; García-Zapata, M. T. A. and Anunciação, C. E. (2011). Why the use of adenoviruses as water quality virologic marker? Food Environ. Virol., 3(3): 138–140.

Silverman, A. I.; Peterson, B. M.; Boehm, A. B.; McNeill, K. and Nelson, K. L. (2013). Sunlight inactivation of human viruses and bacteriophages in coastal waters containing natural photosensitizers. Environ. Sci. Technol., 47(4): 1870–1878.

Simmons, F. J.; Kuo, D. H. W. and Xagoraraki, I. (2011). Removal of human enteric viruses by a full-scale membrane bioreactor during municipal wastewater processing. Water Res., 45(9): 2739–2750.

Sinton, L. W.; Hall, C. H.; Lynch, P. A. and Davies-Colley, R. J. (2002). Sunlight inactivation of fecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. Appl. Environ. Microbiol., 68(3): 1122–1131.

Skraber, S.; Gassilloud, B. and Gantzer, C. (2004). Comparison of coliforms and coliphages as tools for assessment of viral contamination in river water. Appl. Environ. Microbiol., 70(6): 3644–3649.

Sobsey, M. D. and Meschke, J. S. (2003). Virus survival in the environment with special attention to survival in sewage droplets and other environmental media of fecal or respiratory origin. Rep. World Heal. Organ. Geneva, Switz. 70.

Sobsey, M. D.; Hall, R. M. and Hazard, R. L. (1995). Comparative reductions of hepatitis A virus, enteroviruses and coliphage MS2 in miniature soil columns. Water Sci. Technol., 31(5–6): 203–209.

Staley, C.; Reckhow, K. H.; Lukasik, J. and Harwood, V. J. (2012). Assessment of sources of human pathogens and fecal contamination in a Florida freshwater lake. Water Res., 46(17): 5799–5812.

Stewart- Pullaro, J.; Daugomah, J. W.; Chestnut, D. E.; Graves, D. A.; Sobsey, M. D. and Scott, G. I. (2006). F+ RNA coliphage typing for microbial source tracking in surface waters. J. Appl. Microbiol., 101(5): 1015–1026.

Stoeckel, D. M. and Harwood, V. J. (2007). Performance, design, and analysis in microbial source tracking studies. Appl. Environ. Microbiol., 73(8): 2405–2415.

Symonds, E. M.; Griffin, D. W. and Breitbart, M. (2009). Eukaryotic viruses in wastewater samples from the United States. Appl. Environ. Microbiol., 75(5): 1402–1409.

Symonds, E. M.; Nguyen, K. H.; Harwood, V. J. and Breitbart, M. (2018). Pepper mild mottle virus: A plant pathogen with a greater purpose in (waste) water treatment development and public health management. Water Res., 144, 1–12.

Tandukar, S.; Sherchan, S. P. and Haramoto, E. (2020). Applicability of crAssphage, pepper mild mottle virus, and tobacco mosaic virus as indicators of reduction of enteric viruses during wastewater treatment. Sci. Rep., 10(1): 1–8.

Tandukar, S.; Sherchand, J. B.; Bhandari, D.; Sherchan, S. P.; Malla, B.; Ghaju Shrestha, R. and Haramoto, E. (2018). Presence of human enteric viruses, protozoa, and indicators of pathogens in the Bagmati River, Nepal. Pathogens, 7(2): 38.

Tawfik, A.; Badr, N.; Taleb, E. and El-Senousy, W. (2012). Sewage treatment in an up-flow anaerobic sponge reactor followed by moving bed biofilm reactor based on polyurethane carrier material. Desalin. Water Treat., 37(1–3): 350–358.

Teunis, P. F. M.; Moe, C. L.; Liu, P.; E. Miller, S.; Lindesmith, L.; Baric, R. S.; Le Pendu, J. and Calderon, R. L. (2008). Norwalk virus: how infectious is it? J. Med. Virol., 80(8): 1468–1476.

Thurston-Enriquez, J. A.; Haas, C. N.; Jacangelo, J. and Gerba, C. P. (2005). Inactivation of enteric adenovirus and feline calicivirus by chlorine dioxide. Appl. Environ. Microbiol., 71(6): 3100–3105.

Thurston-Enriquez, J. A.; Haas, C. N.; Jacangelo, J.; Riley, K. and Gerba, C. P. (2003). Inactivation of feline calicivirus and adenovirus type 40 by UV radiation. Appl. Environ. Microbiol., 69(1): 577–582.

Tian, P.; Yang, D.; Shan, L.; Wang, D.; Li, Q.; Gorski, L.; Lee, B. G.; Quiñones, B. and Cooley, M. B. (2017). Concurrent detection of human norovirus and bacterial pathogens in water samples from an agricultural region in central California coast. Front. Microbiol., 8, 1560.

Tiwari, S. and Dhole, T. N. (2018). Assessment of enteroviruses from sewage water and clinical samples during eradication phase of polio in North India. Virol. J. 15(1): 1–8.

Tonani, K. A. A.; Padula, J. A.; Julião, F. C.; Fregonesi, B. M.; Alves, R. I. S.; Sampaio, C. F.; Beda, C. F.; Hachich, E. M. and Segura-Muñoz, S. I. (2013). Persistence of *giardia*, *cryptosporidium*, rotavirus, and adenovirus in treated sewage in São Paulo state, Brazil. J. Parasitol., 99(6): 1144–1147.

Toribio-Avedillo, D.; Blanch, A. R.; Muniesa, M. and Rodríguez-Rubio, L. (2021). Bacteriophages as fecal pollution indicators. Viruses, 13(6): 1089.

Toribio-Avedillo, D.; Martín-Díaz, J.; Jofre, J.; Blanch, A. R. and Muniesa, M. (2019). New approach for the simultaneous detection of somatic coliphages and F-specific RNA coliphages as indicators of fecal pollution. Sci. Total Environ.,655, 263–272.

Tran, N. H.; Gin, K. Y. H. and Ngo, H. H. (2015). Fecal pollution source tracking toolbox for identification, evaluation and characterization of fecal contamination in receiving urban surface waters and groundwater. Sci. Total Environ.,538, 38–57.

Tufenkji, N. and Emelko, M. B. (2011). Groundwater Pollution: Impacts on Human Health: Fate and Transport of Microbial Contaminants. Encyclopedia of Environ. Heal.,J. Nriagu, Ed. Elsevier Publishing Inc.

Verheyen, J.; Timmen-Wego, M.; Laudien, R.; Boussaad, I.; Sen, S.; Koc, A.; Uesbeck, A.; Mazou, F. and Pfister, H. (2009). Detection of adenoviruses and rotaviruses in drinking water sources used in rural areas of Benin, West Africa. Appl. Environ. Microbiol., 75(9): 2798–2801.

Vijayavel, K.; Byappanahalli, M. N.; Ebdon, J.; Taylor, H.; Whitman, R. L. and Kashian, D. R. (2014). Enterococcus phages as potential tool for identifying sewage inputs in the Great Lakes region. J. Great Lakes Res., 40(4): 989–993.

Villena, C.; El-Senousy, W. M.; Abad, F. X.; Pintó, R. M. and Bosch, A. (2003). Group A rotavirus in sewage samples from Barcelona and Cairo: emergence of unusual genotypes. Appl. Environ. Microbiol., 69(7): 3919–3923.

Vogel, J. R.; Stoeckel, D. M.; Lamendella, R.; Zelt, R. B.; Santo Domingo, J. W.; Walker, S. R. and Oerther, D. B. (2007). Identifying fecal sources in a selected catchment reach using multiple source- tracking tools. J. Environ. Qual. 36, 718–729.

Walker, D. I.; Adriaenssens, E. M.; McDonald, J. E.; Hillary, L. S.; Malham, S. K. and Jones, D. L. (2020). Viral indicators for tracking domestic wastewater contamination in the aquatic environment. Water Res., 181, 115926.

Wang, H.; Naghavi, M.; Allen, C.; Barber, R. M.; Bhutta, Z. A.; Carter, A.; Casey, D. C.; Charlson, F. J.; Chen, A. Z. and Coates, M. M. (2016). Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015. The Lancet, 388(10053): 1459–1544.

Ward, R. L.; Knowlton, D. R. and Pierce, M. J. (1984). Efficiency of human rotavirus propagation in cell culture. J. Clin. Microbiol., 19(6): 748–753.

Wen, X.; Chen, F.; Lin, Y.; Zhu, H.; Yuan, F.; Kuang, D.; Jia, Z. and Yuan, Z. (2020). Microbial indicators and their use for monitoring drinking water quality—A review. Sustainability, 12(6): 2249.

Wetz, J. J.; Lipp, E. K.; Griffin, D. W.; Lukasik, J.; Wait, D.; Sobsey, M. D.; Scott, T. M. and Rose, J. B. (2004). Presence, infectivity, and stability of enteric viruses in seawater: relationship to marine water quality in the Florida Keys. Mar. Pollut. Bull., 48(7–8): 698–704.

WHO. World Health Organization. (2011). Guidelines for drinking-water quality, 4th ed.; World Health Organization: Geneva, Switzerland, pp 216, 303–304.

WHO. World Health Organization. (2022). Drinking-water fact sheet [WWW Document], 3.21.2022. URL. https://www.who.int/news-room/fact-sheets/detail/drinking-water.

Wold, W. S. and Horwitz, M. S. (2007). Adenoviridae: adenoviruses In Fields Virology 5th edn,(eds Knipe, DM et al.) 2395–2436. Lippincott Williams and Wilkins.

Wolf, S.; Hewitt, J. and Greening, G. E. (2010). Viral multiplex quantitative PCR assays for tracking sources of fecal contamination. Appl. Environ. Microbiol., 76(5): 1388–1394.

Wong, K.; Fong, T.-T.; Bibby, K. and Molina, M. (2012). Application of enteric viruses for fecal pollution source tracking in environmental waters. Environ. Int., 45, 151–164.

Wong, K.; Xagoraraki, I.; Wallace, J.; Bickert, W.; Srinivasan, S. and Rose, J. B. (2009). Removal of viruses and indicators by anaerobic membrane bioreactor treating animal waste. J. Environ. Qual. 38, 1694–1699.

Wu, H. M.; Fornek, M.; Schwab, K. J.; Chapin, A. R.; Gibson, K.; Schwab, E.; Spencer, C. and Henning, K. (2005). A norovirus outbreak at a long-term-care facility: the role of environmental surface contamination. Infect. Control Hosp. Epidemiol., 26(10): 802–810.

Wu, J.; Long, S. C.; Das, D. and Dorner, S. M. (2011). Are microbial indicators and pathogens correlated? A statistical analysis of 40 years of research. J. Water Health.,9(2): 265–278.

Wyer, M. D.; Fleisher, J. M.; Gough, J.; Kay, D. and Merrett, H. (1995). An investigation into parametric relationships between enterovirus and faecal indicator organisms in the coastal waters of England and Wales. Water Res., 29(8): 1863–1868.

Wyn-Jones, A. P.; Carducci, A.; Cook, N.; D'agostino, M.; Divizia, M.; Fleischer, J.; Gantzer, C.; Gawler, A.; Girones, R. and Höller, C. (2011). Surveillance of adenoviruses and noroviruses in European recreational waters. Water Res., 45(3): 1025–1038.

Xagoraraki, I. and O'Brien, E. (2020). Wastewater-based epidemiology for early detection of viral outbreaks. In Women in water quality (pp. 75–97). Springer.

Yamahara, K. M.; Sassoubre, L. M.; Goodwin, K. D. and Boehm, A. B. (2012). Occurrence and persistence of bacterial pathogens and indicator organisms in beach sand along the California coast. Appl. Environ. Microbiol., 78(6): 1733–1745.

Yates, M. V. (2007). Classical indicators in the 21st century—far and beyond the coliform. Water Environ. Res., 79(3): 279–286.

Zhang, T.; Breitbart, M.; Lee, W. H.; Run, J.-Q.; Wei, C. L.; Soh, S. W. L.; Hibberd, M. L.; Liu, E. T.; Rohwer, F. and Ruan, Y. (2006). RNA viral community in human feces: prevalence of plant pathogenic viruses. PLoS Biol, 4(1): e3.