Research Journal of Chemical and Environmental Sciences
Res J. Chem. Environ. Sci. Vol 2 [5] October 2014:13-27
Online ISSN 2321-1040
CODEN: RJCEA2 [USA]

Website: www.aelsindia.com/rjces.htm

RJCES

REVIEW ARTICLE

Bacteriological and Physicochemical Quality of Well Water Sources

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INTRODUCTION

Water is one of the most important compounds that constitute the largest part of life. It covers 70.9% of the Earth's surface and 97% of it is found in oceans whereas ice caps hold 2.4% and other land surface water such as rivers, lakes and ponds constitute 0.6 %. About 1.6% of water is retained in the ground (ground water) and 0.001% as vapour, clouds and precipitation [1]. Though, water is continuously disinfected by evaporation and precipitation, it is contaminated with raw sewage and industrial effluents on earth surface and hence water pollution has emerged as one of the most significant environmental problems. The causes of such deterioration are mainly originated from urbanization, industrialization, agricultural activity and an increase in human population for the past one half century [2]. One hundred years ago, the main water contamination problems were faecal and organic pollution from untreated human waste and the by-products of early industries. Although industrialized countries continue to struggle with pollution problems, they have greatly reduced the effects of these pollutants through improved treatment and waste disposal system and improve water quality [3]. However, in most developing countries, the problems of pollution by sewages and agrochemicals still degrade water quality; about 90% of waste-water in developing countries is still discharged directly to rivers and streams without any treatment [4]. Lack of safe water supply and poor sanitation are world's major causes of morbidity and mortality. The World Health Organization estimated that there are four billion cases of diarrhoea each year in the world in addition to millions of other cases of illness associated with lack of access to clean water [5].. Water-related diseases are typically placed in four classes: water-borne, water-washed, water-based, and water-related insect vectors. The first three are clearly associated with lack of improved domestic water supply [5]. Water-borne diseases are caused by the ingestion of water contaminated with human or animal faeces or urine containing pathogenic bacteria or viruses includes cholera, typhoid, bacillary dysentery, certain adenoviruses, reoviruses, and other diseases [6]. There are also over 30 species of parasites that infect the human intestines, of these the most common intestinal parasitic diseases are ameobiasis (caused by *E. hystolytica*), giardiasis (caused by *Giardia lamblia*), taeniasis (caused by *Taenia spps*), ascariasis (caused by *Ascaris lumbricoids*), hookworm disease (caused by hook worms), trichuriasis (caused by *Trichris trichuria*), and strongyloidiasis (caused by *Strogyloids stercoralis*) [7]. Water-washed diseases are caused by skin or eye contact with contaminated water or person to person contact infected with scabies, trachoma, flea, lice and tick-borne diseases. They occur when there is insufficient clean water for washing and personal hygiene [8]. Water-based diseases are caused by parasites found in intermediate organisms living in contaminated water or results from hosts that live in water or require water for part of their life cycle. They are usually transmitted to humans via drinking contaminated water or using of such water for washing and other domestic purpose. The most important examples in this category are schistosomiasis which estimated to infect 200 million people in 70 countries [9]. The water-related vector diseases include those diseases spread by insects such as malaria, onchocerciasis, filariasis, trypanosomiasis, yellow fever and dengue fever [10]. These diseases are not typically associated with lack of access to clean drinking water or sanitation services. It must be noted, however, that their spread is often facilitated by the construction of large-scale water systems that create favourable conditions for breeding the host vectors . Most untreated (un-chlorinated) water supplies contain faecal bacteria but in the case of protected ground water, example spring, protected wells and tube wells, it might be possible to achieve very low levels of contamination [4, 5]. The WHO Guidelines for Drinking Water Quality (GDWQ) describes the need to protect public health through the adoption of a water safety plan (WSP). The GDWQ establishes general guidelines for drinking water quality providing a common point of reference for all nations to determine the safe level of drinking water. The goal is to ensure drinking water quality through source protection, effective treatment and safe storage [11]. In Ethiopia, access to improved water supply and sanitation was estimated as 38% for improved water supply (98% for urban areas and 26% for rural areas) and 12% for improved sanitation (29% in urban areas, 8% in rural areas) [12]. Over 60% of the communicable diseases are due to poor environmental health conditions arising from unsafe and inadequate water supply and poor hygienic and sanitation practices. Three fourth of the health problems of children in the country are communicable diseases due to polluted water and improper sanitation [13]. Therefore, this necessitates proper protection of water supply from contamination and regular surveillance of water sources. Frequent examination of indicator organisms remains one of the methods of assessing the hygienic condition of water. Physicochemical parameters such as turbidity, pH, temperature, nitrate and others with respect to water quality are widely accepted as other critical water quality parameters describing the quality of drinking water. These parameters either directly influence microbiological quality or they may influence disinfection efficiencies or with their direct effect on health [14]. It is generally agreed that surface waters are more vulnerable to contamination than ground water even at times where ground water is assumed to be free from any bacteria. However, recent studies revealed that underground water sources and aquifers in urban areas and their surroundings contain faecal coliforms [15]. Studies on the assessment of the quality of drinking water showed that underground sources and reservoirs in Akakai Kality, Nefas Silk Lafto and Yeka sub cities of Addis Ababa city were contaminated with pollution indicators such as faecal and total coliforms [16]. This work was, therefore, initiated to assess the pollution status of underground water wells and recently dug wells for the supply of drinking water to inhabitants of Addis Ababa and surroundings. This study id to determine the quality of underground water sources and recently excavated bore holes

Drinking Water Quality

According to Fewtrell [17], the basis of good water quality is its importance to human health. In fact it is agreed that the principal risks to human health associated with the consumption of polluted water are microbiological in nature. The provision of an adequate supply of safe water was one of the components of primary health care identified by the International Conference on Primary Health Care [18]. The WHO guideline for drinking water quality set threshold for physicochemical and microbiological contaminants and the guideline indicates that an estimated 80% of all diseases are caused by the consumption of contaminated water and on average as much as one-tenth of each person's productive time is sacrificed to diseases related to water and sanitation [4]. Water quality standards have been developed to minimize the known chemical and microbial risks of human health. Safe drinking water does not imply risk free; it simply denotes risks are very insignificant which could not result in serious health problems [19]. The importance of doing away with microbiological contamination is the major benefit of ensuring good water quality for drinking and reducing of water-borne diseases transmitted by the faecal-oral route. Generally, improvements in microbiological water quality as well as the prevention of causal use of unhygienic water sources are best interventions to prevent water-borne diseases [20].

Ground (Well) Water Quality

Groundwater quality is naturally different from that of surface water bodies due to the materials through which it moves and the time taken for it to migrate between recharge and discharge locations. Groundwater has often of variable salinity and acidic pH with high concentrations of dissolved metals (particularly iron and manganese) and some measure of hardness. The quality of groundwater is affected by the type of material through which it flows and the period of time over which it resides in an aquifer [21]. The dissolved inorganic constituents of groundwater includes commonly major components (calcium, magnesium and sodium which are cations, bicarbonate, sulphate and fluoride which are anions, and dissolved silica), minor components (boron, carbonate, iron, nitrate, potassium, strontium), and trace components (aluminium, arsenic, barium, beryllium, bromide, cadmium, chromium, cobalt, copper, lead, lithium, manganese, nickel, phosphate, selenium, zinc and others). Groundwater commonly exhibits several characteristic of quality attributes such as variable salinity, low pH, dissolved metals and a degree of hardness [22].

Typical Chemical Contamination

Some highly saline groundwater has been found in association with chloride and sodium. They are components of many contaminants and can increase the salt load to a groundwater resource substantially if spills or releases occur. Extremes of pH in groundwater may also be generated by the presence of contamination or by acid sulphate soil disturbance [4]. Commonly, contamination enhances biological and chemical reactions that generate hydrogen as a by-product resulting in very low pH values. Alternatively, alkaline extremes of pH (very high values) may also occur due to the influence of contaminants.

Imbalances in the ionic content of groundwater may also be indicative of contamination and elevated levels of nitrate above the trace levels may suggest excessive use of fertilizers [23].

Sources of Ground (Well) Water Contamination

USEPA (1999) stated that contamination is typically categorized as pollution arising from either point or diffuse sources. Point source contamination is derived from locations that directly discharge pollutants in to water bodies. Examples of point source contamination include landfills, dumps, waste disposal areas, intensive agriculture (e.g. cattle feedlots or piggeries) and cemeteries. Diffuse (non-point) source contamination is derived from contaminants at much lower concentrations than is the case for point sources that are distributed broadly over much larger areas. Diffuse source contamination can arise from broad scale agricultural practices (e.g. fertilizer or pesticide use), urban runoff or the deposition of atmospheric pollutants.

Types of Contaminants

Many contaminants are derived from industrial and commercial activities that take place in urban areas. Contaminants that may be encountered in urbanized environments include industrial effluent and manufacturing wastes (e.g. Hexachlorobenzene, HCB), leachate generated from landfills, stockpiles, cemeteries or contaminated soils, nutrients and salts from Sewage Treatment Plant (STP) and effluent from irrigation activities, hydrocarbons leaking from underground storage tanks (USTs), chemicals and microorganisms from leaking underground pipelines and sewers, fertilizers and pesticides, acidic waters and elevated metal concentrations from the disturbance of acid sulphate soils in coastal areas, nutrients and salts from widespread domestic wastewater irrigation, and leaks of stored organic chemical compounds used in industrial or commercial processes [24].

The occurrence and concentrations of contaminants that may be found in groundwater will vary depending on the vulnerability of the groundwater system, the location and nature of the contaminant source, physical attributes of the chemicals or compounds (that determine how readily the contaminant will pass into and move with the groundwater), residence time of the contaminants in the soil or groundwater, and hydraulic characteristics of the aquifer [25].

Groundwater Quality in Ethiopia

According to the report of British Geological Survey (2001), few data exist on the general state of groundwater quality across Ethiopia. Most of the accessible published information is for water quality within the Rift Valley. From this, it is evident that groundwater in the Rift zone is influenced by geothermal waters with abnormally high concentrations of fluoride and/or total dissolved salts. Fluoride is therefore a recognized major problem, especially for the communities living within the Rift valley. Observed increased salinity in many ground water from sediments in the South, South-East and North-Eastern parts of the country arises from the dissolution of evaporite minerals (the products of evaporation) in certain horizons of the sediments.

Bacteriological Water Quality

Water bodies usually consist of a wide variety of microorganisms, some of which are pathogenic and some of which are not. Some of the non-pathogenic microorganisms may lead to problems in water supplies such as unpleasant taste and odour which may serve as indicator of safety. The principal concern for microbiological quality of water, however, is the potential of contamination by pathogens. Such pathogenic contaminants include bacteria, helminths, protozoa and viruses and most of these organisms are derived from faeces [29]. Indicator organisms, usually bacteria, are practically used to analyze the microbiological quality of drinking water. Among such indicators the most commonly ones are thermotolerant (faecal) coliforms or *E. coli*. In addition to the above mentioned indicators of bacteriological water quality, the broader groups of coliforms known as total coliforms are also used in monitoring program [30].

As with sanitary inspection, data on microbiological water quality may be divided into a number of categories and the levels of contamination associated with each category should be selected based on local circumstances. Since community water supplies are un-chlorinated, they will inevitably contain large numbers of total coliform bacteria which may be of limited sanitary significance. It is, therefore, recommended that the bacteriological classification scheme should be based on thermotolerant (faecal coliform) bacteria or *E. coli* [27].

Water Borne Pathogens and Diseases

The presence of organic matter in substantial quantity in water increases the abundance of saprophytic bacteria. However, water contaminated with sewage may also contain various pathogenic organisms belonging to bacteria, viruses and protozoa in addition to the usually innocuous populations. The consumption of this water, containing faecal matter, may result in severe health hazards [11]. Most human intestinal pathogens do not survive for extended periods outside the body of the host but they can remain sufficiently viable in aquatic environments to infect man. The infected individuals usually excrete large number of these pathogens in urine and faeces which ultimately get their way in to the municipal sewage. The sewage can contaminate water resources from where public water supply is drawn. The contamination of water can also occur in the distribution systems through leaks. The pathogenic organisms are transmitted to the body of people through direct contact or by consumption of contaminated water and food [28].

Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risks associated with drinking water. The wide variety of water-borne diseases and their public health impact is an important concern with far-reaching implications. About 3.4 million people, mostly children, die annually from water related diseases. Out of this number, 2.2 million people die from diarrhoeal diseases (including cholera) [28].

Water-borne diseases are typically caused by enteric pathogens which are mainly excreted in faeces by infected individuals and ingested by others in the form of faecally contaminated water or food. These pathogenic organisms include many types of bacteria, viruses, protozoa and helminths, which differ widely in size, classification, structure and composition. Pathogenic organisms are highly infectious and disease-causing which are responsible for many thousands of diseases and deaths each year especially in tropical regions with poor sanitation [11].

All potential water-borne human pathogens present a serious risk of disease whenever they are consumed in drinking water and are given high priority for health significance. Animals including humans are typically the main carriers of large populations of these bacteria, protozoa, and viruses. Pathogens originating from human sources, often from human faeces, are called enteric (of intestinal origin) pathogens. The most common ones include strains of *Escherichia coli, Salmonella, Shigella, Vibrio cholerae, Yersinia enterocolitica,* and *Campylobacter jejuni*. Some organisms may cause disease opportunistically and cause infection mainly among people with impaired natural defence mechanisms. These people include the very old, the very young, immuno-compromised people and patients in hospitals. Examples of such opportunistic organisms include *Pseudomonas, Klebsiella,* and *Legionella* [28]. Drinking water is the main route of transmission for pathogens of faecal origin. Unhygienic practices during the handling of food, utensils and clothing also play an important role [11].

The persistence of a pathogen in water affects their transmission to humans. A more persistent pathogen that can survive longer outside the host body is more likely to be transmitted to other people. The infective dose (ID) of the pathogen determines the number of organisms needed to produce an infection in humans. The ID_{50} is the dose required to produce a clinically detectable infection in 50% of the subjects. There are many causes of water-borne disease outbreaks. The most common causes include treatment deficiencies and the consumption of contaminated groundwater. Therefore, improvements in the quality and availability of water, sanitation facilities and general hygiene education will all contribute to the reduction of morbidity and mortality rates due to water-borne diseases [31].

Indicator Organisms of Drinking Water

A bacterial indicator of faecal pollution is any bacteria whose presence can indicate contamination of water with faecal matter. Faeces of warm blooded animals including human beings regularly discharge a diverse micro-flora of bacterial taxa like *Streptococcus faecalis, Clostridium perfringens, Lactobacillus bifidum (Bifidobacterium), Escherichia coli, Enterobactor aerogen, Staphylococcus aureus, Pseudomonas aeroginosa, Proteus* and certain spore forming bacteria. In addition, pathogens like *Salmonella, Shigella, Brucella, Micobacterium, Vibrio and Leptospora* together with certain viral and protozoan pathogens may also present (Moe, 1997).

The probability that a person will be infected by a pathogen cannot be inferred from the pathogen concentration alone. This is because different humans respond differently to the pathogens. As a result, there is no real lower limit for acceptable levels of pathogens in water. Instead, it follows that safe drinking water intended for human consumption should contain none of these pathogens. To determine if a given water supply is safe, the source needs to be protected and monitored regularly (WHO, 1996).

There are two broad approaches to water quality monitoring for pathogen detection .The first approach is direct detection of the pathogen itself, for example, the protozoan *Cryptosporidium parvum*. While it will be more accurate and precise if specific disease-causing pathogens are detected directly for the determination of water quality, there are several problems with this approach. First, it would be practically impossible to test for each of the wide variety of pathogens that may be present in polluted water. Second, even though most of these pathogens can now be directly detected, the methods are often difficult, relatively expensive and time-consuming. Instead, water monitoring for microbiological quality is primarily based on the second approach which is to test for indicator organisms [32].

According to the report of Slaats *et al.* [33], water quality indicator organisms should fulfil the following criteria; an indicator organism should always be present when pathogens are present, indicators and pathogens should have similar persistence and growth characteristics, indicators and pathogens should occur in a constant ratio so that counts of the indicators give a good estimate of the numbers of pathogens present, indicator concentrations should far exceed pathogen concentration at the source of pollution, the indicator should not be pathogenic and should be easy to quantify, tests for the indicator should be applicable to all types of water and the test should detect only the indicator organisms thus not giving false-positive reactions.

Another reason for using simple indicator tests is that pollution is often intermittent and/or undetectable. It is often better to monitor drinking water frequently by means of a simple test than to monitor infrequently using a longer and more complicated direct pathogen detection test. While these indicator bacteria or viruses are not necessarily pathogenic themselves, some of them have the same faecal source as the pathogenic bacteria and can therefore indicate faecal contamination of water. One example which fulfils many of the above criteria is the indicator organism thermotolerant coliforms or *E. coli*. Therefore, it may be sufficient to get an indication of the presence of pathogens of faecal origin with the detection and enumeration of *E. coli*. Such a substitution is especially valuable when resources for microbiological examination are limited as in developing countries [28].

Coliform Organisms (Total Coliform)

Coliform bacteria are metabolically defined as aerobic or facultative anaerobic bacilli, gram-negative, oxidase-negative, non spore forming rod-shaped bacteria and can grow in a medium containing bile salts with the production of acid, gas and aldehyde after fermenting lactose at an optimum temperature of 35ºC within 24 to 48 hours. In U.S, coliform bacteria have been recognized by the EPA Safe Drinking Water Act since 1989 as a suitable microbial indicator of drinking water quality. The main reason is because they are easy to detect and enumerate in water and are representative enough for determining microbial contamination of drinking water [4].

However, for developing countries in tropical climates, WHO states that total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies. It is recognized that, in the great majority of rural water supplies in developing countries, faecal contamination is widespread. Therefore, the use of total coliforms (TC) as a microbiological indicator of water quality in developing countries is not appropriate. A better indicator of recent faecal contamination is required. Coliform bacteria traditionally include the genera *Escherichia, Citrobacter, Enterobacter* and *Klebsiella*. The number of *Escherichia* and *Enterobactor* remains much higher in the intestine than the remaining two. Modern taxonomical methods also include lactose-fermenting bacteria, such as *Enterobacter cloacae* and *Citrobacter freundii*, which can be found in both faeces and the environment [28]. The inclusion of both non-faecal bacteria and lactose-fermenting bacteria limits the applicability of this group as an indicator of faecal contamination or pathogens in drinking water. However, the coliform test is still useful for monitoring the microbial quality of treated pipe water supplies despite its lack of specificity to faecal contamination [34].

When coliform organisms are detected in the absence of thermotolerant coliform and *E.coli*, further analysis for other indicator organisms should be undertaken to determine if faecal contamination is present. For total coliforms (TC), an incubating temperature of 37ºC for 24 hours is used. Under the WHO Guidelines for Drinking Water Quality [28], samples are allowed to contain up to 10 coliform per 100 milliliters (ml) of treated water in the distribution sample. For large water supplies, coliforms must not be present in 95% of samples taken throughout any 12 month period. Under the Total Coliform Rule by USEPA, a violation is triggered if 1 sample tests coliform-positive in a system collecting fewer than 40 samples per month. If more than 40 samples are collected per month, not more than 5% of all samples can test positive [27].

Thermotolerant Coliform Bacteria

Thermotolerant coliform comprises bacteria of the genus *Escherichia*, and to a lesser extent, *Klebsiella*, *Enterobacter,* and *Citrobacter*. They are defined as a group of coliform organisms that are able to ferment lactose at 44 to 45ºC. Sometimes, this group is also called faecal coliform (FC) to specify coliforms of faecal origin. This is not appropriate since thermotolerant coliforms other than faecal coliforms may also originate from organically enriched water such as industrial effluents, from decaying plant materials and soils or on vegetation in a tropical rainforest. Of these organisms, only *E. coli* is specifically of faecal origin [27].

However, concentrations of thermotolerant coliforms are usually directly related to that of *E. coli* and thus can be used as a surrogate test for *E. coli*. When a sample tests positive for thermotolerant coliforms, it is usually subjected to further confirmatory tests for *E. coli.* Positive results for both indicators are a strong indication of recent faecal contamination. Since thermotolerant coliforms can be readily detected by simple, single-step methods, it often plays an important secondary role as an indicator of the efficiency of individual water-treatment processes in removing faecal bacteria. The WHO Drinking Water Guidelines state that zero thermotolerant coliform or *E. coli* should be found per 100 ml of drinking sample [4].

Escherichia coli

Escherichia coli are a specific subset of the thermotolerant coliform bacteria which possess the enzymes β-galactosidase and β-glucuronidase that hydrolyzes 4-methyl-umbelliferyl-β-D-glucuronide (MUG). They are found abundantly in faeces of humans (as much as 10^9 per gram of fresh faeces) and warm-blooded animals. Ninety-five percent of all coliform found in human faeces can be *E. coli* [27].

Sewage, treated effluents, all natural water and soils that are subject to recent faecal contamination from humans or wild animals will contain *E. coli*. Usually, *E. coli* cannot multiply in any natural water environment and they are, therefore, used as specific indicators for faecal contamination. Therefore, while the presence of both thermotolerant coliforms and *E. coli* is not able to distinguish between human and animal contamination, nevertheless, they are better indicators than TC for the presence of recent faecal contamination. Both WHO Guidelines and USEPA standards require zero *E. coli* to be found per 100 ml of drinking water sample [28].

Faecal Streptococci and Enterococci

The term faecal streptococci have been used to describe a group of taxonomically distinct streptococci that are gram-positive, catalase-negative, non-spore-forming, facultative anaerobes recoverable from the gastrointestinal tracts of humans and animals. This group has been considered as an indicator of faecal contamination in environmental waters. They are present in relatively high densities in human and animal faeces, in sewage, and it is generally believed that they do not grow and multiply in environmental waters and soils. Recent revisions in the taxonomy of this group have resulted in some members of the group being placed into a new genus called *Enterococcus*. Members of this genus include *E. avium*, *E. casseliflavus*, *E. durans*, *E. faecalis*, *E. faecium*, *E. gallinarum*, *E. hirae*, *E. malodoratus*, and *E. mundtii*. These species usually grow at 45^0C in 6.5% NaCl, and at pH 9.6; most grow at 46^0C. *S. bovis* and *S. equinus,* faecal streptococci generally associated with animal faeces, are retained in the genus *Streptococcus*. Some studies identified the ratio of faecal coliforms to faecal streptococci as useful for differentiation of human from animal faecal pollution sources [31].

Although it appears that animal gastrointestinal contents and faeces have proportionately more faecal streptococci to faecal coliforms than humans, the ratio is not stable and varies with exposure to natural environments. Differential survival of both enterococcal and streptococcal components of faecal streptococci in aquatic environments will occur and further complicates a straightforward interpretation of faecal streptococcal indicator levels. Source specificity is also an issue with this indicator because some faecal streptococcal strains are associated with non faecal plant, insect, reptile and soil habitats. The presence of these 'atypical' strains in the environment can complicate a straightforward interpretation of the sanitary significance of this group [32].

Recent interest in the Enterococci (a subgroup of faecal streptococci) as an indicator derives from the USEPA adoption of an epidemiological-based *Enterococcus* criterion for recreational marine and fresh waters. Generally, the faecal streptococcal habitat is the intestinal content of both warm and cold blooded animals, including insects. None of the enterococci can be considered as absolutely host specific although some species evidence a degree of host specificity. Although certain genera (e.g. *E. faecalis*, *E. faecium*) have been considered specific to faeces from human or other warm-blooded animals, phenotypically similar strains and biotypes can be isolated from other environmental sources [23].

Strains and biotypes of *E. faecalis* and of *E. faecium* can be isolated from a variety of plant materials, reptiles and insects. Functionally, faecal streptococci as indicators are, in effect, defined on the same operational basis as faecal coliforms. Several media have been suggested for the selective isolation and/or enumeration of the faecal streptococci or the enterococci. Some strains of faecal streptococci from anaerobic environments, for example, initiate growth only in the presence of elevated levels of CO_2 until the cultures have been adapted to an aerobic environment. *E. faecalis* and *E. faecium* are the most common enterococci encountered. This undoubtedly reflects the rationale of employing KF streptococcal agar for the estimation of enterococci in foods. M- Enterococcus agar is used most often for water. Validation of the enterococci as an indicator of public health risk in marine waters will require improved recovery methods [35].

The relative occurrence and densities of non faecal biotypes of *E. faecalis* and *E. faecium* in these waters should be determined. Rapid methods for confirmation of selected enterococcal species, based on serological or biochemical characteristics are needed. A colony hybridization method, employing oligonucleotide probes synthesized for specific sequences of 23S rRNA of selected enterococci, was used successfully to detect and identify *E. faecalis*, *E. faecium* and *E. avium* in mixed culture [36].

Clostridium perfringens

Clostridia are mostly opportunistic pathogens but are also implicated in human diseases such as gas gangrene (*C. perfringens),* tetanus *(C. tetani),* botulism *(C. botulinum*), or acute colitis (*C. difficile*). *Clostridium perfringens* is an anaerobic gram-positive, endospore-forming, rod-shaped, and Sulfite-reducing bacterium found in the colon and represents approximately 0.5 percent of the faecal microflora. It produces spores that are quite resistant to environmental stresses and to disinfection. Since it is a member of the Sulfite reducing clostridia (SRC) group, it is detected in growth media containing Sulfite. It is commonly found in human and animal faeces and in wastewater-contaminated aquatic environments [37].

According to European Union (1998), SRC have been traditionally used as indicators of water quality, and the new European Union (EU) regulations consider more specifically *C. perfringens* as the indicator of choice. The EU standard was set at 0/100 ml of drinking water supply. The hardy spores make this bacterium too resistant to be useful as an indicator organism. It has been suggested, however, to use this microorganism as an indicator of past pollution and as a tracer to follow the fate of pathogens.

Clostridium perfringens was also proposed as a suitable indicator for viruses and protozoan cysts in water treatment plants, *Cryptosporidium parvum* oocysts after mixed-oxidant disinfection and the quality of recreational waters. This bacterium is generally much more resistant to oxidizing agents and to UV than bacterial and phage indicators. It also appears to be a reliable indicator for tracing faecal pollution in the marine environment (e.g. marine sediments impacted by sludge dumping) and survives in sediments for long periods (1 year) after cessation of sludge dumping [38].

Heterotrophic Plate Count

The Heterotrophic Plate Count (HPC) represents the aerobic and facultative anaerobic bacteria that derive their carbon and energy from organic compounds. The number of recovered bacteria depends on medium composition, period of incubation (1–7 days), and temperature of incubation (20–35^{0}C). A low-nutrient medium, R2A or HPCA agar is used to determine bacterial numbers in water distribution systems. Plate counts in R2A medium are higher than those obtained on plate count agar or sheep blood agar. This group includes gram-negative bacteria belonging to the following genera: *Pseudomonas, Aeromonas, Klebsiella, Flavobacterium, Enterobacter, Citrobacter, Serratia, Acinetobacter, Proteus, Alcaligenes, and Moraxella*. Some members of this group are opportunistic pathogens (e.g. *Aeromonas, Flavobacterium*) but little is known about the effects of high numbers of HPC bacteria on human health (Toranzos and McFeters, 1997).

Carter *et al*. (2000) reported that in drinking water, the number of HPC bacteria may vary from 1 to 104 CFU/ml and they are influenced mainly by temperature, presence of residual chlorine and level of utilizable organic matter. Heterotrophic plate count level should not exceed 500 CFU/ml. Heterotrophic plate count is useful to water treatment plant operators with regard to assessing the efficiency of various treatment processes including disinfection in a water treatment plant, monitoring the bacteriological quality of the finished water during storage and distribution, determining bacterial growth on surfaces of materials used in treatment and distribution systems and determining the potential for regrowth or after growth in treated water in distribution systems.

Use of Bacteria as Indicators of Pathogenic Organisms in Water

The detection and enumeration of disease-causing organisms in drinking water is difficult, time consuming and expensive, and for many of the pathogens, methods for their routine monitoring and isolation are nonexistent or the costs for their isolation and enumeration are very prohibitive. It is also impossible and impractical to identify all the enteric pathogenic organisms present in the water at any particular time. Moreover, because of their low densities in surface waters and the absence of pathogenic organisms in tested water samples does not guarantee that the organisms are not present in the water from which samples were collected. It is therefore important to identify harmless organisms that could be used as predictors of the presence of pathogenic organisms in groundwater, surface waters or drinking water (Chao, 2003).

As indicated in Table 1 there are bacteria that are found in the gastrointestinal tracts of humans and other warm-blooded animals and there are used as indicators of the occurrence of some pathogenic organisms in water. These are total coliforms, faecal coliforms, *Escherichia coli*, faecal streptococci, and enterococci. A good type of indicator bacteria should occur naturally and exclusively in the gastrointestinal tract and faeces of humans and other warm-blooded animals. It should enter the water along with faecal materials and should be found in the presence of enteric pathogens. The indicator bacteria should also be able to survive longer than the enteric pathogens with which they occur and be removed by water treatment to the same extent as pathogenic organisms and finally it should be easier to isolate and identify than the enteric pathogens (Stevens *et al*., 2003).

Table 1. Bacteria Commonly Used for Evaluating Water Quality

Type	Habitat	Characteristic	Gram Stain	spore forming
Total Coliforms	In the Gut of Warm-blooded animals, soil, plant matter, and water environment	Rod Shaped, ferment lactose, and produce gas at 37	Gram-ve	no
Faecal coliforms	Mainly in the intestine of warm-blooded animals, some in the soil and plant matter, water environment	Rod-shaped; ferment lactose and produce gas at 44.50C–460C	„	„
E.coli	Mainly in the intestines of warm-blooded animals	Rod-shaped; ferment lactose and produce gas at 44.50C–460C; Urease- negative	„	„
Faecal streptococci	Occur exclusively in the intestine of warm- blooded animals	Cocci Catalase- negative	Gram +ve	„
Enterococci	Occur exclusively in the intestines of warm blooded animals	Cocci Catalase-negative	„	„
Cl.perfringens	Occur in the intestines of warm blooded animals	Rod-Shaped anaerobic	„	yes

Source: WHO (1993).

Physicochemical Water Quality

Nitrate is believed to be the most widely spread groundwater contaminant worldwide, primarily as a result of agricultural activities utilizing fertilizers. Other significant and widely spread anthropogenic sources of groundwater contamination with nitrogen are the disposal of sewage by centralized and individual systems, leaking sewers, animal feeding operations and acid rain (Heathwaite *et al*., 1996).

Nitrate is the most oxidized form of inorganic nitrogen. Nitrogen occurs in groundwater as uncharged gas ammonia (NH_3), which is the most reduced inorganic form, nitrite and nitrate anions (NO_2^- and NO_3^- respectively), in cationic form as ammonium (NH^{+4}) and at intermediate oxidation states as a part of organic solutes. Some other forms such as cyanide (CN^-) may occur in groundwater affected by waste disposal. The three gaseous forms of nitrogen that may exist in groundwater are elemental nitrogen (oxidation state of zero), nitrous oxide (N_2O) and nitric oxide (NO). All three, when dissolved in groundwater, remain uncharged gasses (Rees, 1995).

It is also reported that ammonium cations are strongly adsorbed on mineral surfaces, whereas nitrate is readily transported by groundwater and stable over a considerable range of conditions. The nitrite and organic species are unstable in aerated water and easily oxidized. They are generally considered indicators of pollution by sewage or organic waste. The presence of nitrate or ammonium might be indicative of such pollution as well but generally the pollution would have occurred at a site or time substantially removed from the sampling point. Ammonium and cyanide ions form soluble complexes with some metal ions and certain types of industrial waste effluents may contain such species (Keeney, 2002). Under strongly reducing conditions, such as those in human gut, it transforms to nitrite. Nitrite ions pass from the gut into the blood stream and bond to hemoglobin molecules, converting them to a form that cannot transport oxygen (methemoglobin). Nitrite can also react chemically with amino compounds to form nitrous amides, which are highly carcinogenic. Excessive consumption of nitrate in drinking water has been associated with the risk of methemoglobinemia or "blue baby syndrome," an acute effect that is emphasized under poor sanitary conditions such as sewage contamination or dirty drinking vessels. If left untreated, methemoglobinemia can be fatal for affected infants (Seiler, 1996).

The WHO and the European Union have set the standard for nitrate in drinking water at 11.3 mg/l measured as total nitrogen (mg N/l) that corresponds to 50 mg NO_3^-/l. Extensive application of nitrogen fertilizers has caused an increase in nitrate concentrations over large agricultural areas. As a worldwide average, pristine water contain nitrate at approximately 0.1 mg N/l. This is extremely low compared to typical modern groundwater concentrations (Buss *et al*., 2005).

Nitrogen oxides, present in the atmosphere due to the combustion of fossil fuels, undergo various chemical alterations that produce H^+ and finally leave the nitrogen as nitrate. These processes can lower the pH of rain in the same way Sulphur oxides do. None industrially impacted rain may have a total nitrogen concentration of about 6 mg/l. Industrially impacted rain may have a nitrogen concentration higher than 6 mg/l, resulting in higher nitrogen load to the subsurface. To avoid contamination problems in an area, treated sewage effluent can be removed from a basin and discharged elsewhere if wastewater treatment is centralized. Unfortunately, removal is not possible with on-site septic systems and even properly designed and constructed on-site septic systems frequently cause nitrate concentrations to exceed the MCL in the underlying groundwater (Wilhelm *et al*., 1994).

Wilhelm *et al*. (1994) also reported that nitrate concentrations in the effluent below a septic field can be two to seven times the MCL and distinct plumes of nitrate-contaminated groundwater may extend from the septic system. The amount of nitrate from animal wastes that percolates to the groundwater depends on the amount of nitrate formed from the wastes, the infiltration rate and frequency of manure removal, the animal density, the soil texture and the ambient temperature. The decay of natural organic material in the ground can contribute substantial amounts of nitrogen to groundwater. The stable isotope composition of nitrate is known to be indicative of its source and can also be used to indicate that biological denitrification is occurring (Seiler, 1996).

Biochemical Oxygen Demand

The biochemical oxygen demand (BOD) is an empirical test in which standardized laboratory procedures are used to estimate the relative oxygen requirements of drinking water, wastewater, effluents and polluted water. Microorganisms use the atmospheric oxygen dissolved in the water for biochemical oxidation of organic matter, which is their source of carbon. The BOD is used as an approximate measure of the amount of biochemically degradable organic matter present in a sample. The 5- day incubation period has been accepted as the standard method for this test. The BOD test was originally devised by the United Kingdom Royal Commission on Sewage Disposal as a means of assessing the rate of biochemical oxidation that would occur in a natural water body to which a polluting effluent was discharged [26].

As determined experimentally by incubation in the dark, BOD includes oxygen consumed by the respiration of algae. The polluting effect of an effluent on a water body may be considerably altered by the photosynthetic action of plants and algae present but it is impossible to determine this effect quantitatively in 5-day BOD experiments. Consequently, no general ruling can be given on the BOD of samples containing algae (Lester and Birkett, 1999). A further complication in the BOD test is that much of the oxygen consuming capacity of samples may be due to ammonia and organically bound nitrogen, which will eventually be oxidized to nitrite and nitrate if nitrifying bacteria are present. Furthermore, the ammonia added in the dilution water used for the method may also be nitrified so that, the BOD value is not representative of the sample alone. Nitrifying bacteria are extremely sensitive to trace elements that may be present and the occurrence of nitrification is sporadic and unpredictable even with samples known to contain nitrifying bacteria. Moreover, because of the slow growth of nitrifying bacteria, the degree of nitrification will depend on the number of these organisms initially present. Nitrification does not occur to any detectable extent during the 5-day BOD determination of crude and settled sewage and almost all industrial effluents. The BOD test is thus useful for determining the relative waste loadings to treatment plants and the degree of oxygen demand removal provided by primary treatment (Ademoroti, 1996).

The BOD determined by the dilution method has come to be used as an approximate measure of the amount of biochemically degradable organic matter in a sample. For this purpose the dilution test, applied skilfully to samples in which nitrification does not occur, remains probably the most suitable single test. For certain industrial wastes and for waters polluted by them, it may be advisable to determine the oxidation curve obtained. Calculations of ultimate BOD from 5-day BOD values (e.g. based on calculations using exponential first-order rate expressions) are not correct. Conversion of data from one incubation period to another can be made only if the course of the oxidation curve has been determined for the individual case by a series of BOD tests carried out for different incubation periods. The dissolved oxygen content of the liquid is determined before and after incubation for 5 days at 20 °C. The difference gives the BOD of the sample after allowance has been made for the dilution, if any, of the sample (APHA, 1998).

Dissolved Oxygen

Dissolved oxygen is the oxygen gas dissolved in water. Dissolved oxygen is oxygen gas that is entrained in the water as a result of water mixing with air containing oxygen. Different types of water bodies contain different amounts of dissolved oxygen. A fast-flowing river usually contains more dissolved oxygen than a slow-moving one because it mixes rapidly with air containing oxygen while moving over rocks, logs and debris in the stream. The highest concentration of oxygen is found in the water stretches where the greatest amount of mixing occurs. Slow-moving rivers have less oxygen in them because they do not mix as rapidly with the air as they meander along. Almost all water bodies contain dissolved oxygen regardless of their turbulence. Even a still lake contains oxygen because oxygen from the atmosphere will dissolve on its surface. The transfer of oxygen from the atmosphere to the surface of a lake or any other water body is increased by the mixing action of wind and waves. Dissolved oxygen is an important element in water because most aquatic organisms use it for respiration (Chapman, 1996).

Phosphates

Phosphates commonly occur in natural water and are often added in water treatment chemicals. Excessive amount of phosphate actually constitute pollution usually by infiltration of waste water from domestic and industrial sources or agricultural runoff phosphate derived from detergent, hardness treatment. Phosphorus is often the limiting nutrient for growth of organisms in water and too much phosphate can lead to rapid eutrophication especially in lakes, reservoirs and ponds where other nutrients such as nitrate may be present. Such rapid growth in hot climate where the dissolved oxygen in water is already low can create problem of taste and odour [28].

Fluoride in Water

Fluoride is found in all natural waters at some concentration. Seawater typically contains about 1mg /l while rivers and lakes generally exhibit concentrations of less than 0.5 mg /l. In ground waters, however, low or high concentrations of fluoride can occur, depending on the nature of the rocks and the occurrence of fluoride-bearing minerals. Concentrations in water are limited by fluorite solubility, so that in the presence of 40 mg /1 of calcium it should be limited to 3.1 mg /1 (Hem, 1999).

It is the absence of calcium in solution which allows higher concentrations to be stable. High fluoride concentrations may therefore be expected in ground waters from calcium-poor aquifers and in areas where fluoride-bearing minerals are common. Fluoride concentrations may also increase in ground waters in which cation exchange of sodium for calcium occurs. fluorosis has been described as an endemic disease of tropical climates but this is not entirely the case. Waters with high fluoride concentrations occur in large and extensive geographical belts associated with sediments of marine origin in mountainous areas, volcanic rocks and granitic and gneissic rocks (Edmunds and Smedley, 1996).

The most well-known and documented area associated with volcanic activity follows the East African Rift system from the Jordan valley down through Sudan, Ethiopia, Uganda, Kenya and the United Republic of Tanzania. Many of the lakes of the Rift Valley system, especially the soda lakes, have extremely high fluoride concentrations; 1,640 mg/1 and 2,800 mg/1 respectively, in the Kenyan Lakes Elmentaita and Nakuru and up to 690 mg/1 in the Tanzanian Momella soda lakes. In Kenya also a detailed survey of fluoride in groundwater was undertaken (Nair *et al*., 1996).

Of over 1,000 groundwater samples taken nationally in Kenya, 61 per cent exceeded 1 mg/1, almost 20 per cent exceeded 5 mg/1 and 12 per cent exceeded 8 mg/1. The volcanic areas of the Nairobi, Rift Valley and Central Provinces had the highest concentrations, with maximum groundwater fluoride concentrations reaching 30–50 mg/1. Most of the sampled wells and boreholes were providing drinking-water and the prevalence of dental fluorosis in the most affected areas was observed to be very high. A similar picture emerges for the United Republic of Tanzania, where 30 per cent of water used for drinking exceeded 1.5 mg/1 fluoride with concentrations in the Rift Valley of up to 45 mg/1(Manji and Kapila, 1996).

Sulphates

Sulphates occur naturally in groundwater with variation in levels. At high levels, sulphate can give water a bitter or astringent taste and can have laxative effects. As water moves through soil and rock formations that contain sulphate minerals, some of the sulphates dissolve into the groundwater. Minerals that contain sulphates include magnesium sulphates (Epsom salt), sodium sulphate (Glauber's salt) and calcium sulphate (gypsum). The level of Sulphate in most groundwater is less than 250 milligrams per litre (mg/L). But sulphates occur at higher levels, which sometimes can exceed 1000 mg/L, in areas where the above minerals deposit at higher concentration. People unaccustomed to drinking water with elevated levels of sulphate can experience diarrhoea and dehydration. Infants are often more sensitive to sulphate than adults. Animals are also sensitive to high levels of sulphate. In young animals, high levels may be associated with severe, chronic diarrhoea and in few instances, death. Diluting water high in Sulphate with water low in sulphate can help to avoid problems of diarrhoea and dehydration in young animals. High sulphate levels may also corrode plumbing, particularly copper piping. In areas with high sulphate levels, plumbing materials more resistant to corrosion, such as plastic pipe, are commonly used. In developing countries drinking water containing high sulphate can contribute to problem of sewer corrosion and related health hazards (Hutton, 1996).

Physical Water Quality

Total Dissolved Solids (TDS)

The term "total dissolved solids" (TDS) refers to the total amount of all inorganic and organic substances including minerals, salts, metals, cations or anions that are dispersed within a volume of water. In general, TDS is the sum of the cations and anions in water. Ions and ionic compounds making up TDS usually include carbonate, bicarbonate, chloride, fluoride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, and potassium, but any ion that is present will contribute to the total. The organic ions include pollutants, herbicides and hydrocarbons. In addition, soil organic matter compounds such as humic/fulvic acids are also included in TDS. By definition, the solids must be small enough to be filtered through a sieve measuring 2 micrometers. TDS concentrations are used to evaluate the quality of freshwater systems. TDS concentrations are equal to the sum of positively charged ions (cations) and negatively charged ions (anions) in the water. Sources for TDS include agricultural run-off, urban run-off, industrial wastewater, sewage and natural sources such as leaves, silt, plankton and rocks. Piping or plumbing may also release metals into the water (APHA, 1998).

While TDS is not considered as a primary pollutant, high TDS levels typically indicate hard water and may lead to scale build up in pipes, reduced efficiency of water filters, hot water heaters, etc., and aesthetic problems such as a bitter or salty taste. Drinking water needs treatment when TDS concentrations exceed 500 mg/L, or 500 parts per million (ppm) [4].

The TDS concentration is considered a Secondary Drinking Water Standard, which means that it is not a health hazard. The palatability of water with a TDS level of less than 600 mg/L is generally considered to be good; drinking water becomes significantly unpalatable at TDS levels greater than 1000 mg/L. However, further testing may be warranted, as water with a high TDS concentration may indicate elevated levels of ions that do pose a health concern, such as aluminum, arsenic, copper, lead, nitrate and others [27].

A conductivity test provides an estimate of TDS concentration levels. EC in micro Siemens per centimeter (μs/cm) usually ranges from 1 to 2 times the TDS in mg/L. Higher TDS concentrations may follow significant rain events. Treatment options depend on the nature of the cations and anions present in the water. For example, a water softener can reduce problems associated with calcium, magnesium, and iron. A reverse osmosis system or distillation unit may be recommended to treat elevated TDS levels associated with high levels of sodium or potassium. Groundwater with high TDS may be too saline to be accepted by users; when drilling new wells salinity should be tested as early as possible, and certainly before well completion. Sodium and chloride are principal components of TDS, and either ion can give water an unpleasantly salty taste at concentrations above 200-300 mg/L, depending on the associated counter ion [26,27].

pH

The pH level of drinking water reflects how acidic it is. pH stands for “potential hydrogen,” referring to the amount of hydrogen mixed with the water. pH is measured on a scale that runs from 0-14. Seven is neutral, indicating there is no acid or alkalinity present. A measurement below 7 indicates that acid is present and a measurement above 7 indicates alkalinity. The normal range for pH in ground water lies between 6 and 8.5 [28].

By comparison, vinegar measures pH of 3, beer measures between 4 and 5, while the pH in milk measures ranges from 6.4 to 6.8. Water with a low pH can be acidic, soft and corrosive. This water can leach metals from pipes and fixtures, such as copper, iron, lead, manganese and zinc. It can also cause damage to metal pipes and aesthetic problems, such as a metallic or sour taste, laundry staining or blue-green stains in sinks and drains [11].

Water that contains elevated levels of toxic metals could also show a low pH level. Drinking water with a pH level above 8.5 could indicate that the water is hard. Hardness does not pose a health risk, but can cause aesthetic problems, such as an alkali taste to the water that makes coffee taste bitter; build-up of scale on pipes and fixtures than can lead to lower water pressure; build-up of deposits on dishes, utensils and laundry basins; difficulty in getting soap and detergent to foam; and lowered efficiency of electric water heaters. The U.S. Environmental Protection Agency (EPA) does not regulate the pH level in drinking water. It is classified as a secondary drinking water contaminant whose impact is considered aesthetic. However, the EPA and WHO recommends that public water systems maintain pH levels of between 6.5 and 8.5, a good guide for individual well owners (Obasi and Balogun, 2006).

Turbidity

Turbidity in water is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds, planktons and other microscopic organisms. Turbidity measurements relate to the optical property of water that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. The total intensity and angular distribution of light scattered from turbid waters represent the overall effects of intra-particle and inter-particle interactions and depend, in a complex manner, on such factors as the number, size, shape and refractive index of the foreign particles and the wavelength of the incident light. Large particles, with diameters greater than about 10 times the wavelength of the incident light, show predominantly forward scattering of the incident light. The degree of symmetry of scattered light is a function of particle shape, particle size and the refractive index change across the particle/liquid interface. The shorter the wavelength of the

incident light, the greater the scattering observed; indeed, for the smaller particles, there is an approximately 15-fold change of turbidity within the wavelength range of visible light (Chan *et al.*, 2007).
Several methods may be used in the measurement of water turbidity, but only two of these, Nephelometry and Turbidometry, form the basis for present standard methods. Historically, turbidity has been measured in wastewater and drinking water using the Jackson Candle Turbidometer. Turbidity can be considered as indirect indicator for the presence of microbes [11].
A Jackson Turbidity Unit (JTU) is an empirical measure of turbidity based on the depth of a sample water column that is just sufficient to extinguish the image of a burning standard candle observed vertically through the sample. A depth of 21.5 cm corresponds to 100 JTU. The Jackson Candle Turbidometer is applicable only to turbidities greater than 25 JTU and, as such, has limited applicability to the monitoring of drinking water. Improved instruments that use electrical light sources and mirror optics, such as the Patterson Turbidometer can measure lower values. The current method of choice for turbidity measurement, in both Canada and the United States, is the Nephelometric method. Nephelometric Turbidometers measure the intensity of light scattered at90° to the path of the incident light [4].

Electrical Conductivity (EC)

Electrical conductivity is the capacity of water to conduct current and is caused by the presence of salts, acids and bases, called electrolytes, capable of producing cations and anions. The major ions present in water causing EC are chlorides, sulphates, carbonates and bicarbonates, nitrates, calcium, magnesium, sodium and potassium. As the conductivity is directly related to the presence of dissolved salts, its magnitude can give a fair idea of the levels of dissolved solids. Changes in conductivity over time may indicate changing water quality and with its values the salinity (the amount of total soluble salts or the total dissolved solids of water extract) in water can be obtained. With regards to acceptable results, there is no health standard. Sources of conductivity may be natural or manmade dissolved substances [34].

Temperature

In the analysis of the physicochemical quality of water samples, temperature is considered as a critical parameter. It has an impact on many reactions including the rate of disinfectant decay and by-product formation (Volk *et al*., 2002). As the water temperature increases, the disinfectant demand and by product formation, nitrification, microbial activity, algal growth, taste and odour episodes, lead and copper solubility increases. Moreover, calcium carbonate ($CaCO_3$) precipitation also increases [11]. An aesthetic objective is set for maximum water temperature to aid in selection of the best water source or the best placement for a water intake. It is desirable that the temperature of drinking water should not exceed 15^0C because the palatability of water is enhanced by its coolness. In addition to cool water tasting better than warm water, temperatures above 15^0C can speed up the growth of nuisance organisms such as algae which can intensify taste, odour, and colour problems. Temperature also affects water treatment (TID, 2000). If nutrients are available, the microbial activity (as measured by hetero plate count) increases significantly at water temperatures above 15^0C in the absence of a disinfectant residual (WSTB, 2005).
Therefore, water supplies generally tend to keep the temperature as low as possible in order to minimize the growth of bacteria. Keeping the temperature low reduces the risk for pathogenic proliferation and survival since the optimal temperature for most pathogens is close to the human body temperature (Boehansen, 2002).

RECOMMENDATIONS

The following recommendations are forwarded in view of the findings of this present study.

1. The drinking water quality indicator bacterial counts except *Cl. perfringens* and HPC were above the standards set for human drinking purpose. So, basic and proper sanitation and management of bore holes in the city has to be employed to ensure safe water provision for the community.
2. The positive results of the indicator organisms may indicate that there were improper and poor waste disposal practices and poor dumping of wastes as well as poor sanitation and management of bore holes. Therefore, there is a need to manage catchment areas around the bore wells and ground water well fields.
3. The increase in chemical indicators revealed that bore holes were contaminated by either naturally through the aquifer or due to intrusion of certain chemicals such as agricultural fertilizers. So, effective quality assessment program and management should be employed to minimize the impact of these increasing chemical contaminants on human health.
4. The assessment of the sanitary and management of bore holes in the city showed that unhygienic practices around the bore holes, human activities near bore holes like unwise waste disposal and fertilizer application on farms in the well field areas as well as some cracks and leaks might be the causes of positive bacterial counts and increased chemical contaminants.

Proper sanitation, management, regular monitoring and maintenance of bore holes should be carried out.

5. Regular drinking water quality assessment from the source, reservoirs, distribution systems and pipes should be employed to ensure that the water is safe for human use.

REFERENCES

1. Hirsch, R.M., P.A. Hamilton and T.L. Miller. 2006. U.S. Geological Survey perspective on water-quality monitoring and assessment. *Journal of Environmental Monitoring.* 8:512-518.
2. Goel, P.K., 2006. Water pollution. Causes, Effects and Control. 2nd edition. pp. 354. Y.C. College of Science, Vidyanaga, Maharashtra
3. Payment, P., M. Waite and A. Dufour, 2005. Introducing parameters for the assessment of drinking water quality. In: Assessing microbial safety of drinking water, Improving approaches and methods. IWA Publishing, London, UK, pp. 47-77
4. United Nations Children's Fund (UNICEF) and World Health Organization (WHO) Joint Monitoring Programme for Water Supply and Sanitation, 2004. Meeting the MDG Drinking Water and Sanitation Target, A Mid-Term Assessment of Progress. New York, NY: WHO and UNICEF
5. World Health Organization (WHO), 2004. Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe drinking Water. Edited by Mark W LeChevallier and Kwok-Keung Au. ISBN:184339 069 8. IWA, London, UK. World Health Organization. PP: 1-12
6. World Health Organization (WHO), 1993. Water and sanitation: WHO fact sheet no. 112, World Health Organization, Geneva
7. Hunter, P.R., J.M. Colford., M.W. LeChevallier., S. Binder and P.S. Berger, 2000. Waterborne Diseases Panel Summary from the 2000 Emerging Infectious Diseases Conference in Atlanta, Georgia. *Emerging Infectious Diseases Journal*. 7(3): 544-545
8. World Health Organization (WHO), 1997. Guidelines for drinking water quality, surveillance and control of community water supplies. Vol.III, 2nd edition. GenevaWorld Health Organization (WHO), 2002. Global water supply and sanitation assessment 2000 Report, Geneva
9. Pruss, A., D. Kay., L. Fewtrell and J. Bartram, 2002. Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives.* 110(5): 537–542
10. Fewtrell, L., A. Pruss-Ustun., R. Bos., F. Gore and J. Bartram, 2005. Water, sanitation and hygiene quantifying the health impacts at national and local level in countries with incomplete water supply and sanitation coverage. Geneva, World Health Organization. Environmental Burden of Disease Series No. 15.
11. World Health Organization (WHO), 1996. Guidelines for Drinking Water Quality (Health Criteria and Other Supporting Information, Vol. II, 2nd ed., World Health Organization, Geneva
12. World Health Organization (WHO), 2006. Guidelines for Drinking-Water Quality. Third edition incorporating first addendum. Vol. 1, Recommendations. Geneva.
13. Ministry of Health (MOH), 2007. Need Assessment to achieve Universal Access to Improved Sanitation and Hygiene, Unpublished Document, Addis Ababa, Ethiopia.
14. Howard, G., M. Ince and M. Smith, 2003. Rapid assessment of drinking water quality: a hand book for implementation joint monitoring for water supply and sanitation. WEDC, Loughborough University. ISBN184380 042. 1-87 p.
15. Tamiru Alemayehu, Dagnachew Legesse, Tenalem Ayenew, Yirga Tadesse, Solomon Waltenigus and Nuru Mohammed, 2005. Hydrogeology, Water Quality and the Degree of Groundwater Vulnerability to Pollution in Addis Ababa, Ethiopia. P.125. Addis Ababa university printing press , Addis Ababa ,Ethiopia
16. Mengistayehu Birhanu, 2007. Assessment of Physicochemical and Microbiological Quality of Rural Drinking Water Supply at the Sources and selected Communities of Akaki- Kality Sub-City, Addis Ababa City Administration. M.Sc Thesis. Addis Ababa University, Addis Ababa
17. Fewtrell, L., R. B. Kaufmann., D. Kay., W. Enanoria., L. Haller and J. M. Colford, 2007. Water, sanitation, and Hygiene Interventions to Reduce Diarrhea in Less Developed Countries: a Systematic Review and Meta-Analysis. Lancet Infect Dis. 5: 42-54
18. Clasen, T., L. Smith., J. Albert., A. Bastable and J. F. Fesselet, 2006. The drinking water response to the Indian Ocean tsunami including the role of household water treatment. Disaster Prevention and Management. *African Journal of tropical medice.* 15(1): 190-201.
19. Curtis, V., S. Cairncross and R. Yonli, 2000. Domestic Hygiene and Diarrhea: Pinpointing the Problem. *Journal of Tropical Medicine and International Health, 5(1): 22-3*
20. Brown, J., 2003. Evaluation of Point-of-Use Microfiltration for Drinking Water Treatment in Bolivia. Cambridge University press, London. 234p.
21. Neumann, I., S.Brown., P.Smedley., T. Besien., A.R. Lawrence., R. Hargreaves., A.E. Milodowski and M. Barron, 2003. Baseline Report Series: 7. The Great Inferior base line of the Cotswolds District. British Geological Survey and EnvironmentAgency, Keyworth, Nottingham. 62 p
22. Donnison, A.M., C.M. Ross and J.M .Russell, 1999. Quality control of bacterial enumeration. *Appl. Environ. Microbiol.* 59: 922–923
23. Foster, S.S.D., 2000. Assessing and controlling the impacts of agriculture on groundwater from barley barons to beef bans. *Quarterly Journal of Engineering Geology and Hydrogeology*. 33: 263–280

24. Meylan,W.M., 2004. Finding and estimating chemical property data for environmental assessment. *Journal of Environmental Toxicology and Chemistry*. 23: 22–23
25. Hooda, P.S., A.C. Edwards., H.A. Anderson and A. Miller, 2000. A review of water quality concerns in livestock farming areas. *Sci. Total Environ*. 250: 143–167
26. World Health Organization (WHO), 2005. Monitoring Bathing Waters -A Practical Guide to the Design and Implementation of Assessments and Monitoring Program. Sanitary Inspection and Microbiological Water Quality. Edited by Jamie Bartram and Gareth Rees, ISBN 0-419-24390-1. World Health Organization, Geneva. PP: 106-157.
27. World Health Organization (WHO), 1992. Our Planet, our Health: Report of the WHO Commission on Health and Environment, Geneva, World Health Organization
28. World Health Organization (WHO), 1994. Drinking water quality control in small community supplies Vol. II. Geneva
29. Leclerc, H., L. Schwartzbrod and E. Dei-Cas, 2002. Microbial agents associated with waterborne diseases. *Critical Reviews in Microbiology,* 28: 371–409
30. World Health Organization (WHO), 1995. Community Water Supply and Sanitation: Needs, Challenges and Health Objectives. 48thWorld Health Assembly, April 28, Geneva, Switzerland.
31. Geldreich, E.E., B.A. Kenner and P.W. Kabler, 1999. Occurrence of coliforms, faecal coliforms, and streptococci on streams and pond water. *J. Appl. Microbiol.* 12: 63–69
32. APHA.,1989. Standard Methods for the Examination of Water and Wastewater 17th Edition. Part 9000 Microbiological Examination. American Public Health Association, Washington, D.C. PP: 1-140.
33. Slaats,P.G.,G.Rosenthal.,L.P.M.Seiger.,W.G.Boomen.,M.Beuken and R.H.S.Vreeburg, 2002. Process involved in generation of dissolved water. Report no.KOA02.058.American water works association research foundation/Kiwa, the Netherlands
34. Facklam, R.R. and M.D. Collins, 1990. Identification of *Enterococcus* species isolated from human infections by a conventional test scheme. *J. Clin. Microbiol.* 27:731–734
35. Betzl, D., W.Ludwig and K.H. Schleifer, 1990. Identification of *Lactococci* and *Enterococci* by colony hydridization with 23S rRNA-targeted oligonucleotide probes. J. *Appl. Environ. Microbiol*. 56, 2927–2929
36. Ademoroti, C.M.A., 1996. Standard method for water and Effluents Analysis. Foludex press Ltd, Ibadan. pp.22-23
37. AAWSA, 2008, Bacteriological and physicochemical analysis of newly drilled ground water wells of the Addis Ababa city. A report of ground water quality analysis. Addis Ababa, Ethiopia.pp:35-46.
38. American Water Works Association (AWWA). 2000. Introduction to water quality analysis, Colorado, USA. V.4 pp. 23-39 and 81-104
39. BoeHansen, R., 2002. Microbial growth in drinking water distribution systems. Environment and resources, Danish Academy of Technical Sciences. *Journal of Water Supply, Research and Technology*, 51 (7): 399-406
40. Buss, S.R., M.O. Rivett., P. Morgan and C.D. Bemment, 2005. Attenuation of nitrate in the sub-surface environment. Science Report SC030155/SR2, Environment Agency, Bristol, England, 100 p.
41. Carter, J.T., E.W. Rice., S.G. Buchberger and Y. Lee, 2000. Relationships between levels of heterotrophic bacteria and water quality parameters in a drinking water distribution system. *In. J. Water Res*. 34: 1495–1502.
42. Chan, C.L., M.K. Zalifah and A.S. Norrakiah, 2007. Micrbiological and Physicochemical Quality of drinking water. *The Malaysian Journal of Analytical Sciences*. 11(2): 414 – 420
43. Chao, W.L., 2003. Suitability of the traditional microbial indicators and their enumerating methods in the assessment of fecal pollution of subtropical freshwater environments. *Tropical J. Microbiol. Immunol. and Infectious disease*. 36: 288–293.
44. Chapman, p., 1996. Water Quality Assessment. A Guide to the use of Biotic, Sediments and Water in Environmental Monitoring 2nd.ed., Oxford University Press, London.345p.
45. Clasen, T.F., and S. Cairncross, 2004. Household water management: Refining the dominant paradigm. *Journal of Tropical Medicine and International Health*. 9:187-191
46. Edmunds, W.M. and P.L. Smedley, 1996. Groundwater geochemistry and health: an overview. Vol. 113, 91–105. In: Appleton, Fuge and McCall (Eds). Environmental Geochemistry and Health. Geological Society Special Publication, Orlando, Florida.
47. Heathwaite, A.L., P.J. Johnes and N.E. Peters, 1996. Trends in nutrients. Hydrological Processes. 10: 263–293.
48. Hem, J.D., 1999. Study and Interpretation of the Chemical Characteristics of Natural Water. Water Supply Paper 2254, 3rd edition, US Geological Survey, Washington, D.C. 263 pp.
49. Howard, G., 2002. Water Supply Surveillance: a reference manual, WEDC and RCPEH, Loughborough University, UK. *http// www.national academies.org (*Accessed on January 2011)
50. Hutton, G., 1996. Field water sampling techniques for developing countries. *Int. J. drinking water quality analysis*. 6(4):45-47
51. ISO 10359-1, 1992. Water Quality, Determination of Fluoride-part 1: Direct Potentiometric method (Electrochemical probe methods) for potable and lightly polluted water. International Standards Organisation
52. Keeney, D., 2002. Sources of nitrate to ground water. *Critical Reviews in Environmental Control*. 16: 257–304
53. Lester, J. N and J. W. Birkett., 1999. Microbiology and Chemistry for Environmental Scientists and Engineers. pp.453. In: Microbiological and Chemical water quality assessment (2nd edn). New York.
54. Moe, C.L., 1997. Waterborne transmission of infectious agents, In: guide line of Environmental Microbiology, pp. 136–152.

55. Nair, K.R., F. Manji, and J.N. Gitonga, 1996. The occurrence and distribution of fluoride in ground waters of Kenya. In: Challenges in African Hydrology and Water Resources, Proceedings of the Harare Symposium, IAHS Publ. 144: 75–86
56. Obasi, R. A and O. Balogun, 2006. Water quality and Environmental impact assessment of water resources in Nigeria. *African Journal of Environmental Studies. 2(2)*: 228 – 231
57. Rees,T.F., 1995. Geo-hydrology, water quality, and nitrogen geochemistry in the saturated and unsaturated zones beneath various land uses, Riverside and San Bernardino Counties, California, 1991–93. U.S. Geological Survey Water-Resources Investigations Report 94-4127, Sacramento, CA, 267 p.
58. Seiler, R.L., 1996. Methods for identifying sources of nitrogen contamination of ground water in valleys inWashoe County, Nevada. U.S. Geological Survey Open-File Report 96-461, Carson City, 20 p.
59. Stevens, M., N. Ashbolt and D. Cunliffe, 2003. Recommendations to change the use of coliforms as microbial indicators of drinking water quality. National Health and Medical Research Council, Australian Government. 42pp
60. Toranzos, G. A., 1991. Current and Possible Alternate Indicators of Fecal Contamination in Tropical Waters: A Short Review. *Env. Tox. & Water Quality*. 6:121-130
61. Venczel, L.V., M. Arrowood., M. Hurd and M.D. Sobsey, 1997. Inactivation of Cryptosporidium parvum oocysts by a mixed-oxidant disinfectant and by free chlorine. *J Appl. Environ. Microbiol*. 63: 1598–1601
62. Volk, C.J., R. Hofmann., C.Chauret., G.A. Gagnon., G. Ranger and R.C.Andrews, 2002. Implementation of chlorine dioxide disinfection: Effects of the treatment change on drinking water quality in a full-scale distribution system. *J. Environ. Eng.Sci*.1:323–330.
63. Wilhelm, S.R., Schiff, S.L., and J.A. Cherry, 1994. Biogeochemical evolution of domestic waste water in septic systems, Pt. 1, Conceptual model. *Ground Water*, vol. 32, no. 6, pp. 905–916

CITE THIS ARTICLE

Desalegn Amenu. Bacteriological and Physicochemical Quality of Well Water Sources .Res. J. Chem. Env. Sci. Vol 2 [5] October 2014. 13-27

