JOURNAL OF PURE AND APPLIED MICROBIOLOGY, June 2013. Vol. 7(2), p. 1189-1206

Water Quality Deterioration and its Socio-economic Implications

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(Received: 29 September 2012; accepted: 10 November 2012)

From ancient times, people have chosen to live close to water sources, settling in river valleys. Improved water supply and water resources management boosts countries' economic growth and contributes greatly to poverty eradication. An adequate supply of safe drinking water is one of the major prerequisites for a healthy life but, because of surface water pollution, waterborne disease became, and still is, a major cause of death in many parts of the world, particularly in children. Rapid urbanisation has exacerbated surface water pollution by increasing point pollution and non-point source pollution entering surface waterbodies. Physico-chemical and microbiological properties of water are used to assess water quality as they give a good impression of the status, productivity and sustainability of waterbodies. Water pollution control has been a matter of public concern for more than a century. Currently, human beings and natural ecosystems in many river basins suffer from debilitating effects of water pollution. Hence, development of better water conservation practices and policies are critical to the sustenance of our water both in terms of quantity and quality to ensure protection of public health.

Key words: Freshwater, Water quality, Pollution, Public health, Physico-chemical, Microbiological.

From ancient times, people have chosen to live near water, settling in river valleys, beside lakes, or along coastlines [1]. Without freshwater of adequate quantity and quality, sustainable development will not be possible [2]. Water quality reflects the composition of water as affected by natural causes and man's cultural activities expressed in terms of measurable quantities and related to intended water use [2]. Worldwide, waterbodies are the primary dumpsites for disposal of waste, especially effluents from industries located near them[3]. Effluents from industries harbour toxic contents, capable of altering the physical, chemical and biological nature of the receiving waterbodies [4; 5]. First to be degraded by such waste is the physical quality of the water, while the biological degradation becomes evident later in terms of number, variety and organisation of the living organisms in the water [6]. DWAF [7] defined water pollution as the alteration of the properties of a water resource so as to make it, among others, "harmful or potentially harmful to the welfare, health or safety of human beings". Much of the current concern with regards to environmental quality is focused on water because of its importance in maintaining human health and health of the ecosystem [8].

Surface water stress and vulnerability

Water pollution occurs when unwanted or toxic substances are accidentally or intentionally introduced into waterbodies in quantities which affect the resource in providing its services, which include domestic use, irrigation, navigation, recreational and life support (ecological) functions

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[9]. Water stress and vulnerability are linked, since pollution reduces the volume of water available for human use [1]. Thus, preventing pollution is among the most cost-effective means of increasing water supplies.

Rapid urbanisation has exacerbated surface water pollution by increasing point source pollution and non-point source pollution entering surface waterbodies [10]. Both the withdrawal of surface water for human use and economic activities and its subsequent discharge back into surface water resources as effluents can affect the ability of aquatic ecosystems to survive [10]. Such effluents have been reported to also include antibiotics and other pharmaceutical compounds [11]. The occurrence of antibiotics in aquatic environments is of ecotoxicological concern because of potential ecosystem alteration [12]. Prolonged exposure to low doses of antibiotics leads to the selective proliferation of resistant bacteria, which could transfer the resistance genes to other bacterial species [13].

Water quality problems and their effects are different in type and magnitude in developed and developing countries, particularly those stemming from microbial and pathogen content [14]. Currently, human beings and natural ecosystems in many river basins suffer from water scarcity. In global-scale assessments, basins with water stress are defined either as having a per capita water availability below 1,000m^3/yr (based on long-term average runoff) or as having a ratio of withdrawals to long-term average annual runoff above 0.4 [14]. Populations living in such severely stressed basins are estimated to range from 1.4 billion to 2.1 billion[14].

Indicators of surface water pollution

Reporting on the endemic water pollution problem in Zimbabwe, The Herald [9] had this to say,"The presence of pollutants in water is primarily perpetrated by human activities. These pollutants are either discharged directly into rivers or are carried into streams and rivers by surface runoff, leading to serious deterioration of water quality. Water pollution can be categorised into four broad categories viz: organic pollution which occurs when excess of organic matter, such as manure or sewage, enters the water; toxic pollution which occurs when a chemical pollutant that is not a natural component of an aquatic ecosystem is introduced; thermal pollution which occurs when water is used as a coolant near a power or industrial plant and then returned to the aquatic environment at a higher temperature than it was originally and ecological pollution which takes place when chemical pollution, organic pollution or thermal pollution are caused by nature rather than by human activity." The presence of pollutants belonging to any of the above categories can be ascertained by periodically assessing the physicochemical and microbiological properties of in-stream water [15].

Physicochemical parameters

Dissolved constituents of waterbodies are often determined as a major component for baseline limnological studies [16]. Physico-chemical properties of water are used to assess water quality as they give a good impression of the status, productivity and sustainability of such waterbodies[17]. Physico-chemical determinants of pollution in rivers, lakes, and oceans include temperature, pH, total dissolved solids (TDS), turbidity, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), heavy metals and nutrients amongst others [15; 18]. These pollutants originate either from point or non-point sources [1]. DO is the most important factor in the assessment of water quality and is vital for aquatic life [18] while temperature is the most important physical variable affecting the metabolic rate of aquatic microorganisms [19; 20] as well as the chemical reactions in water, thereby determining the solubility of gases (including oxygen) and imparting taste and odour to the water [21]. Healthy freshwater bodies are characterised by a DO concentration of at least 5 mg/L [22]. Surface water temperature is directly affected by changes in ambient air temperatures and indirectly by the inflow of water of a different temperature [23], characteristic of discharge of large volumes of water from industrial plants. The pH of natural waters range from less than 4 to greater than 12, but usually falls between 6 and 9 for unpolluted river systems [24]. pH values above and below this range are indicative of water pollution [18]; and could give rise to toxic effects, largely as a result of disturbances in internal ion homeostasis [23]. High concentrations of dissolved phosphate may lead to osmotic stress, as is the case with high nitrate concentrations [25]. Even though trace quantities of phosphorous are naturally present in surface waters [21], higher concentrations of phosphate could be indicative of pollution from domestic waste and agricultural runoff, and may lead to eutrophication, which has drastic economic, social and ecological consequences [21]. High levels of organic pollution can also result in low DO and high BOD and COD concentrations [26]. High turbidity is harmful to aquatic organisms since it can cause anaerobic conditions, interfere with respiration in aquatic fauna and also reduce light penetration, hindering photosynthesis and natural aquatic life [27]. EC is directly related to TDS in water and its value becomes greater with increasing degree of pollution [28].

Faecal indicator bacteria

Faecal indicator bacteria (FIB) have been used for many years to determine the quality and safety of surface and ground waters [29; 30]. Bacterial groups classified as FIB include the total coliforms (TC), faecal coliforms (FC) and enterococci (synonymously used as faecal streptococci) [31]. Faecal streptococci have been suggested as the recommended indicator for salt water while either faecal streptococci or *Escherichia coli* can be used for monitoring freshwaters [31]. Faecal streptococci are widely accepted as useful indicators of faecal pollution in natural aquatic ecosystems because they show a close relationship with gastrointestinal symptoms associated with bathing in marine and freshwater environments [32; 33] while their persistence patterns are also similar to those of potential water-borne pathogenic bacteria [34].

FC (also known as thermotolerant coliforms) include strains of the genera *Klebsiella* and *Escherichia* [35]. It has been suggested that for the purpose of sanitary water testing, *E. coli* should be used as an indicator of faecal pollution since it possesses a more direct and closer relationship with homeothermic faecal pollution [36]. However, *E. coli* has been detected in some pristine areas [37] and has also been associated with regrowth in drinking water distribution systems [38]. The presence of these bacteria in surface waters is thought to indicate that pathogenic organisms such as *Salmonella* spp., *Shigella* spp. and hepatitis A may also be present [30]. Polo *et al.* [39] reported incidences of serotypes of *Salmonella* spp. isolated from freshwater sources in Spain which were identical to serotypes found in clinical samples, a case that underlines the connection between water quality and public health. However, epidemiological studies in warm tropical waters demonstrate the lack of a strong relationship between faecal indicators and health outcomes, in part, due to the inappropriate nature of *E. coli* or faecal streptococci as indicators of waterborne pathogens in these recreational waters [31]. Alternatively, spores of *Clostridium perfringens* have been proposed as a useful indicator when fresh faecal contamination is being investigated [40] and more importantly, as suitable indicators for parasitic protozoa and viruses in sewage-impacted waters [41]. Bacteriophages have also been suggested as indicators specific for human sewage, and more specifically *Bacteroides fragilis* phages which appear to survive in a similar manner to that of human enteric viruses under a range of conditions [42].

Contamination of surface waters with faecally derived bacteria can occur through point sources like sewage effluents and non-point sources such as agricultural and urban run-off [43]. Sewage effluents contain a wide variety of pathogenic microorganisms that may pose a health hazard to the human population when discharged into recreational waters [31; 44]. The density and variety of these pathogens are related to the size of the human population, the seasonal incidence of the illness, and dissemination of pathogens within the community [45]. Studies also prove that bathers can be a significant source of pathogenic micro-organisms, even in cases where there is no faecal pollution from the outside [31]. Storm events and recreational activity also cause the re-suspension of FIBs resulting in a rapid increase in the load of pathogens in the water phase [43]. The U.S. Environmental Protection Agency [46] reported that 35% of impaired rivers and streams were polluted by FIB which could indicate the presence of enteric pathogens.

Water-borne enteric viruses

Faecal matter of patients suffering from virally-induced gastroenteritis contains high concentrations of human enteric viruses which, if not inactivated during wastewater treatment processes may contaminate surface water sources for drinking water, recreational activities, aquaculture and irrigation [47; 48; 49; 50; 51]. Human enteric viruses include the families *Picornaviridae* (these are enteroviruses like poliovirus, coxsackievirus, and echovirus), *Adenoviridae*, *Caliciviridae* (norovirus, calicivirus), *Astroviridae*, and *Reoviridae* (reovirus, rotavirus) [52]. They cause a wide range of diseases which include epidemic gastroenteritis, meningitis, ocular and respiratory infection, paralysis, myocarditis and hepatitis [53].

Enteric viral pathogens have been shown to be present in environmental waters even when bacterial indicators are absent [54; 55; 56]. Studies focusing on non-enteric viruses like bacteriophages, viruses infecting algae, protozoa, fish and vascular plants [57] have found that the dynamics of these viruses are linked to the dynamics of potential host cells (primarily bacteria and algae) [58; 59]. The abundance of these viruses has been shown to peak following an increase in host cell abundance [60; 61]. However, enteric viruses are obligate intracellular host-specific parasites which cannot grow or survive for extended periods in environmental waters outside their host. These viruses are very small, ranging from 20-70 nm in diameter and consist of a nucleic acid genome surrounded by a protein capsid and, in some cases, a lipoprotein envelope [62]. Survival and/or persistence of enteric viruses in the environment is strongly linked to various environmental factors like exposure to ultra-violet radiation, temperature [63; 64; 65], adsorption to particulate material [66; 67] and salinity [68; 69; 70]. Their susceptibility to the different environmental factors may, however, vary profoundly within the viriosphere as viruses are capable of developing resistance mechanisms to survive in harsh habitats including hypersaline waters and hot springs or hydrothermal vents [71; 72; 73; 74].

Viral persistence in tropical freshwater environment

While specific viruses or strains of viruses are not always present in a community at any one time, representatives of the large groups are, however, generally present on most occasions[62]. Enteric viruses may be found in high numbers in domestic wastewater, their numbers generally varying with the level of virus infection in the community [75]. Wastewater treatment processes that do not include a disinfection step are often inefficient in removing viruses [62].

In previous studies, levels of human viral contamination in sewage and wastewater treatment plants were analysed [76; 77, 78; 79; 80; 81]. All these studies reported high concentrations of viruses in sewage. Viruses outside a host are inert particles possessing no intrinsic metabolism and do not require any nutrients to persist [82]. They are, however, resilient enough to survive in the environment for long periods of time and still retain their infectivity during the various conditions that they may encounter between one host and another [83; 84; 85]. This is illustrated by the number of outbreaks of enteric viral diseases attributable to waterborne transmission [86]. Rzezutka and Cook [82] reviewed works previously done by other researchers on enteroviruses (polio-, echo- and coxsackieviruses). Summarising the observations from these studies and grouping them into freshwater sources gave mean viral inactivation rates of: 0.576 $\log_{10}$ d^{-1} (tap water); 0.325 $\log_{10}$ d^{-1} (polluted river water); 0.25 $\log_{10}$ d^{-1} (unpolluted river water); 0.374 $\log_{10}$ d^{-1} (impounded water); and 0.174 $\log_{10}$ d^{-1} (ground water). These rates were all less than 1 $\log_{10}$ per day, and indicated that viruses could survive in freshwater sources for prolonged periods of time.

Viruses have been found to be inactivated by prolonged holding in reservoirs exposed to sunlight, elevated temperature and extremes of pH[87]. A study carried out by Phanuwan *et al.* [48] in Jakarta, Indonesia, showed a statistically significant correlation between the physicochemical parameters (including conductivity, turbidity, temperature and total dissolved solids [TDS]) with all viruses tested (enterovirus, hepatitis A virus, Norovirus GI & GII and adenovirus). Turbidity showed positive correlation with all the microbes tested while conductivity, temperature, TDS showed negative correlation. The same study also showed a high prevalence of enteric viruses in floodwater compared to river water. While the authors did not explain this phenomenon, possible explanation could be that floods may cause the overflow of sewage treatment plants carrying with them large amounts of untreated and partially treated faecal matter. The erosive power of a flood causes the flood waters to be very muddy (turbid) thereby shielding the viruses (especially the RNA viruses) from the damaging effects of UV-rays of the sun.

In a study done by de Cardona *et al.* [88] in a tropical lagoon, they found that virus inactivation rates were significantly higher in that tropical lagoon than in temperate areas, probably due to higher temperature and salinity. Hurst *et al.* [89] examined the long-term survival of coxsackievirus B3, echovirus 7 and poliovirus 1 in samples of surface freshwater collected from five sites of physically different characteristics (artificial lake, small groundwater outlet pond, large- and medium-sized river and a small suburban creek). Survival was studied at temperatures of – 20°C, 1°C and 22°C. The average viral inactivation was 6.5–7.0 $\log_{10}$ units over 8 weeks at 22°C, 4–5 $\log_{10}$ units over 12 weeks at 1°C and 0.4–0.8 $\log_{10}$ units over 12 weeks at –20°C. Several physical and chemical parameters (hardness and conductivity) appeared detrimental to virus survival. The turbidity of the water and suspended solids represented a beneficial influence for virus survival. These findings concurred to a large extent with the work of Phanuwan *et al.* [48] which was done in Jakarta, Indonesia where turbidity was found to enhance viral survival rates while sunlight and high temperatures were detrimental to virus survival.

Two particularly notable factors that have been associated with the level of human enteric viruses in freshwaters are seasonal changes in water temperature [90] and a "rainy season" effect observed by Keswick *et al.* [91]. Water temperature exerts an extremely strong influence on viral stability, lower temperatures increasing the survival time [87]. The "rainy season" effect arises because of the very high turbidity that characterises freshwater bodies at that time of the year, which correlates in a statistically significant manner with the presence of indigenous viruses in water and with virus stability in water under laboratory conditions [87]. In another study by Espinosa *et al.* [85] in Mexico City (tropical highland), they reported that the presence of enteroviruses (EVs) and rotaviruses (RVs) was significantly more frequent during the cold-dry season (0.75 and 0.35, respectively) with an average low temperature of 4°C and an average precipitation of less than 10 mm than in the warm-rainy season (0.10 and 0.05, respectively) whereas astrovirus showed no significant relationship with the environmental variables recorded (pH, temperature, conductivity and dissolved oxygen concentration). This study also indicated that enteric viruses could be damaged by rising temperatures, as reported previously [87; 92], when EVs and RVs were studied in freshwater at 22°C and 20°C.

Determination of virus infectivity

Virus infectivity is generally believed to provide more relevant estimates of virus decay than disappearance of viral particles [93; 94; 95]. Tropical phages may be presumed to be genetically adapted to protect DNA and capsids against UV damage because of their capsid structure [96], or the dimerisation in DNA that may reduce the susceptibility of destructive enzymes [97]. Experiments on the persistence and infectivity of phage isolates have demonstrated that temperature is a strong determinant of both [98]. Suttle and Chen [67] and Noble and Fuhrman [93] also showed that temperature notably affects the decay of virus infectivity.

While molecular assays such as direct reverse transcription-polymerase chain reaction (RT-PCR) are sensitive, they provide inaccurate estimates of infectious viruses in the environment because they detect both inactivated and infectious virus particles [99]. On the other hand, cell-culture based techniques reveals infectivity of viruses and consequently risk of illness to water consumers [100; 101]. In a study done by Greening and co-workers [99], whose aim was to establish C-PCR methods for detection of culturable enteroviruses and adenoviruses in a broad range of environmental samples, and calibrate these methods against direct RT-PCR, PCR and plaque assay methods for sensitivity, as well as speed and ability to provide virus infectivity data, observed that direct RT-PCR detected 0.05-0.2 pfu/RT-PCR and was 10–100 times more sensitive than other methods but did not provide information on infectivity. Results for adenovirus also indicated that the direct PCR was 10 times more sensitive than C-PCR and detected 0.16 pfuD PCR, but did not give information on infectivity. They concluded that while direct RT-PCR or PCR methods are the most sensitive methods, their main disadvantage is the inability to provide information on infectivity. This limits their use in environmental virology applications where it is important to ascertain virus infectivity. On the contrary, they found that the C-PCR assay provided sensitive detection and confirmation of infectious enteroviruses and adenoviruses within 2–5 days of sampling. However, infectivity can be inferred for certain uncultivable RNA viruses (norovirus, enteroviruses, Hepatitis A and E) from molecular detection data where the viruses have been subjected to chemical but not UV disinfection [99]. Murrin *et al*. [100] also suggested that while the presence of viral DNA does not necessarily indicate the presence of infectious viruses, virus viability is inferred whenever virus nucleic acid is detected because the nucleic acids, single stranded RNAs in particular, are extremely susceptible to degradation in the environment.

Health concerns

Enteric viruses are important waterborne pathogens which are frequently isolated from faecally contaminated water and have been linked to numerous waterborne outbreaks [102; 50; 103]. Discharge of effluents from wastewater treatment plants into rivers that are used as source water in drinking water treatment plants (DWTPs) could present a risk of infection in the population if efficient drinking-water treatment is not applied and properly controlled before tap water distribution and consumption [104]. The presence of viruses and other pathogens in the environment is an indicator of faecal pollution that poses a potential risk to the exposed population, since such pathogens do not constitute normal gastrointestinal microbiota, and are only excreted by sick individuals [105]. Human adenoviruses are present at a higher frequency in sewage compared to other enteric viruses [81] and are excreted in high concentrations of up to 10^{11} viral particles per gram of faeces from infected patients [106]. Adenoviruses are second only to rotaviruses as major etiologic agents of infantile gastroenteritis[107-110] causing a variety of clinical manifestations associated with the gastrointestinal, respiratory and urinary tracts, as well as the eyes [111]. Adenoviruses are ubiquitous in water environments and these viruses are exceptionally resistant to purification and disinfection processes [112]. Enteric human adenoviruses (HAds) have a double-strand DNA genome which is more resistant to UV-light than the single strand RNA of other enteric viruses such as polio and hepatitis A viruses [113]. The occurrence of Ads in treated drinking water and tap water has been reported in South Korea and South Africa [114]. Health outcomes attributed to Ads infection include enteric related illnesses, respiratory system, eye infections and fatal outcome for immunocompromised patients and organ and bone marrow transplant recipients [115]. The consumption of clams harvested from a sewage-polluted area [116] also exposes people to risk of virus-related food poisoning, especially debilitating infectious hepatitis which may also lead to death. Numerous outbreaks of HAV infection have been reported worldwide [117-123] with the most severe occurring in Shanghai, China in 1988 [124]. Viral contamination of wastewater, recreational water, drinking water, irrigation water, ground or subsurface water have been reported frequently as a primary source of gastro-enteritis or hepatitis outbreaks [125-131].

Water quality as an economic growth determinant

Improved water supply and sanitation and water resources management boosts countries' economic growth and contributes greatly to poverty eradication [132]. Economic growth itself can also drive increasing investments in improved water management and services, initiating a virtuous cycle that improves the lives of the people across socio-economic boundaries [132]. The South African Department of Water Affairs and Forestry [25] defined the term *water quality* as the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of aquatic ecosystems. Freshwater resources have important social and economic benefits as a result of tourism and recreation, and are culturally and aesthetically important for people throughout the world [16]. According to CSIR [133], a healthy society and productive workforce play an important role in long-term economic growth and sustainable development. Water pollution therefore causes not only the deterioration of water quality, but also threatens human health, the balance of aquatic ecosystems, economic development and social prosperity [134].

Water quality and agriculture: Irrigation water

Typical sources of agricultural water include surface water, groundwater, and municipal supplies [135]. Sewage spills, runoff from concentrated animal production facilities, storm-related contamination of surface waters, illicit discharge of waste, and other sources of pathogens threaten the quality of both surface water and groundwater used for fruit and vegetable production and therefore the safety of the consumed product [136].

DWAF [25] defines irrigation water as water which is used to supply the water requirements of crops and plants which are not provided for by rain, and refers to all uses water may be put to including water for the production of commercial crops; irrigation water application and distribution systems; home gardening; the production of commercial floricultural crops and potted plants.

Whenever water comes into contact with produce, its source and quality are directly linked to the potential for contamination [135]. These potential contaminants are classified into microbiological (bacteria, virus, and protozoa); chemical, and physical agents [135]. Chemical and physical properties of irrigation water are of paramount importance because they affect crop yield and soil physical conditions; fertility needs; irrigation system performance and longevity [137]. Some of the chemical agents of concern in irrigation water are listed in Table 1.

Table 1. Guidelines for nutrient concentrations in irrigation water (mg/L)

Macronutrient	Low	Normal	High	Very High
Nitrate	<5	5-50	50-100	>100
Ammonium	<2	2-75	75-100	>100
Phosphorous	<0.01	0.1-0.4	0.4-0.8	>0.8
Potassium	<5	5-20	20-30	>30
Calcium	<20	20-60	60-80	>80
Magnesium	<10	10-25	25-35	>35
Micronutrient	Acceptable range	Suggested maximum concentration		
Iron	2.4-4.0	5.0		
Manganese	<0.2	0.2		
Copper	<0.2	0.2		
Zinc	<0.3	2.0		
Boron	<2.0	2.0		

Adapted from Landschoot, [138].

However, current data from the Center for Disease Control and Prevention (CDC) shows that 90% of foodborne illnesses come from microbiological agents [135]. In the 1990s, the CDC estimated that up to 12% of reported foodborne illness outbreaks were linked to fresh produce [135]. Table 2 shows some of the pathogens that have been associated with fresh produce since the 1990s.

Table 2. Selected confirmed multiple outbreaks of foodborne pathogens associated with fresh produce since the 1990s

Produce	Pathogens/chemical
Cantaloupe	*Salmonella* spp./ *E. coli* O157:H7
Raspberries	*Cyclospora cayatenensis*
Tomatoes	*Salmonella* spp.
Basil	*Cyclospora cayatenensis*
Parsley	*Shigella* spp.
Green onions/scallions	Hepatitis A virus, *Shigella* spp.
Various berries	*Cyclospora cayatenensis*
Lettuce	*E. coli* O157:H7
Cabbage	*L. monocytogenes*
Watermelon	*Salmonella* spp./ Aldicarb

Adapted from Simonne, [135].

Most victims of foodborne illnesses contract the diseases either through the ingestion of contaminated water or by eating minimally processed or raw vegetables that were irrigated with contaminated water [139]. Apart from the concern for the safety of consumers, there is also concern over the safety of pickers, handlers, packers and farmers that participate in the production of vegetables during pre-harvest and post-harvest, especially young children from families of farming communities who tend to be most vulnerable to salmonella infection as a result of contaminated irrigation water [139; 140]. Table 3 shows the trigger values for faecal coliforms in irrigation waters used for food and non-food crops.

Table 3. Trigger values for faecal coliforms in irrigation waters used for food and non-food crops.

Intended use	Level of faecal coliforms
Raw human food crops in direct contact with irrigation water (e.g. via sprays, irrigation of salad vegetables)	<10 CFU/100 mL
Raw human food crops not in direct contact with irrigation water (edible product separated from contact with water, e.g. by peel, use of trickle irrigation); or crops sold to consumers cooked or processed	<1000 CFU/100 mL
Pasture and fodder for dairy animals (without withholding period)	<100 CFU/100 mL
Pasture and fodder for dairy animals (with withholding period of 5days)	<1000 CFU/100 mL
Pasture and fodder (for grazing animals except pigs and dairyanimals, i.e. cattle, sheep and goats)	<1000 CFU/100 mL
Silviculture, turf, cotton, etc. (restricted public access)	<10 000 CFU/100 mL

For the protection of public health, WHO [142] set a bacterial guideline of ≤1000 faecal coliforms (FC) per 100 ml for unrestricted irrigation. This figure was reached at after data on pathogen removal by efficient wastewater treatment plants showed that at an effluent concentration of 1000 FC/100 ml, which reflects >99.99% removal, bacterial pathogens would have been eliminated and viruses would be at very low levels [143].

Water quality and public health

Most river stretches are used for various activities such as bathing, drinking, municipal water supply, navigation, irrigation, fishing and recreation [144]. Simultaneously, they are also used as recipients for discharge of industrial effluent, municipal sewage and dumping of solid wastes, which can potentially contaminate surface- and ground water resources [144]. An adequate supply of safe drinking water is one of the major prerequisites for a healthy life [145], but waterborne disease is still a major cause of death in many parts of the world, particularly in children, and it is also a significant economic constraint in many subsistence economies [146]. There is a clear link between the state of the environment and human health and well-being [133]. For example, the run-off of nutrients to surface waters, often combined with sewage discharges, leads to significant growths of cyanobacteria which can produce a wide range of toxins [147] and, where drinking water treatment is limited or non-existent, there is a potential for undesirable concentrations to be present in drinking water [146]. The abundance of organic compounds, radionuclides, toxic chemicals, nitrites and nitrates in water may cause unfavourable effects on the human health especially cancer, other human body malfunctions and chronic illnesses [16]. The World Health Organisation [148] estimates that 23% of all deaths in Africa are the result of avoidable environmental hazards such as contaminated water, poor hygiene, inadequate sanitation and poor water resource management among others. According to DWAF [7], WHO recognises diarrhoeal diseases as the leading cause of death in developing countries where many communities are still relying on untreated water from surface resources for their daily supply, with limited or no access to adequate sanitation facilities. The lack of access to safe water, basic sanitation and good hygiene is the third most significant risk factor for poor health in developing countries with high mortality rates [132]. In South Africa alone, it had been estimated that as many as 43 000 people might die annually as a result of diarrhoeal diseases [7]. The microbiological quality of recreational water bodies is of utmost public health concern since some population groups such as the very young, the elderly, the immunocompromised and tourists might be more susceptible to local endemic pathogens and, thus, may be at higher risk to swimming-associated disease [149]. Children are clearly at higher risk because of their swimming behaviour and immature immune systems, while visiting populations may be at higher risk because they have not been previously exposed to local pathogens [149]. For full body contact recreational waters, USEPA [150] suggested that the geometric mean of bacterial densities should not exceed 126 CFU/100 ml for *E. coli* or 33 CFU/100 ml for Enterococci.

Pollution burden of surface water resources: South Africa as a case in view

South Africa is the 30th driest country in the world [151] and its available freshwater resources are already almost fully-utilised and under stress [152]. At the projected population growth and economic development rates, it is unlikely that the projected demand on water resources in South Africa will be sustainable [153]. Water is increasingly becoming the limiting resource in South Africa [154], and supply will become a major restriction to the future socio-economic development of the country, in terms of both the quantity and quality of available water [155]. Predictions are that South Africa as a whole is likely to have a water deficit of approximately 1.7% by 2025 [156; 157; 158]. A 2010 report issued after experts sat down to roundtable talks with Business Leadership South Africa (BLSA) and the Centre for Development and Enterprise (CDE) (an independent policy research and advocacy organisation that focuses on critical national development issues and their relationship to economic growth and democratic consolidation) issued the following warning…

"On current trends, South Africans may one day have to make do with significantly less water per capita. For a country already using almost all its available water resources, this would be a dramatic change, with far-reaching implications for households, businesses, communities and government," [159].

South Africa is located in a predominantly semi-arid part of the world whose climate varies from desert and semi-desert in the west to sub-humid along the eastern coastal area, with an average rainfall for the country of about 450 mm per year, well below the world average of about 860 mm per year [160]. Only 8.5% of this low average annual rainfall finds its way to rivers as runoff. The total annual surface runoff of South Africa is 1.5×10^6 m^3/a [161] which is less than half that of the Zambezi River [153]. South Africa's local geology of hard rocks also means there are few exploitable aquifers [153] while water which is naturally of poor quality also occurs in some areas, which limits its utilisation [160]. Because of the spatial variability of water resources and the scarcity of water throughout the country, the need for water far exceeds supply in many catchments [155]. While the discrepancies in the water situation of different catchments have been managed through inter-basin water transfers, South Africa cannot afford to build more dams and water transfer schemes as they cost large amounts of money [158]. This situation is likely to worsen as the discrepancies between water requirements and availability in other water-scarce catchments increase. As of 2003, the available surface water resources in South Africa had been fully utilised, with an estimated water deficit of about 600 million m^3 per year [162]. Groundwater resources were said to account for about 350 million m^3 per year, reducing the overall water deficit to about 250 million m^3 per year [163].

South Africa's scarce freshwater resources are also decreasing in quality because of an increase in pollution and the destruction of river catchments [158]. Rivers play a major role in assimilating or carrying of industrial and municipal wastewater, manure discharges and runoff from agricultural fields, roadways and streets, which are responsible for river pollution [164]. Typical pollutants of South Africa's freshwater environment include industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff, and litter. At one point, freshwater pollution (in the form of Chemical Oxygen Demand) was estimated to be 4.74 ton/km^3 while the average phosphorous concentrations (as orthophosphate) were estimated at 0.73 mg/L; values which indicated that South Africa's freshwater resources could be excessively enriched and may be considered to be moderately to highly eutrophic [165]. Access to water was one of the key needs identified by poor communities in 1994, as well as jobs, housing, health care and education [166]. Between 1996 and 2009, the share of South Africa's households with access to clean water rose from 62 percent to 92 percent, inclusive of shared neighborhood taps [159]. However, population growth and economic growth are regarded as the primary determinants with respect to future water requirements, both scenarios for which deficits are generally projected to increase and surpluses to diminish [160]. This necessitates better understanding, management and mitigation of pollution issues to help the situation.

Global perspectives on water quality: legislative approach

Water pollution control has been a matter of public concern for more than a century [167]. The World Health Organization (WHO) has been pro-active in this aspect [168]; developing important guidelines of universal application and has, in recent years, promoted a more preventive approach dubbed the Water Safety Plans [169], which takes into account all factors that endanger the quality of drinking water from the source to the consumer [168]. It has been proven that reactive measures to clean up polluted sites and water bodies are generally much more expensive than pro-active measures to prevent pollution from occurring [170]. It is for this reason that national governments the world-over have been formulating landmark pieces of legislation to safe-guard both the quality and quantity of water available to their citizens. Examples are shown in Box 1 to Box 4.

As more information is disseminated and public awareness of water quality issues increases, national governments continue to develop and enforce better programs aimed at the preservation of water resources. In the face of competing water uses like growing populations, energy production,

Box 2.1: Water quality governance in Zimbabwe

In Zimbabwe, the Environmental Management Act Chapter 20:27 and Statutory Instrument 6 of 2007 are used by the Environmental Management Agency to advocate for the application of the "Polluter Pays" principle in its entirety. Local authorities operating a sewerage system or owner or operator of any trade or industrial undertaking is required to obtain a licence from the Environmental Management Agency to discharge any effluents or other pollutants into the environment. The effluent is divided into four categories denoting risk as safe, low hazard, medium hazard and high hazard (Government of Zimbabwe, 2007). The scale of the charges for the licence are related to the quality and quantity of the effluent, the poorer the management or quality of the effluent, the higher the charge. In addition, the polluter pays for the policing of the regulations and for the monitoring of the effluent. Penalties for polluting that were moderately punitive under the Water Act, 1998 (imprisonment for a period not exceeding one year or/and a fine) are even more punitive under the Environmental Management Act (CAP 20:27) of 2002 (imprisonment not exceeding five years or/and a fine). The polluter also remedies damage caused either to the environment or to a third party. In practice, although this command and control approach is in force, the Water Quality Section is using a co-operative rather than confrontational approach, with fines being used as a last resort [9].

Box 2.2: Water quality governance in Nepal

In Nepal, The Water Resource Act 1992 (2049 BS) contain provisions for the prevention and control of pollution of water resources. Section 19 provides that: No one shall pollute water resources by placing litter, industrial waste, poisons, chemicals or other toxicants to the effect that it exceeds the pollution tolerance limit. The "pollution tolerance limit" for water resources shall be prescribed by His Majesty's Government (HMG), by way of a public notice published in the Nepal Gazette. The prescribed officer (prescribed in the Nepal Gazette) may examine, or cause to examine, a water resource in order to determine whether or not the water resource has been polluted and if pollution tolerance limit has exceeded. Section 22 of the Water Resource Act 1992 (2049 BS) provides that any person or corporation who pollutes water resources will incur a fine of up to NRs.5000 and must pay compensation to any person sustaining a loss as a result of the pollution [171].

Box 2.3: Water quality governance in the USA

In the United States of America, The Clean Water Act (CWA) of 1972 establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, Environmental Protection Agency (EPA) has implemented pollution control programs such as setting wastewater standards for industry and water quality standards for all contaminants in surface waters. The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters [172]

Box 2.4: Water quality governance in South Africa

In South Africa, the National Water Act (NWA) (Republic of South Africa National Water Act (NWA) No. 36 of 1998) provides for protection of the quality of water resources and for the integrated management of water resources. While also dealing with a number of diverse issues, the NWA oversees pollution prevention in South Africa's water resources by putting a responsibility on the person who owns, controls, occupies or uses the land from where the water is polluted to take measures to prevent pollution. If he or she does not take these measures the Catchment Management Agency (CMA) may do what is necessary to remedy the situation and recover the cost from the person that is responsible [173].

and agriculture among others, all of which claim a share from increasingly limited water supplies, conservation of both the quality and quantity of water is now a predominant issue on a global scale. Hence, development of better water conservation practices and policies are critical to the sustenance of our water quantity and quality to ensure protection of public health.

CONCLUSION

Pollution of water resources remains a global concern, moreso with the on-going climatic changes that are negatively impacting on the rainfall patterns in every part of the world. Water quality deterioration will most likely see an escalation in the treatment costs for potable water production with a concomitant negative impact on the world's economies and general lifestyles of the world's citizens. Pollution can also have drastic ecological consequences and if not attended to as a matter of urgency, the world's aquatic ecosystems might face certain demise. Pollution of the world's water resources, coupled with the scarcity thereof, is likely to see powerful tribes and/or nations besieging the weaker ones for their freshwater resources in the near future, as is already the situation of some parts of the world. The only way forward now is pollution reduction by all nations of the world, rich or poor; we all need to take responsibility over the state of our water resources.

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