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Safe Drinking Water: Concepts, Benefits, Principles and Standards

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Additional information is available at the end of the chapter

Abstract

Water is connected to every forms of life on earth. As a criteria, an adequate, reliable, clean, accessible, acceptable and safe drinking water supply has to be available for various users. The United Nation (UN) and other countries declared access to safe drinking water as a fundamental human right, and an essential step towards improving living standards. Access to water was one of the main goal of Millinium Development Goals (UN-MDGs) and it is also one of the main goal of the Sustainable Development Goals (SDGs). The UN-SDG goal 6 states that *"Water sustains life, but safe clean drinking water defines civilization"*. Despite these facts, there are inequalities in access to safe drinking water in the world. In some countries, sufficient freshwater is not available (*physical scarcity*); while in other countries, abundant freshwater is available, but it is expensive to use (*economic scarcity*). The other challenge is the increasing population of the world at an alarming rate, while the available freshwater resources almost remains constant. This chapter presents aspects of safe drinking water - background information, definition of water safety and access, benefits, principles and regulations, factors challenging the sustainable water supply and water quality standards and parameters.

Keywords: accessibility, inequalities, quality standards, safe water, water uses

1. Introduction

Water covers more than two-thirds of the earth's surface, but mostly salty and undrinkable. The available freshwater resource is only 2.7% of the available water on earth but only 1% of the available freshwater (in lakes, rivers and groundwater) is accessible. Most of the available freshwater resources are inaccessible because they are in the hidden part of the hydrologic cycles (deep aquifers) and in glaciers (frozen in the polar ice), which means safe drinkable water on earth has very small proportion (~3%) in the freshwater resources. Freshwater can

also be obtained from the seawater by desalinization process. In some countries, sufficient freshwater is not available (*physical scarcity*). In some countries, abundant freshwater is available, but it is expensive to use (*economic scarcity*).

South Africa receives about 450 mm annual rainfall and is classified as a water-stressed country [1, 2]. The available freshwater resource can sustain 80 million people only. Some African countries (Ethiopia, Congo and Papua New Guinea) have excess freshwater resources, but they are having water shortage due to economic reasons. Ethiopia, the second populous countries in Africa, is the water tower of east Africa due to the availability of abundant water (nine major river basins). However, the country is among the few countries in the world affected by chronic water problem. The water scarcity in the world is further aggravated by the reduced water quantity (or an increased water demands) due to population growth and the declining of water quality by pollution.

As a criterion, an adequate, clean and safe drinking water supply has to be available for various users [3]. There is no universally accepted definition of "safe drinking water." Safe drinking water is defined as the water that does not represent any significant risk to health over a lifetime of consumption [4]. The safe drinking water must be delivered that is pure, wholesome, healthful and potable. Safe water is not necessarily pure, it has some impurities in it. It contains some traces of salts such as magnesium, calcium, carbonates, bicarbonates and others. The degree of purity and safety is a relative term and debatable. Clean/pure water has no minerals and it only contains H and O. According to the Monitoring organizations under the supervision of the Joint Monitoring Programme (JMP), "safe drinking water" is defined as water from an "improved water source," which includes household connections, public standpipes, boreholes, protected dug wells, protected springs and rainwater collections. According to the same organization, "access to safe drinking water" is defined as the availability of at least 20 l per person per day from an "improved" source within 1 km of the user's dwelling.

Safe drinking (potable) water is the water that can be delivered to the user and is safe for drinking, food preparation, personal hygiene and washing [3]. The water must meet the required (chemical, biological and physical) quality standards at the point of supply to the users [5]. Therefore, safe drinking water is a relative term, which depends on the standards and guidelines of a country; the standards set for the different quality parameters are different. The standard of WHO is not exactly the same as that of USA, Canada, European Commission, Russia, India, South Africa, Ethiopia, and so on. The term "safe" depends on the particular resistance ability of an individual. Water that is safe for drinking in some African countries might not be safe in European countries. Some African countries already developed resistance to some of the water-related diseases.

Safe drinking water is anonymously accepted as an international agenda and priority, which is evident from the MDGs and SDGs of the United Nations (UN) initiative and vision (MDGs 7 and SDGs 6). Despite the MDGs effort, still many people lack access to safe drinking water, even lack access to basic water. Globally, more than 1 billion people do not have access to safe drinking water. According to the Third World Academy of Sciences (TWAS) report [6], contaminated/dirty water is killing more people than cancer, AIDS, wars or accidents. Population of the world is increasing and the available freshwater resources almost remain constant.

The number of people without access to safe drinking water is increasing. This is mostly related to the ever-increasing population growth in the developing countries and the inability (or unwillingness) of governments (local and national) to provide adequate water supply facilities in these countries [7].

2. Drinking water safety and access

2.1. Access to safe drinking water

Water is connected to every form of life on earth and is the basic human need, equally important as air. Water is connected to every aspect of human day-to-day activities directly or indirectly. At a basic level, everyone needs access to safe water in adequate quantities for drinking, cooking, personal hygiene and sanitation facilities that do not compromise health or dignity. Therefore, access to safe and dependable (clean and fresh) water is the fundamental/basic right of humans [8]. The UN and other countries declared that access to clean, safe drinking water is a basic human right, and an essential step toward improving living standards worldwide. Access to water was one of the main goals of UN-MDGs and it is also one of the main goals of the UN-SDGs. The South African constitution declares "*access to water and food for all*" as the main goal in the constitution following the 1998 National Water Act [9]. Despite these facts, still there are inequalities in access to safe drinking water in South Africa and in the world, the problem has more impacts on the poor, women and children. There are also inequalities within and among nations [6]. For instance, the population with access to safe drinking water in Congo was 77% for rural dwellers and 17% for rural dwellers by the year 2002 [6]. Inequalities in access to water and sanitation are morally unacceptable, but they are prohibited under international law [3].

Globally, it is estimated that 89% of people have access to water suitable for drinking [10]. According to UNDP [11] report, one out of six people do not have access to clean water, that is, about 1.1 billion people lack access to safe drinking water. In some countries, especially in Africa, almost half of the population do not have access to safe drinking water and hence, is afflicted with poor health [12]. The number of people without safe drinking water is more than the number reported by UNDP [11]. This is due to the fact that most of the water supply facilities initiated during the MDGs in developing countries are not functioning properly.

2.2. Benefits of safe drinking water

Water of satisfactory quality is the fundamental indicator of health and well-being of a society and hence, crucial for the development of a country. Contaminated water not only has the potential to pose immediate threat to human, but also can affect an individual productive rate [13]. According to the WHO [14] report, an estimated 1.1 billion people in the world drink unsafe water. Approximately 3.1% of the global annual death (1.7 million) and 3.7% of the annual burden (disability) (54.2 million) are caused by the use of unsafe water and lack of basic sanitation and hygiene.

Water provides a number of benefits and services for humans and the ecosystem. As reported by OECD [15], the benefit of water is not documented sufficiently, resulting in low political priority for water issues and in suboptimal levels of investment in water infrastructures. The same document also indicates that the benefit of water is mostly hidden in other technical documents. Most researchers have indicated that the benefit-cost ratio of access to water is more than 2, and in some cases, it can reach 7.0. In developing countries like Africa, the benefit-cost ratio of access to water is very high (more than 5:1 ratio) because it is related to every dimension of developmental activities (agriculture, energy, industry, etc.). In such areas, the return on investment in water services usually result in a substantial economic gains, estimated in the range of 5–28 USD per 1 USD [7]. In addition to the economic gains, water supply projects have technical, environmental and political gains. Water sector is interconnected with other development sectors (agriculture, energy, industry, etc.) and factors (social, economic, environmental, health, educational, legal and political) at local, national levels, regional and international levels [16]. In fact, access to safe water has a number of direct and indirect benefits related to health, education, poverty and environment. The UN World Water Development Report [7] indicated that there is a linkage or nexus between water and sustainable development, far beyond its social, economic and environmental dimensions. The report clearly indicated that access to safe water has a great role in addressing the developmental challenges, such as human health, food and energy security, urbanization and industrial growth, as well as climate changes. Especially, there is a strong nexus between water, food and energy [3].

The MDGs of the UN targeted to *"halve the population without access to safe drinking water and basic sanitation"* in the period from 1990 to 2015. According to the report by WHO and UNICEF [17] through their Joint Monitoring Programme (JMP) for water supply and sanitation, about 2.3 billion people have gained access to an improved drinking water. The report indicates an impressive gain has been made in the past two decades, but much has to be done. The success of MDGs is even doubtful since many of developing countries, especially the poor are still struggling to get access to safe drinking water. As stated in Section 2.1, the number of people without access to safe drinking water is more than the value reported by the UN.

Research has shown that the majority of people without access to safe water are from developing nations [18]. This shows that many people in the developing world, especially Africa, still depend on unsafe water sources for daily water need and affected by chronic water problems and water-borne diseases. Millions of people die due to water-related diseases like cholera, diarrhea, malaria, dengue fever, and so on. Globally, water-borne diseases kill more than 25,000 people per day and about 5000 children die per day due to water-related diseases (mainly diarrhea) [12], most of them can be easily prevented. Diarrhea and related diseases kill about 1.8 million children every year, most of them are in developing countries [19]. It is also estimated that about 1.8 billion people drink water contaminated with *Escherichia coli* (indicator of fecal contamination) [20]. In many parts of the world, especially developing countries, water-borne diseases represent the leading cause of death. Thus, access to safe water means a reduction of water-related diseases. It is an opportunity for improved health because it reduces the outbreak of health hazards.

In cognizant to the benefits of water, the newly introduced ambitious Sustainable Development Goal (SDG) by UN in 2014 [21] considers water as one of the main developmental pillars under SDG 6. In fact, water was also one of the main goals of the UN-MDGs. The UN-SDG 6 states that *"Water sustains life but safe, clean drinking water defines civilization."* The UN-SDG 6 recommended a dedicated SDG for water under five target areas such as (i) WASH, (ii) water resources, (iii) water governance, (iv) water quality and wastewater management and (v) water-related disasters. This indicates that the benefit-cost ratio of water is very high since it has social, economic, financial and environmental benefits. The benefit of water extends to other developmental activities/sectors such as health, education, agriculture and food production, energy, industry and other social and economic activities [7]. Therefore, achieving the UN's SDG 6 seems very hard, especially in the poorest countries like Africa where there are lots of problems and challenges. It requires dramatic improvement to the quality of life and longevity [7]. If we declare that "access to clean safe drinking water is a basic human right, then providing the necessary education, infrastructure and support to ensure the success of SDG 6 is the responsibility of us all." In developing countries, improving access to safe water requires the establishment of good governance [22].

3. Basic principles of safe drinking water supply

3.1. Definition of terms

There are basic standards, norms, criterion and indicators for safe drinking water. There are also policies, strategy and program under safe drinking water. These terms are well defined by Bos et al. [3]. Norm refers to the standard of development related to the large group of society. Criterion refers to the agreed norm or standard used for the decision. Indicator refers to the measured value of individual water quality parameters. Standard refers to the agreed target/threshold value established as an agreed target, which is set by an authority. There are various water quality standards and criteria in the world. Details of the water quality standards are provided under Section 5.3.

3.2. Water regulations and act

Water regulations are important for the provision of drinking water that is sufficient in quantity, safe, accessible, acceptable, affordable and reliable. Drinking water regulations include controlling of the water supply systems which are water source, water treatment, distribution, use, wastewater and gray water. Countries regulate drinking water differently depending on the quality of their water source. As stated earlier, different countries regulate drinking water differently depending on the quality of their water source.

In South Africa, water sources are monitored by the Department of Water and Sanitation (DWS). This was achieved by the implementation of the National Water Act (NWA) 36 of 1998 [9]. The purpose of the NWA is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled. Local authorities are responsible for

the supply of water to residents. This was achieved by the implementation of the Water Services Act (WSA) 108 of 1997. WSA are established to provide the following services [9]: (1) ensuring the rights of access to basic water supply and sanitation; (2) setting national standards, norms and tariffs; (3) water service development plans; (4) prepare the regulatory framework for water service institutions and intermediaries; (5) establish and disestablish committee for water boards and water services and their powers and duties; (6) monitoring water services and intervention and (7) providing financial assistance to water service institutions.

As a criterion, an adequate, clean and safe drinking water supply has to be available for various users [3]. Moreover, water has to be accessible for all, including children, elders and disabled ones. Water **availability** refers to both sufficient quantities and reliability of service provisions. **Adequacy** refers to both the quality and quantity of water. **Reliability** refers to continuity of the service provision for the current and future generation, which is covered under the principle of sustainability, system robustness and resilience. **Acceptability** refers to esthetic value of water – the acceptable appearance, taste and odor of water. It is highly subjective parameter and largely depends critically on the perceptions of the local ecology, culture, education and experience and hence, there is no set clear and objective global acceptability standards. **Accessibility** to water refers to the accessibility to a reliable supply of water on a continuous basis close to the point of demand: within everyone's reach: home, school, work, public places. It is related to the distance of water source from the point of demand (30 minutes walk or 0.2 km). That means the water has to be accessible for everyone, including children, elders and disabled ones. The detailed definition of the above water variables can be obtained from Bos et al. [3].

The role of a drinking water supplier is to provide adequate water for the community and prevent/mitigate risk of water contamination in different elements/points of water supply system such as source, treatment and distribution. They also should assure the delivery of a safe and esthetically pleasing drinking water to the consumer's point. In general, the prevention, mitigation and elimination of water contamination are the responsibilities of water providers and regulators. Water regulations are also important for the provision of drinking water that is sufficient in quantity, safe, accessible, acceptable, affordable and reliable. Countries regulate drinking water differently depending on the quality of their water source. According to the WHO [23] and US Environmental Protection Agency [24], there are guidelines and principles that need to be followed for water to be considered fit for use. The guidelines are as follows: physical, microbial, chemical and radiological. The water quality standards for different countries are summarized under Section 6.1.

4. Potential factors challenging water supply systems

The water supply system (WSS) is a system of hydrologic and hydraulic components, including all buildings and installations, used to meet water requirement of industrial and population centers. It consists of capturing raw water, drainage basin, water capturing and transmission pipes, water treatment plants, treated water transfer pipes, drinking water adduction pipes,

pumping stations and pumping, water storage tanks and water distribution networks to the consumers [25–27]. A conventional water supply system is a combination of complex sub-systems, consisting of the water supply catchment, water storage reservoir, water treatment plant and water distribution network [26]. Water supply and distribution systems typically comprise a combination of source works, treatment facilities, service reservoirs, pumping stations, pipes, valves and so on [25].

4.1. Sustainable water supply and challenges

In the ambitious vision 2050 of the SDG, sufficient and safe water has to be available for all to support human's basic needs and ecosystem integrity [7]. The sustainable development of the world largely depends on the sustainable development of water since other sectors are inter-related with water resources. It requires the progress of the three dimensions of the sustainable development (social, economic and environmental) [7]. Thus, the vision of SDGs (goal 6) for water requires management of the available water and related resources in an integrated, inclusive and participatory approach. Huge investment is highly needed for infrastructure, treatment plant systems and water recycling [29].

A WSS may face a number of challenges associated with many factors in provision of quality, efficient, reliable, resilient and sustainable water supply for the present and future generations. Rural areas are facing more financial and technical difficulties than urban areas. According to da Silva et al. [29], wealthier urban areas have more financial capacity and technical expertise than the poor rural communities to raise the capital needed for water infrastructure. Especially in rural areas with arid environment and great hydrologic variability, reliable and dependable WSS requires energy intensive infrastructure. A study made by Chung et al. [30] showed that robust optimization approach is a useful tool in reliable WSS design, under uncertainty, that prevents system failure at a certain level of risk.

Achieving the SDG requires huge **capital investment and good governance**, which is lacking in developing countries. Huge investment is highly needed for infrastructure, treatment plant systems and water recycling [28]. The sustainable development of water sector is affected by the sustainable development of the other sectors. Unsustainable developmental activities are greatly threatening the quantity and quality of renewable freshwater resources. Various driving forces are threatening the sustainability of WSS such as population increase at alarming rate, high rate of urbanization, significant land cover and climate change, the high demand for new energy supplies and poor governance. These driving factors are causing an increasingly frequent water shortage, floods and droughts, deleterious runoff, coastal hypoxia and depleted aquifers [28]. They have challenged the success of MDGs and will continue challenging the achievement of the newly set MDGs.

The other challenge of sustainable water supply is the **lack of appropriate policies and programs that consider rural diversity.** Small rural communities are the most vulnerable to water contamination. Furthermore, they struggle to secure the necessary funds for infrastructure necessary to improve water treatment and delivery systems, and thus fail to meet drinking water quality regulations. Community management is the tendency to provide water to rural areas worldwide. Despite the diversity of rural communities and their

water supplies, policies tend to be uniform. A quantitative and qualitative study made in the Colombian Andes on four rural water supplies by considering aspects of infrastructure, training of human resources, revenue collection, water quality and post-construction support [31]. The study concluded that there is a need to design policies and programs that consider rural diversity to facilitate the sustainable water supply services. According to Kot et al. [32], policymakers have to align small communities with appropriate water quality goals by considering the contextual and cultural differences among rural communities.

In urban areas, the infrequent and insufficient application of **adaptive capacity indicators in urban sustainable water supply** systems has led to the challenge of dynamic and uncertain urban water supply systems. This condition is threatening the sustainability of urban water supply systems and raises concerns about the progress of urban water systems for variation and change [33]. As suggested by Spiller [33], future research should focus on developing methods and indicators that can define, evaluate and quantify adaptive capacity indicators under the three dimensions of sustainable development (*economic, environmental and technical*). Therefore, there is an urgent need to move toward the use of adaptive capacity indicators.

Moreover, there is an urgent need to move toward **sustainable and resilient smart water grids** in urban areas. Urban water supply systems are facing challenges of sustainability and resiliency, including water leaks, over-use, quality issues and response to drought and natural disasters [34]. Information and communications technology could help address these challenges through the development of smart water grids that network and automate monitoring and control devices [34]. While impressive progress has been made on technological elements (information and communication), the application of a smart water grid has received scant attention, especially in developing countries.

In fast-growing urban regions, **water demand and supply modeling** is extremely important. An **accurate prediction** of water demand plays a crucial role for water service providers in the planning, design and water utility asset management of drinking WSS. However, accurate prediction is always challenging due to the fact that predicting models require a simultaneous consideration of a number of factors affecting water demand and supply pattern. Some of the factors include climate changes, economic development, population growth, migration and consumer behavioral patterns [35].

4.2. Challenging factors for water supply systems

There are a number of factors challenging WSS. Some of the factors are aging infrastructure, water service provision thinking horizons, catchment (mountain)-specific issues, climate change, knowledge gaps with respect to present and future hydrology, accurate water demand prediction, land use/cover change, optimal operation of water supply systems, cost recovery, operating cost, water quality (water pollution), water scarcity, water leaks, low water pressure, over-use, response to drought and natural disasters, rapid urbanization, population growth, migration, demographic changes, economic development, consumer behavioral patterns, efficiency and reliability of a water supply system, self-sufficiency through use of alternative water sources, dynamic and uncertain urban water systems, complex dynamic

human-environment coupled systems (non-holistic or siloed management), lack of adaptive capacity indicators to assess sustainability of water systems, scant attention of smart water grids (not supported by information and communications technology), lack of policies and programs that consider rural diversity and cultural differences and neglecting wastewater management are mentioned as challenges to water supply systems for provision of sustainable and reliable water services, which meet acceptable standards for present and future generations [14, 25, 26, 28–49].

According to Berg and Danilenko [38], WSS has faced a number of global challenges in the twenty-first century. The major challenges are population growth, uncertain climate changes, socio-environmental issues, limited water resources, economic crises and continuous aging process. There are a number of problems associated with the continuous aging process, including low pressure, water loss and water quality deterioration [36]. The major challenges in the provision of safe water and sanitation on a global basis are [37]: (1) water contamination within distribution systems; (2) increasing water scarcity and shortages; (3) implementing innovative and low-cost sanitation systems; (4) providing sustainable water supply systems and sanitation for megacities; (5) reducing the disparities in access to water and sanitation and (6) developing financially feasible water and sanitation services.

Increasing urban water self-sufficiency: The main drivers for increased self-sufficiency were identified to be direct and indirect lack of water, constrained infrastructure, high-quality water demands and commercial and institutional pressures. Public water service providers should plan to achieve a high level of reliable, stable and dependable water supply, which can be achieved by combining alternative water supply systems with the conventional ones. A case study made by Rygaard et al. [39] demonstrated an increase in water self-sufficiency ratios to more than 80% when the conventional water supply was supplemented by water recycling, seawater desalination and rainwater harvesting. However, the study indicated that care should be made during the introduction of alternative freshwater sources since it may raise several challenges such as very high-energy requirements (>*tenfold*) by the alternative techniques, appearance of trace contaminants in recycled wastewaters and the possible resistance from consumers due to the changes made to the drinking water system. The study concluded that despite the challenges, urban water self-sufficiency concepts in combination with conventional water resources are already helping to reach the goal of urban WSS.

Infrastructure development: Water services are in crisis or approaching crisis conditions due to the neglect of infrastructure, particularly underground water mains and sewers, largely because of political unwillingness to allow charges to be set high enough to achieve sustainable cost recovery. This is true in both developed and developing countries [43]. In developed countries, the solutions are relatively affordable; what is needed is the political commitment to take action. In developing countries, the situation is more serious due to a combination of neglect and rapidly growing urban populations. Without doubt, infrastructure is essential for sustainable water development. But infrastructure alone will not contribute to the improvement of the quality of life unless it is part of an overall framework: development, economic growth, social equity and environmental protection. As mentioned by the Nobel laureate Amartya Sen [45], "the absence of infrastructure has a pervasive influence on poverty, but at

the same time is not a free-standing factor in lifting people from it." Thus, the focus should be the use of physical infrastructure as a driver for sustainable development. But infrastructure development takes more time beyond the life of most governments. The thinking of water service providers has to be based on long-term horizons. In order to improve the accountability and social welfare of relatively low-income households, there is a need for more comprehensive frameworks (institutional, legal, regulatory, policy and management) than the existing ones at present [45]. Venkatachalam [47] suggested that improving the existing public water supply to a satisfactory level will improve the household's willingness to pay because the willing households could reap significant benefits from the improved supply. This would help the government agencies to come out with an improved water tariff policy that will cover cost of investment and maintenance.

Urban water pricing (*cost recovery, affordability and water conservation*): Policymakers increasingly consider pricing as an important tool for cost recovery, affordability and water conservation to address water scarcity issues. However, implementing **tariff reforms** is often difficult in practice due to political factors and the absence of governance structures that can result in quality service provision. Additionally, institutional replication of successful water pricing policies has been difficult due to incomplete information and the contextual uniqueness of local institutions, politics and social relations. Water service provision thinking has to be based on long-term horizons. Infrastructure development takes time beyond the life of most governments. In those countries without such political continuity, there is a need for all political factions to agree on goals, policies and plans. It is unlikely that water can ever be separated from politics, but city political consensus must be attempted [53].

Climate change: Climate change is affecting the frequency of extreme weather events and hence increasing the uncertainty about water availability and reliability [50]. A properly planned, developed and managed infrastructure and related institutional capacities are required in order to buffer seasonal climatic variations and address water demand issues. More emphasis should be given to mountain-specific issues. Major priority areas include water governance for transboundary basins, cross-border information systems, establishing a knowledge base for mountain regions and sharing benefit between mountain and downstream communities [42].

Knowledge gaps: With respect to present and future, hydrology poses a serious constraint for infrastructure development. Changing hydrology will pose special challenges to the design, planning and management of infrastructure [42]. Land use influences raw surface water quality and treatment costs for drinking water supply [51]. Anthropogenic disturbances to the environment can compromise valuable ecosystem services, including the provision of potable water. These disturbances decrease water quality, potentially increasing treatment costs for producing drinking water.

Efficiency and reliability of a water supply system: Water inflow is among primary determinants of the successful functioning of the entire water supply system since it influences water storage. Developing an approach to assess the resilience of WSS under limited rainfall provides useful insights into effective system management [26]. For instance, understanding WSS resilience can support the identification of the minimum/threshold rainfall value by which WSS can maintain its operation without failure. It can also help to understand and identify the sensitivity of the WSS to a changing rainfall amount and distribution pattern.

In this regard, the water service providers are well aware of the stability of WSS and know when the system experience a pressure or disruptive influences.

Challenges for water supply and Governance: Cities struggling to keep pace with population and demographic changes are not unique. According to a study conducted in Dublin [41], collectively there are combinations of factors that create an inordinately challenging situation for those attempting to plan for the city's current and future water resources needs. Their main challenges related to topography, old infrastructure (the nineteenth century), population growth and development needs, water charges, climate change and water supply history.

5. Drinking water quality

5.1. Definition and concepts

Water is most fundamental in shaping the land and regulating the climate. It is one of the most important resources that profoundly influence life. Water quality is the most fundamental controlling factor when it comes to health and the state of diseases in both humans and animals. According to WHO report [23], about 80% of all the human diseases in human beings are caused by water.

Depending on the purpose of water quality analysis, water quality can be defined based on a set of biological, physical and chemical variable, which are closely linked to the water's intended use. As a principle, drinking water is supposed to be free from harmful pathogens and toxic chemicals [3]. Contamination of freshwater (especially groundwater) sources is one of the main challenges currently faced by the South Africans, more especially in communities who depend almost exclusively on groundwater [52]. Groundwater is used for domestic, industrial and agricultural water supply in all four corners of the world. Therefore, the presence of contaminants in natural freshwater continues to be one of the most important environmental issues in many areas of the world, more especially in developing countries [53]. Once the groundwater is contaminated, its quality cannot be restored back easily, the best way is to protect it.

The concept and theory of water quality is very broad since it is influenced by many factors. Water quality is based on the intended uses of water for different purposes, that is, different water uses require different criteria to be satisfied. In water quality analysis, all of the accepted and unaccepted values must be clearly defined for each quality variable. If the quality variables meet the pre-established standards for a given use is considered safe for that use. When water fails to meet these standards, it must be treated if possible before use.

5.2. Description of water quality parameters

5.2.1. Physical parameters

Physical quality parameters are related to total solids content, which is composed of floating matter, settleable matter, colloidal matter and matter in solution. The following physical parameters are determined in water [12]:

- **Color**: caused by dissolved organic materials from decaying vegetation or landfill leachate.

- **Taste and odor**: can be caused by foreign compounds such as organic compounds, inorganic salts or dissolved gases.

- **Temperatures**: the most desirable drinking water is consistently cool and does not have temperature fluctuation of more than a few degrees. Groundwater generally meets these criteria.

- **Turbidity**: refers to the presence of suspended solid materials in water such as clay, silt, organic material, plankton, and so on.

5.2.2. Chemical parameters

The chemical constituents have more health concerns for drinking water than for the physical constituents. The objectionability of most of the physical parameters are based on esthetic value than health effects. But the main objectionability of some of the chemical constituents is based on esthetic as well as concerns for adverse health effects. Some of the chemical constituents have an ability to cause health problems after prolonged period of time [54]. That means the chemical constituents have a cumulative effect on humans. The chemical quality parameters of water include alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved gases, nitrogen compounds, pH, phosphorus and solids (organic). Sometimes, chemical characteristics are evidenced by their observed reactions such as in laundering, redox reactions, and so on [12, 54].

Below is a list of some of the chemical compounds and elements found in water:

- **Arsenic**: occurs naturally in some geologic formation. It is mostly used in agricultural chemicals in South Africa. In drinking water, it has been linked to lung and urinary bladder cancer.

- **Chloride**: most waters contain some chloride. The amount found can be caused by the leaching of industrial or domestic waters. Chloride should not exceed 100 mg/L in domestic water to be palatable.

- **Fluoride**: is a natural contaminant of water. It is one of those chemicals given high priority by WHO [14] for their health effects on humans. High F in drinking water usually causes dental and skeletal fluorosis. Excessive F (>2 mg/L) causes a dental disease known as fluorosis (mottling of teeth), while regular consumption in excess may give rise to bone and skeletal fluorosis [12]. On the other hand, F < 2 mg/L causes dental cavities in children.

- **Zinc**: is found in some natural waters, particularly in areas where zinc ore deposit have been mined. Though it is not considered detrimental to health, but it will impart a bad taste to drinking water.

- **Iron**: small amounts of iron frequently are present in water because of the large amount of iron in the geologic materials. This will cause reddish color to water.

- **Manganese**: naturally occurring manganese is often present in significant amounts in groundwater. Anthropogenic sources include discarded batteries, steel alloy production and agricultural products.

- **Toxic substances**: generally classified as inorganic substances, organic substances and heavy metals. The toxic inorganic substances include nitrates (NO_3), cyanides ($CN\_$) and heavy metals. These substances are of major health concern in drinking water. High NO_3 content can cause *Methemoglobinemia* in infants ("infant cyanosis" or "blue baby syndrome"); while CN can cause oxygen deprivation [12]. There are more than 120 toxic organic substances [24], generally exist in the form of pesticides, insecticides and solvents. These compounds produce health effects (acute or chronic). The toxic heavy metals are arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se) and silver (Ag) [12]. Like the organic substances, some of these substances are acute poisons (As and Cr) and others produce chronic diseases (Pb, Cd and Hg).

5.2.3. Biological parameters

Biological parameters are the basic quality parameters for the control of diseases caused by pathogenic organisms, which have human origin. Pathogenic organisms found in surface water include bacteria, fungi, algae, protozoa, plants and animals and viruses. Some of these disease-causing organisms (bacteria, fungi, algae, protozoa and viruses) are not identifiable and can only be observed microscopically. Microbiological agents are very important in their relation to public health and may also be significant in the modification of physical and chemical characteristics of water [12]. Water for drinking and cooking purposes must be free from pathogens. The greatest microbial risks are associated with consumption of water that is contaminated with human or animal feces. Feces can carry pathogenic bacteria, protozoa, helminthes and virus. Pathogens originating from feces are the principle concerns in setting health-based targets for microbial safety. Water-borne diseases are particularly to be avoided because of the capacity of result in the simultaneous infection of large number of people. While water can be a very significant source of infectious organisms, many of the diseases that may be waterborne may also be transmitted by other routes, including person-to-person contact, droplets and aerosols and food intake [54].

The techniques for comprehensive bacteriological test are complex and time consuming. Different tests have been developed to detect the relative degree of bacterial contaminations in terms of an easily defined quantity. There are two mostly used test methods widely used to estimate the number of microorganism of coliform groups (*Escherichia coli and Aerobacter aerogenes*). These include: total coliforms or *E. coli*, but the second one is found to be a better indicator of biological contamination compared to the first one [12].

5.3. Water quality standards

As presented in Section 3.1, standard is defined as a basis for judging the quality. A standard for drinking water quality is thus the reference that will ensure that the delivered water will not pose any threat or harm to human health. The water quality standard is the framework

against which a water sample can be considered satisfactory or safe for use [54]. There are a number of standard guidelines for drinking purposes such as World Health Organization [54], Commission for European Union [55], U.S. Environmental Protection Agent [24], Environmental Canada [56], Russian Standard [57], Indian Standard [58, 59], South African National Standard [60] and Ethiopian Standards [61]. Most developing and other developed countries use the WHO standards for drinking water [54]. **Table 1** summarizes water quality guidelines of different countries.

5.4. Water quality index

It is difficult to quantify the overall suitability of water for drinking based on the various guidelines presented in **Table 1**. The interpretation of the various water quality parameters separately is usually a difficult task for general public as well as decision and policy makers. Therefore, the calculation of a general water quality index (WQI) is extremely important in order to communicate the quality of water in a better and understandable ways. There are different approaches of calculating WQI. In this section, a brief description has been provided for the weighted Arithmetic Water Quality Index Method proposed by Tiwari and Mishra [62] and adopted by others [63–67]. The quality rating (q_i), the sub-index (SI) [65] and the relative weights (W_i) are calculated using Eqs. (1)–(3).

$$q_i = 100\left(\frac{V_i - V_{o,}}{S_i - V_i}\right) \tag{1}$$

$$SI_i = (W_i)(q_i) \tag{2}$$

$$W_i = \frac{w_i}{\sum w_i} \tag{3}$$

where V_i and S_i are the analytical and the standard value for the ith parameter, respectively, V_o is the ideal value of the ith parameter in pure water ($V_o = 0$, except pH =7.0). The standard value is usually considered as the maximum permissible level set by WHO [10, 14, 54] or as per the standards for different countries presented in **Table 1**. W_i is the relative weights for various water quality parameters, assumed to be inversely proportional to the recommended standards for the corresponding parameters. w_i is the unit weight of each parameter according to its relative importance in the overall quality of water for drinking purposes. The w_i values are provided by Tiwari and Mishra [62], which depend on the number of parameters considered in the calculation of WQI. Note that the $\sum W_i$ should be equal to 1.

Finally, the overall WQI (Eq. (4)) is calculated for each of the water sources by aggregating the quality rating (q_i) linearly and taking their weighted mean.

$$WQI = \sum_{i=1}^{n} SI_i \tag{4}$$

WQI classes are as follows: 0–25 (excellent, grade A), 26–50 (good, grade B), 51–75 (poor, grade C), 76–100 (very poor, grade D), >100 (unfit for drinking, Grade E).

Parameters	Standard concentrations								
	WHO[a]		USA (USEPA[b])	Europe (CEU[c])	Russia[d]	Canada (EC[e])	India[f]	South Africa[g] (SANS)	Ethiopia[h] (ESA)
	HDL	MPL							
PH	7.0–8.5	6.5–8.5	6.5–8.5	6.5–8.5	6.0–9.0	6.5–8.5	6.5–9.2	6.5–9.0	6.5–8.5
EC	300	1400	–	–	2000	–	–		–
Na^+	–	200	–	–	200	20	150	100	200
Ca^{2+}	75	100	–	–	–	–	100	32	75
Mg^{2+}	30	50	–	–	–	–	100	30	50
K^+	12	200	–	–	–	–	–	50	1.5
Cl^-	200	600	250	250	350	250	1000	200	250
CO_3^-	–	45	–	–	–	–	–	–	–
HCO_3^-	–	500	–	–	–	–	400	–	–
TH	200	500	–	–	–	300	600	–	300
F	1.0	1.5	2.0	1.5	1.5	1.5	–	1.0	1.5
B	–	0.3	–	1.0	0.3	5.0	5	–	0.3
SO_4^-	200	250	250	250	500	250	400	200	250
TDS	500	600	500	–	1000	500	1500	450	1000

P – probability (%); HDL – highest desirable limit; MPL – maximum permissible limit; USEPA – United States Environmental Protection Agency; CEU – Commission of European Union; EC – Environmental Canada.

Sources: [a]WHO [54], [b]USEPA [24], [c]CEU [55], [d]UNESCO/WHO/UNEP [56], [e]Health Canada [57], [f]ISI [58] and BIS [59], [g]SANS [60], [h]ESA [61]. Note that the values indicated for the different standards other than WHO are the maximum permissible limits.

Table 1. Comparison of the different drinking water standards.

6. Conclusion

As water is a basic need for human life, access to clean, safe drinking water is a basic human right. As a criterion, an adequate, reliable, clean, acceptable and safe drinking water supply has to be available for various users. Moreover, everyone needs access to safe water in adequate quantities for drinking, cooking and personal hygiene and sanitation facilities that do not compromise health or dignity. Access to water is one of the most important catalysts given high priority by the UN for sustainable development. Despite these facts, there are inequalities in access to safe drinking water in the world. There are a number of factors challenging the sustainable WSS. Some of the factors are related to infrastructures (aging), clean water issues (quality, scarcity), natural factors (climate change, flood and drought), human factors (population growth, migration, demographic change, economic development, willingness to pay for water supply services, overuse), water management and delivery problems (pressure, leakages, lack of smart water meters, cost recovery, operation costs, etc.).

MDG fails to achieve its goal for access to safe water and sanitation. The chance for the success of the newly set SDG is also not different from that of MDGs, especially in some African countries. Some of the African leaders are reporting a false number of people with access to safe drinking water and sanitation to get a donation from the UN and using the donated money to buy weapons and use it to suppress the right of the people. In developing countries, improving access to safe water requires provision of good quality education and the establishment of good governance. Priorities should be given to the development of a democratic government and community empowerment.

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