Systematic Review on Microbiological and Physicochemical Indicators of Water Quality

Ruhuoma Wosu Kinika[1], Chisom Ejileugha[1], Asiton-a Asifamabia Dick[2]

[1]Department of Microbiology, Faculty of Science, University of Port Harcourt, P.M.B 5323, Port Harcourt, Rivers State, Nigeria
[2]Department of Science Laboratory Technology, School of Science and Technology, Rivers State College of Arts and Science, P.M.B. 5936, Rumuola, Port Harcourt, Nigeria.
unipas013@gmail.com; asitona@yahoo.com

Abstract: Water is one of the most important natural resources, and there are many conflicting demands upon it. Skillful management of water bodies is required if they are to be used for such diverse purposes as domestic and industrial supply, crop irrigation, transport, recreation sport, and commercial fisheries, power generation and waste disposal. Water quality simply refers to the overall characteristics of aquatic environment. Once maximum acceptable concentrations of selected variables in relation to water use have been exceeded, or the aquatic habitat and biota have been markedly modified, the water quality is usually defined as polluted. Water that is free of disease-producing microorganisms and chemical substances deleterious to health is called potable water. Water contaminated with either domestic or industrial wastes is called non-potable or polluted water. The assessment of portability generally is based on knowledge of sanitary condition of the supply as determined by bacteriological monitoring. Water quality monitoring is based on the detection of coliform and the specific indicator of human faecal contamination, *Escherichia coli*. Description of the quality of the aquatic environment can be carried out in a variety of ways. It can be achieved either through quantitative measurement (in the water, particulate material or biological tissues) and biochemical/biological or through semi-qualitative descriptions such as biotic indices, visual aspects, species inventories, odour and others.

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Introduction

Unequivocally, water is essential for the development and the maintenance of the dynamics of every ramification of society (UNCSD, 2000; Meybeck *et al*., 1989). All water is part of the hydrological system. All fresh water bodies are interconnected, from the atmosphere to the sea, via the hydrological cycle.

This water constitutes a continuum, with different stages ranging from rainwater to marine water (Meybeck and Helmer, 1996; Pelczar *et al*., 1993; Bonde, 1977; Atlas, 1991). Inland freshwaters that appear in the form of rivers, lakes or ground waters are closely inter-connected and may influence each other directly or through intermediate stage. The modern world is aware of the relationship between water and waterborne disease as a vital public health issue. Throughout the world, about 2.3 billion people suffer from diseases that are linked to water related problems (WHO, 1997), which continue to kill millions of people yearly, debilitate billions, thereby undermining developmental efforts (Nash, 1993; Olshansky *et al*., 1997).

Recent studies have demonstrated that underground water systems are increasingly vulnerable to both microbiological and heavy metals contamination, especially by arsenic (Islam *et al*., 2001). Such problems arise even in developed countries. For example, in 1994, an outbreak of cryptosporidiosis occurred in a rural community in Washington State, where water was supplied by two deep, unchlorinated wells (Dworkin *et al*., 1996). In most urban and rural settings in the Niger Delta area, major sources of water for drinking and domestic purposes are: rivers/creeks/streams/ponds, hand-dug wells and harvested rain water (FGN, 2000).

The provision of potable water has been a major problem in Nigeria, a characteristic feature of developing countries (Ashbolt, 2004). Water borne disease such as cholera, gastroenteritis, bacillary dysentery, typhoid fever, and diarrhoea are associated with ingestion of water that is contaminated with human and animal excreta.

Bacteriological examination of water is therefore a powerful and foremost tool in order to foreclose the presence of microorganisms that might constitute a health hazard (Bonde, 1977). Water related microbial pathogens include *Salmonella* spp., *Vibrio* spp., *Shigella* spp., enterotoxigenic *Escherichia coli* and over 100 different types of pathogenic viruses (Paul *et al*., 1995).

However, bacterial resistance to antibiotics has become an emerging issue threatening the public health because of the wide availability of antibiotics and, sometimes, misuse without proper prescription (Davis and Ambile-Cuevas, 2003). More and more pathogenic microorganisms have been shown to be resistant to one or a suite of antibiotics (Levy, 2001). In some cases, the virulent or pathogenic factors are carried by the same vectors responsible for antibiotics resistance.

According to Yah *et al*. (2007), antimicrobial resistance on enteric pathogen is of great public health concern in the developing world where the rate of diarrhoea is highest. Researchers have also reported an increasingly widespread use of antibiotics in food and animals contributing to high dissemination of resistant enteric infections to humans. Plasmids have been found to confer drug resistance to their host bacteria (Tolmarby and Towner, 1990; Levis, 1993). One of the most important environmental issues today is ground water contamination (Vodela *et al*., 1997) and between the diversity of contaminants affecting water resources, heavy metals receive particular concern considering their strong toxicity even at low concentrations (Marcovecchio *et al*., 2007).

Some of the metals are essential to sustain life – calcium, magnesium, potassium and sodium must be present for normal body functions. Also, cobalt, copper, iron, manganese, molybdenum and zinc are need at low levels as catalysts for enzyme activities (Adepoju-Bello *et al*., 2009). The modern era of industrialization has increases the spread of environmental contamination by heavy metals.

Heavy metal toxicity dates back to the ancient period, especially the famous story of the decline of the Roman Empire being caused by lead toxicity which resulted in mental retardation of the rulers (Asonye *et al*., 2007). According to Freedman (1989) “the chemical form of toxic elements dissolved in water is generally relatively available to biota, even seemingly small aqueous concentration may exert a powerful toxic effect.

Characterization of water bodies

Water bodies can be fully characterized by three major components: hydrology, physico-chemistry and biology. A complete assessment of quality is based on appropriate monitoring of these components (Meybeck and Helmer, 1996).

All freshwater bodies are interconnected, from the atmosphere to sea, via the hydrologic cycle. Thus water constitutes a continuum, with different stages ranging from rainwater to marine salt waters. The part of the hydrological cycle which is considered is the inland freshwater which appear in the form of rivers or groundwater. These are closely interconnected and may influence each other directly, or through intermediate stages. Each of these water bodies has distinctly different hydrodynamics properties as described below (Meybeck and Helmer, 1996).

Rivers are characterized by unidirectional current with a relatively, average flow velocity ranging from 0.1 to 1.0 ms^{-1}. The river flow is highly variable in time, depending on the climatic situation and drainage patter (Meybeck and Helmer, 1996). In general, thorough and continuous vertical mixing is achieved in rivers due to prevailing currents and turbulence.

Lateral mixing may take place only over considerable downstream of major confluences. Groundwater is subterranean water that occurs where all pores in the soil or rock-containing materials are saturated (Pelczar *et al*., 1993). Groundwater is characterized by a rather steady flow pattern in terms of direction and velocity.

The average flow velocities commonly found in aquifers range from 10^{-10} to $10^{-3}ms^{-1}$ and are largely governed by the porosity and permeability of the geological material (Meybeck and Helmer, 1996). As a consequence mixing is rather poor and, depending on local hydrogeological features, the groundwater dynamics can be diverse.

The hydrodynamics characteristics of each type of water body are highly dependent on the size of the water body and the climatic conditions in the drainage basin. The governing factor for rivers is their hydrologic regime, i.e. their discharge variability. Groundwater greatly depends upon their recharge, i.e. infiltration through the unsaturated aquifer zone, which allows for the renewal of groundwater body (Meybeck and Helmer, 1996).

Physical and chemical properties

Each freshwater body has an individual pattern of physical and chemical characteristics which is determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer.

Summary characteristics, such as total dissolved solids, conductivity, and redox potential, provide a general classification of water bodies of similar nature. Mineral content, determined by the total dissolved solids present, is an essential feature of the quality of any water body resulting from the balance between dissolution and precipitation (Meybeck and Helmer, 1996).

Oxygen content is another vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life. The chemical quality of the aquatic environment varies according to local geology, the climate, the distance from the ocean and the amount of soil cover.

Biological characteristics

The development of biota (flora and fauna) in surface waters is governed by a variety of environmental conditions which determine the selection of species as well as the physiological performance of individual organisms (Meybeck and Helmer, 1996). The degradation of organic substances and the associated bacterial production can be a long-term process which is not directly exposed to sunlight.

In groundwater, bacteria as well as suspended particles are removed by filtration, in varying degrees, depending on the permeability characteristics of the soil and the depth to which the water penetrates (Pelczar *et al.*, 1993). In contrast to chemical quality of water bodies, which can be measured by suitable analytical methods, the description of the biological quality of a water body is a combination of qualitative and quantitative characterization.

Biological monitoring can generally be carried out at two levels: the response of individual species to changes in their environment or, the response of biological communities to changes in their environment (Meybeck and Helmer, 1996).

Biological quality, including the chemical analysis of biota, has a much longer time dimension than the chemical, and/or hydrological, events that have lasted only a few days, some months or even years before monitoring was carried out.

Monitoring/assessment of water quality

Water quality monitoring can be defined as the actual collection of information at set locations and at regular intervals in order to provide the data which may be used to define current conditions, establish trends (Bartram and Balance, 1996).

Bartram and Balance (1996) also defined water quality assessment as the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself.

Water quality assessment includes the use of monitoring to define the condition of the water, to provide the basis for detecting trends and to provide the information enabling the establishment of cause-effect relationships.

Important aspects of an assessment are the interpretation and reporting of the results of monitoring and the making of recommendations for the future action. Thus, there is a logical sequence consisting of three components: monitoring, assessment and management.

Anthropogenic impacts on water quality

With the advent of industrialization and increasing populations, the range of requirements for water has increased together with greater demands for higher quality water.

Over time, water requirements have emerged for drinking and personal hygiene, fisheries, agriculture (irrigation and livestock supply), navigation for transport of goods, industrial cooling in fossil fuel (and later also in nuclear) power plants, hydropower generation and recreation activities such as bathing or fishing (Meybeck and Helmer, 1996).

Fortunately, the largest demands for water quantity, such as for agricultural irrigation and industrial cooling, require the least in terms of water quality (i.e. critical concentrations may only be for or two variables). Drinking water supplies and specialized industrial manufacturers exert the most sophisticated demands on water quality but their quantitative needs are relatively moderate.

In parallel with these uses, water has been considered, since ancient times, the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, mine drainage waters, irrigation returns). Each water use, including abstraction of water and discharge of wastes, leads to specific and generally rather predictable, impacts on the quality of the aquatic environment.

In addition to these intentional water uses, there are several human activities which have indirect and undesirable, if not devastating effects on the aquatic environment. Examples are uncontrolled land use for urbanization or deforestation, accidental (unauthorized) release of chemical substances, discharge of untreated chemical substances, and discharge of untreated wastes or leaching chemical substances, and discharge of untreated wasted or leaching of noxious liquids from solid waste deposits (Meybeck and Helmer, 1996).

Similarly, the uncontrolled and excessive use of fertilizers and pesticides has long-term effects on ground and surface water resources. Structural interventions in the natural hydrological cycle through canalization or damming of rivers, diversion of water within or among drainage basin, and over-pumping of aquifers are usually undertaken with a beneficial objective in mind. Experience has shown, however that the resulting long-term environmental degradation often outweighs these benefits.

Sources of groundwater contamination

Groundwater makes up about twenty percent (20%) of the world's fresh water supply, which is about 0.61% of the entire world's water, including oceans and permanent ice. Groundwater is naturally replenished by surface water from precipitation, stream, and river when this recharge reaches the water table.

It is estimated that the volume of groundwater comprises 30.1% of all freshwater resource on earth compared to 0.31% in surface water; the ice caps and glacier are the only larger sources of fresh water on earth at 68%.

Certain problems have beset the use of groundwater around the world. Just as river water have overused and polluted in many parts of the world, so too have aquifers. Groundwater contamination can occur in many ways and from many sources, both natural and human-induced.

Groundwater commonly contains one or more naturally occurring chemicals, leached from soil or rocks by percolating water, in concentrations that exceed federal or State drinking water standard or otherwise impairs its use (Moody, 1996).

Dissolved solids and chloride

One of the most common water quality concerns is the presence of dissolved solids and chloride in concentrations that exceed the recommended maximum limits if Federal secondary drinking water standards. Five hundred milligrammes per litre (500mg/l) for dissolved solids and 250mg/l for chloride.

Such concentrations are found at the seaward ends of all coastal aquifers and are quite common in aquifers at depths greater than a few hundred feet below the land surface in many parts of the United States of America.

Human activities

Contaminants can enter groundwater from more than thirty (30) different generic sources related to human activities. The sources commonly are referred to as either point or non-point sources. Point sources are localized in areas of an acre or less, whereas non-point sources are dispersed over broad areas.

The most common sources of human-induced groundwater contamination can be grouped into four categories: wastes disposal practice; storage and handling of materials and wastes; agricultural activities, and saline water intrusion.

Waste disposal practices

Perhaps the best-known sources of groundwater contamination are associated with the storage or disposal of liquid and solid wastes. The organic substances most frequently reported in groundwater as resulting from waste disposal in decreasing order of occurrence, are trichloroethylene (TCE), chloroform, benzene, pentachlorophenol, tetrachloroehtylene (PCE), creosote, phenolic compounds, 1,1,1-trichloroethane, toluene and xylene. Water disposal can take a number of forms.

Septic systems are the largest source of volume of waste discharge to the land. These systems are sources of bacteria, viruses, nitrate, phosphorus, chloride and organic substance, including organic solvents such as trichloroethylene that are sold commercially to ‘clean’ the systems.

Municipal and industrial landfills

About 150 million tons of municipal solid waste and 240 million tons of industrial solid wastes are deposited in 16,400 landfills each year (Moody, 1996). Some hazardous wastes materials may be deposited in municipal landfill and underlying groundwater may become contaminated. Wastes deposited at industrial landfills include a large assortment of trace metals, acids, volatile organic compounds and pesticides, which may cause significant local contamination.

Surface impoundments

Surface impoundments are used to store, treat or disposal of oil and gas brines, acidic mine wastes, industrial wastes (mainly liquids), animal wastes, municipal treatment plant sludge and cooling water. Some of these impoundments have significant potential for contaminating groundwater.

Injection well

Injection wells dispose of liquid wastes underground of particular concern is the widespread use of drainage well to dispose of urban storm water runoff and irrigation drainage. Contaminants associated with drainage well included suspended sediments, dissolved solid, bacteria, sodium, chloride, nitrate, phosphate, lead and organic compounds, including pesticides.

Land application of wastes

In many places, solid and liquid wastes are sprayed on the land, commonly after treatment and stabilization. The United States Environmental Protection Agency (USEPA) has estimated that more 7 million dry tons of sludge from at least 2,463 publicly owned waste treatment plants are applied to about 11,900 parcels of land each year. Contamination can occur from improper land disposal techniques (Moody, 1996).

Storage/handling of materials and wastes

Groundwater contamination as a result of storage and handling of materials includes: Leaking Underground Storage Tank. Possibly as many as seven (7) million steel tanks are used to store petroleum products, acids, chemicals, industrial solvents and other types of waste underground.

The potentials of these tanks to leak increase with age, presently petroleum products ranges from 25-30 (Moody, 1996). Underground storage tanks appear to be a leading source of benzene, toluene and xylene contaminants, all of which are organic compounds in diesel and gasoline.

Transporting and stockpiling

Many materials and wastes are transported and then temporarily stored in stockpiles before being used or shipped elsewhere. Precipitation can leach potential contaminants from such stockpiles; storage containers can erode and leak, and accidental spill can occur as many as 10,000 to 16,000 per year, according to United State Environmental protection Agency estimates (Moody, 1996).

Mining practices

Mining of coal, uranium and other substances and the related mine spoil can lead to underground contamination in several ways; shafts and tunnels can intersect aquifer, exposing coal to oxygen can form tetraoxosulphate (IV) acid, which can degrade water quality and contaminants from tailings can leach into groundwater.

Oil-well brines

Since the 1800s, hundreds of thousands of exploratory and production wells have been drilled for oil and gas in the United States. During production, oil wells produce brines that are separated from the oil and stored in surface impoundments. The United States Environmental Protection Agency (USEPA) estimates that 125,100 brine-disposal impoundments exist that might affect local groundwater supplies.

Agricultural activities

Agriculture is one of the most widespread human activities that affect the quality of groundwater.

Fertiliser, pesticides and feedlots

If nitrogen supply (from nitrogen, phosphorus and potassium fertilisers) exceeds nitrogen uptake by crops, excess nitrogen can be leached to groundwater. In such areas, local nitrate-nitrogen concentrations may exceed the Federal drinking water standard of 10mg/l.

Pesticides have been used since 1940s to combat a variety of agricultural pest. In addition, to crop applications, infiltration of spilled pesticides can cause contamination in locations where they are stored, and where sprayers and other equipment used to apply pesticides are loaded and washed.

Pesticides most frequently detected in groundwater are the fumigant ethylene dibromide (EDB) and 1,2-dichloropropane; the insecticides aldicard, carbofuran and chlordane and the herbicides alachlor and atrazine.

Feedlots confine livestock and poultry and create problems of animal-waste disposal. Feedlots wastes often are collected in impoundments from which they might infiltrate to groundwater and raise nitrate concentrations. Runoff from farmyards may also directly enter an aquifer along the outside of a poor sealed well casing.

Irrigation

Percolation of irrigation water into soils dissolves soil salts and transports downward. Evapotranspiration of applied water from the root zone concentrates salts in the soil and increase the salt load to the groundwater (Moody, 1996).

Chemigation, the practice of mixing and distributing pesticides and fertilisers with irrigation water, may cause contamination if more chemicals are applied than crops can use. It may also cause local contamination if chemicals back-siphon from the holding tank directly into the aquifer through irrigation well.

Saline water (saltwater) intrusion

Saltwater intrusion is the movement of salt water into freshwater aquifers. Most often, it is caused by groundwater pumping from coastal wells, or from construction of navigation channels or oil-field canal. The channels and canal provide conduits for saltwater to be brought into freshwater marshes.

But saltwater intrusion can also occur as the result of a natural process like a storm surge from a hurricane. Saltwater intrusion occurs in virtually all coastal aquifers, where they are in hydraulic continuity with seawater.

When freshwater is withdrawn at a faster rate than it can be replenished, the water is drawn down as a result; the draw-down also reduces the hydrostatic pressure. When this happens near an ocean coastal area, saltwater from the ocean is pulled into the freshwater aquifer. The result is that the aquifer becomes contaminated with salt water. This is happening to many coastal communities (Todd, 1960; Delluer, 2006; Frank-Briggs, 2003).

Seawater intrusion happens when saltwater is drawn-in (from the sea) into freshwater aquifers. This behaviour is caused because seawater has higher density (which is because it carries more solutes) than freshwater.

This difference in density causes the pressure under a column of saltwater to be greater than the pressure under a column of the same height of freshwater. If these two columns are connected at the bottom, then the pressure difference would cause a flow of saltwater column to the freshwater column until the pressure equalises. Generally, there are documented groundwater pollutions.

An example of widespread groundwater pollution is the Ganges Plain of Northern India and Bangladesh where severe contamination of groundwater by naturally occurring arsenic affected 25% of water wells in shallower of two regional aquifers. The pollution occurs because aquifer sediments contain organic matter (dead plant material) that generates anaerobic conditions in the aquifer.

These conditions result in the microbial dissolution of iron oxides in the sediment and thus the release of arsenic, normally strongly bound to iron oxides, into the water. As a consequence, arsenic-rich groundwater is often iron-rich, although secondary processes often obscure the association of dissolved iron.

Generally, reduction of waste, control of contamination sources and improved land management practices can significantly reduce the risk of contamination in the future.

Water-related diseases

Of the various terms for disease linked to water, water related disease is the most comprehensive. Water-related disease is defined as any significant or widespread adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by condition, or changes in the quantity or quality of any waters.

The causes of water related disease include microorganisms, parasites, toxins and chemical contamination of water. Other terms include 'waterborne disease', which implies direct spread and is used mainly to refer to disease caused by microbiological pathogens or chemical contaminants in water.

Water associated disease cover the wide range of disease in which water plays a part, such as Legionnaires ' disease, as well as diseases related to lack of water for washing and hygiene. There are three essential components for the classification: the pathogens and other agents involved in water related diseases; the type of water exposure and the level of probability of water cause.

Water related diseases are classified into: Water-borne Diseases (diseases transmitted by water), Water-Washed Diseases, Water-Related Insect Vectors Diseases and Water-Based Diseases (Stanwell-Smith, 2001).

Water-borne Diseases (Diseases transmitted by water) are caused by ingestion of water contaminated by human or animal excrement, which contain pathogenic microorganisms. These include cholera, typhoid, amoebic and bacillary dysentery, hepatitis A & E, giardiasis and other diarrhoeal diseases.

In addition, water-borne diseases can be caused by the pollution of water with chemicals that have an adverse effect on health (Halage, 2010). Water-Washed Diseases are diseases resulting from poor personal hygiene due to inadequate amounts of water supply for washing and bathing and eye contact with contaminated water.

These include skin diseases-scabies, lice (typhus & relapsing fevers), tick-borne diseases and fungal infections-ringworms, eye infections (trachoma and conjunctivitis) and parasitic infection like jiggers.

Water-related insect vectors diseases are diseases spread by insects that breed or feed near contaminated water or bite near water such as malaria, onchocerciasis, trypanasomiasis, Dengue fever, Bancroftian and yellow fever.

They are not typically associated with lack of access to clean drinking water or sanitation services. Water-Based Diseases are diseases transmitted by hosts which live in water or require water as part of their life cycle e.g. Schistosomiasis, Dracunuliasis, Bilharziasis, Filariasis, Threadworm and Guinea Worm. Transmission is more likely due to human activities like fishing, swimming and farming-rice (Halage, 2010).

Detection of microorganisms in water

The traditional methods for detecting coliform bacteria rely on culturing on a medium that selectively permits the growth of Gram-negative bacteria and differentially detects lactose utilising bacteria for example, using M-Endo, Eosin Methylene Blue (EMB) or brilliant Green Lactose Bile Broth (BGLB) media (Mahbubani *et al*., 1990).

Rapid and sensitive, non-culture, genetically based procedures for the environmental detection of coliforms i.e., using the Polymerase Chain Reaction (PCR) and detection of amplified DNA with gene probes had been developed (Mahbubani *et al*., 1990; Atlas, 1991).

Islam *et al*. (2001) reported that after microbiological analysis of tube-well water in a rural area of Bangladesh, the result showed that all tube-well water samples contain zooplankton and bacteria. Idakwo and Abu (2004) also reported that in Lake Alau in the arid Northern Nigeria (Borno State), the total coliform represented 32% of twenty-two (22) isolates and of this 10% represented the faecal coliform bacteria.

As a potential carrier of pathogenic microorganisms, water can endanger health and life. The pathogens most frequently transmitted through water are those which cause infections of the intestinal tract; namely, typhoid and paratyphoid bacteria, dysentery (bacilliary and amoebic) and cholera bacteria and enteric viruses (Pelczar *et al*., 1993).

Diseases such as typhoid fever, salmonellosis, cholera, infectious hepatitis and polio, amoebic dysentery, etc. which is rampant today is indicative of the poor water quality and this calls for the need to monitor the few potable water sources to determine their public healthy quality.

It is worthy to note that natural water has its own plethora of harmless group of bacteria, thus the mere isolation of bacteria in water does not indicate pollution. The presence of a few pathogenic microorganisms is more significant than water containing many saprophytic bacteria.

However, water of good quality is expected to give a low count, less than 100 per millilitre (Pelczar *et al*., 1993). Control of microbiological water quality (drinking and domestic water) is a key issue not only because of the health impact of potential contamination, but also because water resources must be protected to ensure long-term sustainability (Abu and Egenonu, 2008).

Nevertheless, there is a rather limited knowledge on the microbiological principles governing the prevalence and pathogenesis of emerging microbial pathogens in drinking water (Leclerc *et al*., 2002; Albinana-Ginmenez *et al*., 2006). One of the main reasons for the lack of knowledge is the accurate detection, identification and quantification of microbial pathogens with a combination of conventional and molecular biology methods (Purohit and Kapley, 2002; Bej, 2003).

Escherichia coli

Presence of *Escherichia coli* from water supply indicates faecal contamination. *Escherichia coli* have been reported in a variety of infections including gastroenteritis, urinary tract infection (Baker and Breach, 1980; Chessbrough, 1984), haemolytic colitis and haemolytic uremic syndrome (Karmali *et al*., 1983).

The organism is also the leading cause of diarrhoea in developing countries (Alabi, 1991) and responsible for a considerable degree of morbidity and mortality among children and poor communities (WHO, 1980).

Escherichia coli that cause diarrhoea currently belong to four major groups namely enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC), enteroinvasive *E. coli* (EIEC) and enterohaemorrhagic *E. coli* (EHEC) (WHO, 1987).

Enterotoxigenic *E. coli*, (ETEC) is an under-recognised but extremely important cause of diarrhoea in the developing world where there is inadequate clean water and poor sanitation.

Enterotoxigenic *E. coli*, (ETEC) is the most commonly isolated bacterial enteropathogen in children below 5 years of age in developing countries, and accounts for several hundred million cases of diarrhoea and several tens of thousands deaths each year.

Disease caused by ETEC follows ingestion of contaminated food or water and is characterised by profuse watery diarrhoea lasting for several days that often leads to dehydration and malnutrition in young children.

ETEC was thought to account for approximately 200 million diarrhoea episodes and 380, 000 deaths annually. In infants living in the Nile delta area, who experienced between 4.6 and 8.8 diarrhoeal episodes per year, ETEC accounted for 66% of these episodes (WHO, 2010).

Vibrio cholerae

Vibrio cholerae serotypes O1 and O139 cause the classical cholera illness, characterised by fulminating and severe watery diarrhoea. The O1 serotype has been further divided into “classical” and “El Tor” biotypes.

The classical biotype is considered responsible for the first six cholera pandemics, while the El Tor biotype is responsible for the current “seventh” cholera pandemic started in 1961 and still in progress.

As many as 60% of untreated patients may die as a result of severe dehydration and loss of electrolytes, but well established diarrhoeal disease control programmes can reduce fatalities to less than 1percentage.

Cholera is typically transmitted by the faecal–oral route, and the infection is predominantly contracted by the ingestion of faecal contaminated water and food. The presence in drinking-water supplies is of major public health importance and can have serious health and economic implications in the affected communities.

The disease is now endemic in many parts of Africa and Asia. Africa accounts for over the 94 % of cases reported annually. Explosive outbreaks usually occur in areas with inadequate sanitation, poor hygiene, and lack of safe water supplies (Ali *et al*., 2012).

The current wave of cholera outbreaks affecting Central Africa resulted in 40,468 cases and 1,879 deaths in four countries (Cameroon, Chad, Niger and Nigeria). Seasonal factors, such as the rainy season with flooding, as well as poor hygiene conditions and population movements in the area contribute to this unusually high incidence of cholera (WHO, 2008).

Salmonella

Salmonellosis has two forms i.e. typhoid /paratyphoid fever and gastroenteritis. The principal habitat of *Salmonella* is the intestinal tract of humans and animals. Salmonellae are constantly found in environmental samples, because they are excreted by human, pets, farm animals and wild life.

Municipal sewage, agricultural pollution is the main sources of these pathogens in natural waters (Cabra, 2010). Salmonellae isolated from environmental sources are predominantly non-typhi or paratyphi serovars. In developing world, the new multi-drug resistant strains causing bacteriamia are far more common and serious.

Fatality rates among children under two years old can be as high as almost one in four and even higher in HIV-infected adults. Invasive non-typhi *Salmonella* (NTS) is endemic in Sub-Saharan Africa. Seasonal peaks of NTS disease occur with the rainy season.

Faecal organisms are found at highest concentrations in drinking water sources in Africa at the onset of the wet season and this may correspond with increase risk of waterborne non-typhi Salmonella (NTS) (Marpeth *et al*., 2009).

Water quality index

Water quality index (WQI) is one of the most effective expressions which reflect a composite influence of contributing factors on the quality of water for any water system (Sharivastava and Shonawane, 2010). A water quality index provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters.

The objective of an index is to turn complex water quality data into information that is understandable and useable by the public (Kumar and Dua, 2009). The water quality index (WQI) has been considered as one criterion for drinking water classification, based on the use of standard parameters for water characterization.

The index is a numeric expression used to transform large quantities of water characterization data into a single number, which represents the water quality level (Bordalo *et al*., 2006; Sanchez *et al*., 2007).

Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Miller *et al.,* 1986).

There are several water quality indices that have been developed to help water quality divisions in some U.S. states, Canada, and Malaysia. However, most of these indices are based on the WQI developed by the U.S. National Sanitation Foundation (NSF).

The WQI and classification proposed by Department of Environment, Malaysia (DOE, 2001), has been used to assess the quality of major water supply sources indicating the level of pollution (Sari and Wan, 2008). The commonly used Water Quality Index (WQI) was developed by the National Sanitation Foundation (NSF) in 1970 (Brown *et al*., 1970).

Water quality index regulation

The National Sanitation Foundation Water Quality Index (NSF WQI) was developed to provide a standardised method for comparing the water quality of various water sources based upon nine water quality parameters, i.e., temperature, pH, dissolved oxygen, turbidity, faecal coliform, biochemical oxygen demand, total phosphates, nitrates, and total solids.

The water quality index ranges have been defined as excellent, good, medium, bad, and very bad. The WQI can be calculated with less than nine parameters as well, employing available test results for determination of WQI (Chaturvedi and Bassin, 2009). The index ranges from 0 to 100, where 100 represent an excellent water quality condition.

Sanitary quality risk assessment

The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer.

Surveillance is the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking-water supplies. Surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, access, affordability, and continuity of water supplies and is complementary to the quality control function of the drinking-water supply agency.

Each component of the drinking-water system, i.e. source, treatment, storage, and distribution - must function without risk of failure. Water is vulnerable to contamination at all stages in the process of supply; hence the need for constant vigilance is essential (Water Aid in Nepal, 2011).

The sanitary inspection can point out the obvious points of risk of information on contamination while single water sampling may not be representative for the real situation of water quality.

However, sanitary inspection alone also may not generate an accurate picture of likely water quality at source either. Therefore, a combination of both i.e. sanitary inspection and water testing results is highly recommended for the evaluation of water facilities. WHO and UNICEF (2010) stated that the most effective way to undertake sanitary inspections is a semi-quantitative, standardized approach using logical questions and a simple scoring system.

Sanitary inspections complement water-quality analyses by providing a longer term perspective on the risks of microbiological contamination, rather than the “snapshot” view of water quality analyses, and there is an increase in the power of analysis when both types of data are available.

Microbial quality risk assessment

Haas *et al.* (1999) defined quantitative microbial risk assessment (QMRA) as the application of principles of risk assessment to estimate the consequences from a planned or actual exposure to infectious microorganisms.

Risk assessments have also been developed for describing the public health consequences of exposure to pathogens from drinking water, based on its initial use within the food and chemical sectors.

Quantitative microbial risk assessment (QMRA) is today applied to establishing standards, guidelines and other recommendations regarding drinking water and consumer health (Rose and Gerba, 1991; Macler and Regli, 1993; Eisenberg *et al*., 2002).

It has a central role in the new drinking water guidelines from the WHO for assessment of the accomplishment of established health targets and for the evaluation of Water Safety Plans (WHO, 2004). In the latter, it is used to support decisions regarding barriers and treatments necessary to safeguard public health in water supply systems.

Other researchers have assessed the infectious risks in drinking water from viruses (Haas *et al*., 1993; Gerba *et al*., 1996; Crabtree *et al*., 1997) and protozoa (Haas *et al*., 1996; Teunis *et al*., 1997; Pouillot *et al*., 2004).

Microbial risk assessment has both been used to qualitatively (Parkin *et al.*, 2003) and quantitatively (Ashbolt *et al.*, 1997; Soller *et al.*, 2003) assess the health risks of recreational swimming water and it is incorporated in the World Health Organisation Guidelines for Safe Recreational Waters (WHO, 2003).

QMRA are often focused on a specific pathogen or pathogen group and only consider one exposure pathway.

A holistic approach is needed in order to assess the impact on public health of a whole water and wastewater system and in order to make comparisons of different systems (Westrell, 2004).

In some countries, there is an increasing move towards a regulatory requirement for water suppliers to perform risk assessments on their supplies to validate their performance. For example, in the Netherlands, water companies already apply this approach to estimate infection risks from primary contamination, i.e. contamination from insufficient treatment of source water (Dechesne *et al.* 2006).

In many developing countries, health-based targets may not exist or may take some time to be established. However, it is still in the water supplier's interest to determine how their system is performing in relation to likely health burdens and therefore they should consider undertaking a QMRA as a means of validating current performance and developing future plans.

In practical terms, health-based targets are often translated into performance targets for water supply in terms of log-reductions in pathogens and toxic chemicals through source protection measures, treatment processes and distribution management. Targets are of particular value for water suppliers and the risk assessments can be used to establish them.

This may be done through either quantitative risk assessment approaches or through epidemiological studies. In the latter case, this will focus on investigations to establish the level of disease that can be attributed to a water supply. Such approaches have been used in a number of cases (Payment *et al*., 1991; Hellard *et al*., 2001; Hunter and Syed, 2001).

However, water suppliers are unlikely to have epidemiological expertise and it may be expensive to contract this expertise. Interpretation of the results for non-specialists may also be difficult.

An alternative approach is to use quantitative risk assessment approaches that use data on water quality and derive a disease burden from the water supply based on the likely risks associated with the levels of pathogens, indicator organisms or chemicals found in water.

This disease burden will be defined as a risk rather than proven level of disease. Haas *et al.* (1999) stated that quantitative microbial risk assessment is typically performed for individual causative agents rather than undifferentiated health effects.

Initial work in the United States developed risk models for Giardia and rotavirus, which provided the levels of treatment required to meet targets related to acceptable levels of risk of diseases (Regli *et al.*, 1991).

This analysis was possible because the health data required for the analysis were readily available. For chemicals, this would be most logically performed on those toxic chemicals known to be present in the water.

For pathogens, the very wide range potentially present, the usually limited data and intermittent nature of pathogen presence means that risk assessment process is often best performed on a selected range of pathogens to act as reference pathogens.

A reference pathogen should be an organism whose severity of impact and persistence in water is such that its control would provide confidence that health risks from pathogens of a similar nature had also been controlled (WHO, 2003).

Selecting the reference pathogens for the risk assessment is the first important stage to consider. Where there are large amounts of data, such an approach would most logically be based on a review of the available clinical laboratory data of causative agents. In reality, this data may be limited or difficult to access and pathogens will be selected using expert knowledge.

Summary

The World Health Organization (WHO, 2004) outlines that the delivery of safe drinking-water is most effectively achieved by a Water Safety plan (WSP) framework that encompasses three elements:

1. establishing health based targets for drinking-water based on evaluation of health concerns,
2. Developing a management system to meet these targets that is termed Water Safety Plan (WSP), and
3. A system of independent surveillance that verifies that the above are operating properly.

The purpose of Water Safety Plans (WSPs) is to minimize risks through identification and management of vulnerable points within a water supply which allow hazards (both microbial and chemical) to cause contamination (Godfrey *et al*., 2002).

The vulnerability of the system is defined by its potential susceptibility to known hazards. The combination of hazard and vulnerability can be described as a hazardous event (NHMRC, 2002).

Control measures must be identified that reduce the risk of hazardous events occurring and where there are particular points in a water supply where control is essential, these are termed control points.

For both control measures and control points, simple means of monitoring linked directly to process control are required and thus focus on aspects such as chlorine residual, turbidity and sanitary inspection.

Analysis of the microbial quality is retained, but as a means of validating and verifying performance and not as a routine tool for monitoring process compliance (Godfrey *et al*., 2002).

Conclusion

The principles and methods used in Water Safety Plans (WSPs) draw on other risk management and quality assurance methods.

In particular they are based on the Hazard Analysis Critical Control Point (HACCP) approach applied in the food industry.

As described by the multiple barrier principle, source protection is the first stage in the production of safe drinking-water (WHO, 1993; 2004).

Maintaining these barriers to exposure is critical because, by and large, each barrier in series can offer order of magnitude (log) levels of protection to the drinking water supply (Hrudley *et al*., 2006; WHO, 2004).

The level of barriers required must be a function of the level of challenge posed by the source water. When sources are managed effectively, subsequent treatment cost are minimized and the risks of exposures resulting from failures in treatment processes are reduced.

Recommendations

The absence of specific information on causative agents, the use of *Escherichia coli* O157:H7, *Cryptosporidium parvum* and rotavirus as reference pathogens will provide a reasonable basis for the risk assessments.

Control of these organisms would provide reasonable confidence that all bacteria, protozoan and viral pathogens had been controlled.

For each of the reference pathogens, water is a well-proven route of infection. In undertaking a QMRA, both morbidity and mortality burdens must be considered to build a full picture of the health impact of a pathogen.

The use of Disability Adjusted Life Years is an accepted approach to defining health burdens. In calculating a daily score different outcomes are allocated a severity weight between 0 (no effect) and 1 (death) to reflect the health impairment caused to an infected person.

The higher the severity weight the greater the health impairment. These weights are grouped into seven classes where class I has a weight between 0.00 and 0.02 and class VII a weight between 0.7 and 1(Murray and Lopez, 1996). Sources and resources protection is vital for efficient risk management and safe water for the people.

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