CHAPTER-2
REVIEW OF LITERATURE

In developing countries, drinking water is a major source of microbial pathogenicity and related ailments. Understanding of the transmission of various pathogens that causes diarrhoea indicates it route via drinking water (Hunter et al., 2002). The World Health Organization (WHO) estimates that about 1.1 billion people globally drink unsafe water (Kindhauser, 2003) and the vast majority of diarrhoeal disease in the world (88%) is attributable to unsafe water, sanitation and hygiene (WHO, 2003a). Approximately 3.1% of annual deaths (1.7 million) and 3.7% of the annual health burden (disability adjusted life years [DALYs] worldwide (54.2 million) are attributable to unsafe water, sanitation and hygiene (WHO, 2003a).

Poor water quality spreads disease, causes death and hampers socio-economic progress. Around five million people die due to waterborne diseases. In addition, these diseases affect education and result in loss of work days. In India it is estimated that 180 million person days are lost annually. The annual economic loss is estimated at Rs.112 crores (Pathak, 2015).

However supplying clean water alone would not solve health-related problems. Only an integrated approach of water quality improvement with improvement in water availability combined with sanitation and hygiene education will help to address this issue.

This chapter provides a brief review of our understanding of issue of drinking water all over the world and waterborne pathogens with a focus on specific issues relevant to developing regions of the world. It begins by describing the significance water for human health continuing with waterborne disease with respect to total global disease burden, members of the four major pathogen groups – bacteria, viruses, protozoa and helminthes; and contamination, purification and sanitation problems with summarization of the related investigations conducted in country and abroad concluding with emerging issues and global efforts.
2.1 Importance of Water to Human Health and Disease potential via drinking water

Water is an indispensable component of the environment. The quality of drinking water has a direct link with the human health and providing clean water to the consumers is one of the most important public health priorities (UNCED, 1992). Drinking water should have high quality so that it can be consumed without threat of immediate or long-term adverse impacts to human health (WHO, 2017). Good and adequate water supply services are the most critical prerequisite for public health and well-being (Eassa and Mohmood, 2012). Many water resources in developing countries are unhealthy because they contain harmful physical, chemical and biological agents (WHO, 2011). To maintain good health, water should be safe to drink and meet the local standards for taste, odor and appearance (Cheesbrough, 2000). Majowicz et al., (2004) estimated under-reporting of acute gastrointestinal illness (from all causes) in a Canadian community to be 313 cases to one. Severe disease can sometimes occur, often in the very young, the elderly and in people with immune systems compromised by other illness or chemotherapy (CDC, 2014). One of the important UN Millennium Development Goals laid down was to reduce by half the proportion of people without sustainable access to safe drinking water by the year 2015. The United Nations Convention on the Rights of the Child stipulates that states and their partners have the obligation to provide clean drinking water to all children (WHO and UNICEF, 2006).

Water is basic necessity for human health and biological activity within living things. It is well known that access to safe water and sanitation are important in reducing disease transmission. In order to prevent infectious water borne diseases, it is important to take necessary precautions. Water has long been known being the source of many illnesses of man. Definite proofs of disease transmission through water are available.

The use of water treatment technology is not new, but dating back 6000 years when the Greeks used charcoal filters, boiling, straining and exposure to sunlight to improve the aesthetic quality of drinking water (WHO, 2003b). Yet the drinking water associated outbreak of cholera in Germany during 1892 was the foundation point of our modern under-standing of waterborne pathogens. It was
shown that residents of Hamburg suffered a very high mortality due to cholera, whilst people in neighboring Altona served by the same-source water as in Hamburg, but a treatment by slow-sand filtration, helped them to escape the worst ravages of the outbreak (Ashbolt, 2004). John Snow in his essay in 1955 *On the Mode of Communication of Cholera* conclusively demonstrated the role of the water supply in spreading the cholera epidemic in Soho (Gunn and Masellis, 2008). The German microbiologist, Robert Koch proposed the Germ theory of disease in 1867 and later isolated the causative agent of cholera in 1883, which he named Vibrio comma (later renamed to *V. cholerae*). These findings lead to the norm from 1897 for the treatment of piped water in the then developing regions of Europe, United Kingdom and North America. These late nineteenth century innovations resulted in the largest reduction in global disease burden of any intervention since (Ashbolt, 2004). Similar improvements have been sought in various developing regions of the world, many of which have been reported by Saunders and Warford (1976) and subsequent World Bank funded developments.

Data resolving the waterborne component in the interactions between exposure to enteric pathogens via poor quality water, lack of sanitation and inadequate hygiene is not generally available. However, estimates in North America suggest up to 15–30% of gastrointestinal disease may come via water (Payment *et al.*, 1997) with a similar component via food (Tauxe, 2002).

In developing regions, there is a higher rate of endemic (background) gastrointestinal disease and pathogen concentrations in wastewater (Martins *et al.*, 1983; Jimenez *et al.*, 2002), but, the proportion specifically waterborne is rarely identified (Ashbolt, 2004). Still, some specific insights are there. In a random sample of 2355 Filipino infants over the first year of life, it has been suggested that improving drinking water quality would have no effect in the neighbor-hoods with very poor environmental sanitation; yet in areas with better community sanitation, reducing the concentration of thermo-tolerant (faecal) coliforms by two orders of magnitude would lead to a 40% reduction in Diarrhoea (Vanderslice and Briscoe, 1995). Further, providing private excreta disposal would be expected to reduce Diarrhoea by 42%, while eliminating excreta around the house would lead to a 30% reduction in disease (Ashbolt, 2004).
The data of estimating waterborne disease in sensitive groups, such as human immunodeficiency virus (HIV) infected patients from Sao Jose Hospital, Fortaleza, Brazil was provided by Wuhib et al., (1994). Of the potential parasitic causes of Diarrhoea, only Cryptosporidium parvum and microsporidia were significantly associated with diarrhoeal disease in HIV-AIDS patients. And, since C. parvum infections were associated with the rainy season, it suggested that contaminated water may be important in its transmission (Wuhib et al., 1994).

As estimated, overall water, sanitation and hygiene-related death (99.8%) occur in developing countries and 90% are deaths of children (WHO, 2003a). Among the 20 leading risks factors for health burden in developing regions, unsafe water, sanitation and poor hygiene is third, behind being underweight or practicing unsafe sex (WHO, 2003a). A significant factor is higher concentrations of pathogens in sewage from developing regions. WHO guidelines based on the same level of E. coli (assuming the majority come from human excreta) will represent significantly higher risk in developing regions versus the developed regions. In addition, freeing up of food trade from developing to developed regions, pathogen guidelines may need to be tightened, given the practice of irrigated crops with faecally contaminated waters (Ashbolt et al., 2001).

The drinking water treatment efficacy (by filtration and chlorination) to remove the bacterial pathogens responsible for cholera (Vibrio cholerae) and typhoid fevers (Salmonella typhi and S. paratyphi) is well indexed by the common faecal indicator bacterium Escherichia coli (E. coli), which is excreted in the faeces of all warm-blooded animals and some reptiles (Edberg et al., 2000; Enriquez et al., 2001). However, many enteric pathogens behave differently to E. coli, particularly with respect to disinfection existence and environmental persistence (Ashbolt et al., 2001). The chlorine-resistant parasitic protozoa, such as the environmentally shed oocysts of Cryptosporidium parvum and various enteric viruses matter of particular concern (Hambidge, 2001; Li et al., 2002). It is therefore important to match the appropriate indicator for the group of pathogen(s) of interest, noting that there is no universal indicator, as often assumed with thermo-tolerant (faecal) coliforms or E. coli (Ashbolt, 2004).
2.2 Broad safety concerns of drinking water

Safe drinking water as defined by various guidelines ‘not represents any significant risk to health over a lifetime of consumption including different sensitivities that may occur between life stages’ (WHO, 2017). The current major obstacles to human health in developing regions are well understood and a large component relates to unsafe water, poor sanitation and inappropriate hygiene (WHO, 2003a). There are, however, several emerging waterborne issues. Foremost is the rapid urbanization of humans in developing regions and the further stress that places on inadequate water supply and sanitation. Associated with increased human activity is the eutrophication of waterways and the resultant increases in diseases. For example, cholera outbreaks are well known to be associated with phytoplankton blooms in nutrient-rich coastal waters. Climate change too is now seen as a reality, with not only a change in the distribution of rainfall, but also of greater extremes in global weather patterns (Vanderslice and Briscoe, 1995). Major waterborne outbreaks typically follow large storm events in developing regions. Yet, perhaps the greatest threat of all lies with the nature of microbial evolution, significantly increases with high density living and closes association with animals. SARS (severe acute respiratory syndrome) has been a recent messenger to remind us of the significance small genetic changes can have in what was regarded as a relatively benign Coronavirus (Kuiken et al., 2003). Not only do we have to contend with continual evolution of new pathogens, but decline of the ozone layer also has microbial health implications. For example, various diseases have been shown to increase due to UV light suppression of human defense systems (Norval, 2003).

As indicated in the guidelines of WHO and other agencies one of the primary concerns of water authorities is to ensure that the drinking water they supply does not pose an unacceptable health risk to consumers. The safety of drinking water is generally monitored in a number of ways:

1. Constituents of drinking water (such as chemicals and microbes), which can compromise human health, can be measured directly;

2. Barriers designed to protect water quality (such as catchment activities, filtration and disinfection) can be monitored; and
3. Indicators of water quality that can be measured to assess the potential presence of broad groups of parameters.

2.3 Global Scenario of Safe drinking water availability

WHO fact sheet on drinking water scenario updated in July 2017 reports that 844 million people in the world lack even a basic drinking-water service, including 159 million people who are dependent on surface water. And, globally at least 2 billion people use a drinking water source contaminated with faeces, which can transmit diseases such as diarrhoea, cholera, dysentery, typhoid, and polio. It is estimated that by 2025 half of the world’s population will be living in water-stressed areas. Situation is worse in low- and middle-income countries, 38% of health care facilities lack an improved water source, 19% does not have improved sanitation, and 35% lack water and soap for hand washing. Another report by WHO and UNICEF (2017) points out that 844 million people still lacked even a basic drinking water service and 159 million people still collected drinking water directly from surface water sources, 58% lived in sub-Saharan Africa. Some good pointers in this report indicates that 71 per cent of the global population (5.2 billion people) used a safely managed drinking water service; that is, one located on premises, available when needed and free from contamination. And, 89 per cent of the global population (6.5 billion people) used at least a basic service; that is, an improved source within 30 minutes’ round trip to collect water. The proportion of the population with at least basic drinking water services has increased by an average of 0.49 percentage points per year between 2000 and 2015, but the increase was substantially faster in Eastern Asia and South-eastern Asia (0.97) and sub-Saharan Africa (0.88). Australia and New Zealand and North America and Europe are already very close to achieving universal basic drinking water services, while Latin America and the Caribbean, as well as Eastern Asia and South-eastern Asia are on track to achieve universal access by 2030. Some figures related to the issue have been mentioned in previous section also.

Bansal, (2004) in his study he observed that, in developing countries especially in Africa and Asia remained in midst of water crisis that is exacting of millions causalities. Although water scarcity is worsening worldwide and face lack
of access to safe drinking water and burden on socioeconomic status yet People’s quality of life depends on their access to water. For improving water quality privatization of water, supplies as a violation of people’s basic right of water argue that because private water companies are ultimately seeking profits. They will not be served that need to the poor. In reference to India, its situation is also pitiable because population is increasing at very fast rate while availability of drinking water is decreasing. Apart from repercussion on health, this also affects the overall well-being. Moreover, 70-80 per cent of illnesses are related to water contamination and poor sanitation.

Dinesh Chand, (2009) in his study point out that, most burning problem an enormous challenge of safe drinking water of the world. Most of the people across the world do not have access to adequate and safe drinking water facility especially in rural areas. The latest report indicates that about 15 per cent of the total rural habitants in India facing water quality problem mainly due excess of fluoride, arsenic, iron, nitrate contamination, and salinity. The Government chalked out many strategies in sector of the drinking water supplies, recognized reform to adopt community participation in the rural water supply programme, and lanced sector reform projects in the country on a pilot basis in the country.

The climate change is also aggravating the problem. By 2030, the world is projected to face a 40% global water deficit under the business-as-usual climate scenario (UNESCO, 2015). The fact is there is enough water to meet the world’s growing needs, but not without dramatically changing the way water is used, managed and shared. The global water crisis is one of governance (WWAP, 2006), much more than of resource availability.

It has been estimated that the total global economic losses associated with inadequate water supply and sanitation were estimated at US$ 260 billion annually, or 1.5% of Gross Domestic Product of the countries surveyed (WHO, 2012).
2.4. Waterborne illness and pathogenic contaminants

2.4.1. Diarrhoea

According to the fact sheet of WHO on Diarrhoeal disease (updated in 2017), this is the second leading cause of death in children under five years old, though it is both preventable as well as treatable. Diarrhoea is also a leading cause of malnutrition of children under five. The fact sheet also says that each year diarrhoea kills around 5,25,000 children under five globally, and there are nearly 1.7 billion cases of childhood diarrhoeal disease every year. Parashar et al., (2003) reported that diarrhoeal disease is one of the leading causes of illness and death in young children in developing countries, especially Bangladesh and most countries of south Asia.

It has also been stated in the report that a significant proportion of diarrhoeal disease can be prevented through safe drinking water and adequate sanitation and hygiene. Diarrhoea is caused by a variety of microorganisms including viruses, bacteria and protozoan’s. Diarrhoea causes a person to lose both water and electrolytes, which leads to dehydration and, in some cases, to death. Excreta are the main causes of childhood diarrhoeal diseases. Repeated episodes of diarrhoea make children more vulnerable to other diseases and malnutrition. Diarrhoea is the most important public health problem directly related to water and sanitation. The simple act of washing hands with soap and water can cut diarrhoeal disease by one-third. Next to providing adequate sanitation facilities, it is the key in preventing waterborne diseases. Diarrhoea, having a high attribution of 88% to inadequate sanitation, was used as the primary indicator for understanding the effect of improper sanitation practices and behavior (WSP, 2011). It is to be noted that open defecation was the prevailing mode of defecation in both the member households and non-member households.

2.4.2 Cholera and typhoid

While estimating enormous endemic disease burden in developing regions, WHO verified 578 infectious disease outbreaks in 132 countries from July 1998 until August 2001 and cholera was the most frequent, with acute diarrhoea as the fourth (WHO, 2002). Further behind in importance were typhoid and paratyphoid fevers (caused by Salmonella typhi and S. paratyphi, respectively), resulting in an
annual incidence of about 17 million cases world-wide (Kindhauser, 2003). Both typhoid pathogens are passed in the faeces and urine and people become infected after eating food or drinking beverages that have been handled by a person who is infected or by drinking water that has been contaminated by sewage containing the bacteria. Once the bacteria enter the person’s body they multiply and spread from the intestines, into the bloodstream. Even after recovery from typhoid or paratyphoid, a small number of individuals (called carriers) continue to carry the bacteria. Cholera behaves slightly differently. In warm regions of the world, the serogroups that cause epidemic cholera (Vibrio cholerae O1 and O139) are endemic in freshwater zooplankton (Colwell et al., 2003) and outbreaks occur in a regular seasonal pattern in developing regions in association with poverty and poor sanitation. The disease is characterized by devastating watery Diarrhoea that leads to rapid dehydration and death occurs in 50–70% of untreated patients (Faruque et al., 1998). Cholera toxin (CT), which is responsible for the profuse diarrhoea, is encoded by a lysogenic bacteriophage designated CTX Phi, which probably results in a continual emergence of new epidemic clones. Hence, the ecosystem comprising V. cholerae, CTX Phi in the aquatic environment and the mammalian host offers a complex relationship between pathogenesis and the natural selection of a pathogen (Faruque et al., 1998), wherever there continues to be a lack of adequate water filtration and/or disinfection.

So, in prevailing combinations of poverty, poor water treatment and presence of V. cholerae, the re-entry of cholera into Africa in 1970 and Peru in 1991, although devastating, was not a total surprise. Cholera in Africa, after an absence for over a 100 years, accounted for 94% of the total global cholera cases reported to WHO in 2001 (WHO, 2002). In the first half of 2002, outbreaks involving thousands of cases occurred in the Dominican Republic of the Congo, Malawi and Mozambique. A similar story has been seen in South America, with the seventh pandemic reaching Peru in 1991, after an absence of over 100 years in Latin America. Within a year, 400 000 cases and 4000 deaths were reported from 11 South American countries (WHO, 2002).
2.4.3 Pathogens of concern

In 2001, infectious diseases accounted for an estimated 26% of deaths worldwide (Kindhauser, 2003). Furthermore, social and environmental changes continue to result in new or re-emerging waterborne pathogen issues. For example, climate change was estimated to be responsible in 2000 for approximately 2.4% of worldwide Diarrhoea, 6% of malaria in some middle-income countries and 7% of dengue fever in some industrialized countries. In total, the attributable mortality was 154000 (0.3%) deaths and the attributable burden was 5.5 million (0.4%) DALYs. About 46% of this burden occurred in WHO-designated regions of SEAR-D (Bangladesh, South East Asia) (23% in AFR-E, Botswana) and a further 14% in EMR-D (Afghanistan) (WHO, 2003a). The better-known waterborne pathogens of concern in developing regions are listed in Table 1. All of these infectious agents are spread by the faecal–oral route, in which water may play an intermediate role (Table 2). Hence, environment, water, food, poor hygiene (poverty and nutritional status) is all factors of importance.

By 2001, a total of 1415 species of infectious organisms known to be pathogenic to humans had been recorded (WHO, 2003b). Some of the more important ones in developing regions are now described.

Table 1: Waterborne pathogens of concern in developing regions
(After Ashbolt, 2004)

<table>
<thead>
<tr>
<th>Name of micro-organisms</th>
<th>Major diseases</th>
<th>Major reservoirs and primary sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Salmonella typhi</em></td>
<td>Typhoid fever</td>
<td>Human faeces</td>
</tr>
<tr>
<td><em>Salmonella paratyphi</em></td>
<td>Paratyphoid fever</td>
<td>Human faeces</td>
</tr>
<tr>
<td>Other <em>Salmonella</em></td>
<td>Salmonellosis</td>
<td>Human and animal faeces</td>
</tr>
<tr>
<td><em>Shigella spp.</em></td>
<td>Bacillary dysentery</td>
<td>Human faeces</td>
</tr>
<tr>
<td><em>Vibrio cholera</em></td>
<td>Cholera</td>
<td>Human faeces and freshwater zooplankton</td>
</tr>
<tr>
<td>Enteropathogenic <em>E. coli</em></td>
<td>Gastroenteritis</td>
<td>Human faeces</td>
</tr>
<tr>
<td><em>Yersinia enterocolitica</em></td>
<td>Gastroenteritis</td>
<td>Human and animal faeces</td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>Gastroenteritis</td>
<td>Human and animal faeces</td>
</tr>
<tr>
<td><strong>Legionella pneumophila</strong> and related bacteria</td>
<td>Acute respiratory illness (legionellosis)</td>
<td>Thermally enriched water</td>
</tr>
<tr>
<td>Leptospira spp.</td>
<td>Leptospirosis</td>
<td>Animal and human urine</td>
</tr>
<tr>
<td>Various mycobacteria</td>
<td>Pulmonary illness</td>
<td>Soil and water</td>
</tr>
<tr>
<td>Opportunistic bacteria</td>
<td>Variable</td>
<td>Natural waters</td>
</tr>
</tbody>
</table>

**Enteric viruses**

- Enteroviruses
- Polio viruses
- Coxsackie viruses A
- Coxsackie viruses B
- Echo viruses
- Other enteroviruses
- Rotaviruses
- Adenoviruses
- Hepatitis A virus
- Hepatitis E virus
- Norovirus

**Protozoa**

- Acanthamoeba castellani
- *Balantidium coli*
- Cryptosporidium hominis, *C. parvum*
- Entamoeba histolytica
- Giardia lamblia
- Naegleria fowleri

**Helminths**

- Ascaris lumbricoides

<table>
<thead>
<tr>
<th><strong>Enteric viruses</strong></th>
<th><strong>Protozoa</strong></th>
<th><strong>Helminths</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Polio viruses</td>
<td>Acanthamoeba castellani</td>
<td>Amoebic meningoencephalitis</td>
</tr>
<tr>
<td>Coxsackie viruses A</td>
<td><em>Balantidium coli</em></td>
<td>Balantidosis (dysentery)</td>
</tr>
<tr>
<td>Coxsackie viruses B</td>
<td>Cryptosporidium hominis, <em>C. parvum</em></td>
<td>Cryptosporidiosis (gastroenteritis)</td>
</tr>
<tr>
<td>Echo viruses</td>
<td>Entamoeba histolytica</td>
<td>Amoebic dysentery</td>
</tr>
<tr>
<td>Other enteroviruses</td>
<td>Giardia lamblia</td>
<td>Giardiasis (gastroenteritis)</td>
</tr>
<tr>
<td>Rotaviruses</td>
<td><em>Naegleria fowleri</em></td>
<td>Primary amoebic meningoencephalitis</td>
</tr>
<tr>
<td>Adenoviruses</td>
<td>Ascaris lumbricoides</td>
<td>ascariosis</td>
</tr>
</tbody>
</table>
### Table 2: Water supply related diseases (After Ashbolt, 2004)

<table>
<thead>
<tr>
<th>Group</th>
<th>Diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-borne diseases: diseases spread through water in which water acts as a passive carrier for the infecting pathogens. These diseases depend also on sanitation</td>
<td>Cholera, Typhoid, Bacillary dysentery, Infectious hepatitis, Leptospirosis, Giardiasis, Gastroenteritis etc.</td>
</tr>
<tr>
<td>Water-related diseases: diseases spread by vectors and insects that live in or close to water. Stagnant ponds of water provides the breeding place for the disease spreading vectors such as mosquitoes, flies and insects.</td>
<td>Yellow fever, Dengue fever, Encephalitis, Malaria, Filariasis (all by mosquitoes), Sleeping sickness (Tsetse fly), Onchocerciasis (Simulium fly) etc.</td>
</tr>
<tr>
<td>Water-based diseases: diseases caused by infecting agents spread by contact with or ingestion of water. Water supports an essential part of the life cycle of infecting agents such as aquatic snails.</td>
<td>Schistosomiasis, Dracunculosis, Bilharziosis, Philariosis, Oncholersosis, Treadworm and other helminths</td>
</tr>
<tr>
<td>Water-washed diseases: diseases caused by the lack of adequate quantity of water for proper maintenance of personal hygiene. Quantity of water for proper maintenance of personal hygiene. Some are also depended on poor sanitation.</td>
<td>Scabies, Trachoma (eye-infection), Leprosy, Conjunctivitis, Salmonellosis, Ascariasis, Trichuriasis, Hookworm, Amoebic Dysentery, Paratyphoid fever etc.</td>
</tr>
</tbody>
</table>
Table 3: Selected cholera pandemics since 1817 and principal outcomes

(After Ashbolt, 2004)

<table>
<thead>
<tr>
<th>Period</th>
<th>Principal outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1817–1823</td>
<td>Possible emergence of a more virulent strain of Vibrio cholera (V. cholerae). Global trade with the Indian Sub-continent carried the cholera vibrio around the world.</td>
</tr>
<tr>
<td>1829-1851</td>
<td>Waterborne transmission of <em>cholerae</em> suspected.</td>
</tr>
<tr>
<td>1852-1859</td>
<td>First isolation of cholera bacterium. Fear of cholera stimulated international co-operation in health.</td>
</tr>
<tr>
<td>1881-1896</td>
<td>Conclusive demonstration that cholera was caused by a bacterium.</td>
</tr>
<tr>
<td>1961</td>
<td>Emergence of V. cholerae O1, biotype El Tor (sixth pandemic)</td>
</tr>
<tr>
<td>1992</td>
<td>Emergence of V. cholerae O139 (seventh pandemic)</td>
</tr>
</tbody>
</table>

2.4.3.1 Major bacterial pathogens

It has been noted earlier in the reports that children are most vulnerable for infection from enteric microbes. Study of Albert et al., (1999) in Dhaka, Bangladesh have demonstrated that some 75% of diarrhoeal children and 44% of control children have an enteric pathogen in their stools. The major pathogens associated with diarrhoea being rotavirus, *Cryptosporidium parvum* are followed by bacterial pathogens: *Campylobacter jejuni*, enteric toxigen *Escherichia coli*, enteric pathogen *E. coli*, *Shigella* sp. and *Vibrio cholerae* (O1 or O139) and to a lesser degree *Aeromonas* sp., *Bacteroides fragilis* and *Clostridium difficile*. Other bacterial pathogens *Plesiomonas shigelloides*, *Salmonella* sp. diffusely adherent *E. coli* and entero-aggregative *E. coil*, along with the parasitic protozoa *Entamoeba histolytica* and *Giardia lamblia* were not significantly associated with diarrhoea. Entero-invasive *E. coli*, entero-hemorrhagic *E. coli* and *Cyclospora cayetanensis* were not detected in any of the children in the Dhaka studies. Viral and parasite pathogens are discussed below, but the two other leading enteric pathogens EPEC and Campylobacter spp. are briefly discussed next.
The *E. coli* entero-pathogenic (EPEC) strains are a leading cause of infantile diarrhoea in developing countries, though they are rare in industrialized countries, where atypical EPEC seems to be a more important cause of diarrhoea (Trabulsi *et al.*, 2002). The only reservoir of typical EPEC (and the closely-related *Shigella* spp.) is humans that suggest poor handling of human excreta/water quality as the major problem. For atypical EPEC, both animals and humans can be reservoirs (Trabulsi *et al.*, 2002).

The Campylobacters (*Campylobacter jejuni* and *C. coli*) are generally regarded as one of the most common bacterial cause of gastroenteritis world-wide (and 5–14% of all diarrhoea). In both developed and developing countries, they cause more cases of diarrhoea than *Salmonella*. In developed countries, the disease is found mainly in children under the age of 5 years and in young adults. In developing countries, children under 2 years are most affected. It is also a frequent cause of traveller’s diarrhoea (WHO, 2003 a, b; http://www.who.int/water sanitation health/diseases/ disease fact/en/). A matter of particular concern is that in some individuals a reactive arthritis (painful inflammation of the joints) can occur due to such infections, or in rare complications, seizures due to high fever or neurological disorders such as Guillain–Barré syndrome or meningitis may also be observed (Havelaar *et al.*, 2000).

### 2.4.3.2 Environmental bacterial pathogens

Apart from the zooplankton-found cholera bacteria, many aquatic species of bacteria are opportunistic pathogens of humans (Ashbolt, 2003). Such as *Legionellae* that cause legionnaires disease and Pontiac fever (Atlas, 1999). Drinking waters may be the medium of be transportation in several species of Legionella; however, it is the growth of certain serogroups (sub-types) in warm waters/ biofilms that results in the high numbers necessary to be aerosolized and inhaled into human lungs, where the target (phagocyte) cells reside. Environmental growth is most commonly noted in cooling towers and institutional hot water systems (which are deliberately maintained below 50°C). Environmental pathogens that may well be transmitted directly by drinking water in developing regions are fast-growing atypical mycobacteria *Burkholderia pseudomallei* and *Helicobacter pylori*. In tropical regions, *Mycobacterium ulcerans* is found in aquatic
environments and *M. avium* complex and *M. intracellular* bacteria appear to grow in piped (and chlorinated) water biofilms and are a major concern to immuno-suppressed individuals (Falkinham *et al.*, 2001). *Burkholderia pseudomallei* cause melioidosis, which is hyper endemic in the top end of the Northern territory of Australia and in parts of south-east Asia. It is the commonest cause of fatal community-acquired septicemic pneumonia (Currie *et al.*, 2000) and has been shown to be associated with drinking water (Inglis *et al.*, 2000). *Helicobacter pylori* causes up to 95% of duodenal ulcers and 80% of stomach ulcers and between 50 and 90% of all stomach cancers (Rupnow *et al.*, 2000). In developing countries, 70 to 90% of the population carries *H. pylori* (Dunn and Cohen, 1997). Epidemiological studies in Peru and other developing regions strongly support the transmission of *H. pylori* via drinking water (Hulten *et al.*, 1996).

### 2.4.3.3 Enteric viruses

Gastroenteritis owing to virus occurs with two epidemiologic patterns—diarrhoea that is endemic in children and out-breaks that affect people of all ages. Viral diarrhoea in children is caused by group A rotaviruses, enteric adenoviruses (mainly types 40, 41 and subgenus F), astroviruses (three serogroups) and the human caliciviruses (predominantly *Noroviruses*). The illness affects all children worldwide in the first few years of life regardless of their level of hygiene, quality of water, food or sanitation, or type of behavior (Glass *et al.*, 2001).

Rotaviruses represent 80% of recognized viral etiologies and 140 million cases of diarrhoea per year (Albert *et al.*, 1999). They strike young children with similar frequency throughout the world, but the mortality rate is high in developing countries only, with some 870 000 deaths per year (WHO, 1997). This is to be noted that while UV disinfection is much more effective disinfectant than chlorination for some pathogens (*Cryptosporidium*, enteroviruses), adenoviruses are very resistant to UV disinfection (Meng and Gerba, 1996).

Epidemic viral diarrhoea is caused primarily by the Norovirus genus of the human caliciviruses. These viruses affect people of all ages, are often transmitted by fecally contaminated food or water and probably represent the most important cause of diarrhoea in developed countries (Lopman *et al.*, 2003). For most of the enteric
viruses infections early in life provide immunity from severe disease upon re-infection. But, tremendous antigenic diversity of caliciviruses and short-lived immunity to infection permit repeated episodes throughout life (Glass et al., 2001), but infection appears to be blood-group related. In addition to childhood rotavirus disease, adults in developing regions also suffer large outbreaks from rotaviruses (Hung et al., 1984).

Some other important waterborne enteric viruses that cause non-diarrhoeal disease include Hepatitis A and E, enterovirus 71 and other enteroviruses (Polio, Coxsachie and ECHO (enteric cytopathic human orphan) viruses). Despite worldwide immunization and near eradication of polio virus, there have been recent outbreaks in large metropolitan cities in India due to high population density and the presence of large urban slums (Deshpande et al., 2003). Of further worry have been the outbreaks in the Dominican Republic and Haiti due to derivatives from an attenuated polio virus vaccine (OPV) in use during 1998–1999 (Kew et al., 2002).

Hepatitis A and hepatitis E viruses are associated with inadequate water supplies and poor sanitation and hygiene, leading to infection and inflammation of the liver. Poor sanitation in developing regions, however, results in early infection of Hepatitis A and lifelong protection from the severe ill effects seen in unexposed people of 50 years or older in developed regions (Kindhauser, 2003). In the case of hepatitis E, although the mortality rate is usually low (0.07–0.6%), the illness may be particularly severe among pregnant women, with mortality rates reaching as high as 25% (Aggarwal and Krawczynski, 2000), as seen in large outbreaks in China and sporadic outbreaks in the Indian subcontinent, southeast and central Asia, the Middle East, parts of Africa and Mexico (Naik et al., 1992). Recent isolation of a swine virus resembling human HEV has also opened the possibility of zoonotic HEV (hepatitis E virus) infection (Halbur et al., 2001). A study in India on hepatitis E infections indicated that 70% of the cases were due to contaminated water and 20% due to food (Gerba and Rose, 2003). Of particular recent concern in developing regions have been the possibly water-related outbreaks of enterovirus 71, which causes hand-foot-and-mouth disease associated with severe neurological problem and death in a small proportion of cases (McMinn, 2002).
Enteric viruses can be transported in the water environment through groundwater, estuarine water, seawater, rivers, aerosols emitted from sewage treatment plants, insufficiently treated water, drinking water, and private wells that receive treated or untreated wastewater either directly or indirectly (Bitton and Gerba, 1984; Lipp et al., 2002; Sobsey et al., 1986; Yates et al., 1985). The viruses concerned are highly host specific. Their presence in water environments is a sound evidence of human fecal pollution. The extent of the host specificity of enteric viruses is such that it is used as a valuable tool to distinguish between fecal pollution of human and animal origin, or to identify the origin of fecal pollution. (Hundesa et al., 2006).

2.4.3.4 Parasitic protozoa

Waterborne and foodborne parasitic protozoa in developing countries include; Cryptosporidium parvum, Giardia lamblia and Toxoplasma gondii, all of considerable concern in immuno-compromised people, along with Entamoeba histolytica, Cyclospora cayetanensis and Sarcocystis sp. These parasites are responsible for persistent diarrhoea, which is defined as an episode that begins acutely and lasts for at least 14 days (Black, 1993).

Cyclospora cayetanensis and Sarcocystis spp. have emerged as causes of traveller’s diarrhoea in developed region acquired overseas (CDC, 1997; Doller et al., 2002). Therefore, along with Cryptosporidium parvum and Giardia lamblia these protozoa seem to be endemic to developing regions. Studies in a peri-urban shanty town in Lima, Peru, suggest that Giardia lamblia is hyperendemic in children (up to 10 years old) and despite treatment, 98% of the children became re-infected with the pathogen within 6 months. Hence, treatment of all symptomless Giardia lamblia infections in a developing country hyperendemic for the disease is of questionable value because of rapid re-infection (Gilman et al., 1988).

2.4.3.5 Helminths

Ascariasis caused by Ascaris lumbricoides occurs with greatest frequency in tropical and subtropical regions and in any areas with inadequate sanitation. Up to 10% of the population of the developing world is infected with intestinal worms, and a large percentage of which is caused by Ascaris; and world-wide severe Ascaris
infections cause approximately 60,000 deaths per year, mainly in children (Kindhauser, 2003). The 85,000 hectares in the Mezquital Valley of central Mexico is a classic example where raw sewage is used to irrigate food crops and causes significant Diarrhoea and Ascariasis (Cifuentes et al., 1993). WHO have long recognized the importance of wastewater associated Ascariasis and set a guideline of less than 1 ova per litre (in 1989), which is likely to remain in future guidelines (Blumenthal and Peasey, 2002). Other important enteric helminths in developing regions include *Strongyloides* spp. and *Trichuris trichiura* (Hodges, 1993). There are a range of helminths potentially transmitted by water, but due to their large size (ova >40 mm dia.) they readily settle out in treatment ponds and are easily removed from drinking water by filtration. Hence, helminthes are generally less of a problem via drinking water than the smaller microbial pathogens.

**Major Water- and Excreta-Related Pathogens since 1973 (Adapted from Satcher 1995; Grabow 1997; and Lederberg 1997)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Pathogen</th>
<th>Type</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>Rotavirus</td>
<td>Virus</td>
<td>Diarrhoea</td>
</tr>
<tr>
<td>1976</td>
<td><em>Cryptosporidium parvum</em></td>
<td>Protozoan</td>
<td>Acute enterocolitis</td>
</tr>
<tr>
<td>1977</td>
<td><em>Legionella pneumophila</em></td>
<td>Bacterium</td>
<td>Legionnaires’ disease</td>
</tr>
<tr>
<td>1977</td>
<td><em>Campylobacter jejuni</em></td>
<td>Bacterium</td>
<td>Diarrhoea</td>
</tr>
<tr>
<td>1982</td>
<td><em>Escherichia coli O157:H7</em></td>
<td>Bacterium</td>
<td>Hemorrhagic colitis, haemolytic uremic syndrome</td>
</tr>
<tr>
<td>1983</td>
<td><em>Helicobacter pylori</em></td>
<td>Bacterium</td>
<td>Gastric ulcers, stomach cancer</td>
</tr>
<tr>
<td>1985</td>
<td><em>Enterocytozoon biennisi</em></td>
<td>Protozoan</td>
<td>Diarrhoea</td>
</tr>
<tr>
<td>1986</td>
<td><em>Cyclospora cayetanensis</em></td>
<td>Protozoan</td>
<td>Diarrhoea</td>
</tr>
<tr>
<td>1988</td>
<td>Hepatitis E</td>
<td>Virus</td>
<td>Enteric hepatitis</td>
</tr>
<tr>
<td>1991</td>
<td><em>Encephalitozoon hellem</em></td>
<td>Protozoan</td>
<td>Cholera</td>
</tr>
<tr>
<td>1992</td>
<td><em>Vibrio cholerae O139</em></td>
<td>Bacterium</td>
<td>Cholera</td>
</tr>
<tr>
<td>1992</td>
<td>Hepatitis F</td>
<td>Virus</td>
<td>Enteric hepatitis</td>
</tr>
</tbody>
</table>
Therefore, the major pathogenic issues to human health in developing regions are now understood and a large component relates to unsafe water, poor sanitation and inappropriate hygiene (WHO, 2003a). However, there are some other concerns. The rapid urbanization of humans in developing regions is symptomized by inadequate water supply and sanitation. The increased human activity causes eutrophication of waterways and the resultant increases in diseases. For example, cholera outbreaks are well known to be associated with phytoplankton blooms in nutrient-rich coastal waters. Climate change leading to greater extremes in global weather patterns also aggravates the vulnerability to infection and disease (Vanderslice and Briscoe, 1995). Major waterborne outbreaks typically follow large storm events in developing regions. Yet, the greatest threat of all perhaps lies with the nature of microbial evolution, which significantly increases with high density and living with close association with animals. SARS (severe acute respiratory syndrome) has been a recent messenger to remind us of the significance small genetic changes can have in what was regarded as a relatively benign Coronavirus (Kuiken et al., 2003). Decline of the ozone layer also has microbial health implications as various diseases have been shown to increase due to UV light suppression of human defense systems (Norval, 2003). So, it can be concluded that despite our efforts, pathogens will always be a major issue for human health, and particularly so in developing regions.

2.5 Biological concerns with water

Water also plays a major role in regulating body temperature as our bodies can overheat if not for perspiration from sweat glands in the skin and evaporation, which produce a cooling effect. This is all due to the movement of water within our cellular systems as the vital blood plasma, which is 92% water (APEC, 2015). It is difficult to understand the biological phenomenon fully because the chemistry of water revels much about the metabolism of the ecosystem and explain the general hydro - biological relationship (Basavaraja Simpi et al., 2011). There are trends in developing countries to use sewage effluent as fertilizer has gained much importance as it is considered a source of organic matter and plant nutrients and serves as good fertilizer (Riordan, 1983). Farmers are mainly interested in general benefits, like increased agriculture production, low cost water source, effective way of effluent
disposal, source of nutrients, organic matter etc., but are not well aware of its harmful effects like heavy metal contamination of soils, crops and quality problems related to health. Research has proven that long-term use of this sewage effluent for irrigation contaminates soil and crops to such an extent that it becomes toxic to plants and causes deterioration of soil (Quinn 1978, Hemkes 1980). This contains considerable amount of potentially harmful substances including soluble salts and heavy metals like Fe^{2+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, Ni^{2+}, and Pb^{2+}. Additions of these heavy metals are undesirable. Plants can accumulate heavy metals in their tissues in concentrations above the permitted levels which is considered to be a threat to the life of humans, and animals feeding on these crops and may lead to contamination of food chain, as observed that soil and plants contained many toxic metals, that received irrigation water mixed with industrial effluent (Adnan Amin, 2010).

Abiotic environment of freshwater ecosystem affects the biotic component of the ecosystem. If any change occurs in physico-chemical characteristics of water, it causes a direct impact upon the biotic data. Availability of clean and potable water has become a key issue in several developing countries. Burgeoning population and water scarcity is affecting the quality of life significantly; India is no exception to this (Parashar et al., 2006).

2.6 Quality standards of water and Water Quality Index (WQI)

Clean water is an essential ingredient to economic growth and development and investing in water and sanitation has high economic and social returns. Water has two dimensions that are closely linked: quality and quantity. Water quality and quantity are critical to every aspect of life. Water quality is commonly defined by its physical, chemical, biological and aesthetic characteristics; it is an important indicator of environmental health. A healthy environment is one in which the quality of water present can support a rich and varied community of organisms while protecting public health (NSW, 2014). The quality of a water supply normally influences the activities for which individuals can use the water from drinking to cooking, washing clothes, bathing, household cleaning to irrigating crops and watering stock. It is most important that the water which people drink and use for these activities is clean water, free of harmful germs and chemicals. When water is safe for drinking it is referred to as potable water (Commonwealth of Australia,
While many contaminants are found at levels not enough to cause immediate discomfort or sickness, it has been proven that even low-level exposure to common contaminants can cause severe illness over time. Infants, young children, pregnant women, the elderly and individuals with comprised immune systems may be especially susceptible to illness from contaminants (CDC, 2014). As discussed already before, ingestion of water contaminated with microbial pathogens is known to cause gastrointestinal issues such as Diarrhoea, cholera, stomach infections, and typhoid fever among others. Chemical contaminants may provoke various health issues such as trouble breathing, Dermatitis, heavy metal poisoning, methaemoglobinemia, etc. (WHO, 2015).

One of the primary concerns of water authorities is to ensure that the drinking water they supply does not pose an unacceptable health risk to consumers. The safety of drinking water is generally monitored in a number of ways:

1. Constituents of drinking water (such as chemicals and microbes), which can compromise human health, can be measured directly;

2. Barriers designed to protect water quality (such as catchment activities, filtration and disinfection) can be monitored; and

3. Indicators of water quality (such as turbidity) can be measured to assess the potential presence of broad groups of parameters.

To address microbial health risk, primary assessment can only be achieved by monitoring source water and barriers. Monitoring treated water in distribution systems for microorganisms is a means of verification only. Of the three methods used to assess drinking water listed above, indicators are most often used to monitor microbial water quality, as direct measurement of all pathogenic microorganisms is difficult, expensive and time consuming. In most cases, risks from chemicals in drinking water are due to chronic exposure meaning that there is no urgency between sampling, testing and acting on results.

There are two major reasons for monitoring drinking water quality:

- To determine if the water supply system is being operated correctly, implying that the water is safe for consumers (Primary Assessment); and
• Proof that the water was safe after it was supplied. This includes monitoring for compliance (Verification).

A standard testing of water's potability consists of drawing a sample from a known property or water source, providing State Certified Nitrate/Nitrogen and Coliform Bacteria testing, along with *E. coli* testing. It also means providing testing for Total Dissolved Solids, Water Hardness, pH, and Iron Content Testing. A Certified Laboratory must provide proper operation of all Water Softening and Filtration Systems, and provide written results of the above testing with a standardized period. However, such studies are necessary for Dungarpur.

During the study of water sample of hand pump and well if amount of chloride higher than ISI limits hypo chloride of chlorine will indicate organic pollution. If the amount of total dissolved solid higher than ISI limit alum salt will used for water treatment. If the amount of calcium and Magnesium higher then ISI limit settlement of water for overnight is the treatment method. Red not brick placed in water used for treatment of microbial flora. Sewage disposal affects people for water related illness such as Diarrhoea (Pandey B *et al.*, 2014).

The quality of drinking water at the point of delivery to the consumer is crucial in safeguarding consumer's health. Makhmoor *et al.*, 2015 studied the likely causes of the transit de-chlorination of water and recommended carrying out compulsory chlorination at water sources while maintaining reasonable residuals at the consumers end to eliminate the bacteriological contamination.

Surface water and roof top storage tank water was more liable to contamination whereas, ground water and aqua-guard water was safer for human consumption. Chlorine was effective in removing these bacteria from water (Thakur *et al.*, 2012). Ground Water is the major source of drinking water in both urban and rural areas. The importance of ground water for the existence of human society cannot be over emphasized. Ground water crisis is not the result of natural factors. It has been caused by human action much of ill health, which effects humanity especially in the developing countries, can be traced to lake of safe and wholesome water supply (Shyamala *et al.*, 2009). Prolonged discharge of industrial effluents, domestic sewage and solid waste dump causes the groundwater to become polluted.
and create health problems (Raja et al., 2002). Water of good drinking quality is of basic importance to human physiology has continued existence depends very much on its availability (Lamikarna et al., 1999). Only 1% part is available on land for drinking, agriculture, domestic power generation, industrial consummation, transportation and waste disposal (Mishra et al., 2002; Gupta et al., 2008; Tahir et al., 2008). Water quality means the physical, chemical and biological characteristics of water (Diersing, 2009).

**Role of disinfectant residuals in maintaining drinking water quality**

The purpose of treating drinking water is to provide a product that is microbiologically and chemically safe for consumption. In all public and semi-public systems applying disinfection, a disinfectant residual should be maintained throughout the distribution system at all times. Maintenance and monitoring of a residual disinfectant offer two benefits. First, a residual will limit the growth of organisms within the system and may afford some protection against contamination from without; second, the disappearance of the residual provides an immediate indication of the entry of oxidizable matter into the system or of a malfunction of the treatment process. It is therefore recommended that a disinfectant residual be maintained and monitored daily throughout the entire system. The minimum disinfectant residual that needs to be maintained is determined by the responsible authority and may vary from jurisdiction to jurisdiction. It is recognized that excessive levels of disinfectant may result in taste and odour problems. If this occurs, the responsible authority may provide guidance as to the type and concentration of disinfectant residual to ensure that water remains microbiologically safe. When a residual concentration measured at a sampling point is less than that required by the responsible authority, another sample should be taken immediately. If this sample is also unsatisfactory, the line should be flushed and sampling continued until a satisfactory concentration is obtained. If the residual does not return to the allowable minimum, the disinfectant dosage should be increased. If increasing the dosage is ineffective or if excessive disinfection is required, a sanitary survey for potential sources of contamination should be made in cooperation with the responsible authority. Special samples should be taken for coliform analysis.
Should all these measures prove inadequate, the responsible authority should be consulted for further advice, and action should be taken as appropriate.

2.6.1 Parameters of concern

Water quality assessment provides the base line information on water safety. Since water quality in any source of water and at the point of use, can change with time and other factors, continuous monitoring of water is essential. WHO (1996) guidelines provide values for 96 substances (out of 128 chemicals initially reviewed). It is very expensive, time consuming, difficult and largely unnecessary to test for all these parameters. The list of parameters to be selected from the guidelines and included in any water assessment and monitoring program will vary according to the local conditions. This Technical Bulletin aims at providing parameters that are basic and generally considered priorities in any water quality assessment programme. It also presents the testing kits that have been identified so far by UNICEF for assessment and monitoring programmes.

The following basic parameters should be included:

1. **Microbiological parameters:** Basic microbiological tests should cover thermo-tolerant coliforms (a group of bacteria that grow at 44°C) and fecal streptococci. In addition, physical and chemical parameters, such as disinfectant residuals, pH and turbidity, affect the microbiological quality of water.

2. **Physical parameters:** In addition to turbidity, mentioned above, conductivity, colour, taste and odor might cause rejection of water.

3. **Harmful chemicals:** Nitrate, iron, arsenic, fluoride, lead, cyanide, metals (aluminium, cadmium, chromium, copper, manganese, mercury), selenium, organics (including pesticides and disinfectant by-products), alkalinity and corrosivity.

2.6.2 Microbiological Contamination and Indicators

Faecal streptococci regularly occur in faeces but in much smaller numbers than *E.coli*. In doubtful cases, the finding of faecal streptococci in water is regarded as important confirmatory evidence of recent faecal pollution of water. Streptococci are highly resistant to drying and may be valuable for routine control testing after
laying new mains or repairs in distribution systems or for detecting pollution by surface runoff to ground or surface waters.

Contamination of the water supplies through the failure of septic tanks was further confirmed by the presence of faecal streptococci in the water samples. This group of organisms is consistently present in the faeces of all warm-blooded animals and in the environment associated with animal discharges (Sandhu et al., 1979 and Geldreich et al., 1967). Understanding the contributions of land use and watershed protection measures is important for assessing microbial risks. In Ontario, E. coli O157:H7 cases were found to be more common in rural areas where direct and indirect contact with livestock sources of pathogens may be more common (Michel et al., 1999)

Waterborne pathogens are spread through contaminated drinking water, exposure to contaminated water while swimming or other activities, or secondarily through food contaminated with bad water (Rose et al., 2001). A Study of sewage effluent found that Cryptosporidium oocytes were presents in sewage effluent and surface waters, with likely sources including septic tank leakage, recreational bathing and agricultural runoff (Madore et al., 1987). Human waste is often a source of water contamination (Stirling et al., 2001; Hafliger et al., 2000). Cryptosporidium is found in a wide range of mammals, particularly cows (Howe et al., 2002; Jellison et al., 2002 and Kistemann et al., 2002).

Excess rainfall resulted in surface contamination of groundwater and contributed to the Walkerton outbreak of E.coli O 157:H7 (Auld et al., 2001). Kiestemann et al., 2002, found that floods make extremely large contributions to the bacterial and parasite loads of drinking water reservoirs. A literature review of 144 studies by Esrey et al., 1991 represents the old paradigm, concluding that sanitation and hygiene education yield greater reductions in Diarrhoeal disease (36 % and 33% respectively) than water supply or water quality interventions. Since 1996, a large body of published work has examined the health impact of interventions that improve water quality at the point of use through household water treatment and safe storage (HWTS) (Fewtrell and Colford, 2004). These recent studies, many of them randomized controlled intervention trials, have highlighted the role of drinking water contamination during collection, transport and storage (Clasen and Bastable, 2003),
and the health value of effective HWTS (Reller et al., 2003; Quick et al., 2002; Conroy et al., 1999 and 2001).

Several researchers have attempted to estimate the total burden of waterborne disease worldwide. Huttly et al., (1990) reported a total number of 1.4 billion annual episodes of diarrhoea in children below five years of age, with an estimated 4.9 million children dying as a result (although these were due to all causes of diarrhoea and not just water-related cases). While Prüss et al., (2002) estimated that water, sanitation and hygiene was responsible for 4.0% of all deaths and 5.7% of the total disease burden occurring worldwide (accounting for diarrhoeal diseases). Clearly, in countries where a large part of the population does not have access to safe drinking water, a substantial number of these infections will be waterborne, indeed, Hunter (1997) estimated that waterborne disease might account for one-third of the intestinal infections worldwide. All waterborne infections may lead to an estimated 1,200 deaths a year. Even if these rough figures are overestimated, both the health and economic burden are considerable even for an industrialized society (Payment, 1997).

Drinking water that contains pathogenic microorganisms may cause illness and, as such, it is important to have some measure (or a measure) that establishes whether it is safe to drink. For the most part, there are too many different pathogens to monitor and as the majority of pathogens are derived from faecal, material the idea of using non-pathogenic bacteria as an index of faecal pollution was developed (Dufour et al., 2003). Initially only a few such parameters were used, but now there are more techniques and methodologies available. It is possible to monitor a wide range of index/indicator parameters (microbial and non-microbial) and pathogens and there is a move towards using a variety of different parameters throughout the water production process and, indeed, a catchment to consumer approach to water safety plans. New methods are constantly being developed, ranging from increased pathogen detection to more real-time microbial and non-microbial parameter monitoring. The development of new and improved methodologies, along with the need for vigilance with regard to emerging hazards, results in the need for frequent re-evaluation of the best approaches and indicator parameters (WHO, 1996).
The protozoan’s *Cryptosporidium parvum*, *Cyclospora*, and *Giardia lamblia* are of greatest concern because of their devastating effects on individuals with weak or compromised immune systems, including very young children, the elderly, persons with cancer, and individuals with acquired immunodeficiency syndrome (AIDS). In 1993, an outbreak of cryptosporidiosis in Milwaukee’s drinking water supply resulted in over 400,000 people becoming ill and contributed to the deaths of many persons (Mac Kenzie *et al.*, 1994). Diseases caused by bacteria, viruses and protozoa are the most common health hazards associated with untreated drinking and recreational waters. The main sources of these microbial contaminants in wastewater sources of these microbial contaminants in wastewater are human and animal wastes (WHO, 1997; Environmental Canada, 1998; 2003 EPA, 2000; WHO, 2006). These contain a wide variety of viruses, bacteria, and protozoa variety of viruses, bacteria, and protozoa that may get washed into drinking water supplies or receiving water bodies (Kris, 2007). Microbial pathogens are considered to be critical factors contributing to numerous waterborne outbreaks. Hepatitis A, one of the oldest diseases known to humankind, is a self-limited Diarrhoea is most often spread through faecally contaminated food, hands or surfaces touched by objects or hands put into the mouth (fecal-oral route). Water contaminated by human or animal feces (e.g., swimming pools) or trips to sites with animals (e.g., farms, pet stores, petting zoos) are also possible routes of transmission (Doocy and Burnham, 2006). If acute Diarrhoea lasts 2 days or less, diagnostic tests are usually not necessary. If Diarrhoea lasts longer or is accompanied by symptoms such as fever or bloody stools, a doctor may perform tests to determine the cause. (NIH, 2011). Just as clinicians are often required to implement immediate treatment measures before a patient’s diagnosis is confirmed by the laboratory, public health authorities are often obliged to take initial steps to prevent the spread of an outbreak or epidemic before the cause has been identified through laboratory testing. Epidemiologic information from the initial cases or their families may indicate a common exposure, such as a meal, a particular type of food, or a specific food vendor. Outbreaks of cholera and of many other enteric pathogens that case acute watery Diarrhoea may be food borne, and these leads should be investigated aggressively and appropriate prevention measures implemented (Sack *et al.*, 2004).
The detection, isolation and identification of the different types of microbial pollutants in wastewater are always difficult, expensive and time consuming. To avoid this, indicator organisms are always used to determine the relative risk of the possible presence of a particular pathogen in wastewater (Paillard et al., 2005). Viruses are among the most important and potentially most hazardous pollutants in wastewater. They are generally hazardous pollutants in wastewater. They are generally to detect and require smaller doses to cause infections (Toze, 1997; Okoh, et al., 2007). Because of the difficulty in detecting viruses, due to their low numbers, bacterial viruses (bacteriophages) have been examined for use in faecal pollution and the effectiveness of treatment processes to remove enteric viruses (Okoh et al., 2007). Bacteria are the most common microbial pollutants in wastewater. They cause a wide range of infections, such as Diarrhoea, dysentery, skin and tissue infections, etc. Disease-causing bacteria found in water include different types of bacteria, such as *E. coli* O157:H7; *Listeria, Salmonella, Leptospirosis, Vibrio, Campylobacter*, etc. (CDC, 1997a). Wastewater consists of vast quantities of bacteria, most of which are harmless to man. However, pathogenic forms that cause diseases, such as typhoid, dysentery, and other intestinal disorders may be present in wastewater. The tests for total coliform and faecal coliform nonpathogenic bacteria are used to indicate the presence of pathogenic bacteria (Akpor and Muchie, 2011).

United Nation Environmental Programme (UNEP) and World Health Organization (WHO) have established criteria for coliform concentration for primary contact recreation purposes. Fecal coliform concentration of geometric mean of at least five samples should be less than 100/100 ml for 50% and less than 1000/100 ml for 90%. The U.S. EPA requires *E. coli* density to be less than 126/100 ml in fresh water to the logarithmic average for a period of 30 days of at least five samples (USEPA, 1999).

**INDICATER ORGANISMS—**

(a) Total Coliform Bacteria

Fecal coliform – *Escherichia coli*.

(b) Fecal Enterococci / Streptococci

(i) Enterococcus – *E. faecalis, E. Faecium, E. avium*
(ii) Streptococcus – S.bovis, S.equirus

**Relationships between indicator organisms (after EPA 2001)**

Pathogen levels in the water can be estimated by measuring the pathogen indicator concentration. Pathogen indicator organisms, often called indicator organisms, refer to pathogen-associated microorganisms, typically chosen for easier isolation and identification of contamination. The indicator organism:

(i) should be easily detectable using simple laboratory tests;
(ii) should not generally be present in unpolluted water;
(iii) should appear in concentrations that can be correlated with the extent of contamination;
(iv) should have a die-off rate that is not faster than the die-off rate for the pathogens of concern (Thomann and Mueller 1987; USEPA 2001).

Pathogen levels in surface water are regulated in many countries to guarantee water quality for recreational use, drinking water supply, and aquatic life protection.

The coliform group includes both fecal and non-faecal organisms. Typical example of the faecal group is *Escherichia coli* and of the non-fecal group *Klebsiella aerogens*. There are several reasons why coliform organisms are chosen as indicators of fecal pollution rather than the water borne pathogens directly.

1) The coliform organisms are constantly present in great abundance in the human intestine. It is estimated that an average person excretes 200-400 billion of these organisms per day. These organisms are foreign to potable waters and hence their presence in water is looked upon as evidence of faecal contamination.

2) They are easily detected by culture methods - as small as one bacterium in 100 ml of water, whereas the methods for detecting the pathogenic organisms are complicated and time consuming.

3) They survive longer than the pathogens which tend to die out more rapidly than coliform bacilli.
4) The coliform bacilli have greater resistance to the forces of natural purification than the water borne pathogens. If the coliform organisms are present in a water sample, then the probable assumption is that there will be intestinal pathogens.

**TOTAL COLIFORMS**

According to EPA an indicator organism is “a species, whose presence or absence may be characteristic of environmental conditions in a particular area of habitat” (EPA, 2010). According to Bonde (1966) the criteria for indicators are related to occurrence and environmental resistance as pathogens, indicators should be correlated to health risk and have analogous fate and transport characteristics as pathogens. Bacteria such as *E. coli* and *Enterococci* will continue to be used for risk assessment of microbial a pathogenic contamination and to indicate the presence of fecal contamination. Using molecular tools the development of new rapid pathogen detection methods (Guy, Payment, Krull, and Horgen, 2003) will allow the monitoring of a greater number of pathogens and raises the question of the potential effectiveness of microbial indicators (Committee on Indicators for Waterborne Pathogens, 2004). A count of the total coliforms (including faecal coliform and *Escherichia coli*) provides an indication as to whether other potentially harmful bacteria may be present. These coliforms are naturally present in the environment as well as faeces; however faecal coliforms and *E.coli* only come from human and animal waste (EPA, 2008).

Wastewater consists of vast quantities of bacteria, most of which are harmless to man. However, pathogenic forms that cause diseases, such as typhoid, dysentery, and other intestinal disorders may be present in wastewater. The tests for total coliform and faecal coliform nonpathogenic bacteria are used to indicate the presence of pathogenic bacteria (Akpor and Muchie, 2011).

Total coliforms are a group of bacteria commonly found in the environment, for example in soil or vegetation, as well as the intestines of mammals, including humans. Total coliform bacteria are not likely to cause illness, but their presence indicates that your water supply may be vulnerable to contamination by more harmful microorganisms. Coliforms or indicator microorganisms are present in the intestinal tracts of warm blooded animals, including humans (Leclerc *et al.*, 2001).
and therefore can be excreted in the feces of these animals, although there have been some associations between high levels of indicator bacteria and disease outbreaks (Chou et al., 2004). The occurrence of coliforms in surface water has been used as an indicator of fecal contamination, signaling the possible presence of fecal pathogens such as Salmonella and Shigella species (USEPA 1986). Identifying sources of fecal pollution in waters used for human recreation and fish breeding is necessary to reduce the potential for human contact with enteric pathogens. Water contaminated with fecal matter has the capability serious health risks for fish consumers to pose and swimmers (Trevett et al., 2005).

Total (TC) and fecal coliforms (FC) have traditionally been regarded as indicators of microbial contamination of waters (Clark et al., 1991; Rompre et al., 2002). Recent reviews, however, have shown E.coli to be the best indicator for the assessment of fecal contamination (Clark et al., 1991; Edberg et al., 2000) and the possible presence of enteric pathogens (Geissler et al., 2000; US EPA, 2002). The most commonly employed method for the detection of total and fecal coliforms in water is multiple tube fermentation (MTF) technique. A major limitation of MTF is the length of time (24-96 h) required to complete the testing (Edberg et al., 1988; George et al., 2000). This considerable delay in the assay response makes it impossible to take sanitary measures immediately after a fecal pollution has occurred. Moreover, it is labor intensive, uses several different types of media and two different incubation temperatures (Eckner, 1998; Rompre et al., 2002).

COLIFORM BACTERIA

Escherichia coli is the only member of the total coliform group of bacteria that is found only in the intestines of mammals, including humans. The presence of E.coli in water indicates recent fecal contamination and may indicate the possible presence of disease-causing pathogens, such as bacteria, viruses, and parasites. Although most strains of E.coli, bacteria are harmless, certain strains, such as E.coli 0157:H7, may cause illness. Waterborne zoonotic agents such as Escherichia coli O157:H7, Campylobacter jejuni, and Cryptosporidium parvum have emerged in recent years (Cotruvo et al., 2004). Many other water-associated human pathogens, including Vibrio cholerae O139, hepatitis viruses, Cyclospora, Microsporidia, Yersinia enterocolitica, and environmental bacteria (e.g., Legionella pneumophila),
have been the nature and impact of water-related infectious diseases are mediated by both ecologic and socioeconomic processes (Eisenberg et al., 2007; United Nations Environment Programme (UNEP), 2007). The parameter *E. coli* is of paramount importance for the assessment of the microbiological quality of drinking water. It has been used for many years as an indicator of contamination by fecal matter. Properly treated and disinfected water will not contain *E. coli*. If *E. coli* is detected in treated or distributed water, there is a potential risk to human health. The cause of the presence of *E. coli* must be investigated immediately and remedial action must be taken promptly. The parameter *Enterococci* comprises another group of fecal indicator organisms and its determination complements and supplements that of *E. coli* associated with waterborne illnesses over the past few decades (Sharma et al., 2003).

Rainfall wolf from the grazed area contained 5 to 10 times more FC than runoff from ungrazed area. Faecal streptococci (FS) counts were higher in runoff from the ungrazed area and reflected the contributions from wild life. The FC/FS ratio in pasture runoff was useful in identifying the relative contributions of cattle and wildlife. Ratios below 0.05 were indicative of wildlife sources and ratios above 0.1 were characteristic of grazing cattle (Doran and Linn, 1979).

**FAECAL STREPTOCOCCI**

Contamination of the water supplies through the failure of septic tanks was further confirmed by the presence of fecal *streptococci* in the water samples. This group of organisms is consistently present in the faeces of all warm-blooded animals and in the environment associated with animal discharges (Sandhu et al., 1979; Geldreich, 1967). Faecal *streptococci* regularly occur in faeces but in much smaller numbers than *E. coli*. In doubtful cases, the finding of fecal streptococci in water is regarded as important confirmatory evidence of recent fecal pollution of water.

**Additional Methodology for microbial detection**

Although, modern microbiological techniques have made possible the detection of pathogenic bacteria, viruses and protozoa in sewage and sewage effluents, it is not practical to attempt to isolate them as a routine procedure from samples of drinking water. Pathogens present in water are usually greatly
outnumbered by normal intestinal bacteria, which are easier to isolate and identify (Murray, 2005). The presence of such organisms indicates that pathogens could be present; if they are absent, disease-producing organisms are probably also absent. Contamination is often intermittent and may not be revealed by the examination of a single sample. The most a bacteriological report can prove is that, at the time of examination, bacteria indicating fecal pollution did or did not grow under laboratory conditions from a sample of water. Therefore, if a sanitary inspection shows that a well is subject to contamination or that water is inadequately treated or subject to contamination during storage or distribution, then the water should be considered unsafe irrespective of the results of bacteriological examination. MacConkey (1905, 1914) defined the aerogenes group on the basis of fermentative reactions with five sugars and the ability to produce acetylmethylnarbinol in the Voges-Proskauer (VP) reaction. Coliforms can also be differentiated by the ratio of carbon dioxide to hydrogen produced. Coliforms derived from non-fecal sources produced two or more times as much carbon dioxide as hydrogen; in feces-derived strains, the ratio was 1:1. Low-ratio cultures also produced indole from tryptophan (Rogers et al., 1914). Clark and Lubs (1915) were able to correlate the gas ratio data with the much easier to perform methyl red (MR) test. Low-ratio cultures—faecal coliforms—turned the methyl red indicator a brilliant red. Koser (1924) found the MR and VP tests inadequate for faecal coliform characterization and suggested a citrate utilization procedure to differentiate coliforms in VP and citrate tests as the combination of four procedures that would yield the best classification and introduced the mnemonic IMViC to facilitate the expression of results. Although all the coliform genera (Escherichia, Klebsiella, Citrobacter and Enterobacter) are present in fresh feces and in fresh pollution from fecal sources, they may not all persist in water for the same length of time (APHA, 1998). Escherichia coli for example, is generally most sensitive to environmental stresses and least likely to grow in the environment. Klebsiella, Citrobacter and Enterobacter on the other hand, are more likely to persist and to grow on organic-rich materials or inorganic-rich waters. They may also form a biofilm within the distribution system that is resistant to chlorination and other eradication measures (Martin et al., 1982; Geldrich et al., 1987). Regrowth of coliforms in the distribution systems presents a
serious problem to water purveyors: the sporadic positive coliform results make it difficult to assess the true hygienic status of the water.

The enzymatic assays for detection of total coliforms and *E.coli* are based on the hydrolysis of chromogenic or fluorogenic substrates by β-galactosidase and β-glucuronidase activity, two enzymes found in total coliforms and *E.coli*, respectively (Brenner *et al.*, 1993; George *et al.*, 2000; Rompre *et al.*, 2002; Bitton, 2005; APHA, 2005). Enzymatic assay showed a rapid and less labor method, allowing the simultaneous detection of total coliforms and *E.coli*. This method is particularly useful in the early warning of fecal pollution of drinking water. (Nikaeen *et al.*, 2009)

The definition of an episode of AGI (Acute Gastrointestinal Illness) not only requires specification of the symptoms involved, it also requires identification of the end of an illness episode. The varying definitions of AGI used in the studies we have reviewed significantly reduce their comparability. Not only are different symptoms considered in the definitions, even the definitions of the symptoms themselves vary. For example, Diarrhoea was defined as loose stools or stools with abnormal liquidity (Majowicz *et al.*, 2004); loose stools present for fewer than 14 days (Roderick *et al.*, 1995); two or more loose stools a day (Hoogenboom-Verdegaal *et al.*, 1994; de Wit *et al.*, 2000; Hellard *et al.*, 2001); or liquid versus soft stools (Payment *et al.*, 1991, 1997). However, Diarrhoea was most commonly defined as three or more loose or watery stools in a 24-hour period. The use of this last definition is supported by data in the scientific literature. Denno *et al.*, (2005) showed a statistically significant trend exists between the number of stools in a 24-hour period and the presence of detectable bacterial and viral enteric pathogens. Denno and co-workers suggested that an incidence of fewer than three loose stools in the previous 24 hours should be used as an exclusion criterion for stool cultures.

Microbiologists rely on the principle that higher the incidence of sewage indicator bacteria in any environment, higher would be the chances for human pathogenic bacteria to be present (Brock *et al.*, 1994; Fujioka, 2002). Nagvenkar and Ramaiah (2009) reported *Vibrio cholerae* is the dominant bacterium in the sewage discharges, it can compete and rapidly outgrow the native micro flora leading to increased levels of indicator bacteria in natural water bodies. Pathogenic bacteria of
human health concern have been studied mostly for their survival in the river environment (Lipp et al., 2001; Baghel, 2005; Sood, 2008; Nagvenkar and Ramaiah, 2009).

It is evident that the abundance of pathogenic bacteria we studied fluctuates widely in the water and sediment samples in the study area. Coliform bacteria are the most reliable indicators of fecal contamination. However, presence of streptococci is strong evidence of fecal pollution (Park, 2000). E. coli has the advantage of not being capable of growing and multiplying in water (except warm and food laden waters). Therefore, the presence of this bacterium in water is indicator of recent fecal pollution (Madigan et al., 2000).

2.6.3 Physico-chemical indicators

**pH and ALKALINITY**

The pH of an aqueous system is a measure of the acid-base equilibrium achieved by various dissolved compounds and in most natural waters is controlled by the carbon dioxide, bicarbonate - carbonate equilibrium system (WHO, 1984). One of the main objectives in controlling the pH is to minimize corrosion and incrustation in the distribution system. pH levels of less than 7 may cause severe corrosion of metals in the distribution pipes and elevated levels of certain chemical substances such as lead may result. At pH levels above 8 there is a progressive decrease in the efficiency of the chlorine disinfection process. An acceptable pH of drinking water is between 6.5 and 8.5 (Park, 1997). Unpolluted rainwater is acidic due to the dissolution of CO₂. Hard water is slightly alkaline. Decrease in pH increases the solubility of metals (Reeve, 1994). In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25°C. In water with a buffering capacity imparted by bicarbonate, carbonate and hydroxide ions, this temperature effect is modified (WHO, 1984). The pH of most raw water sources lies within the range 6.5 - 8.5 (WHO, 1984). Hydrogen ion concentration may be significantly altered during water treatment. Chlorination tends to lower the pH, whereas water softening using the excess lime/soda ash process raises the pH level. pH is related in several different ways to almost every other water quality parameter. The formation of gaseous hydrogen sulfide yielding foul odours in waters prone to sulphur
contamination is thermodynamically favored at pH values less than about 7.0. In the chlorination process the objectionable pungent odour of nitrogen tri-chloride tends to be formed in greater concentrations at pH values less than 7.0. It is claimed that at high pH levels drinking water acquires a bitter taste. Colour intensity in a given water sample is increased by raising the pH. This effect known as the indicator effect has led to the suggestion that all colour measurements for water quality control be carried out at the standard pH of 8.3. There is no direct relationship between human health and pH of drinking water (WHO, 1984).

The pH is also most important in determining the corrosive nature of water. Lower the pH value higher is the corrosive nature of water. pH was positively correlated with electrical conductance and total alkalinity (Gupta, 2009). Navneet Kumar et al., (2010) suggested that the underground drinking water quality of study area can be checked effectively by controlling conductivity of water and this may be applied to water quality management of other study areas. Carbon dioxide is the product of organic carbon degradation in almost all aquatic environments and its variation is often a measure of net ecosystem metabolism (Smith 1993, 1997; Hopkinson 1985). Dissolved Oxygen is one of another most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata and Vikal, 2009).

Mohanta and Patra (2000) reported that the pH of the river Sanamachhakandana (Orissa) ranges from 7.90 to 8.31 in winter, 7.54 to 7.76 in summer and from 7.01 to 7.12 in rainy season. Klein (1973) has pointed out that the pH values between 6.7 to 8.4 are suitable while pH below 5.0 and above 8.3 is detrimental. Srivastava et al., (1996) reported that the pH value decreased due to mass bathing in the river Ganga at Phaphamau on Mauni Amvavasya Maghpurinima and Mahashivaratri. According to the central pollution control board (CPCB) criteria the pH of the drinking water after disinfection ranges between 6.5 - 8.5 (class A) (Rarnakrishna, 2001).

Alkalinity of the water is its capacity to neutralize a strong acid and is characterized by the presence of all hydroxyl ions capable of combining with the hydrogen ion. The alkalinity fluctuates in accordance with the fluctuations in the
pollution load. The alkalinity was in the range of 20 to 80 mg/l in 1987-88 while in 1993-94 it ranged between 20 to 90.4 mg/l in Khandspar River, Goa, India. Least values were recorded during monsoon and the highest in January in both the study periods (Desai et al., 1995). Ground water alkalinity was determined by Patil et al., (2001) at Armori town, Maharastrea indicated that the alkalinity is due to carbonate and bicarbonate. Carbonate alkalinity varies from 30 to 120 mg/l and it is less than the maximum limit. Hence, water is suitable for drinking purpose. The total alkalinity varies from 115 to 500 mg/l and it is within the limit.

TOTAL DISSOLVED SOLIDS AND ELECTRICAL CONDUCTIVITY

The total dissolved solids (TDS) in water comprise inorganic salts and small amounts of organic matter. The principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulfate, nitrate, sodium, potassium, calcium and magnesium. Total dissolved solids influence other qualities of drinking water such as taste, hardness, corrosion properties and tendency to incrustation. Total dissolved solids in water may originate from natural sources, sewage effluent discharges, urban runoff or industrial waste discharges. There is no direct evidence of deleterious physiological reactions occurring in persons consuming drinking water supplies that have TDS levels in excess of 1000 mg/l. The common dissolved mineral salts affect the taste of water. As stipulated by WHO (1996) the palatability of drinking water according to the TDS level can be classified as follows:

Excellent less than 300 mg/l
Good between 300 and 600 mg/l
Fair between 600 and 900 mg/l
Poor between 900 and 1200 mg/l
Unacceptable greater than 1200 mg/l

Water with extremely low TDS levels may also be unacceptable because of its flat, insipid taste (WHO, 1984). The palatability of water with a TDS level of less than 600 mg/litre is generally considered to be good (Park, 1997). Total solids and electrical conductivity are very much interlinked. Both values are directly proportional with each other.
Adak and Purohit (2001) reported that the total solids level of Mandiakudar, Orissa, ranged between 169 mg/l to 442 mg/l. Pande and Sharma (1998) reported simultaneous increase of total solids and electrical conductivity in Ram Ganga River at Moradabad. Pradeep kumar (1999) reported that the surface water quality of Khnoop reservoir in Chhatwpur (M.P.) revealed a range of electrical conductivity from 645-665 mhos/cm. Conductivity and total dissolved solids were high in monsoon months. Whenever there is good total solids and electrical conductivity they would support a good fish fauna and the value lies between 150-500 p mhos/cm (Pande and Sharma, 1998).

**SODIUM, POTASSIUM and CHLORIDE**

Sodium is present in a number of minerals the principal one being rock salt (sodium chloride). Sea water contains relatively high levels of sodium. Overall, sodium represents about 26 g/kg of the earth's crust. The sodium ion is ubiquitous in water owing to the high solubility of its salts and the abundance of mineral deposits. Sea water contains about 10g of sodium per liter. The highest sodium levels are found in low lands rivers and in ground water. Upland streams and associated reservoirs tend to have relatively low sodium content. In most countries the majority of drinking water supplies contain less than 20 mg of sodium per liter, but some countries sodium levels can exceed 250 mg/l (WHO, 1984). The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At average room temperature, the average taste threshold for sodium is about 200 mg/l (Park, 1997).

An epidemiological survey in the USA and the Netherlands have demonstrated that school children (particularly girls) living in areas with moderate levels of sodium in the drinking water (128-161 mg/l) had slightly high blood pressure (3-5 mm Hg) than those living in areas with low levels of sodium 28 mg/l. A somewhat similar study in the USSR, with people in the age range 16-60 years demonstrated a similar relationship between sodium in water and blood pressure (WHO, 1984).

Potassium is less important cation present in lesser concentration than sodium in water. Any increase in potassium concentration would be linked with
chloride and other anions. Abnormally high concentration of potassium is indicative of increased pollution load. Such increase would decrease the quality of drinking water. Chloride is widely distributed in nature, generally in the form of sodium (NaCl), potassium (KCl) and Calcium salts. It constitutes approximately 0.05% of the lithosphere. By far the greatest amount of chloride in the environment is present in the oceans. All waters including rainwater contain chlorides. The presence of chloride in natural waters can be attributed to leaching of salt deposits, contamination resulting from salting of roads to control ice and snow, discharge of effluents from chemical industries, oil well operations, sewage discharges, irrigation drainage, contamination, refuse leachates and seawater intrusion in coastal areas. Each of these sources may result in local contamination of both surface water and ground water. Chloride is one of the important indicators of pollution. Chloride is generally present at low concentrations in natural surface water. Chloride levels in unpolluted water are often less than 10 mg/l and may often be less than 1 mg/l (WHO, 1984). The standard prescribed for chloride is 200 mg/l. The maximum permissible level is 600 mg/l (Park, 1997).

Chloride contamination is an indicator of river pollution owing to sewage waste. Chloride content of different Indian rivers was studied by various workers. High concentration of chloride was reported for river Sabarmathi with the value of 720 mg/l. Rivers Yamuna (Sengar et al., 1985), Tungabhadra (Reddy and Venkateswarulu, 1985), Adayar (Govindan et al., 1987) and Jhelum (Raina et al., 1984) also showed significant levels of chloride content. The taste threshold for chloride in drinking water is dependent upon the associated cation, but it is usually within the range 200-300 mg/l (WHO, 1984). Srivastava et al., (1996) reported that mass bathing in the river Ganga at Phaphamau caused an increase in the chloride level. Chloride is considered as the pollution indicator when present in high concentration. It has been prescribed that the permissible limits of chloride is 30 mg/l for clean water and 50 mg/l for doubtful (Patralekh, 1994).

**HARDNESS, CALCIUM and MAGNESIUM**

The hardness is defined as the sum of the polyvalent cations present in the water and the most common divalent cations are calcium and magnesium. The total hardness is an important parameter of quality of water, whether it is to be used for
domestic or industrial purpose. As per Durfor and Backer's classification 1880 ppm of hardness can be categorized as very hard (Rajgopal, 1984). Depending on the interaction of other factors such as pH and alkalinity water with hardness above 200 ppm may cause scale deposition in the distribution system and results in excessive soap consumption and subsequent scum formation. Soft water with hardness of less than 100 ppm may have low buffering capacity and more corrosive effect for water pipes. It have been established a consistent statistical association between drinking water hardness and incidence of cardiovascular problems. The greater hardness of potable water protects consumers' incidence of cardiovascular problems (NRC, 1977).

Hardness permissible limit for drinking water is 200 ppm as CaCO₃ and 150 ppm according to Indian standards and WHO respectively. Hardness of ground water quality of Hyderabad ranged from 204 to 1288 mg/l. The main cause of high hardness and total solids concentration is due to unprotected wells and surface water pollution (Srinivas et al., 2000). Generally in summer the hardness is maximum than the rest of the season. The hardness expressed as CaCO₃ ranged between 13.3 to 264 and 12.5 to 208 mg/l in two periods of study by Desai (1995). Hardness of the river Sanamachhakandana at Keonjhar Garh, Orissa, varied from 9.77 mg/l to 26.81 mg/l, 12.39 mg/l to 28.4 mg/l and 17.22 mg/l to 34.11 mg/l in upstream, dam reservoir and downstream respectively. Minimum values of hardness were observed in the rainy season while maximum values during the summer. High values of hardness are probably due to the regular addition of large quantities of sewage, detergents and large-scale human use (Mohanta and Patra, 2000). Presence of Calcium and magnesium cations causes hardness to water. This is also contributed by certain anions like nitrate, sulphate and phosphates. The amount of calcium and magnesium in water should not be increased. Such increase might cause permanent hardness to water. Calcium and magnesium levels in surface water, ground water, polluted water were studied by various authors (Lehr et al., 1980). Increase in hardness in winter could be due to the increase in Ca⁺⁺, Mg⁺⁺ and Mn⁺⁺ ions (Mishra and Saksena, 1991). Calcium content of Sanamachhakandana at Keonjhar Garh, Orissa, ranged from 4.55 mg/l to 7.06 mg/l, 4.69 mg/l to 7.2 mg/l and 4.5 mg/l to 7.5 mg/l in upstream, dam reservoir and downstream respectively (Mohanta and Patra, 2000).
DISSOLVED OXYGEN and BIOCHEMICAL OXYGEN DEMAND

Oxygen is found in rivers as a result of photosynthesis by plants and by dissolution of oxygen from the atmosphere into the water. Water saturated with oxygen at 25°C contains 8.24 mg/l. A fast flowing mountain stream would take up oxygen most quickly. The turbulence caused by the fast flow cascading over rocks in the mountains would ensure that oxygen is taken up rapidly and the water saturated with oxygen. The concentration of oxygen in saturated waters is dependent on temperature pressure and salinity (Reeve, 1994). The primary effect of dissolved oxygen in water is an oxidation-reduction reaction involving iron, manganese, copper and compounds that contain nitrogen and sulphur. Depletion of oxygen in drinking water leads to microbial reduction of nitrate to nitrite and also sulfates to sulfide often giving rise to odour problems. It can also cause an increase in the concentration of ferrous iron in solution (WHO, 1984). Dissolved oxygen is of great importance to all the living organisms and is considered the sole parameter, which largely can reveal the nature of whole water body. Eutrophic water bodies have a wide range of dissolved oxygen and as such, oligotrophic water bodies have narrow range of dissolved oxygen (Rucinski et al., 2010). Organic matter can remove oxygen from water by oxidation. It is a microbiological process known as aerobic decay. This converts the major elements in plant matter (C, H, N, and S) into CO₂, H₂O, NO₃ and SO₄ (Reeve, 1994). Patralekh (1994) reported that the river water contains more dissolved oxygen compared to ponds and thermal spring which might be due to greater turbulence, aeration, fast water current and wind velocity. Lowest dissolved oxygen observed in ponds may be due to standing state of water, lesser current, greater decomposition and increased respiration by heterotrophic organisms. The dissolved oxygen content was found to be in decreased level after mass bathing in Ganga river at Phaphamau during Mahakumbh (Srivastava et al., 1996). Mohanta and Patra (2001) observed minimum oxygen levels in the river Sanamachhakandana (Orissa) during rainy season and maximum values during winter. This may be due to the differential growth of phytoplankton, ambient water temperature transparency of water and solar illumination.

The level of water pollution in the country can be gauged by the status of water quality around India. The water quality monitoring results carried out by
CPCB particularly with respect to the indicator of oxygen consuming substances (biochemical oxygen demand, BOD) and the indicator of pathogenic bacteria (total coliform and fecal coliform) show that there is gradual degradation in water quality (CPCB, 2009).

Biochemical Oxygen Demand (BOD) is also the most important parameter used to determine the degree of pollution in river water at any time. Oxygen depletion level in water is detrimental to the aquatic life (Narain and Chauhan, 2000). The waste water entering into the rivers contribute a significant settleable pollution load. The magnitude of such loads depends on the degree of treatment received by the waste waters before their release into the streams (Bhargava, 1984). Biological oxygen demand (BOD) also indicates the amount of organic compounds in water as measured by the volume of oxygen required by bacteria to metabolize it under aerobic condition. Biochemical oxygen demand is represented by the amount of organic matter present in water. For more organic matter, bacteria for its decomposition require more oxygen. This results in release of organic nutrients in water bodies resulting in death of organisms thriving on water (Rustum et al., 2008, Jonasson et al., 2012). The settable material thus removed also removes a significant portion of BOD which may be present in a settleable and colloidal form. Bioflocculation naturally takes place in the streams and provide the necessary mean velocity gradient values resulting in a consequent removal of the colloidal BOD. Microbes naturally die out in the natural environment of the streams. The microbes that thrive in the human system, cannot find similar favoring conditions in the streams for survival. Some microbes, however, survive for longer durations than the others. This naturally devoid the streams to a great extent of potentially dangerous microbes in the course of time (Pande and Sharma, 1998). BOD, the significant pollution parameter of streams is naturally decayed in a stream system through a biochemical oxidation whose kinetic rates would control the rate of BOD removal from the streams. The dissolved oxygen level decreased with simultaneous increase in BOD in the river Ram Ganga at Moradabad. Hence, an inverse relationship could be established between dissolved oxygen and biochemical oxygen demand (Pande and Sharma, 1998).
NITRATE, SULPHATE and PHOSPHATE

Nitrate, sulphate and phosphate concentrations of the water bodies are influenced with the geochemical conditions, organic load, and the rate of their mineralization. The rainfall is said to be responsible for increasing the amount of nitrate in water (Prasad and Saxena, 1980). Use of detergent may increase the phosphate concentration to great extent, higher amounts of nitrate and phosphate represent high pollution load and are causes of eutrophication of the aquatic body. Nitrate and phosphate are the most important nutrients for the growth of algal flora (Bosten et al., 2000). Nitrate is a valuable plant nutrient which indicates the productive nature of aquatic systems. But, its presence in potable water is harmful. The high concentration of nitrates is found to be associated with leaching from fertilizers, ground slope ground water movement, sewage disposal and lime stone mining. Nitrate concentration increases from 4-60 mg/l following the direction of ground water flow. Water quality monitoring is essential for preventing the harmful concentration of nitrate. Contamination of ground water with nitrate is the cause of one of the most serious impacts of human activities on hydro geological system (Narain and Chauhan, 2000). Bureau of Indian Standard (2012) and WHO (1984) have proposed a guideline value of 45 mg/l for drinking water, a concentration that is exceeded under diverse agricultural management system. Since nitrate is mobile in most of the soils leaching losses of nitrate from fertilized soils also cause economic implications due to high cost of agriculture fertilizer. With increase in nitrate level coliform count also increases (Mishra and Richariya, 1999). Greater decomposition of organic matter may be the reason for higher concentration of nitrate in water (Patralekh, 1994). Nitrates are widely present in substantial quantities in soil, in most waters and in plants including vegetables. Fertilizer use, decayed vegetable and animal matter, domestic effluents, sewage sludge disposal to land, industrial discharges, leakages from refuse dumps and atmospheric washout all contribute to nitrate, sulphate and phosphate ions in water sources (Prasad and Saxena, 1980). When nutrients are applied in excess of plant needs, they had a potential to pollute surface and ground water (Blackbum and Sorensen, 1985). Nitrate in water is present as highly soluble salts. Standard water treatment practices such as sedimentation, filtration, chlorination or pH adjustment with lime application do not affect nitrate concentration. Nitrates from water can be removed
by specialized water treatment technologies, such as ion exchange, biochemical de-nitrification and reverse osmosis. Incorporation of these technologies for removal nitrates into a water system could substantially increase the cost of water treatment. Once an aquifer is contaminated with nitrate, it will cost a large amount of money to use that aquifer as a source of drinking water. A more prudent approach is needed to prevent nitrate contamination of ground water. Before initiating pollution prevention practices for nitrate, knowing the factors that contribute to nitrate contamination of an aquifer is important (Blackbum and Sorensen, 1985; Deshpande et al., 1999). Most of the higher levels of nitrate are found in ground water, nitrates in surface waters tend to be depleted by aquatic plants. Marked seasonal variation can occur in concentration in rivers and high levels may be exhibited particularly after heavy rainfall following severe drought periods. The levels in ground water tend to be much steadier during the year (WHO, 1984). Normally 1-2% of the body's hemoglobin is in the methemoglobin form but when the proportion is in excess of 10% clinical effects are detectable (methemoglobinaemia) 30-40% leads to anoxia. Water supplies containing high levels of nitrate have been implicated in cases of infantile methemoglobinaemia and death. It has been recommended that water supplies containing high levels of nitrate (> 100mg of NO$_3$ per liter) should not be used for the preparation of infant foods. The stomach pH in infants being about neutral enables bacterial growth to occur in both the stomach and upper intestine. Infants, in contrast to adults are deficient in two specific enzymes that can convert methaemoglobin back to haemoglobin.

Domestic sewage, agricultural effluents containing fertilizers and industrial wastes contribute to the increase in PO$_4$ concentrations. Sharma and Pathak (1981) observed comparatively low PO$_4$ concentrations in polluted river Yamuna. But, in the present studies conducted later comparatively high concentrations of PO$_4$ have been found indicating higher degree of pollution load (Hassan et al., 2017). Similarly Rana and Palria (1988) have reported high PO$_4$ concentration (7.6 mg/l) for Bandi River (Rajasthan). The phosphate concentrations usually above 2.0 mg/l can be considered as an indication of pollution.

The high SO$_4$ concentration indicates pollution of the river water. In summer, the evaporation of water and rise in temperature could result in rise in SO$_4$ level. The
majority of sulfates are soluble in water, the exceptions being the sulfates of lead, barium and strontium. The concentration of sulfate in most fresh waters is very low although 20-50 mg/l are known. Certain springs (Epson, France) have high SO₄ contents. Taste threshold concentration for the most prevalent sulfate salts are 200-500 mg/l for sodium sulfate, 250-900 mg/l for calcium sulfate and 400-600 mg/l for magnesium sulfate (WHO, 1984). Saluja and Jain (1998) reported the Machna annicut Dam water contains sulphate in the range between 171.1 - 198.2 mg/l. Venkatamohan and Jayarama reddy (1995) observed low concentrations of sulphate in all the samples varying from 11mg/l to 26mg/l with the mean of 16mg/l indicating the samples are within the permissible limits at Tirupati. Domestic sewage, agricultural effluents containing fertilizers and industrial waste contribute to the increase in phosphate concentration (Desai, 1995). The mean phosphate content of Parvathyputhen AR ranged between 0.06 mg/l and 0.15 mg/l with the maximum concentration of 0.21 mg/l (Prasanthan and Nayar, 2000).

Another aspect of water pollution in India is inadequate infrastructure, comprising of monitoring stations and frequency of monitoring for monitoring pollution. Monitoring is conducted by CPCB at 1,700 stations under a global environment monitoring system (GEMS) and Monitoring of Indian National Aquatic Resources (MINARS) programmes (CPCB, 2009). There is an urgent need to increase the number of monitoring stations from their current number, which translate as one station per 1,935 km² to levels found in developed nations for effective monitoring. The water quality monitoring results obtained by CPCB during 1995 to 2009 indicate that organic and bacterial contamination was critical in the water bodies. The main cause for such contamination is discharge of domestic and industrial wastewater in water bodies mostly in an untreated form from urban centers.

Our dependence on fresh water resources has accelerated in last century due to rapid growth in world population and economic development (Postel, 1992). Ground water contains high amount of various ions, salts etc. so if we were using such type of water as potable water then it leads to various water-borne diseases (Mishra et al., 2010). The consumption of unsafe water has been implicated as one
of the major causes of this disease most gradual deterioration of water quality was resulted by the increase in human population and urbanization (Chan et al., 2007).

Water is the most basic and vital resource of our planet. According to the United Nation Report, consumable water level is up to 2-7% of the total water content. One percent of the ground water level is threatened either directly or indirectly by pollution (Davis and Carnwell, 1991). Therefore, it has become necessary to monitor water quality to observe the demand and pollution level of ground water.

If no action is taken to address unmet basic human needs for water, as many as 135 million people will die from these diseases by 2020. Even if the explicit Millennium Goals announced by the United Nations in 2000 are achieved – unlikely given current international commitments – between 34 and 76 million people will perish from water related diseases by 2020. This problem is one of the most serious public health crisis facing us, and deserves far more attention and resources than it has received so far (Gleick, 2002).

2.6.4 Contaminant Monitoring and Mitigation

On an average one tenth of each person's productive time is sacrificed to water-related diseases (Singh et al., 2001). In India about 75% of urban population and 30% of rural population were covered with nominally protected drinking water supply. Large segment of the population, particularly in rural areas, suffers from water-borne and water related diseases and needs constant monitoring. Efforts have been made to accomplish this requirement.

In 1977, Bradley observed that many waterborne diseases are actually “water washed” disease due to inadequate quantities of water available for washing hands, food, laundry and cooking utensils. There is an emerging consensus among researchers, policy makers and the general public that unsafe drinking water polluted by faecal and chemical pollution directly threatens the health and life of each individual worldwide (Lee et al., 2002; Semenza et al., 1998; Bacud et al., 1994 and Torres et al., 1991).

For decades water treatment systems have been used to treat water to reduce the incidence of waterborne disease in some communities. Decreases in waterborne
disease incidence were found when communities switched from untreated to treated water systems (Doocy and Burnham 2006; Altherr et al., 2008), or when communities improved water treatment standards (Semenza and Nicholas, 2007); however, other studies did not produce similar findings (McCounell et al., 2001, Hellard et al., 2002). There are numerous treated water distribution systems worldwide, many people still rely on untreated drinking water from private wells or surface water. For example, over 4 million Canadians (20% of the population) rely on private water supplies for drinking water (Corkal et al., 2004). Often this water is treated poorly, if at all, which could increase the risk of exposure to waterborne pathogens (Corkal et al., 2004). Indeed, consumption of contaminated raw water has been associated with Diarrhoea in every continent worldwide as listed in Table 2. The World Health Organization estimates that improved water quality would reduce the global burden of gastro-intestinal (GI) infection by 31% (Pruss-ustun et al., 2008).

Some pathogens are resistant to certain methods of water treatment. For example, Giardia and some viruses are highly resistant to chlorination treatment; however, high quality filtration can reduce the prevalence of these pathogens in water. This resistance might explain why some studies found waterborne disease attributable to treated water that met established standards for safe drinking water (Goldstein et al., 1996). For example, a Canadian study found that at least 14% of GI cases were attributable to drinking treated water that met or exceeded water standards (Payment et al., 1997).

Inadequate water treatment can be a result of human error or system malfunction. Manual or digital chlorine residual monitoring is a common way to provide rapid indication of microbial water quality. Sudden drops in free-chlorine residual levels can indicate early stages of microbial contamination which requires intervention (e.g. additional chlorination) to protect public health (WHO 2008). Studies have linked low chlorine residuals levels with cases of self-reported diarrhoea (Egorov et al., 2002; Semenza et al., 1998). Moreover, other studies associated malfunctioning water treatment systems with waterborne disease rates in developing (Mahdy et al., 2008; UNICEF, 2008; Yassin MM et al., 2006) and developed countries (Olsen SJ et al., 2002, McCarthy N 1998; Fernandes TMA et
The United States Public Health Services (USPHS) first conducted coliform indicator criteria on studies during 1940’s and early 1950’s. In the 1960’s the USPHS adopted the fecal coliform standard by using a fixed ratio (18%) of fecal coliform to total coliform bacteria (USEPA, 1986). Indicator organisms are used as diffused pollution indicator as well. Maul and Cooper (2000) used enterococci and fecal coliform bacteria concentrations to assess the variability of water quality in an agricultural field during wet weather. Aitken (2003) investigated the potential risk of fecal contamination due to diffuse pollution on river catchments and coastal bathing water using indicator organisms. Indicator organisms are often used as a tool to identify the contaminant sources. Whitlock et al., (2002) used fecal coliform to identify the contaminant sources in an urban watershed. The presence of Escherichia coli, a more common microbial constituent used for water quality examination indicates fecal contamination, since E. coli is the subset of fecal coliform. Fecal streptococci are also often used as an indicator. The U.S. EPA has published a protocol for developing pathogen TMDLs (Total maximum daily loads, that is the calculation of the maximum amount of a pollutant allowed to enter a water-body, so that it will meet and continue to meet water quality standards for that particular pollutant.) that provides guidance for this process (USEPA 2001).

Reliance on culture-based methods exaggerates treatment efficacy and reduces our ability to identify pathogens/indicators; however, next-generation sequencing and polymerase chain reaction approaches are on the cusp of changing that (Ashbolt, 2015).

Unsanitary means of disposing human waste and fecal droppings from livestock are routes through which fecal matter may enter aquatic systems. Fecal matter degrades water quality due to the possible introduction of pathogens, nutrients and organic matter (Vinneras et al., 2003; Langergraber and Muellergger 2005; Vikaskumar et al., 2007).

Water related diseases might be divided into those caused by a biological agent of disease (a pathogen) and those caused by some chemical substances in
water. Bhavnani et al., (2014) finds that use of safe water sources and improved sanitation facilities are most protective under opposing rainfall conditions highlights the need for integrated interventions to reduce the burden of Diarrhoeal disease. The minimum estimated annual cost associated with the treatment for AGI (Acute Gastrointestinal Illness) pose a huge economic burden on people (Glasgow et al., 2013; Persuad et al., 2013; Ingram et al., 2013 and Gabriel et al., 2013). The association between drinking water treatment and distribution network disturbances with health call centre and Nurse advice calls relating to acute gastrointestinal illness has also been reported. There is an increased frequency of contacts with the Health Call Centre (HCC) concerning gastrointestinal symptoms at times when there is a risk of impaired water quality due to disturbances at water works or the distribution network (Malm et al., 2013 and Tornevi et al., 2013). So, data from HCC contacts may also be useful in monitoring process. People become infected after eating or drinking beverages that have been handled by person who is infected or by drinking water that has been contaminated by sewage containing the bacteria (Freebase, 2011). Isolating excreta to a consolidated area is a positive step but is minimally effective in lowering water-related disease rates (Bolaane and Ikgopoleng, 2011). 

E. coli and Vibrio cholera poses major health risk to human population causing range of gastro-enteric diseases and is also a source of pandemics in human infant population (Olaniran et al., 2011).

In July 2011, the UN General Assembly declared safe and clean drinking water and sanitation a human right essential to the full enjoyment of life and all other human rights. In India, domestic sewage contributes about 75 per cent of waste as 115 million homes are there without toilets (UNESCO, 2008). Hence, the culture of using bottled and sachet mineral water is now widespread and water business is flourishing. Some of the studies say that even these waters are also not safe (Kassenga et al., 2007; Olaoye et al., 2009 and Flora and Michael, 2012). In a WHO report, it has been reported that 80% of all sickness and diseases in third world is due to consumption of contaminated water (Songara et al., 1999).

Several examples from the UK, USA, Germany, Japan and few other countries are valuable that they resulted in an improved understanding of the protection of the water sources and protection of the water supplies from
contamination, improvements of water treatments technologies and initiation to develop strategies to prevent further outbreaks. (Craun et al., 2005; Nichols et al., 2003; Jakubowski and Craun, 2002; Olson et al., 2002; Ono et al., 2001; and Yamamoto et al., 1996). Considering the distribution of emerging pathogens according to the main group of micro-organism to which they belong Taylor et al., (2001) estimated that 11% of the emerging pathogens were protozoa, 6% were helminthes in comparison to viruses or prions (44%), bacteria or rickettsia (30%) and fungi (9%). Although water treatment technologies are effective to remove microorganisms in water during the treatment process, current data on the prevalence of Giardia and Cryptosporidium in water clearly show that these parasites evade the filter barriers in the absence of treatment deficiencies and contaminate drinking water (Karanis et al., 1996).

Causes of sewage problems, disposal of sewage is a major problem in developing countries particularly and in Pakistan; especially because settlement populations in these countries do not have access to proper sanitary conditions and clean water (Hyvonen and Sewn, 2003). Industrial waste water often contains toxic compounds of several types that are detrimental to the health of aquatic life, and distributed through injection into the whole food chain. According to Joseph et al., (2007) this can cause immune suppression, reproductive failure or acute poisoning.

Sewage contains a large number of faecal bacteria some of which may be pathogenic. Therefore, the sewage should be treated prior to disposal (Ramesh and Anbu, 1996). Coliforms enter water supplies from the direct disposal into streams and lakes or run off from wooded areas, pastures, feedlots or ground water. The possible reason for the higher bacterial load of well water might be due to their closeness to the septic tank (Salle, 1974). Unhygienic practices of the population and unsanitary conditions in the area are the reasons for the poor microbial quality of ground water (Venkatachalam and Jebanesan, 1998).

Study carried out by Standridge et al., (1979) in a public swimming beach experienced intermittent faecal coliform contents during the late summer and early winter. A public health survey identified a combination of waterfowl’s wastes and metrological events as the explanation for the high bacteria counts. Faecal coliform bacteria were deposited by mallard ducks and multiply in the beach sands. The
bacteria were subsequently transported into the lake and resulted in high faecal coliform in the swimming area.

The world is facing a global water quality crisis. Continuing population growth and urbanization, rapid industrialization, and expanding and intensifying food production are all putting pressure on water resources and increasing the unregulated or illegal discharge of contaminated water within and beyond national borders. This presents a global threat to human health and wellbeing, with both immediate and long-term consequences for efforts to reduce poverty whilst sustaining the integrity of some of our most productive ecosystems (Corcoran et al., 2010).

The health of a community and its water resources must be protected from the harmful effects of inadequately treated wastewater. These harmful effects include waterborne diseases other illnesses and the pollution of rivers, streams, lakes, groundwater supplies, or other water bodies. Persons generate wastewater, as they go about their daily activities of washing dishes and clothes, showering and bathing, and using the toilet. To protect public health and environmental quality, wastewater must be cleaned (treated) before it is returned to the environment for further use (Simms, 2006). Wastewater can cause health risks to people; it is well known that wastewater is the accumulation of human wastes such as feces and urine. Because of its characteristic, it is indeed true enough that it has various pathogens and allergens that can be very harmful to people's health. There are several diseases caused by wastewater. The people are at great risk of acquiring infectious diseases due to exposure to wastewater. Not only are the general public affected, wastewater damage also poses risks to workers who usually venture in the remediation process, wastewater treatment and other wastewater-damage related activities. There is a big possibility for them to acquire chronic respiratory illnesses and other chronic illnesses whether it could be viral, fungal, bacterial and parasitic (Nov, 2005).

Drinking water is not treated, or treatment is minimal Humans exposed to contaminated water are highly susceptible to infection because they are immunologically naive or immunologically compromised because of age or chronic disease. Cryptosporidium parvum is known to cause prolonged severe and life-threatening diarrhoea in immunocompromised individuals (Colford et al., 1996;
Fayer et al., 2000; Slifko et al., 2000; Hunter and Nichols 2002). Young children and the elderly are most at risk for infection with E. coli O157:H7 (Karmali 1989). There also appears to be age- and exposure-related resistance to infection with these pathogens. Cryptosporidium parvum and Giardia duodenalis are resistant to the levels of chlorination used in drinking-water treatment (Jarroll et al., 1981; Korich et al., 1990). E. coli O157:H7, like most other enteric bacteria, is not highly resistant to chlorine (Rice et al., 1999); however, certain strains may be more resistant than others (Zhao et al., 2001) may. Waterborne outbreaks normally occur where there has been no chlorination or a failure in chlorination (Friedman et al., 1999; Hrudey et al., 2003). Efforts should be focused on improving water treatment in rural areas and in small communities and improving, the safety of water used in the irrigation of crops, in particular raw edible field crops.

Contaminated water resulting from washing, bathing, construction, and personal hygiene, must be treated before it is returned to the environment. Water is the primary component of a wastewater stream and is the component that is reused after contaminants have been removed through treatment processes. A typical resident uses about 45-60 gallons per day and a family of four may generate up to 240 gallons (908.5 Liters) of wastewater per day (Simms, 2006). Early efforts in water pollution control prevented human waste from reaching water supplies or reduced floating debris that obstructed shipping. Pollution problems and their control were primarily local, not national, concerns. Since then, population and industrial growth have increased demands on our natural resources, altering the situation dramatically (EPA, 2004).

Sources of drinking water are subject to contamination and require appropriate treatment to remove disease-causing contaminants. Contamination of drinking water supplies can occur in the source water as well as in the distribution system after water treatment has already occurred. There are other sources of water contamination, including naturally occurring chemicals and minerals (for example, arsenic, radon and uranium), local land use practices (fertilizers, pesticides, and concentrated feeding operations), manufacturing processes, and sewer overflows or wastewater releases (WHO, 1996).
Source water protection, to prevent contamination of water sources, as well as water treatment is often utilized in the provision of safe drinking water. Water treatment can use one or more of the following to control pathogens in water: coagulation, flocculation, sedimentation, filtration, and disinfection.

2.6.5 Water Quality Index (WQI)

Water Quality index is a single calculated value that provide an overall quality index of the water at a particular location. It is based on the computation of all relevant parameters in the context of the reference values. The objective of this index is to provide an overall qualitative indicator for the tested sample, usable for all concerned. In general, water quality indices incorporate data from various parameters into mathematical equation that rates the health of the water body with a number (Yogendra and Puttaiah, 2008).

For calculation of WQI the formula suggested by Ramakrishna et al., (2009) is as follows:

\[
WQI = \sum S_i \times W_i \times q_i
\]

Where \( S_i \) = concentration of each parameter

\( q_i = \frac{C_i}{S_i} \times 100 \)

\( W_i \) = Unit weight of the water quality parameter. \( W_i = \frac{k}{S_i} \)

\( k = \frac{1}{\sum \frac{1}{S_i}} \)

\[
WQI = \sum_{i=1}^{n} q_i W_i
\]

As per Hortan (1965), WQI = \( WQI = \sum q_i W_i / \sum W_n \)

WQI 0-25 is said be excellent and above 100 is not suitable for drinking.

In the study of Yogendra and Puttaiah (2008) the water body of Shimoga, Karnataka, WQI indicated the water to be eutrophic and not fit for drinking and the
pollution load was found to be higher in summer in comparison to other seasons. Study of Sharma and Chhipa (2016) conducted in city of Jaipur and adjoining area in Rajasthan for assessment of water quality indices of different water sources. Values of water quality indices revealed that the drinking water in most locations in study area was found to be highly contaminated.

2.7 Sanitation

Clean water is an essential ingredient to economic growth and development—and investing in water and sanitation has high economic and social returns. The dictionary meaning of the word sanitation is the science of safeguarding health. One of the best definitions that can be given is as follows: Sanitation is a way of life. It is the quality of living that is expressed in the clean home, the clean farm, the clean business, the clean neighborhood and the clean community. In the past, sanitation was centered on the sanitary disposal of human excreta. Even now to many people sanitation still means the construction of latrines. In actual fact, the term sanitation covers the whole field of controlling the environment with a view to prevent disease and promote health (Park, 1997). Exposure to waterborne pathogens can occur via ingestion, inhalation, and/or direct contact with contaminated water. Waterborne diseases vary in severity from mild self-limiting gastroenteritis to fatal Diarrhoea. The different types of waterborne pathogens identified to-date broadly fit under three categories: bacterial, viral, and protozoan pathogens (illustrated in Table 1earlier). Agents in all three pathogen categories can be introduced to water sources via animal and/or human faeces, and then once ingested, grow and reproduce in the animal or human gastrointestinal tract (WHO 2008). These pathogens can cause sporadic waterborne disease or outbreaks, depending on a variety of factors, such as pathogen type, pathogen virulence, infectious dose, geographical distribution, host factors, and ecosystem factors. Modern agricultural practices, increased global trade and rapid forms of transportation facilitate the transmission of various parasites from developing regions to urban areas (Gajadhar and Allen, 2004).

A review of past studies (Kumar and Harade, 2002; Tumwine et al., 2002 and Swaddinwudhipong et al., 1995) indicated that water-borne illnesses, particularly Diarrhoea occur when people live in conditions where there are poor water and sanitation facilities, poor health promotion, poor personal hygiene
practices and lack of safe water. The era of the Millennium Development Goals (MDGs) from 2000–2015 had specific targets for “improved” access to drinking water supply and “basic sanitation”; however, coverage fell short of the sanitation target. (Alexander et al., 2016) The pH was within the national standard (6.5–8.5). The schools, households, and communities mostly had a natural water source, and hence, pH levels were expected to be in this range. Similar observations have been reported from studies conducted in Myagdi district and Dharan, where pH levels of 7.6 were reported (Pant et al., 2016).

Study of WASH (WASH is the collective term for Water, Sanitation and Hygiene as defined by UNICEF) in schools in Nicaragua it was advised that the school committee or parents’ associations might focus their efforts also on building an adequate number of toilets for girls and boys. In addition to latrines, building more urinals for boys (which have considerably lower costs than latrines) could also be beneficial for school children. Jordanova et al., (2015) found that the surveyed schools had usually one or two water taps available at a school for hand washing, and these were located at central places, far away from latrines and were without adequate sanitation infrastructures and hand washing facilities, highlighting several WASH challenges. This applies for remote rural pockets of our country also.

Another such study conducted in Nepal by Shrestha et al., (2017) observed inadequate washing of drinking water storage containers, containers having no lids, or lids not fitting properly, and drinking water cups left on dirty grounds, as well as kitchens in close proximity to animal sheds. Similar observations have been made in a study conducted in Botswana by Tubatsi et al., (2015) where the drinking water containers were kept without lids.

Kirby et al., 2016 found a significant association between the presence of TTC (thermo-tolerant Coliforms) contamination of drinking water and domestic animals freely roaming within the households compared to households where domestic animals were kept outside. This might be due to faecal contamination of water sources by domestic animals. Such faecal contamination of drinking water and possession of different types of livestock was also reported in studies conducted in Burkina Faso and Rwanda.
Scientific evidence has demonstrated that the economic cost associated with poor sanitation is substantial. At the global level, failure to meet the MDG water and sanitation target would have ramifications in the area of US$38 billion, and sanitation accounts for 92% of this amount. In developing countries, the spending required to provide new coverage to meet the MDG sanitation target (not including program costs) is US$142 billion (US$ year 2005). This translates to a per capita spending of US$28 for sanitation. Annually, this translates to roughly US$14 million. The evidence complied in this paper demonstrates that investing in sanitation is socially and economically worthwhile. For every US$1 invested, achieving the sanitation MDG (Millennium Development Goals) target and universal sanitation access in the non OECD (Organization for Economic Co-operation and Development) countries would result in a global return of US$9.1 and US$11.2, respectively (Minh and Hung, 2011).

To protect public health against waterborne disease, the World Health Organization (WHO) recommends a holistic approach to drinking water supply management, including creation of water safety plans (WSP) to manage all steps from water source to consumption (WHO 2008), as well as emergency preparedness plans and policies.

These WSP should:

(i) Assess the potential hazards that can affect the water system including microbial, non-microbial, and aesthetic aspects;

(ii) Identify control measures to reduce and then monitor the hazards; and

(iii) Develop management plans to describe both normal and incident conditions (WHO 2008).

The burden of waterborne diseases is paramount in the globe. According to WHO reports (2003a, 2008a, 2015) about 4% of the global burden of diseases is attributable to water, sanitation and hygiene. Nearly 2.2 million people die every year due to Diarrhoeal diseases globally. Of these, 1.8 million deaths occur alone in low-income countries. Further, in low and middle-income countries one of the tenth leading causes of death is attributable to Diarrhoea-related diseases. Globally, Diarrhoea alone kills more children compared to malaria and tuberculosis together.
In Bangladesh, every year more than one hundred thousand under-five children die due to Diarrhoea related diseases. On average, episodes of Diarrhoea occur more than twice a year among the children. Research indicates that more than half of acute illnesses are attributable to water, sanitation and hygiene-related across all age groups. These diseases are commonly reported in low-income countries as provision of safe water, sanitation and hygiene is sub-optimal. Recent research also shows that due to climate change waterborne diseases such as Diarrhoea is increasing gradually (Vanderslice and Briscoe, 1995). In low-income countries, waterborne diseases are well-known public health problem. Although burden of waterborne diseases is substantial in most of the low-income countries, intervention for reducing these medical conditions is fragmented. The global use of improved water sources is up to 87% but still 884 million people do not have access to safe drinking water. Along with improved water supply, proper sanitation and adequate hygiene practices are pivotal for sustaining high water quality and reduce water related diseases. Today, only 61% of global population uses improved sanitation facilities, which leaves out 2.6 billion people (Masud Rana, 2009).

Water-borne diseases represent a major burden on human health worldwide. Every year, 1.8 million people die from Diarrhoeal diseases, of which 1.5 million are children under the age of five (WHO document on Water, Sanitation and Hygiene Links to Health; FACTS AND FIGURES, updated November 2004; http://www.who.int/water_sanitation_health/publications/facts2004/en/). Access to safe drinking water, basic sanitation and proper hygiene education could not only prevent Diarrhoeal diseases by nearly 90% but also furthermore lead to improved health, poverty reduction and socio-economic development (WHO and UNICEF 2017). Goal 7 of the Millennium Development goals (MDG) set by the United Nations in 2000 was to halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation. As per the highlights of the WHO and UNICEF (2017) report three out of four people (5.4 billion) used improved sources free from contamination and only 68% of the total population were using basic sanitation services in world. Chronic political conflicts, natural disasters, disparities in urban-rural settings and rapid population growth are only some of the obstacles to accelerating the rate of progress for African populations (Palmgren and Small 2000, Masud Rana 2009). In rural Africa 2 out of 3 people, do not have access
to an improved water supply. Today, as basic infrastructure for wide surveillance of water sources is unavailable, a household water management approach appears to be the most attractive short-term intervention (Atteaikn, 2011).

Even though the percentage of people practicing open defecation is decreasing worldwide, in Southern Asia and SSA open defecation is practiced widely 44% and 27% respectively. (Macdonald et al., 2007). As WHO and UNICEF (2017) report says 892 million people worldwide were practicing open defecation in 2015. Control strategies for waterborne pathogens that are most frequently associated with waterborne illness - the enteric bacteria Salmonella enterica, Campylobacter jejuni, and Escherichia coli, the spirochete Leptospira interrogans, and the protozoa Cryptosporidium parvum and Giardia duodenalis — are discussed, as are the unique challenges associated with them. Cryptosporidium parvum and Giardia duodenalis infections are very common in domestic and wild animals (Thompson 2000; Ralston et al., 2003). Recreational water has been identified as an important source of waterborne disease (e.g., Gilbert and Blake 1998). Lee et al., (2002) reported that while the number of outbreaks in the USA associated with drinking-water has declined over the past 20 years, the number of outbreaks associated with recreational water has increased and become more common than drinking water associated outbreaks (39 versus 59 in the period between 1999 and 2000). Water contaminated with animal wastes used for irrigation or processing was the likely source of these agents in some of these outbreaks. Leptospirosis is commonly associated with occupational and recreational use of water (Lomar et al., 2000; Haake et al., 2002).

Jalan and Ravallion (2000) study raised question that piped water reduce Diarrhoea for children to Rural India. In his study using primary survey data for the period 1993-94 found that overall prevalence of Diarrhoea is in the sample with an average of 33 days of illness and mean expenditure of 0.74 per cent episode of Diarrhoea. Disease prevalence and length of illness fall with higher income and education. Access to piped water significantly reduces Diarrhoea prevalence and duration. Diseases prevalent amongst those with piped water would be 21% higher without it. Health impacts from piped water were found to be larger and significance is more families with better-educated women. They found a similar pattern when
stratified instead by the highest education of household head. Finally, they concluded that there are striking differences in the child health gains from piped water according to family income and adult female education. Health gains from piped water tend to be lower for children with less well-educated women in the household. They also found that the illness reduced significantly if households have drinking water source with the premises, the impact is greater in households where the female member is illiterate. Suggesting that the piped water within, the house helps to compensate the knowledge of disadvantages and the illiterate member.

Water-borne diseases are simple to explain but very complex to understand. Constant humanitarian aid over the last decades has yet failed to deliver to the people in need the basic human priorities by not implementing serious, locally adjusted water management programs that secure long lasting infrastructure and maintain a dignified level of public health. The failure to provide safe drinking water and adequate sanitation services to all people is perhaps the greatest development failure of the 20th century. The most egregious consequence of this failure is the high rate of mortality among young children from preventable water-related diseases (Peter H. Gleick, 2002).

2.7.1 Non-Point Source (NPS) Pollution:

Non-Point Source pollution is different from industrial and sewage treatment plants. It comes from many disperse sources. In this type of pollution, rainfall or snowmelt moves over and through the ground; collect and carries away natural and human-made pollutants. These runoffs finally depose them into lakes, rivers, wetlands, coastal waters, underground drinking water source and create non-point source pollution (Trivedi and Goel, 1984).

There are three types of NPS models: screening, simulation, and distributed process based models. In 1972, Section 303(d) of the Clean Water Act required states to identify waters that did not meet water quality standards, to institute a schedule for developing TMDLs (total maximum daily loads), and to establish TMDLs for each water body on the 303(d) list. The EPA revised their regulations in July 2000, requiring states to develop implementation plans for each TMDL (Copeland, 2005).
Water, sanitation and hygiene improvements can be classified into two groups of related interventions:

(a) Provision of an improved source of water and/or improved distribution, such as piped water or standpipes, provided at either public (source) or household (point-of-use) levels.

(b) Provision of improved means of excreta disposal, through latrines or connection to the public sewer.

Access to safe drinking water is estimated by the percentage of the population using improved drinking water sources. An improved drinking water source is one that by the nature of its construction adequately protects the source from outside contamination, in particular with fecal matter. An improved sanitation facility is one that hygienically separates human excreta from human contact. In addition, water should be provided in sufficient quantities to enable proper hygiene. Hands should be washed immediately after defecation, after handling babies’ feces, before preparing food and before eating.

2.8 Socioeconomic status as influential factors

Waterborne diseases such as Diarrhoea, cholera, typhoid etc. have a very strong relationship with poverty and unhygienic environment. Poverty directly associates with poor housing conditions, over crowded house, lack of access to sufficient clean water and sanitary disposal of fecal waste, and cohabitation with domestic animals that may carry human pathogens. All of the above-mentioned issues are common among the rural parts of developing countries, especially of South Asia, and these factors are considered the major risk factors to increase both diarrhoeal morbidity and mortality.

The health status of these individuals can theoretically be tied to their economic status. Young and Briscoe (1987), Baltazar et al., (1988) and Daniels et al., (1990) considered socioeconomic conditions, e.g., per capita income, occupation or literacy rate, as important factors affecting diarrhoeal morbidity. El-Fadel et al., (2014) found statistically significant difference in diarrhoeal cases in their study areas (Tripoli, Lebanon and Irbid, Jordan) which was correalted with the educational level of household head and financial status.
Level of income and better socioeconomic conditions also has a lot to do with having better living styles. Malik et al., (2012) considered that people having better life styles and socio-economic condition showed more acceptability to pay for water services in the rural communities of the developing countries. This eventually reduces the chance of getting waterborne disease. Environmental factors contribute to 60 years of ill health per 1,000 populations in India compared to 54 in Russia, 37 in Brazil, and 34 in China. Lack of water, sanitation, and hygiene results in the loss of 0.4 million lives annually in India (WHO, 2007).

2.8.1 Health and Economic Burden

As Parikh (2004) estimated socio-economic costs of water pollution are extremely high: 1.5 million children under 5 years die each year due to water related diseases, 200 million person days of work are lost each year, and the country loses about Rs 366 billion each year due to water related diseases. McKenzie and Ray (2004) also observe similar effects of water pollution; however, the magnitude of the effect was modest. The study shows that India loses 90 million days a year due to water borne diseases with production losses and treatment costs worth Rs. 6 billion. Poor water quality, sanitation, and hygiene result in the loss of 30.5 million disabilities adjusted life years in India.

Poor water quality spreads disease, causes death and hampers socio-economic progress. Around five million people die due to waterborne diseases. Pathak (2015) reports that these diseases affect education and result in loss of workdays, estimated at 180 million person days annually. The annual economic loss is estimated at Rs.112 crores. Water-related diseases put an economic burden on both the household and the nation’s economy. Poor water quality, sanitation, and hygiene result in the loss of 30.5 million disabilities adjusted life years (DALY) in India (McKenzie and Ray, 2004). At household levels, the economic loss includes cost of treatment and wage loss during sickness. Loss of working days affects national productivity. On the other hand, the government spends a lot of money and time on treatment of the sick and providing other supportive services.

as per census of India, if a household has access to drinking water supply from a tap or a hand pump/tube well situated within or outside the premises, it is considered to safe drinking water. Millions of people in the country suffer from water borne diseases because of lack of access to be safe drinking water. A poor suffer from higher prevalence of diseases as compared to rich. Siddiqui et al., (2012) also found waterborne diseases to be significantly associated with financial status and literacy rate. Colombara et al., (2013) had also explained that maternal education and income were the factors influencing Diarrhoeal risk.

Pathak (2015) further states that cost benefit analysis in respect of India could save billions, if drinking water and sanitation services were improved. It is estimated that around 37.7 million Indians are affected by waterborne diseases annually; 1.5 million children are estimated to die of diarrhea alone and 73 million working days are lost due to waterborne disease each year. The resulting economic burden is estimated at $600 million a year. The problem of chemical contamination is also prevalent in India with 195,813 habitations in the country are affected by poor water quality (Pathak, 2015). This total doesn’t even take into consideration the human right to water, and the immeasurable cost of losing a friend or family member to a waterborne illness. In India, 60-80 per cent of the resources in the health system is spent on hospital care, leaving a much lower proportion for basic services. In addition, the focus is on urban-curative services, leaving rural areas more vulnerable.

2.8.2 Socio-economic implications

Diarrhoeal diseases are preventable if a patient receives appropriate care. However, getting appropriate treatment and preventive care is even harder in the developing countries due to the lack of adequate, readily available and affordable medical care (Fewtrell and Colford, 2004). First, the people residing in the rural parts of developing countries are less educated and people usually remain unknown about the severity of waterborne diseases. Second, the income level in the rural communities of developing countries is so low that their willingness to pay for illness is almost negligible (Malik et al., 2012). Thus, they have less desire to be treated at a hospital, which usually is very far away from the place they live, and
charges a lot for service. This leaves them untreated and increases the Diarrhoeal morbidity and mortality rate; mostly amongst children less than 5 years.

The pollution of water sources also has socio-economic implications. The water quality monitoring results obtained by CPCB during 1995 to 2009 indicate that organic and bacterial contamination was critical in the water bodies (CPCB, 2009). An inadequate supply of water and sanitation facilities could reduce the likelihood of safe disposal of human waste thereby increasing risks or exposure to disease and death. An adequate water supply promotes good health and improves the prospects of new livelihood activities which are otherwise denied and are a key step out of poverty (UNESCO, 2006). Where water and sanitation investments are not made, the likelihood of contracting diseases such as Diarrhoea, dysentery, cholera, typhoid and schistosomiasis is high. When the ‘bread winner’ or family head becomes victim to these diseases, it has implications for the livelihood of the household, particularly that of a poor household. Working days as well as productivity are lost and household incomes are greatly reduced where alternative sources of income are limited or non-existent. Household incomes might not be able to support the buying of water from expensive alternatives thus it is caught up in the cycle of poverty due to the lack of good quality water for drinking, irrigation and sanitation (WHO, 2001). Majority of those who suffer this trend are women. According to the WHO, almost 70 percent of the 1.3 billion people living in extreme poverty are women and often trapped in a cycle of ill health (WHO, 2001). The Bhargava (2006) also maintains that “labour is often the only asset that poor households have and that sickness and death can have intergenerational effects. Any improvements in environmental health can have long-term impacts on households’ ability to move out of poverty”. An improved water supply could therefore trigger a reduction in working hours and increase rest for women and children who hitherto, had to walk long distances or join long queues to fetch water of questionable quality. For poor rural women, the time saved could be used for household childcare, the collection of more water for hygiene or the engagement in productive activities as trading to supplement household incomes. In addition, children could gain more time to attend school (Whitlock et al., 2002).
However supplying clean water alone would not solve health-related problems. Only an integrated approach of water quality improvement with improvement in water availability combined with sanitation and hygiene education will help address this issue.

2.9 Public Health Responsibility of various agencies

As depicted in the official website- the Ministry of Drinking Water and Sanitation, Government of India, formerly under the Ministry of Rural Development as Department of Drinking Water and Sanitation, is presently headed by the Cabinet Minister, Drinking Water and Sanitation. The Accelerated Rural Water Supply Programme (ARWSP) was the first major intervention in the water sector that started in 1972-1973. To accelerate coverage, a Technology Mission on Drinking Water was launched in 1986. In 1991-92, this mission was renamed Rajiv Gandhi National Drinking Water Mission, and in 1999, the Department of Drinking Water Supply (DDWS) was formed under Ministry of Rural Development, for focused attention on drinking water and sanitation. The first major sector reform project (SRP) was started in the same year. Later was renamed as Department of Drinking Water and Sanitation in 2010 and in 2011, it was conferred the Ministry status, keeping in view the extreme importance given to the sector by the ruling government. The Ministry of Drinking Water and Sanitation is the nodal department for the overall policy, planning, funding and coordination of programmes of drinking water and sanitation in the country.

The ministry document (background paper) says that ‘The primary responsibility of providing drinking water facilities in the country rests with the State Governments. The Government of India supplements the efforts of State Governments by providing financial assistance under the centrally sponsored Accelerated Rural Water Supply Programme (ARWSP), now renamed as National Rural Drinking Water Programme (NRDWP)’. This Programme is to provide a renewed focus with a mission approach to implement programmes for rural drinking water supply. About Rs.70,000 crore have been invested in the Rural Water Supply Sector since independence by the Central and State Governments.
The role of the Central government is to guide investments in this sector, encourage the need for training and research, and to promote water quality monitoring and human resources development programmes. The states plan, design and execute water supply schemes and operate through departments like Public Health Engineering Departments, Panchayati Raj Engineering Departments or Rural Development Engineering Departments and Water Boards. The Central Water Commission (CWC) in the Ministry of Water Resources (MoWR) is responsible for regulating the use of surface water for irrigation, industry and drinking water purposes. It also mediates in inter-state water allocation disputes. Central Groundwater Board (CGWB) under the MoWR has an overseeing responsibility for the monitoring of groundwater levels and rates of depletion and the production of water resource inventories and maps.

National Rivers Conservation Directorate (NRCD) under the Ministry of Environment and Forests (MoEF) oversees the implementation of Action Plans to improve the quality of the rivers in India Central Pollution Control Board (CPCB) under the Ministry of Environment and Forests (MoEF) promotes basin-wide pollution control strategies. It liaises with State Water Pollution Control Boards for laying down standards for treatment of sewage and effluents. The Board is also responsible for action in the case of non-compliance by agencies. Rajiv Gandhi National Drinking Water Mission (RGNDWM) under the Department of Drinking Water Supply, Ministry of Rural Development (MoRD) formulates policies, sets standards, and provides funds and technical assistance to the states for rural water supply and sanitation activities. Ministry of Agriculture (MoA) is involved in planning, formulation; monitoring and reviewing of various watersheds based developmental project activities.

Ministry of Urban Development (MoUD) is the nodal ministry for policy formulation and guidance for the urban water supply and sanitation sector. The Ministry’s responsibilities include broad policy formulation, institutional and legal frameworks, setting standards and norms, monitoring, promotion of new strategies, coordination and support to state programmes through institutional expertise and finance. BIS (Bureau of Indian Standard) is responsible for drafting of standards pertaining to drinking water quality.
A new initiative for cleanliness and sanitation has been launched by the Government of India is Swachh Bharat Mission (SBM). SBM is being implemented by the Ministry of Housing and Urban Affairs (M/o HUA) and by the Ministry of Drinking Water and Sanitation (M/o DWS) for urban and rural areas respectively. As per the drafted guideline document of the mission “The Swachh Bharat Mission emanates from the vision of the Government articulated in the address of The President of India in the Joint Session of Parliament on 9th June 2014: “We must not tolerate the indignity of homes without toilets and public spaces littered with garbage. For ensuring hygiene, waste management and sanitation across the nation, a “Swachh Bharat Mission” will be launched. This will be our tribute to Mahatma Gandhi on his 150th birth anniversary to be celebrated in the year 2019.”

Water Aid (2005) India Report examined that access to safe drinking water and sanitation in rural-urban area in India. The growth of population is increasing very fast while the supply of drinking water is not at par. Therefore, people face many problems to get drinking water especially in urban poor area. The public resources often provide insufficient amounts of water in congested urban areas. In fact, the survey noted that 15% of the urban households did not get sufficient water from their principal water source in April, May and June, so it is a matter of serious concern.

Dinesh Chand (2009) discussed how community could manage rural water supply. This study has described also some important act given by government of India to provide better drinking water in rural area. The government of India has created a Nation drinking water mission, which has been renamed as Rajiv Gandhi National drinking water mission, 1986 with the mandate to provide financial, policy and technological support and develop a multipronged approach relating to rural drinking water supply sector in 1991.

2.10 Similar studies conducted earlier

Historically, considerations on the effects water pollution on health have focused on waterborne illnesses, especially since the problem of water pollution has contributed to 70 to 80% of the health problems in developing countries (Chabala and Mamo, 2001). Saxena et al., (2004) studied the status of common water borne
diseases epidemiological trends in the desert city Bikaner (NW Rajasthan). In survey highest incidence of diseases was noted during summer (58.8%) followed by winter (34.1%) and monsoon (7.0%).

Bhattacharjee et al., (1989) noted Most Probable Number (MPN) of Coliforms/100ml in water of Mizoram to be less than 10 Coliforms/100ml. Agarwal A.(1993) registered total Coliform bacteria MPN/ 100ml in range of 191/100ml to 22,0001/100ml in river Betwa. Kataria et al., (1997) studied river Halali and reported MPN/100ml in range of 240 to 2400 +/-100ml. Doctor et al., (1998) recorded MPN between 300 and 1600/100ml in river Bhadar. Raka et al., (1999) registered the faecal pollution in drinking water of Maharashtra State and reported the total coliform in range of 21/100ml to 180/100ml. Bhosle et al., (1994) recorded coliform bacteria from Godavari river water more than 1600 in number per 100 ml and above. Water from the river indicates the high load of biological waste received from the discharge source during study period. The bacteriological population of ground waters of Chidambaram was 2073/ml (Total bacterial count) 206.67/100 ml (Total coliform count) and 33.83/100ml (Faecal streptococci) respectively.

A study was conducted to assess the status of waterborne diseases in India for future strategies and better planning. Data from survey of causes of death, India collected and analyzed. The survey was confined to the sample village of population 2000-5000 of the selected Primary Health Centres (PHCs); and forms were used for data collection. Result was deaths from dysentery (amoebic and bacterial), cholera, Diarrhoea (plus gastroenteritis), typhoid (plus paratyphoid) and polio were 218 (95 males, 123 Females), 52 (24 males, 28 females), 453(215 males, 238 females), 423 (200 males, 223 females) and 23 (16 males, 7 females) respectively during 1998 in India. Deaths due to Diarrhoea of newborn (<1 yr) alone was 121 (57 males, 64 females). At last conclusion was Improvements in water and sanitation coverage including the implementation of low-cost, simple technology systems-can reduce the incidence of dysentery (amoebic and bacterial), cholera, Diarrhoea (plus gastroenteritis), typhoid (plus paratyphoid), polio, hepatitis A, ascariasis, guinea worm, schistosomiasis and other water-related diseases (Yadav, 2011).

A study was done on ‘Children at Increased Risk of Waterborne Contamination’. Epidemiological study have been conducted to evaluate the relative
incidence of gastroenteritis among consumers of tap water vs. those drinking tap water filtered by reverse osmosis (RO), designed to remove waterborne pathogens. Children who drank non-filtered tap water suffered a greater incidence of gastrointestinal disease. In another study, families were provided with purified bottled water, tap water bottled at the treatment plant, and tap water from the same plant that was delivered through the distribution system. Those consuming the bottled tap water were 14 percent more likely to become ill than those drinking purified bottled water. Even worse, drinking tap water from the home tap resulted in 19 percent greater illness. An evaluation of children from 2-5 years old shows an even more dramatic difference with an excess of illness in 17% of those consuming bottled tap water and 40% of those drinking water from the tap. Studies have shown that children consuming municipal water, which has been treated with RO filtration designed to remove microbes, had a substantial reduction of their risk of gastrointestinal illness from water. RO and other point-of-use systems, designed for removal of infectious organisms, promise to provide additional measures of safety for children consuming treated and untreated drinking water (Reynolds, 2002).

Naaz Abaas et al., (2007) determined the bacteriological analysis of hand pump water in Pakistan for fecal contamination. He found that 67% of the samples were positive for fecal streptococci. The minimum most probable number (MPN) was 03 and maximum was >2400 for fecal streptococci. Of the 54 samples of fecal streptococci strains, 72.2% were identified as enterococci. Rashed and Younis (2012) investigated the physicochemical and bacterial characteristics of Nasser Lake water and houses drinking water, as well as fish cultures and its wastewater, in three villages west of Lake Nasser, Egypt. The obtained results indicated that the produced water, supposed to be for domestic use in the three villages, contained all the tested organisms. Scoaris et al., (2008) identified the presence of Aeromonas sp. in the bottled mineral water, well water and tap water from the municipal supplies. The positive samples for mineral water are 12.7%, well water 8.3% and tap water 6.5%. The recovery of Aeromonas sp. was significantly higher in the bottled and well water when compared with tap water from municipal supplies.

A study was conducted with an objective to determine Effect of Water, Sanitation and Hygiene Intervention in Reducing Self-reported Waterborne Diseases
in Rural Bangladesh. Total 29,885 households were selected randomly for this study through multi-stage 30 clusters sampling design. The intervention included promotional activities to install tube wells, sanitary latrines and health education for improving hygienic behavior. Findings reveal that overall prevalence of waterborne diseases reduced from 10% at baseline to 7% at follow-up (p<0.001). Among under-five children it reduced from 22% to 13% (p<0.001). Although, prevalence was higher among women than men at baseline were (p<0.001), but, no significant difference was noted between them during follow-up. Prevalence was found to be significantly higher between illiterate and who reported to use unsanitary latrine. Logistic regression analyses show that among the under-five children probability of reporting waterborne diseases was significantly higher at both periods. This study underlines that to reduce waterborne disease water, sanitation and hygiene intervention plays important role. Attenuation of waterborne diseases might influence child mortality and economic status of the households where out-of-pocket medical expenditure is pervasive (Rana, 2009).

A study was done to assess water-borne infection risk perception and water boiling habits in a remote Sankhuwasava region of Nepal using a brief interview-style questionnaire. All subjects were aware of the risks associated with drinking unpurified water, but a majority (65%) reported they did not boil water regularly, and almost 60% of villagers interviewed had history of infection despite their boiling practices. In contrast to reports from other communities in Nepal, risk awareness was sufficient in this region. Water boiling alone did not confer protection. Future efforts should target sanitation, screening, and other sources of contamination (Kovalsky et al., 2008). Another investigation was conducted to assess the knowledge, attitudes and practices on water handling, sanitation and defecation practices in rural southern India in rural Tamilnadu, using questionnaires and focus group discussions, in a village divided into an upper caste main village and a lower caste Harijan colony. Survey showed that all households stored drinking water in wide-mouthed containers. The quantity of water supplied was less in the Harijan colony, than in the Main village (P<0.001). Residents did not associate unsafe water with Diarrhoea, attributing it to 'heat', spicy food, ingesting hair, mud or mosquitoes. Among 97 households interviewed, 30 (30.9%) had toilets but only 25 (83.3%) used them. Seventy-two (74.2%) of respondents defecated in
fields, and there was no stigma associated with this traditional practice. Hand washing with soap after defecation and before meals was common only in children under 15 years (86.4%). After adjusting for other factors, perception of quantity of water received (P<0.001), stated causation of Diarrhoea (P=0.02) and low socio-economic status (P<0.001) were significantly different between the Main village and the Harijan colony. It was concluded that traditional practices may pose a significant challenge to programmes aimed at toilet usage and better sanitation (Banda et al., 2007).

Study was conducted with a goal to improve health and educational opportunities for children, women and communities in Ibadan (Nigeria) through implementation of safe water use and appropriate sanitation practices. Target group includes Primary school and secondary school children, Community women, Religious associations, market associations, and other related community organizations with the aim of outreach to the communities. The main method to be employed in this project is to create awareness on how to prevent and manage waterborne diseases. In conclusion they believe that if the local communities are aware of the dangers and threat posed by waterborne and sanitation related diseases, they will be more equipped both technically and morally to mitigate the spread of such diseases. This will also enhance a common front to fight against the outbreaks of such disease as cholera, dysentery at households, communities and local levels in both rural and urban communities in eradication of waterborne Diarrhoea and related diseases. (Water Sanitation, Health and Hygiene Program, 2011).

A study was conducted on Cryptosporidiosis surveillance and waterborne outbreaks in Europe. Cryptosporidiosis is a modifiable disease at European Union level, and surveillance data are collected through the European Basic Surveillance Network. The disease distribution in Europe for 2005 showed 7,960 cryptosporidiosis cases reported from 16 countries. The crude incidence rate was 1.9 cases per 100,000, although there were considerable differences in the rates of cryptosporidiosis between countries. Infection was more commonly reported in young children. A pronounced seasonal peak was observed in the autumn of 2005, with 59% of the cases reported between August and November, although Ireland and Spain experienced a peak in spring and summer, respectively. Routine
cryptosporidiosis surveillance from North West England over 17 years showed that the cases occurred predominantly in spring and autumn. Conclusion was Improvements in cryptosporidiosis surveillance such as detection, recording and reporting would help to recognize outbreaks and monitor interventions (Semenza and Nichols, 2007).

A research was conducted with a purpose to evaluate the epidemiology of waterborne Diarrhoea among children aged 6-36 months old in Busia town, western Kenya. The study was carried out between Feb. 2008 and Feb. 2010. Cases of Diarrhoea reported in 385 households were linked to household water handling practices. A mother with a child of 6-36 months old was also included in the study. Diarrhoea prevalence among children 6-36 months was 16.7% in Busia town, 19.6% in Bwamani and 10.6% in Mayenje clustered in Mayenje sub-location reported the highest and the lowest prevalence of Diarrhoea. There was a positive correlation between the prevalence of Diarrhoea in children and the level of the mother’s education. Diarrhoea cases decreased in range from 35.5% (n=102) to 4.8% (n=16), corresponding to increase in age from 6-35 months on average. In conclusion, prevalence of Diarrhoea in children of 6-36 months old was 16.7% in Busia town, higher in children whose that’s age was below 18 years and with low level of education and the rate decreased with increase in age of children (Onyangol and Angienda, 2010).

Between 1997 and 2004, the researchers conducted a community health needs and resources assessment study in Newfoundland and Labrador, Canada to assess health beliefs and practices, satisfaction with health and community services and concerns in relation to community health. The data collection methods used was a random household survey, key informant interviews and focus group sessions. The results indicated that the quality of drinking water was of serious concern. The study findings concludes and the implications for nursing practice in relation to developing healthy public policy and population health initiatives (Pike-MacDonald et al., 2007).

In rural east-central Mali a study was conducted with an objective of finding correlation between water sources and childhood Diarrhoea prevalence. Interviews were conducted with parents or guardians of children less than 7 years of age in
seven villages with access to a variety of water supplies. Water sources used, breastfeeding status, demographics and recent Diarrhoea symptoms were determined for 1117 children. Findings were Children whose water was drawn exclusively from wells had a significantly lower prevalence of Diarrhoea as compared with children whose water was drawn from a spring or stream (5.9% vs. 8.7%; P=0.04). The exclusive use of improved water sources had no impact on Diarrhoea prevalence among children who were exclusively breastfed. Similarly, the strongest protective effect was observed among children who were not exclusively breastfed. Conclusion was that using surface water as a primary or secondary water source exposes children to greater risk of diarrhoeal disease than using only improved sources such as wells. It is particularly beneficial for young children who are not exclusively breastfed to be supplied with water drawn from improved sources (Plate et al., 2004).

With an aim to find that solar disinfection of drinking water protects against cholera in children less than 6 years of age a was carried out in Kenya. In the original trial, all children aged fewer than 6 in a Maasai community were randomized by household. In the solar disinfection arm, children drank water disinfected by leaving it on the roof in a clear plastic bottle, while controls drank water kept indoors. There were 131 households in the trial area, of which 67 had been randomized to solar disinfection. There was no significant difference in the risk of cholera in adults or in older children in households randomized to solar disinfection. However, there were only three cases of cholera in the 155 children aged less than 6 years drinking solar disinfected water compared with 20 of 144 controls. Results confirm the usefulness of solar disinfection in reducing risk of water borne disease in children (Conroy et al., 2001).

Many workers in India made various discoveries and had various studies on water pollution problems in several parts of India. It was noticed that the hazardous waste released in river and reported the episode when the river Ganges was set aflame near Monghyr, Bihar State in 1968 (Sunderesan et al., 1983). Discharge of crude oil and other petroleum products along with the refinery effluents into the river and subsequent fire resulted in the suspension of drinking water supply to the town of Monghyr for a few days. This resulted in serious drinking water problems to
the residents of the city. In Madhya Pradesh state, serious environmental pollution hazard hangs over vast tracts of rich forest and agricultural lands, situated along the 32 km long course of river Sankini, which carries huge quantities of fine iron ore dust, wash out from the prestigious Bailadila Iron Ore project. The pollution threat has assumed such a serious proportions over the past few years that the entire river has been turned red thus seriously hampering the drinking water needs of the people in villages on the banks of the river (Sunderesan et al., 1983).

Daniel et al., (1982) analyzed the water quality of the French river. Foster (1988) investigated the impact of urbanization on the aquifers at various cities of South America. The presence of contaminants like nitrates, toxic metal ions, organic compounds and bacteria in the studied aquifers was attributed to domestic and industrial effluents of the regions. Jacobson et al., (1988) examined water from a large number of wells in Australia for different chemical parameters and found contamination in a majority of the cases, caused by influx of industrial and domestic wastewater.

Jais et al., (1993) studied drinking water in and around Vijapur. Kataria and Jain (1995) observed turbidity in groundwater of Bhopal city. Kataria (1996) observed phosphate and sulphate content in bore-well waters of Bhopal city. Rengaraj et al., (1996) reported nitrogen in groundwater in of suburban regions of Madras city. Harish Babu et al., (2006) made a study on groundwater samples during December 2004 in Tarikere Taluk, Karnataka. The samples were analyzed for trace metals, such as iron, lead, cadmium copper, zinc, nickel and barium. Lang et al., (2006) observed that the major anthropogenic components in the surface and groundwater include K⁺, Na⁺, Cl⁻, SO₄²⁻, NO₃ with Cl⁻ and NO₃ being the main contributors to groundwater pollution in Guiyang, China and its adjoining areas. Ram et al., (2006) observed that the high value of TDS, Iron, Total Hardness, Calcium Hardness, Calcium and Magnesium in the ground strata.

Where the aquifer is available or due to leaching of various pollutants through the sides and bottom of unlined drains. Tatawat and Singh Chandel, (2006) studied the groundwater quality of Jaipur city experienced degradation due to rapid urbanization and industrialization. Eleven groundwater samples were collected from Jaipur City, Rajasthan (India) from different hand pumps to study the chemical
parameter with the help of standard methods of APHA during pre-monsoon. Groundwater samples were collected from different locations in Churu tehsil, Rajasthan by Sinha, (2007), for their physicochemical studies. On comparing the results against drinking water quality standards laid by Indian Council of Medical Research (ICMR), it is found that most of the water samples are non-potable for human beings because of having much higher TDS value.

Maheepal singh et al., (2014) studied the Correlation of physicochemical character with total coliform count and reveals that there is a strong positive association with temperature, turbidity, pH and alkalinity. Chloride, fluoride and DO are negatively correlated with total coliform count.

Various technical research paper on the assessment of water quality for lake, river, sea and different areas have been published. Bhagat and Sagar (2013) reported assessment of physical-chemical parameter and quality of Sutlej River in Nangal area of Punjab (India). The Physico-Chemical parameter were studied and analyzed for the period of one year i.e. July 2010 to June 2011. Various physico-chemical parameters such as water temperature, water colour, turbidity, free ammonia, total dissolved solid, pH, dissolved oxygen, free CO2, total hardness, total alkalinity, chlorides, BOD, Nitrates, Phosphates, Sulphates were studied. The results revealed that there was significant seasonal variation in some physico-chemical parameters and River water was moderately polluted in Nangal area. On the basis of primarily study, it was apparent that water was not potable but can be used for propagation of wildlife, fisheries and irrigation. Bohr et al., (2013) has studied Water quality assessment of the River Godavari, at Ramkunda, Nashik. Three samples collected from three locations along the area. Study area during the months June, August, and October respectively. The result of the study shows that, the river is polluted at Ramkunda. It is believed that continued pollution of the water sources by various human activities may lead to any health problem to human. The values of correlation coefficients and their significance levels will help in selecting the proper treatments to minimize the contaminations of river water of Godavari at Ramkunda.

Tambekar et al., (2013) have studied physico-chemical parameters of water quality around Chandrapur (Maharashtra). The water sample was collected from the
Wardha River at 3 different selected stations over a period 12 months. Many values of parameter crossed the maximum permissible limit. The study suggested immediate need to take extensive water quality monitoring studies and to find the remedial measures to protect the natural water source.

Vijaya Kumar and Vijaya Kumara (2013) has studied physico-chemical analysis water quality of Kundapurs Mangrove fores (Karnataka). The result of the study shows that as the season changes there is fluctuation in the physico-chemical characters of the water. In addition, intense pollution from both agricultural input and shrimp culture ponds deteriorates the water quality of mangrove ecosystems.

Koliyar and Rokade, (2008) have studied the water quality in Powai Lake, Mumbai. Many parameters were found to be increased during summer season and got diluted during rainy season. Lack of oxygen content can cause fish kills and lack of fish enable malaria hosting mosquitoes as mosquitoes are natural food for fish. Throwing waste material and garbage in the lake water should be strictly prohibited proper bioremediation techniques should also use in order to improve the water quality.

Prabhakar et al., (2014) have studied water quality in the Karanja creek (Raigad, Maharastra). Monitoring of coastal water quality on a regular basis plays an important role in the detection and evaluation of marine water pollution. Different physical and chemical parameters were monitored during spring low and high tides for nightly from the Karanja creek for the period of 24 months (January -2004 to December -2005). It was observed that at that time the Karanja creek water was relatively clean. The variation observed with respect to physical and chemical variables of surface water are seasonal and are not significantly impacted by the anthropogenic pressure. The load of pollution in the Karanja creek was within the assimilative capacity of the creek. The data on nutrient level also indicate that sewage added into the creek, either gets diluted or utilized as a source of nutrients for the photosynthesis.

Bhavare et al., (2013) studied different physico-chemical characteristics and nutrients in water of Bhatye estuary, Ratnagiri central, West coast of
India. Results were similar to other studies. Andrade et al., (2011) have investigated Manglore coastal water pollution by analysis of physical, chemical parameter. The effluent samples were collected from 6 different locations of the study area in three different seasons of year. Due to rapid industrialization and the formation of SEZ, there is an urgent need to arrest the spread of pollution of coastal water. Manikannan et al., (2011) conducted similar study of seasonal variation in physicochemical properties of the Great Vedaranyam Swamp, Point Calimere Wildlife Sanctuary, South East coast of India.

Sen et al., (2011) studied the some physico-chemical parameter of pond and river water with reference to correlation study. The surface water sample was taken and collected from pond and river in around of Lumding town of Assam. The result was considered for correlation analysis and it was observed that many of the parameters bear good positive correlation and other a negative correlation, and pollution level of the various surface water of the locality was also observed.

Velsamy et al., (2013) analyzed physicochemical variations in sea water sample Uppanar estuary, Cuddalore, Tamilnadu (India). Study comprised sampling at two stations along the Cuddalore coast during July-December-2012 monthly. It was noted that the variation of physicochemical parameter depended mainly on Monsoon rain.

WHO and UNICEF’s joint research in the year 2000 showed that 1.1 billion people throughout the world did not have enough water and 2.4 billion people lived without adequate sanitation. The situation was much worse in the rural areas than in the urban areas (UNESCO, 2008). In 2000, the percentage of those with an adequate supply of water was found to be 94% in urban areas and 71% in rural areas worldwide. Similarly, the percentage with adequate sanitation was 86% in urban areas compared to 38% in rural areas. From the year 2000, the percentage of water supply and sanitation in the world have increased in the urban areas but situation in the rural areas were still unchanged. Until 2000, the percentage of the population with adequate sanitation in rural areas was half of that of the population in cities across the globe (WHO and UNICEF, 2000). Elimelech (2006) mentioned that 2 million deaths per year were reported worldwide due to unsafe water, mostly due to
waterborne, preventable Diarrhoeal diseases. Out of the total mortality rate, 90% belongs to the group of children under 5 years in the developing countries. In a meta-analysis by Fewtrell et al., (2005), improvement in water supply, water quality, and sanitation reduced the risk of Diarrhoea-related morbidity by 25%, 31%, and 32 %, respectively. Bhavnani et al., (2014) concluded unimproved water source (rivers, ponds, lakes and unprotected springs) and unimproved sanitation to be the major risk factors of Diarrhoea in Ecuador. The study showed that unimproved water source and unimproved sanitation increased the adjusted odds of Diarrhoea. Water and sanitation management practices can actually decrease Diarrhoea incidences by one-third to one-fourth (Ozkan et al., 2007).

2.11 2030 Vision for Water, Sanitation and Hygiene

On 25 September 2015, Member States of the United Nations adopted the 2030 Agenda for Sustainable Development. The 2030 Agenda comprises 17 Sustainable Development Goals and 169 targets addressing social, economic and environmental aspects of development, and seeks to end poverty, protect the planet and ensure prosperity for all. The SDGs (Sustainable Development goals) are aspirational global targets that are intended to be universally relevant and applicable to all countries, “with each Government setting its own national targets guided by the global level of ambition, but taking into account national circumstances” (para. 55). Global indicators will be tracked by mandated agencies, using consistent international definitions and methods to compare data from national sources. National targets will be tracked by national authorities, and in some cases indicators, definitions and methods may differ from those used at the global levels (WHO and UNICEF, 2017).

In March 2016, the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDG) published a list of global SDG indicators for monitoring the goals and targets of the 2030 Agenda. The list included a subset of the indicators recommended by the JMP following international consultations with water and sanitation sector stakeholders. WHO and UNICEF serve as the custodian agencies responsible for global reporting on SDG targets 6.1 and 6.2, and contribute to the wider UN-Water integrated monitoring initiative for Goal 6. The JMP (Joint Monitoring Programme for Water Supply, Sanitation and Hygiene) also collaborates
with custodian agencies responsible for monitoring other SDG goals and targets related to WASH, including SDG target 1.4 on universal access to basic services, SDG target 3.9 on the disease burden from inadequate WASH, and SDG target 4.a on basic WASH in schools (WHO and UNICEF, 2017).