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The Risk of Waterborne Enteric Viral Infection in Africa as Revealed Through Quantitative Microbial Exposure Analysis

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Abstract

This study investigates the prevalence and sources of waterborne enteric viral infections in Africa, where poor access to safe water and sanitation facilities poses significant public health risks. The waterborne enteric virus has proven to be a biological hazard and contaminant in potable water, natural water, and wastewater systems. Thus, this research employs quantitative microbial exposure analysis (QMEA) to determine the likelihood of infection and identify the sources of viral contamination in water sources. This study found 105 articles, 12 reported 292 positive cases, and 1187 comprehensively reviewed and analyzed datasets. The analyzed articles were from six African countries: Morocco, Egypt, Uganda, Nigeria, Ghana, and South Africa. In all articles considered, the probability of infection and risk of illness of those who were subjected to the river and dam water via drinking, recreational, domestic, or irrigation activities were too high and exceeded the acceptable risk of 0.01% (10^{-4} infection/individual/year) proposed by WHO. Hepatitis A virus (HAV) with 13-30% mortality rates and Human adenovirus (HAdV) dominates the surface water in African countries. This study underscores the need for better water and sanitation facilities to mitigate the risk of waterborne viral infections and promote public health in Africa. Therefore, by highlighting the risks of waterborne enteric viral infections,

the study calls for more targeted interventions to prevent the spread of these infections and improve health outcomes in African communities.

Keywords: Risk assessment; Untreated water; Enteric virus; Probability of infection; Risk of Illness; African countries.

1. Introduction

Waterborne enteric viral infections pose a significant health threat to populations in Africa, particularly in areas where access to clean water and sanitation is limited. According to the World Health Organization (WHO), viral gastroenteritis is responsible for approximately 20% of all cases of diarrheal disease worldwide, resulting in an estimated 1.3 million deaths annually [1]. In Africa, the burden of viral gastroenteritis is particularly high, with outbreaks of diseases such as norovirus and rotavirus occurring frequently [2]. The lack of safe drinking water and poor sanitation infrastructure are major drivers of waterborne viral infections in Africa. Despite efforts to improve water and sanitation infrastructure in Africa, waterborne viral infections continue to pose a significant public health threat. Irrespective of the high level of water-borne infection in Africa, most of the microbiological data that has been collected is not from Africa because Africa is dominated by low-income countries, making it impossible to effectively research the extent and effect of microbial risk on people's health from water-borne viruses.

Notwithstanding the given constraints in African countries, Quantitative Microbial Risk Assessment (QMRA) is still used to calculate health hazards, define potential threats from the water supply, and choose water safety management measures [3]. The detrimental effects on human health after exposure to a medium where enteric viruses are present can be evaluated by microbial risk assessment [4]. The process is made up of four steps which include hazard identification, exposure assessment, dose-response assessment, and risk characterization. This research, therefore, reveals epidemiological data on viral infection rates in Africa, exposure analysis, risk assessment, QMRA dose-response model, and detection problems and limitations of these viruses in surface water in Africa.

Most viruses are introduced into the water through fecal contamination and are responsible for diarrhea outbreaks in most countries [5]. They are transferred by drinking contaminated water during recreation and by contact with contaminated water. Viral diarrhea is the second cause of mortality among children under five years in developing countries, with rotavirus and norovirus being the most common viral agent. Much interest is drawn to viral studies because of their persistence in water, even in the presence of disinfectants and other processes used to remove pathogens in water treatment plants [6]. Norovirus and Rotavirus have been detected in treated water [7]. They persist in water far longer than bacteria, and contact with such contaminated water can infect a person. Furthermore, the viral infective dose is very low, between the range of 10-100 viral particles, which means that a little number of the virus can cause infection in humans [4]. Not to mention the difficulty in detecting their presence in water, because due to their low concentration in water, so many samples are required for viral detection. All these make them unique and propel human beings to seek solution against them.

Water is a primary entity that connects all species and facilitates exposure to waterborne viruses. Irrespective of the progress in sanitation and hygiene, diarrhea is still a public health threat in Africa due to the lack of basic amenities such as treated water, forcing people to depend on surface water for survival. Without water, there is no life. That is why enteric viral presence in rivers, dams, and streams may not only pose a concern to the public's health but also act as a sign of the water's quality. Water matrix in wastewater can serve as an early warning for the types of pathogens being excreted by the human population in an area. The occurrence of these pathogens (e.g. viruses) in potable drinking water depicts their post-treatment persistence, poor treatment, or lack of treatment. It also describes the potential human health risks associated with their use. Recent studies have used quantitative microbial exposure analysis (QMEA) to investigate the prevalence and distribution of enteric viruses in various African settings. For example, a study in Ghana found that norovirus was present in 47% of surface water samples collected from communities with limited access to clean water and sanitation [7]. Another study in South Africa detected norovirus in 9.7% of river water samples tested [7]. These findings highlight the need for improved water and sanitation infrastructure to reduce the risk of viral gastroenteritis in African communities. Overall, the use of quantitative microbial exposure analysis (QMEA) to assess the risk of waterborne enteric viral infection in Africa has the potential to inform public health policy and improve the health outcomes of vulnerable populations. Further research in this area is needed to better understand the prevalence and distribution of viral pathogens in water sources and to develop effective prevention and control strategies.

2. Methodology

2.1. Selection of Database and Identification of Enteric Viruses in Water

As revealed through quantitative microbial risk analysis, specific databases were correlated to identify studies on the risk of waterborne enteric viral infection in Africa. PubMed, Web of Science (WoS), and Scopus were used because of their effortless ability to navigate specific locations, as this article is specific to Africa. The archives were rummaged for QMRA-related research, then a quick evaluation of the title and abstract was conducted following the study's inclusion criteria. Google Scholar revealed more references through the “cited by” links. The Africa waterborne enteric virus risk document identification in Web of Science employed both title- and topic-specific fields using ‘(microbial risk* OR risk assessment*) AND water*) AND enteric virus*)’ spanning through all the years. All African countries were selected and individually listed. In Scopus, waterborne enteric virus risk articles were spotted using the expression TITLE-ABS-KEY ((microbial AND risk* OR risk AND assessment* OR water) AND enteric AND virus) AND (LIMIT-TO (AFRICA COUNTRIES, "ar"). Finally, in PubMed, waterborne enteric virus risk articles were located using advanced search together with title and abstract-field search expressed

as “(microbial risk*[tiab] | risk assessment*[tiab]) AND enteric virus [tiab] AND water[tiab] [Title/abstract]” and filtered by abstract, full text, and journal article. Using the broadest and most general search term possible, it was verified that the subject-specific extraction of articles in the databases covered all relevant topics, which include ‘risk analysis’, ‘waterborne’, and ‘enteric viruses.

The articles acquired were saved into libraries on the three data sets following the research inclusion and exclusion measures for computer-assisted duplication elimination. The exclusion criteria for this research were mainly the risk of enteric viral infection in other samples apart from groundwater samples and other nations outside Africa. After processing each article's title, duplicate removal with computer assistance was done. Step-by-step instructions and information on waterborne enteric viral infection risk in Africa are presented. Identification and screening for the enteric virus. Fig 1 explains the estimation of enteric virus in natural waters, drinking water, and wastewater. The unduplicated publications' whole texts were obtained for data analysis and evaluation while taking note of the inclusion criteria.

2.2. Inclusion Criteria

This study is confined to scholarly journals such as publications whose results were from the analysis carried out in African water bodies. Such journals provided meaningful data and facts in understanding African actual and current state of health from the international perspective, especially the low-income nations. Excluded from this study were book reviews, review essays, news articles, encyclopedia entries, interviews, website content, commentary, and studies conducted in languages other than English. This research study was carried out without regard to the chronological range to ensure that as many pertinent papers as readily available were found.

This analysis included studies on quantitative microbial risk analysis and risk analysis evaluation of the waterborne enteric viruses. Consideration was also given to articles on natural waterbodies and wastewater treatment methods that were fully written in English and were accessible. Finally, priority was given to a thorough explanation of the methods used to concentrate enteric virus particles for QMRA, molecular detection methods, and exposure pathways.

2.3. Data Extraction

After being screened to weed out any duplicates and pointless studies, 12 pertinent studies were finally found for review. The screening method is revealed using the PRISMA flow diagram below (see Fig. 1). The reason for the small sample size obtained is due to the sparse research being conducted in African countries because they are dominated majorly by low-income countries. This is shown in Figure 2 below. Information obtained from relevant research includes author, year, positive cases, sample size, sample type (water type), sampling site, observed activities around the sampling site, viral concentration techniques, viral nucleic acid extraction techniques, and detection techniques. Further information on the name of the country where the study was performed, probability of infection, route of exposure, and infective dose were also obtained. To guarantee that the generated data was of high quality and that the presented results were accurate, a proper reevaluation of the extracted data was carried out. The thesis and antithesis of the research were evaluated, and results were descriptively synthesized.

2.4. Data Analysis

This review explains the extent of waterborne enteric virus infection risk in Africa. The status quo was determined by examining the research's main topics, key phrases, and areas of interest.

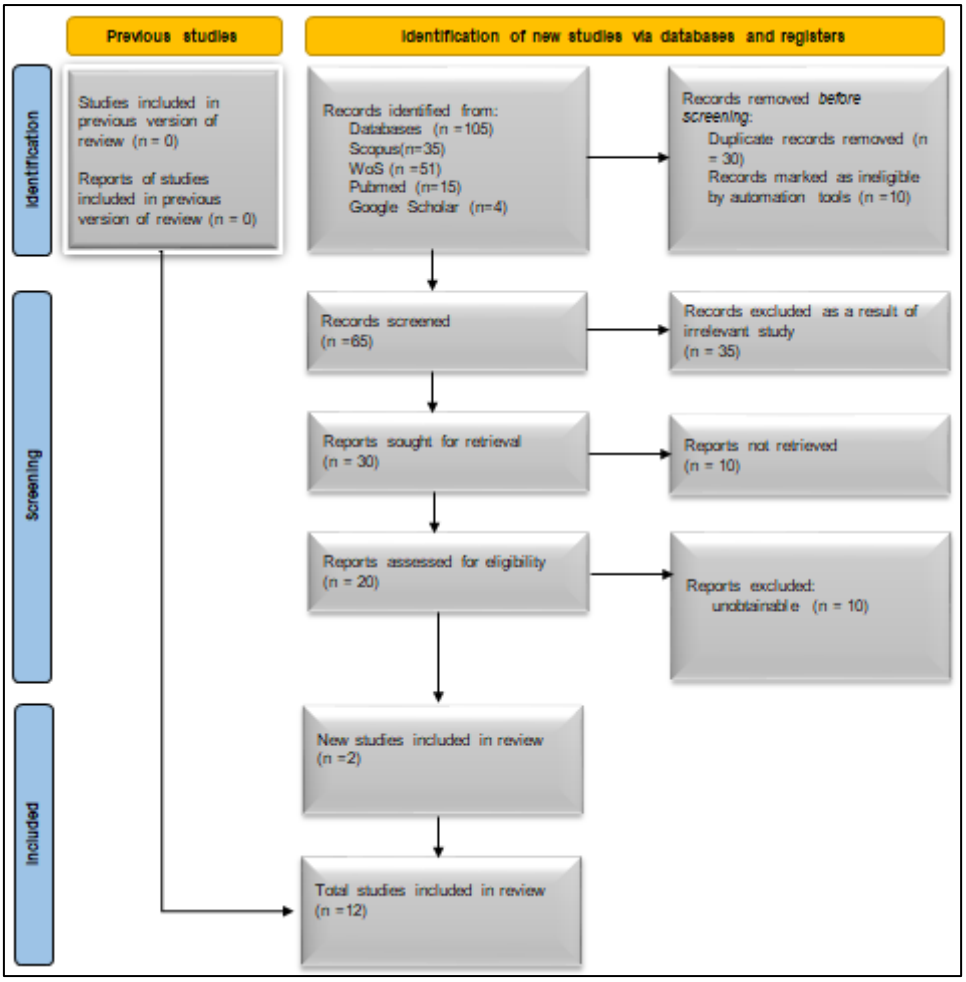

Figure-1. Flowchart of the study selection process using PRISMA flow diagram for systematic review

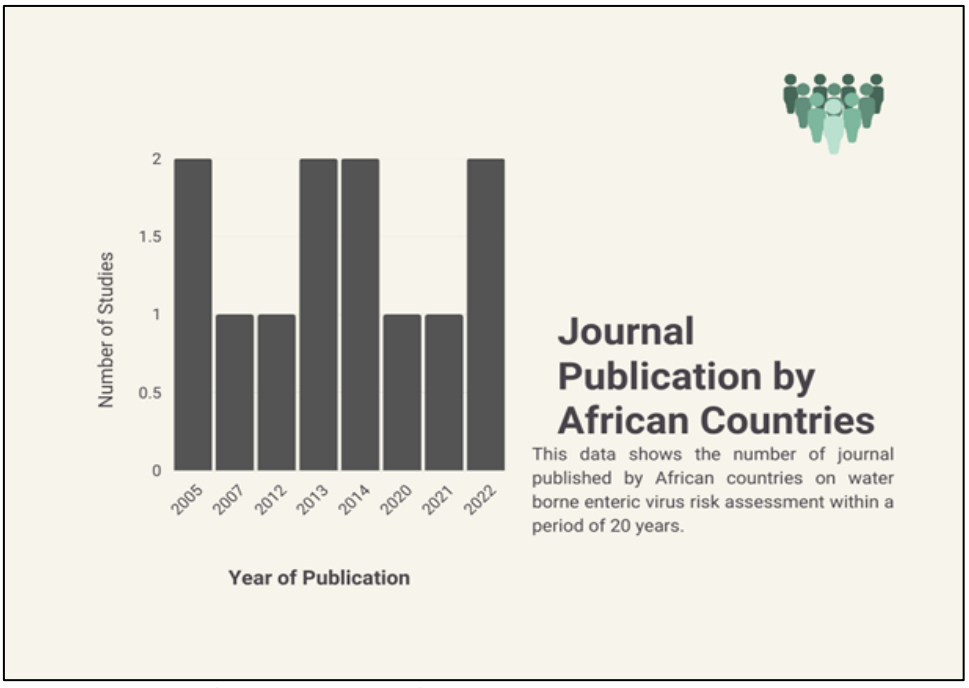

Figure-2. Number of studies published in African countries on waterborne enteric virus risk assessment.

3. Result and Discussion

3.1. Epidemiological Data on Viral Infection Rates in Africa

3.1.1. Description of the Water Supplies and Routes of Drinking Water Contamination in Africa

Africa, the earth's second-largest continent, which accounts for one-fifth of all the planet's land, is mainly comprised of low-income countries with little or no basic amenities. The absence of basic amenities has forced people to look for an alternative source to satisfy their daily needs. These sources are often contaminated with

human and animal waste due to poor sanitation practices, inadequate waste management, and a lack of access to clean water as shown in table 1 below. Thus, house chores that require water are being done in rivers like laundry and dishwashing. Also, agricultural activities and recreational activities depend on water from the river, as reported by Chigor, *et al.* [4] in the Buffalo River in South Africa. So many activities are being carried out in surface water in Africa, and these are major sources of surface water contamination. Potgieter, *et al.* [8], reported dumping chicken feathers and blood in the Tshinane River in South Africa. Table 1 below shows the sampling sites and observed activities carried out around the site. In Uganda, the use of an alternative source of water was common among 70% of the population due to a lack of clean and safe water for consumption. The alternative supplies were protected springs, many of which are contaminated and associated with diarrhea [9]. In Ghana, despite the poor sanitation, 90% of household-generated wastewater is discharged directly into the environment and finds its way automatically into urban streams, rivers, and open sewers, which are the primary irrigation source for urban farmers [10]. Adenovirus is present in surface water at a higher frequency than any other enteric virus because it can survive for prolonged periods outside a host. Therefore, 90% of the population living around the Buffalo River is seropositive for one or more adenovirus serotypes [5].

Due to the availability of funds, people from the low social economic group consume dam water daily for drinking purposes and take in about 2 liters of water per day. This thus increased their exposure to hepatitis A and other viruses [11]. In a study on the quantification of microbial risk to human health conducted by Katukiza, *et al.* [12], the study area Bwaise III in Kampala, Uganda, is a distinct ghetto area in sub-Saharan Africa because it has inadequate sanitary facilities, with a significant population size of over 250 people per hectare, and limited access to basic amenities [12]. Africa's current excreta, grey water, and solid waste management systems are insufficient, coupled with the fact that 80% of the resident are not officially working and therefore engaged in little-scale businesses; thus, their monthly salary varies between US$ 10 and US$ 250, and thus they like to collect free water from the already-existing, polluted spring sources, which are contaminated continuously by excreta [12].

Table-1. Sampling sites and observed activities carried out around the different surface water site

Water type	Sampling site	Observed activities	Country	Year	Reference
River	Buffalo River	Laundry, dishwashing, Agricultural activities, Recreational activities	South Africa	2013	[4].
River	River Ala	Bathing, drinking, domestic and irrigational activities	Nigeria	2018	[13].
Slum	Bwaise III	Drinking, bathing, cooking, and eating are common	Uganda	2010	[12]
River	Mutale River	Washing cars, clothes washing, body washing, and letting livestock drink from the river	South Africa	2020	[8]
River	Sambandou River	Clothes washing, cows and horses drink from it, animals are grazing thus their feces are littered around the water, and people fetch water for building construction.	South Africa	2020	[8]
	Tshinane River	Clothes washing, body washing, and disposing of chicken blood and feathers in the water	South Africa	2020	[8]
	Mutshundudi River	Clothes washing, body washing, and leaving trash around the water	South Africa	2020	[8]
	Madadzhe River	Agricultural activities, domestic sewage disposal, car washing	South Africa	2020	[8]
	Luvuvhu River (Mhinga site)	Clothe washing, washing cars, catching fish, swimming, and body washing	South Africa	2020	[8]
	Luvuvhu River (Mutoti site)	Fishing, car washing, livestock drinking from rivers, people fetching water for construction projects, clothes washing, and body washing.	South Africa	2020	[8]
	Luvuvhu river (Tshino site)	Grazing cow and fish hunting	South Africa	2020	[8]
	Nzhelele River	Washing cars, drawing water, body washing, and farm work	South Africa	2020	[8]
	Dzindi River	Agricultural activities	South Africa	2020	[8]
River	Gauteng River	Recreational activities, drinking, domestic purposes	South Africa	2000	[11]
River	Tyume River	Irrigation, recreation, stock watering, and domestic purposes. Supply of water samples for a nearby treatment facility for drinking water.	South Africa	2010 -2011	[14]
Stream	Onyansa Stream	It is contaminated by effluent from the non-functioning Roman Ridge wastewater treatment plant and it is used for irrigation	Ghana	2010	[15]
Stream	Marine Drive Stream	Irrigation			
River	Odaw River	Irrigation			

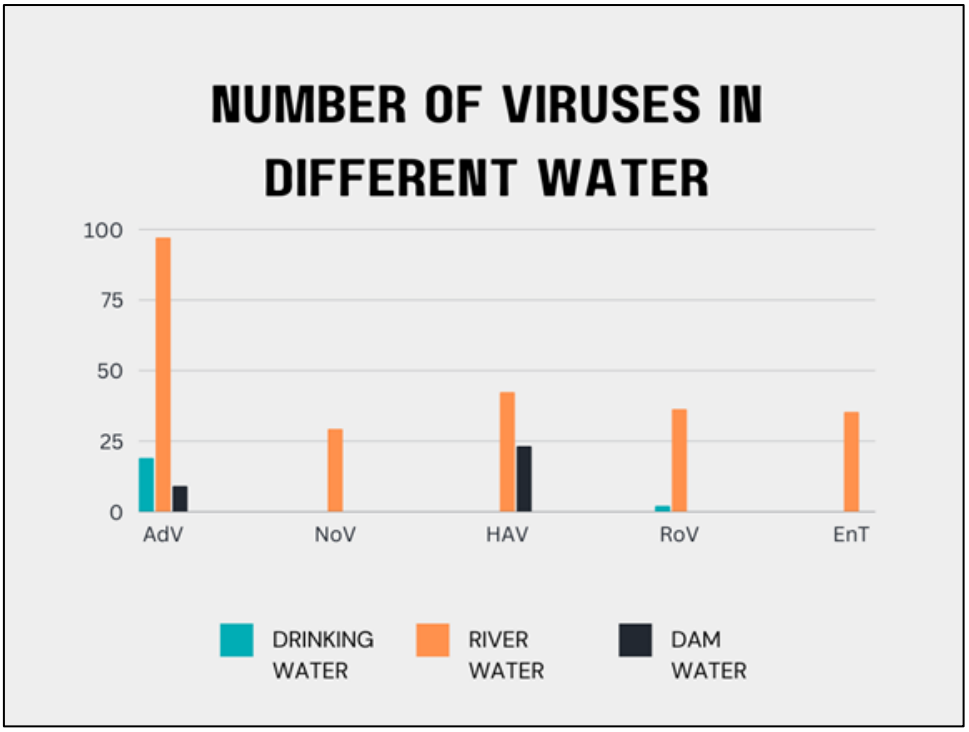

Figure-3. Graph showing the types of viruses identified and their quantity in the different water bodies

3.1.2. Epidemiology of Waterborne Viral Infection Rates in Africa

Waterborne viral infections are a significant public health concern in Africa, affecting millions of people annually. Rotavirus is the leading cause of diarrhea among young children, with an estimated 611,000 deaths per year worldwide, and half of this death is estimated to have occurred in Africa [4]. However, in this research they were not found at all in dam water as shown in figure 3 above. In the research work carried out in the Buffalo River in South Africa's Eastern Cape, the estimated concentration of infectious virus particles was unacceptably high, unlike other viruses. Also, HAdV was reportedly liable for the highest risk with a daily probability of infection of 52-100%, followed by RoV with a daily probability of infection of 53-65%, while HAV had EnV had a lesser daily probability of infection of 2-30% and 1-6% respectively. All these viruses can be obtained by drinking at least 100 ml of untreated water out of the Buffalo River in South Africa according to Chigor, *et al.* [4]. The yearly probability of infection for HAdV and RoV was within the range of 93-100% in Buffalo River, where it was detected. It was also found that the infection probability was reduced in irrigation workers than for individuals exposed through drinking, domestic, and recreational activities. This is because, during irrigation, it is estimated that the person involved consumes not more than 10 ml of water compared to drinking, where an individual consumes 2 liters of water per day thus increasing the exposure rate to the viruses. It is important to note that Buffalo River served as a source of water supply to 880,000 people in Buffalo City [4]. Although the removal efficiency was not reported, 5-18.7% of viruses were detected in treated drinking water [4]. Although high rates of viral inactivation have been demonstrated as a result of sunshine, hot environments, and dry conditions. If a sufficient time of 14 days is allowed between cultivation and eating of produce, then exposure to the infectious virus by irrigation will be low. Unfortunately, farmers want their vegetables always to look fresh. The physiochemical stability of Rotavirus enables them to undergo sewage treatment without being inactivated and reach other types of ecological water, while the HAV's composition and structure make it extremely stable and resistant to the physiological agent, therefore, HAV may endure for a very long time in the water [14]. Irrespective of these features which increase the stability of these viruses in the environment, their quantity in the environment is still high as shown in Figure 3, above and this is a threat to humanity.

In research carried out in the Netherlands, it was found that treated sewage water and naturally contaminated raw water contained the same concentration of Rotavirus RNA [16], which is the same as the results in Africa obtained by Venter, *et al.* [11]. Venter, *et al.* [11] calculated the risk assessment of Hepatitis A virus in Gauteng, South Africa's rivers and dams using a deterministic exponential approach, he considered the population as immunocompetent and further grouped the population into the high socio-economic group and the low socio-economic group. During his study, he found out that the high socio-economic group is not exposed to infection daily, because they use the river water only for recreational purposes. On the other hand, the low social economic group drinks both the river and dam water daily and uses them for recreational purposes. Thus, they acquire immunity at an early age against the disease. He found out that the high yearly probability of mortality is significant mainly for the elderly and immunocompromised that drink 2 liters of untreated water daily. He obtained an estimated daily risk of infection of one per 1000 recreational users per day for river water and 0.12 per 1000 users of dam water for sport activity in the high socio-economic group. In the low socio-economic group, the daily probability of infection was 220 per 10000 consumers with a yearly probability of 100% in river water, and communities consuming dam water had a daily probability of infection of 23 per 10,000 and a yearly probability of infection of 5800 per 10,000 consumers. This is because each person consumed 2 liters of water per day and 100 ml during recreation [11]. This

exceeded the preferred risk of 0.01% (10^{-4} infections/individual/year) proposed by WHO and therefore people should not be allowed to drink such water. In another research carried out by Van Heerden, *et al.* [17] on clean and sterilized water based on the international specification for potable water generation. The water system in the research supplied water to 10 million water users in South Africa, Van Heerden detected and isolated 4.41% of HAdV DNA from 204 water samples collected. It looks impossible to run away from this virus, and now it is proven that microorganisms are indeed ubiquitous.

Though, there are many controversies over the acceptable level of risk proposed by the U.S. EPA which is one infection per 10000 individuals in a given year as a reasonable level of safety for drinking water. The result obtained from Chigor, *et al.* [4] and Venter, *et al.* [11] did not conform to that when compared. Other studies have been carried out in other African countries to ascertain the microbial risk analysis, the results have been compiled and presented in Table 2 below. In Nigeria, Olalemi and Akinwumi [13] researched the significant risk posed by surface water frequently used for consumption, swimming, domestic, and agricultural activities in Akure using the dose-response model. He discovered that the probability of disease associated with rotavirus was 3.3×10^{-3} if 10 ml of the surface water was ingested during irrigation. This same river water is being consumed daily by the area's inhabitants, which are about 600,000 in number for swimming, bathing, agriculture, and consumption purposes. With this risk of infection, which already exceeded the acceptable risk proposed by the WHO, it is possible to confidently say that more than half of this population is already asymptomatic with rotavirus infection and any individual relocating to such an environment needs to be extremely careful. The concerned government needs to swing into action and provide basic amenities such as treated water to reduce the spread of the virus in the community.

Table 2 below highlights the potential health risks associated with consuming contaminated water, particularly for those living in low-income or impoverished areas. The results suggest that there is a need for improved water treatment and sanitation practices to minimize the risk of waterborne diseases and reduce the disease burden in affected communities.

Table-2. Probability of infection and risk of illness on exposure to individual water bodies

Author	Disability-adjusted life years (DALYs)	Probability of infection per day	Probability of infection per year	Risks of illness per day	Risks of illness per year	The volume of water consumed	Morbidity (%)
[18]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
[4]	N/A	HAdV (7.31 x10^{-3} to 1),RoV (4.23 x 10^{-2} to 6.54 x10^{-1}), HAV (2.32 x 10^{-4} to 1.73 x 10-1), EnV (1.32 x 10^{-4} to 5.70 x 10^{-2})	N/A	6.58 x 10^{-5} to 5.0 x 10^{-1}	N/A	100mL for drinking water, 30mL for recreational activities, for domestic application 10ml of untreated water, for irrigation 1ml per person	N/A
[11]	N/A	Both high and low socioeconomic group for recreation (1.1 x 10^{-3} for river,1.2 x 10^{-4} for dam), Low social economic group for drinking (2.2 x 10^{-2} for river, 2.3 x 10^{-3})	Both high and low socioeconomic group for recreation (3.3 x 10^{-1} for river, 4.2 x 10^{-2} for dam), low socio-economic group for drinking (1 in river, 5.8 x 10^{-1} in dam)	high income group for recreation (4.1 x 10^{-4} for river,5.3 x 10^{-5} for dam), Low-income group for recreation (1.1 x10^{-4} for river, 1.2 x 10^{-5} for dam), Low-income group for drinking (2.2 x 10^{-3} for river, 2.3 x 10^{-4} dam)	high income group for recreation (1.5 x 10^{-1} for river, 1.9 x 10^{-2} dam), Low-income group for recreation (3.3 x 10^{-2} for the river, 4.2 x 10^{-3} for the dam), Low-income group for drinking (1 x 10^{-1} for river,5.8 x 10^{-2} for the dam)	Recreational 0.1L per day, for drinking 2L per day.i.e 100ml and 2000liter	high socio-economic group 45%, low socio-economic group 10%
[19]	N/A	0.2 per person per day	N/A	3.5×10^{3} ± 1.6×10^{3} gc/day dose of exposure	N/A	N/A	N/A
[12]	total disease burden was 680 disability-adjusted life years (DALYs) per 1000 persons per year	HAdV is 1 from the main open drainage channel. Nsooba inlet (AdV 9.98 x 10^{-1}, RoV 8.09 x 10^{-1}), Nsooba outlet (AdV1 .00 x 10^{0}, RoV 7.03 x 10^{-1}), JN Nsooba/Nakamilo (AdV 6.70 x 10^{-1}, RoV 6. 44 x 10^{-1}), Nakamilo inlet (AdV 7.44 x 10^{-1}, RoV 6.07 x 10^{-1}), Grey water in tertiary drain (st.Francis Zone)(AdV 2.45 x 10^{-1}, RoV 3.36 x 10^{-1}), Grey water tertiary drain (Katogo zone)	Grey water exposure was 1 for HAdV and RV, this was the highest. Nsooba inlet (AdV 1.00 X 10^{0}, RoV 1.00 X 10^{0}), Nsooba outlet (AdV 1.00 X 10^{0},9.99 x 10^{-1} RoV), JNNsooba/Nakamilo (AdV 9.99 x 10^{-1}, RoV 9.98 x 10^{-1}), Nakamilo inlet (AdV1.00 x 10^{0}, RoV 9.96 x 10^{-1}), Grey water in tertiary drain	N/A	N/A	N/A	N/A

		(AdV 8.03 x 10^{-1}, RoV 6.92 x 10^{-1}), Unprotected springs (7.96 x 10^{-1} AdV)	(st. Francis Zone) (AdV 8.95 x 10^{-1}, RoV 9.62 x 10^{-1}), Grey water tertiary drain (Katogo zone) (AdV 1.00 x 10^{0}, RoV1.00 x 10^{0}), Unprotected springs (AdV 1.00 x 10^{0})]				
[20]	N/A	4.1 × 10^{-1} per exposure event	8.61 × 10^{-1} per week. 0.037 probability of infection per year.	N/A	N/A	100ml	N/A
[13]	N/A	Ingestion of 1 ml of water gives 0.0033, consumption of 10 ml of water gives 0.033 and ingestion of 100 ml of water from the river was 0.33 probability of infection.	Ingestion of 1 ml of water is 0.7; 10 ml of water from the river is 1.0	N/A	N/A	100ml for drinking, 1-10ml accidental consumption	N/A
[14]	N/A	1:2000 for rotavirus	N/A	N/A	N/A	10 ml for domestic purposes and 100ml for recreational purposes	N/A
[15]	N/A	N/A	N/A	N/A	N/A		N/A
[17]	N/A	N/A	N/A	N/A	N/A		N/A
[21]	N/A	Consumption of 30ml per day(River water 1.71 x 10^{-4}, Dam water 3.12 x 10^{-5}) Consumption of 2litre of water per (Water supply A 2.93 x 10^{-4} and Water supply B 5.10 X 10^{-4})	1.01 x $10^{-1}$and 1.7 x 10^{-1} for drinking water supplies A and B,	Drinking water supply A:1.5 x10^{-4} Drinking water supply B:2.6 x10^{-4} River water: 8.6 x 10^{-5} Dam water: 1.6 x10^{-6}	N/A	2 L per day-1 for drinking water and 30ml per day for river and dam water	0.5

3.1.3. Water Matrix as an Early Warning Sign for Pathogenic Viral Persistence in the Human Population

Water is an essential resource for human life, and its quality plays a crucial role in the health of human populations. In recent years, researchers have been investigating the use of water matrices as an early warning sign for pathogenic viral persistence in the human population. A water matrix is a complex mixture of various organic and inorganic compounds that can act as a carrier for viruses. Pathogenic viruses, such as hepatitis A, norovirus, and rotavirus, are known to persist in water matrices and can cause waterborne disease outbreaks. These outbreaks can lead to significant health and economic impacts, making it essential to monitor and prevent their spread. According to Sibanda and Okoh [14] as shown in table 2 above, before the age of 10, 100% of adolescents in underdeveloped countries in Africa have suffered from Hepatitis A and gained immunity to the virus, which they acquired as a result of playing in the water at an early age. Therefore, it is crucial to monitor water sources as an early warning sign for the potential presence of pathogenic viruses. Several studies have reported the detection of viruses in various water matrices, such as groundwater, surface water, and wastewater [18-20]. The presence of these viruses in water matrices indicates a potential risk of exposure and infection in humans. Additionally, the detection of pathogenic viruses in water can serve as an early warning sign for the potential spread of diseases, such as viral gastroenteritis, hepatitis A, and polio [21, 22]. In recent years, advancements in technology have made it possible to detect and identify viruses in water matrices more effectively. These advancements have allowed researchers to better understand the persistence and behavior of viruses in water matrices. Additionally, new technologies, such as metagenomics, have provided a more comprehensive analysis of viral populations in water matrices, leading to improved monitoring and risk assessments. In South Africa's Eastern Cape province, Sibanda and Okoh [14] failed to find the hepatitis A virus or the Rotavirus in water samples taken from the middle to downstream Tyume River. They explained this failure by pointing out that the virus is not present in the environment because it is not present in the host population. Thus it can be established that a virus found in an environment such as a water body gives an idea of the kind of disease that is common within a community and if this is found out on time it can be treated and eradicated before it becomes endemic. Tourists and travelers on the other hand can have an idea of the particular disease associated with the particular environment they are about to visit and can plan ahead of time, either by taking a vaccination or by taking the drug of choice with them.

3.2. Virus Recovery and qPCR Inhibition

Virus recovery and qPCR inhibition in surface waters used for domestic purposes are important concerns for public health. The detection and quantification of viral pathogens in surface waters are essential to assess the safety

of these water sources. One of the most powerful molecular biology tools used in the last few decades for viral detection in water is the quantitative polymerase chain reaction (qPCR) assay. It involves the exponential amplification of the genomic DNA using a specific primer molecule [15]. Reduced sensitivity or false-negative results are the main effects of PCR inhibition. Organic or inorganic substances can appear as PCR inhibitors, however, most of the known inhibitors are organic compounds such as bile salts, urea, phenol, ethanol, polysaccharides, sodium dodecyl sulfate (SDS), humic acids, tannic acid, melanin as well as different proteins, such as collagen, myoglobin, and proteinases which could be deposited in the water during the different activities that are carried out in the surface water as shown in table 1 above. Apart from the presence of inhibitory substances, the concentration of the inhibitory substance is very important for its inhibitory effect to take place. PCR inhibitors interfere with the different steps of PCR analysis in different ways which include modification of the DNA template, degradation of the DNA by the nucleases, cross-linking of RNA by phenols, and inhibition of reverse transcription by direct interaction of the enzyme with melanin. These effects could partly be reversible by adding Tween 20, dimethyl sulphoxide, or polyethylene glycol 400.

PCR inhibition also occurs when substances in the water sample interfere with the amplification of the target DNA sequence, leading to an underestimation of the viral load [23]. In addition to qPCR inhibition, virus recovery from surface waters used for domestic purposes can also be challenging. Factors such as the type of virus, the presence of organic matter, and the season can all affect virus recovery rates [24]. Poor virus recovery can lead to an underestimation of the viral load in surface waters, which can also compromise public health. To overcome these challenges, researchers have explored various methods for virus recovery and qPCR inhibition mitigation in surface waters used for domestic purposes as shown in table 3 below. These include the use of different sample preparation methods, such as ultrafiltration and polyethylene glycol precipitation, to improve virus recovery rates [25]. Additionally, the use of DNA extraction kits that can effectively remove qPCR inhibitors from water samples has been suggested to improve the accuracy of qPCR results [26]. Table 3 below is a compilation showing all the research work on enteric virus risk analysis carried out in African countries indicating their concentration method to recover the specific viruses and the recovery efficiency of the virus obtained. The various method of viral extraction and detection form reviewed articles are shown below in Table 3 below.

Table-3. Different methods used for viral concentration, extraction, detection, and recovery efficiency

Author & Year	Sample size	Positive case	Water type	Concentration Method	Viral Extraction	Detection Method	Country	Recovery efficiency	Microbe
[27]	54	EnT (32.69%)	Lagoon	Chopping and smashing of digestive tissues of Oysters collected	PureLink™ Viral RNA/DNA Mini Kit	qRT-PCR	Morroco	N/A	Enteric virus
[5]	72	HAV (43.1%) RoV (13.9%) EnT (9.7%)	River	Adsorption-elution method	Quick-gDNA MiniPrep (Zymo Research, USA),	real-time quantitative PCR	South Africa	56 ± 32%	Adenovirus
[4]	6 Site	HAdV (83%); HAV (100%); RoV(50%); EnV(50%)	River and a source water dam	Adsorption-elution method	Quick-gDNA MiniPrep (Zymo Research, USA),	real-time quantitative PCR	South Africa	56 ± 32%	HAdV, HAV, RoV, Enterovirus
[11]	154	River (HAV 17.5%); Dam (HAV 14.9%)	River and dam	glass wool adsorption-elution technique and PEG	N/A	Cell culture-reverse transcriptase-polymerase chain reaction (RT-PCR)-oligonucleotide probe hybridization assay	South Africa	40%	HAV
[28]	32	AdV (94%) NoV (31%), RoV (50%),	River Nile	polyethylene glycol precipitation	QIAamp MiniElute Virus Spin Kit (Qiagen, Germany)	RT-qPCR	Egypt	N/A	Norovirus, Rotavirus Adenovirus
[12]	26	65%	Stormwater drainage, grey water tertiary drains, and unprotected springs	glass wool filtration protocol	N/A	qPCR for adenovirus and Quantitative RT-PCR for rotavirus	Uganda	38%	Rotavirus HAdV F and G
[29]	164	RoV (1.2%)	tap water	N/A	N/A	nested multiplex polymerase chain reaction (PCR)	South Africa	N/A	rotavirus (RV)
[30]	48	RoV (16%)	River	Aluminum chloride and filtered using 0.22 µm eluted by 6% glycine through the filter	RNeasy® mini kit (QIAGEN)	RT-qPCR	Nigeria.	N/A	Rotavirus
[14]	72	HAV: 13%, RoV: 4%, NoV: 4%	River	adsorption-elution method	Quick-RNA™MiniPrep (Zymo Research	real-time RT-PCR (reverse transcription-polymerase chain reaction)	South Africa	56%	Hepatitis A, Rotavirus Enterovirus.
[12]	20	NoV (80%), AdV (55%)	Stream and river	N/A	PowerWater DNA and RNA isolation kits	reverse transcription qPCR (RT-qPCR)	Ghana	N/A	Adenovirus and norovirus
[31]	188 treated water 45 river water	Treated water (AdV; 5%) and River water (AdV; 22%)	Treated drinking water and river water	glass wool adsorption elution method and PEG	High Pure NucleicAcid Kit	the conventional nested PCR method	South Africa	40%	Adenovirus
[17]	204 drinking water, 51 river water, 51 dam water	Drinking water (AdV; 4.41%) River sample (AdV;7.8%); Dam water (AdV; 17.7%)	River, dam, and treated drinking water	glass wool adsorption elution method	High Pure NucleicAcid Kit	the conventional nested PCR method	South Africa	40%	Adenovirus

3.3. Exposure Analysis

In Africa, surface water use for domestic purposes is a serious public health concern because it exposes people to enteric viruses and other pathogens as shown in table 4 below. The contamination of surface water sources is usually a result of improper wastewater treatment and a lack of suitable sanitation facilities [32]. Human exposure to enteric viruses can occur through several routes, which include ingestion, inhalation, and dermal contact with contaminated surface water. Route of exposure is a major determinant of infection in microbial risk assessment as seen in table 4. For an individual to be infected, the virus must have a successful passage into the host system, which is determined by exposure to the contaminated water. In exposure assessment, the amount of enteric virus present in surface water, to which the individual is exposed, matters a lot. If a little amount of the virus is present in the water, then that means the viruses are sparsely distributed and the probability of being infected when exposed to such a water body is low. Unfortunately, this is not the case as high concentrations (10^5 –10^{13}/g faces) of the human enteric virus are excreted and disseminated into the surface water through the fecal-oral route [4]. During recreational activities, gastrointestinal viruses are secreted in large amounts, up to 10^5—10^{12} per gram in water. HAV's infectious dose is assumed to be 10-100 viruses; therefore, even a tiny amount of fecal contamination can be dangerous [11]. When analyzed in the laboratory, the efficiency of the virus recovery procedure cannot be overlooked or taken for granted. Due to the large size of water bodies, enteric viruses in water bodies must be concentrated using an efficient and effective technique as stated earlier. The quantity of the virus recovered determines the dose of exposure or the amount to which an individual has been exposed. However, the route of exposure determines the dose of exposure because it reveals the amount of untreated water containing the virus been consumed. Singh, *et al.* [33], indicated that bioaerosol inhalation exposure is approximately 10^5 times more effective than dermal exposure, however, it cannot be compared to direct water intake. The higher the amount of water consumed, the higher the exposure rate. It is not sufficient for a virus to be present to cause disease, it must be able to cause infection. This is the major issue with the detection of enteric viruses because most times, real-time PCR is used to identify enteric viruses, and it cannot assess the virus's vitality and contagiousness. Therefore, to determine the proportion of infectious viruses, infective viral ratios that have been previously estimated are divided by the total virus particles. It is also important to note that this varies with the environment in which the water sample is obtained and also with the organism used [4]. Only a viable virus can cause disease in a population. The volume of water taken during exposure determines the dose of organism consumed, which in turn determines the level of risk an individual is exposed to. Although there is a default volume by WHO for estimating exposure which is 2,000 mL/individual/day for drinking water and 100 mL/day for recreational activities, some nations have used different volumes, as revealed in different articles [4]. Chigor, *et al.* [4], assumed 100mL for drinking water, 30mL for recreational activities, for domestic application 10ml of untreated water, and for irrigation 1ml of untreated water consumed per person per day to estimate risk via exposure. It's crucial to remember that viruses are primarily found during the winter season in environmental samples due to low temperatures, which lower the deactivation rates of these organisms. The summertime is when the virus circulates among people [14]. Table 4 below shows the route of exposure and the amount of virus being exposed to by the individuals.

Table-4. Route of exposure and the amount of virus exposed to by the individual who consumes surface water

Author	Route of Exposure	Concentration of virus	Infectivity	Dose of Exposure	Probability of mortality per day	Probability of mortality per year
[18]	consumption of shellfish or oysters	4.31 to 2E+05 RNAc/g copy number	N/A	N/A	N/A	N/A
[5]	consumption of water while playing or swimming and direct contact with water	Parkside: 1.51 x 10^3 GC/l (3.25 x 10^2–4.71 x 10^3 GC/); King William's Town: 1.39 x 10^3 GC/l (1.02 x 10^2–4.56 x 10^3 GC/l); Eluxolzweni:2.60 x 10^2 GC/l (1.17 x 10^2 –3.97 x 10^2 GC/l). Bridle Drift Dam:1.86 x 10^1 GC/l (1.2x10^1-2.3 x 10^1 GC/l). Rooikrantz Dam (1.74 x 10^1 GC/l), Maden Dam: None	N/A	N/A	N/A	N/A
[4]	drinking, recreational, domestic, or irrigational activities	Rooikrantz dam: (HAdV:1.6 X 10^1viruses/L, HAV: 4.4 X 10^2) Bridle drift dam: (HAdV: 1.7 x10^1, HAV: 1.6 X 10^3), King Williams Town: (HAdV: 1.2 x10^3, HAV: 7.6 X10^1, RoV: 1.1 X10^2, EnV: 3.6 X 10^{-1}) Eluxolzweni: (HAdV: 2.3 x 10^2, HAV: 4.2 X 10^1, RoV: 2.8 X 10^2, EnV: 2.8 X $10^{-1)}$, Parkside (HAdV: 1.4 X 10^3viruses/L, HAV: 3.8 X 10^1, RoV: 7.9 X 10^1, EnV: 1.3 X 10^0), Maden Dam: (HAV: 5.1 X 10^2).	HAdV1:2, HAV 1:60, RoV 1:10, EnV 1:100 i.e 50,1.7,10 and 1 respectively	N/A	6.58 x $10^{-9}$to 5.0 x 10^{-5}	N/A
[11]	Recreation and drinking	River water: HAV 7.94 x 10^{-3}viruses/L Dam water: HAV 8.53x10^{-4} viruses/L	1	N/A	high socioeconomic group for recreation(4.1 x 10-6 river	high socio-economic group for recreation (1.5 x 10-3

					water, 5.3 x 10-7 dam water), low socioeconomic group for recreation(1.1 x 10-6 for river, 1.2 x 10-7 for dam), low socioeconomic group for drinking (2.2 x 10-5 for river, 2.3 x 10-6 dam)	river, 1.9 x 10-4 dam), low socio-economic group for recreation (3.3 x 10-4 river,4.2 x 10-5 dam),low socio-economic group for drinking (1 x 10-3 river,5.8 x 10-4 dam)
[19]	Consumption of vegetable	Mean RVA load (gc/L)(Min-Max) 6.3×10^5 (5×10^5-8.8×10^5)	RoV 1:10	$3.5\times10^3 \pm 1.6\times10^3$ gc/day dose of exposure	N/A	N/A
[12]	Ingestion, Dermal contact Inhalation.	Nsooba inlet [HAdV 1.53 (±1.1), RoV 2 .98 x 10^1 (± 3.66 x 10^1)]. Nsooba outlet [HAdV 2. 65 x 10^1 (± 1 .9 x 10^1), RoV 5.12 (±6 .2)]. JN Nsooba/Nakamilo [HAdV 5.32 x 10-1 (±4. 0 x 10-2), RoV 2.48 (± 9.61 x 10-2)], Nakamilo inlet [HAdV 3.27 x 10-1 (± 4. 8 x 10-2), RoV 1 .66 (±5.63 x 10-1)]. Grey water in tertiary drain (st. Francis Zone) [HAdV1.35 x 10^{-1} (± 1 .9 x 10^{-1}), RoV 3. 44 x 10-1 (± 4. 86 x 10^{-1})]. Grey water tertiary drain (Katogo zone): [HAdV 7. 80 x 10-1 (± 1.6), RoV:8. 85 (± 16 .3)]. Spring water source: HAdV 7.62 x 10^{-3} (1 x 10^{-2})	N/A	Nsooba inlet (1.53 x 101 HAdV, 2.98 x 102 RoV), Nsooba outlet (2.65 x 102 HAdV, 5.12 x 101 RoV), JN Nsooba/Nakamilo(2.66 x 100 AdV, 2. 48 x 101 RoV), Nakamilo inlet (3.27 X 100 AdV, 1.66 x 101 RoV), Grey water in tertiary drain (st. Francis Zone)(6.75 x 10-1 AdV, 1.72 x 100 RoV), Grey water tertiary drain (Katogo zone)(3. 90 x 100 AdV,4.43 x 101 RoV), Grey water tertiary drain-Bombo road (2.03 x 102 AdV), Unprotected spring (3.81 x 100 AdV)	N/A	N/A
[20]	Drinking,	N/A	N/A	N/A	N/A	N/A
[13]	Drinking and accidental consumption	1.3 $\log_{10}$ genome copies 100 ml^{-1}	N/A	N/A	N/A	N/A
[14]	Recreational and domestic water uses	Uncorrected concentration (genome copies/ℓ) (HAV: 8.05×10^3, RoV: 1.89×10^3), Corrected concentration (genome copies/ℓ) (HAV: 1.44×10^4, RoV: 3.37×10^3), Calculated concentration of infectious viruses (genome copies/ℓ)(HAV: 2.4×10^2, RoV: 8.43×10^{-2})	N/A	N/A	N/A	N/A
[15]	Consumption of contaminated plant	Odaw River (AdV:1.70 ± 0.44 × 10^4 NoV:2.62 ± 0.14 × 10^3); Onyansa Stream (AdV:3.77 ± 1.26 × 10^2;3.71 ± 0.34 × 10^2 NoV: 1.04 ± 0.47 × 10^3; 2.18 ± 0.58 × 10^3)	N/A	N/A	N/A	N/A
[21]		River sample (4.16 x 10^{-2} to 4.24 x 10^{-5}); Treated drinking water (5.25 x 10^{-3} to 1.5 x 10^{-6})	N/A	N/A	N/A	N/A
[17]	Drinking and accidental consumption	Drinking water supply A: 1.40 x10^{-4} Drinking water supply B:2.45 x 10^{-4} River water: 5.46 x 10^{-3} for the Dam water: 9.97 x 10^{-4}	1	N/A	Drinking water supply A:1.5 x10^{-6} Drinking water supply B:2.6 x10^{-6} River water: 8.6 x10^{-7} Dam water: 1.6 x10^{-7}	N/A

3.4. Risk Assessment

Enteric viruses are a common cause of waterborne illnesses in Africa, with millions of people being affected each year. The risks associated with exposure to these viruses can be significant, and risk analysis is an essential tool for identifying and managing these risks. Risk analysis is a process of identifying and assessing potential risks, determining their likelihood and severity, and developing strategies to mitigate them. Risk analysis involves identifying the sources of contamination, the pathways of exposure, and the factors that increase or decrease the likelihood of infection. The microbial risk of waterborne infection and public health hazards is caused by enteric

viral contamination of source water [4]. This allows the organism to harm healthy human beings when human beings ingest the contaminated water. The ability of the virus to cause infection is heavily reliant on the host's maturity level, pregnancy, immunity, natural environment, diet, conduct, and behavioral skill. All the articles reviewed utilized the four-step static QMRA which involves hazard identification, exposure assessment, dose-response assessment, and risk characterization as seen in table 5 below. The risk of infection data is entered into statistical equations that connect the average dose consumed to the likelihood of infection. The two prevalent models that do this perfectly are the exponential and the Beta Poisson models. In the exponential model, microorganisms are distributed randomly or haphazardly in the water, and at least one virus must get through within the host, despite all organisms having the same fixed likelihood of getting through and reaching the host site at which disease can occur. In the Beta Poisson model, the possibility of illness per water consumed depends on the population and the likelihood of an organism being alive until it reaches the host site. The exponential model is most times used for adenovirus and enterovirus. The Beta Poisson model is used most times for Hepatitis A and Rotavirus. The choice of the model to be used is based on the accessibility of dose-response parameters as shown in table 5 below. However, Dissimilar trends have been observed in both models, in the exponential model as the risk of HAdV infection increased the dose-response parameter (r) also increased, while in the Beta-Poisson model, an increase in the dose-response parameter (a) decreased the risk of infection in HAV [4]. Viruses can survive and stay contagious for 130 days in seawater and up to 120 days in fresh water, sewage, and tropical temperatures (30°C). Rotavirus particles can survive up to 2 months and maintain infectivity for more than 32 months at ≤10°C [14]. This is enough time for a whole community to be infected and completely wiped out because this is a public health risk to the consumer either during domestic activities or recreational activities because the presence of the virus is ascertained in the water, especially in low-income areas with no portable water source of which majority is found in Africa. Enteric HAdV is a virus with a double-stranded DNA genome, and both strands serve as a template for replication incase environmental factors damage any strands. This double-stranded DNA genetic material is immune to ultraviolet light. This is due to the ability of the host cell DNA repair mechanism to repair UV-induced pyrimidine dimers in the viral genetic material [31]. Table 5 below shows the different models used by researchers in this review and their output

Table-5. The Model used, the Probability of infection, and their output.

Author	Model/ approach used	Probability of infection (%)	The dose-response parameter (r) in the exponential model	Using the beta-Poisson (β-Poisson) model the value of alpha and beta	N_{50}
[18]	N/A	N/A	N/A	N/A	N/A
[5]	N/A	N/A	N/A	N/A	N/A
[4]	Exponential model and the beta-Poisson model	For drinking untreated water HAdV (52-100%), HAV (2-30%), RoV (53-65%), EnV (1-6%)	HAdV 0.4172 and 0.0145 for EnV	HAV α = 0.200 RoV α = 0.2531 RoV β = 0.4265	1000 was assumed for HAV. However, Reported N_{50} values ranged from 5.6 to 10,000 (WHO, 2001)
[11]	Deterministic exponential model and all individuals are assumed to be immunocompetent	N/A	0.549	N/A	N/A
[19]	The β-Poisson dose-response mode	N/A	N/A	α = 0.2531	N_{50} = 6.17
[12]	β-Poisson model for rotavirus infections and exponential model for the adenovirus	HAdV 35%, RoV 20%	N/A	N/A	N/A
[20]	β-Poisson model	N/A	Adenovirus r = 0. 4172	Rotavirus α= 0. 2531	N_{50} = 6. 17 for Rotavirus
[13]	β-Poisson model	N/A	N/A	N/A	N/A
[14]	N/A	N/A	N/A	α = 0.265; β = 5.6	N/A
[15]	N/A	N/A	N/A	Rotavirus α = 0.2531 Rotavirus β = 0.4265, HAV, α = 0.2,	for HAV, N_{50} =100 ,
[21]	N/A	N/A	N/A	N/A	N/A
[17]	Exponential model	N/A	0.4172	N/A	N/A

3.5. QMRA Dose-Response Model

The procedure known as quantitative microbial risk analysis (QMRA) involves determining the risks connected to the presence of microorganisms in food and water sources. It is a useful tool that is frequently used to evaluate the possible dangers related to consuming surface water in Africa, where microbial infections are frequently a problem. A crucial element of QMRA is the dose-response model. It assesses the likelihood of infection or sickness linked to a certain pathogen at a given degree of exposure as shown in table 5 above. The dose-response model is used to calculate the risk of infection or sickness brought on by exposure to microbial pathogens such as enteric viruses in the instance of surface water in Africa [34]. There are numerous methods for creating a dose-response model for waterborne pathogens. One commonly used method is to conduct controlled human studies in which volunteers are exposed to various doses of the pathogen and monitored for the development of symptoms. However, conducting such studies can be challenging and expensive, particularly in resource-limited settings like Africa. As an alternative, mathematical models can be developed based on the available data on the pathogen's properties and the epidemiology of the associated illnesses. The probability of daily infection for the enteric virus can be obtained using the models that are either the Beta Poisson model or exponential model or the dose-response model. In Africa, where surface water is often contaminated with a variety of microbial pathogens, QMRA is a critical tool for estimating the risks associated with exposure to these pathogens. The development of accurate and reliable dose-response models is

essential for the accurate assessment of these risks and for informing the development of effective interventions to reduce the risk of waterborne illnesses.

3.6. Detection Problems and Limitations

3.6.1. Misdiagnosis of Viral Enteric Infection as Bacterial Infection

Viral enteric infections are a common cause of diarrhea in African countries, with rotavirus being the most common pathogen. Misdiagnosis of viral enteric infections as bacterial infections is a significant problem, as it leads to inappropriate use of antibiotics, which can increase the risk of antibiotic resistance and have negative health consequences on patients. A study conducted in Ghana found that healthcare providers often prescribe antibiotics for diarrhea without testing for the presence of bacterial pathogens or considering the possibility of viral enteric infections. The study identified rotavirus as the most common cause of diarrhea in children under five, yet many healthcare providers prescribed antibiotics for these cases despite their ineffectiveness against viral infections [35]. A similar study in Nigeria found that more than half of the children diagnosed with bacterial diarrhea were infected with rotavirus. The study also found that antibiotic use was higher among children misdiagnosed with bacterial diarrhea compared to those correctly diagnosed with viral diarrhea [30]. Diagnostic tests are essential to accurately identify the cause of diarrhea and reduce unnecessary antibiotic use. Healthcare providers must be educated on the appropriate use of antibiotics for diarrhea and the importance of testing for viral enteric infections to improve patient outcomes and reduce the spread of antibiotic resistance.

3.6.2. The use of the Wrong Tools and Techniques

The diagnosis of enteric viruses is crucial for the management and prevention of infections in Africa. However, the use of the wrong tools and techniques can result in misdiagnosis, leading to inappropriate treatment and increased disease burden. The presence of the infectious enteric virus in the environment is estimated using the cell culture technique, however, the cell culture of Hepatitis A seems to be long and has less sensitivity and specificity, in particular when using environmental samples with a low concentration of the virus. A combination of approaches has been utilized for the identification of rotavirus which comprises cell culture, electron microscopy (EM), latex agglutination (LA), and enzyme immunoassay (EIA). Molecular methods have improved the detection of rotavirus in clinical and environmental samples. However, so many authors have detected a higher yield of rotavirus using reverse transcription and real-time PCR compared to other molecular methods and real-time RT-PCR for Rotavirus identification in clinical samples is 1000 times more sensitive. It is important to note that PCR techniques are vulnerable to inhibitors found in water samples, which could result in a false negative result [14].

3.6.3. Limited Funding for Expensive Viral Research

Limited funding for expensive viral research in African countries is a major hindrance to the effective control of viral outbreaks and epidemics in the continent. Various studies have reported insufficient funding for research on viral diseases in Africa, which has resulted in poor preparedness and response to outbreaks such as Ebola and COVID-19. Viral research is costly; the tools and equipment for isolating, identifying, and characterizing these viruses are extremely expensive. This is the primary reason we have limited research on the waterborne enteric virus in Africa. Africa is dominated by low-income countries and therefore does not have enough resources and finance to fund this project. A report by the World Health Organization [36] indicated that the limited funding for viral research in Africa had resulted in the slow development and deployment of effective interventions against COVID-19 in the continent. The report called for increased investment in research and development to improve the capacity of African countries to detect, prevent, and respond to viral outbreaks.

3.7. Mitigation and Strategies

Waterborne enteric viruses are one of the major causes of waterborne diseases globally, especially in developing countries, where inadequate water, sanitation, and hygiene (WASH) facilities are common. In Africa, the situation is even worse, as the continent has the highest burden of waterborne diseases compared to other continents. The detection and mitigation of waterborne enteric virus contamination in Africa face various limitations, including the lack of appropriate detection methods, inadequate surveillance systems, and poor water, sanitation, and hygiene (WASH) facilities. Effective surveillance systems are crucial for monitoring waterborne diseases and identifying outbreaks early. However, many African countries lack adequate surveillance systems for waterborne diseases, including waterborne enteric viruses. A study by Oluremi, *et al.* [30] highlighted the need for strengthening waterborne disease surveillance systems in Africa by establishing a comprehensive network for monitoring water quality and disease outbreaks. The study recommended the integration of existing WASH programs with disease surveillance systems to improve waterborne disease control and prevention. It is thus very advisable that water should be boiled before consumption. Recreational activities such as swimming and playing in surface water such as streams and rivers should be reduced as much as possible. Dumping of dirt and excreting faces in rivers or close to the rivers should be avoided as much as possible. Government and policymakers should place laws to restrict movement around contaminated surface water to reduce the activities carried out around the water and in turn, protect the public at large.

3.7.1. Advocacy for Improved Funding for Viral-Related Research in Africa

Africa is home to a variety of viral diseases, including HIV/AIDS, Ebola, Lassa fever, yellow fever, and many others. These diseases have had a devastating impact on the continent's health and economic well-being. However,

despite the high incidence of viral diseases in Africa, research funding for these diseases is limited. Funding for viral research in Africa has historically been low. The World Health Organization estimates that less than 2% of all research funding globally is allocated to diseases that primarily affect low-income countries, which includes many of the viral diseases prevalent in Africa [37]. This funding gap has led to limited progress in developing effective treatments and vaccines for these diseases. Advocates for improved funding argue that increased research funding would not only improve health outcomes but also contribute to economic growth. According to a report by the Global Health Technologies Coalition, investments in global health research have the potential to generate economic benefits that are several times greater than the initial investment [38]. By investing in viral research, Africa could potentially develop new treatments and vaccines that could be used worldwide, creating economic opportunities for the continent.

3.7.2. Intra-Africa and Africa-External Collaborations for skill Acquisition and Knowledge Transfer

We use this opportunity to call for collaborations from other continents and nations to provide resources and funding for research in African countries, especially on enteric viruses. This will go a long way to encourage research; the more research is done, the more useful output will be published in this area. The process of collaboration from other nations will also help with skill acquisition and knowledge sharing among the participants. Thus, making the world a better place.

4. Conclusion

In conclusion, this study has shown that waterborne enteric viruses are a significant hazard and contaminant in African countries. The analysis of journal articles from six African countries revealed that the probability of infection and risk of illness for individuals exposed to river and dam water through drinking, recreational, domestic, or irrigation activities were alarmingly high in Africa countries. The findings suggest that there is a need for urgent action to improve water quality in Africa and reduce the risk of waterborne infections. With only 105 articles identified on this topic, it is evident that more research is needed to better understand the prevalence, transmission, and mitigation of these viruses. The high mortality rate associated with hepatitis A virus and the predominance of human adenovirus in surface water in African countries underscore the urgency of implementing effective surveillance and control measures. The WHO's acceptable risk limit of 0.01% (10^{-4} infection/individual/year) is consistently being exceeded in all articles reviewed, indicating the need for immediate interventions to improve water quality and reduce the risk of enteric viral infections in Africa.

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Competing Interests

Authors have declared that no competing interests exist.

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