Chapter

Drinking Water Treatment and Challenges in Developing Countries

Josephine Treacy

Abstract

Safe drinking water remains inaccessible to many humans in the developing countries. Research continuously innovates to develop efficient and cheap methods to sustain clean water for developing countries. Developing nations are a broad term that includes countries that are less industrialised and have lower per capita income levels than developed countries. This chapter will discuss clean water for drinking water purposes. Pollution concerns of water in developing countries will be categorised in terms of physical, chemical and biological pollutants such as turbidity, organic matter and bacteria. Natural and anthropogenic pollution concerns linking with seasonal factors will be outlined. The multi-barrier approach to drinking water treatment will be discussed. Abstraction points used will be researched. Water treatment systems, medium- to small-scale approaches, will be discussed. The processes involved in removing the contaminants including physical processes such as sedimentation, filtration such as slow-sand filtration, coagulation and flocculation, and disinfectant processes such as chlorination will be reviewed. Other important methods including solar disinfection, hybrid filtration methods and arsenic removal technologies using innovative solid phase materials will be included in this chapter. Rainwater harvesting technologies are reviewed. Safe storage options for treated water are outlined. Challenges of water treatment in rural and urban areas will be outlined.

Keywords: drinking water, water source treatment pollution

1. Introduction

Drinking water remains inaccessible to 1.1 million people globally. Safe and readily available drinking water is important for public health. Drinking water can be used for many purposes including cooking, drinking, washing, personal hygiene, irrigation, recreational and industrial use. Water can be classified aided by the 'environmental quality objective' for what it is used for and the 'environmental quality standard' for what is the quality of water for its purpose. Improved water supply, sanitation and better management of water resources can boost countries' economic growth and can contribute greatly to poverty reduction. The sources of drinking water in developing countries can range from surface water, groundwater, spring water, saline water, bottled water and harvested rainwater [1]. Access to drinking water is monitored by the World Health Organization (WHO), the United

Nations Children's Fund (UNICEF) and the Joint Monitoring Programme for water supply and sanitation (JMP) [2].

Efforts to develop efficient, economical and technologically sound methods to produce clean drinking water for developing countries have increased worldwide [3].

Figures 1 and **2** highlight the importance of scientists to develop and sustain technologies to improve drinking water quality due to the percentage of society lacking suitable drinking water [4]. Water is a key variable within sustainable development goals in terms of environmental, social and economic initiatives as highlighted by the United Nations in 2014 [5]. The discussion on the role of water

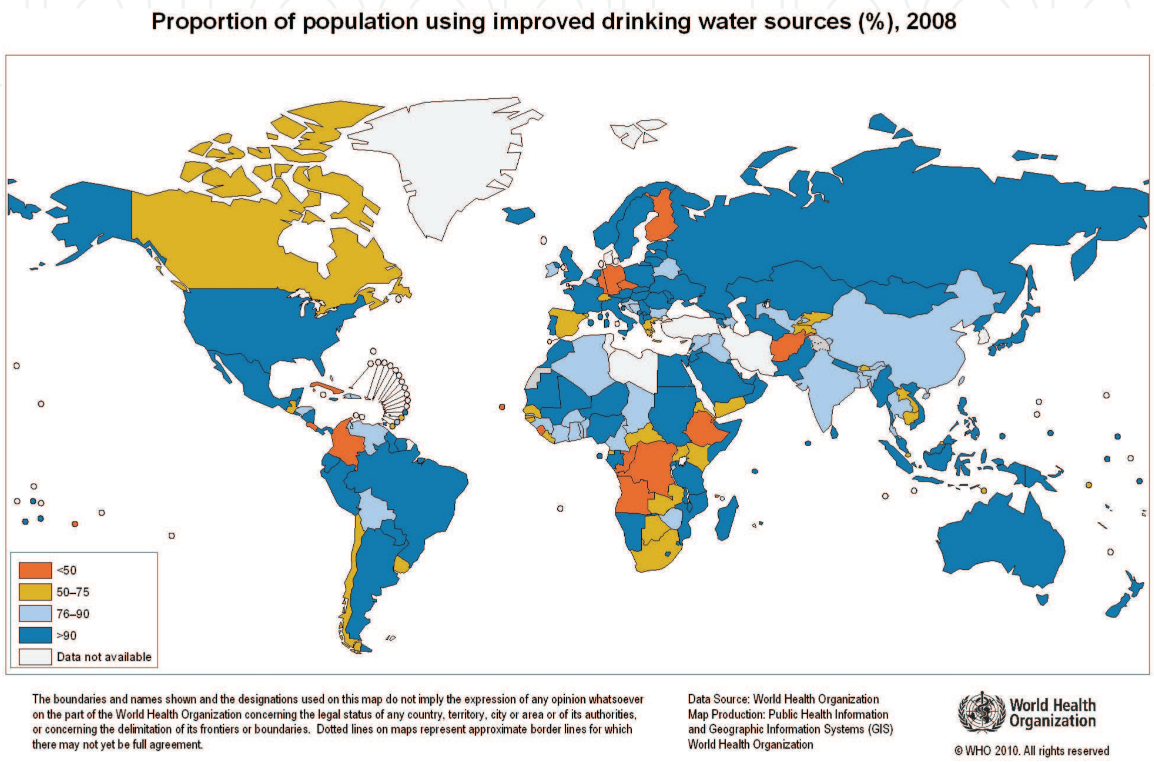

Figure 1.
Proportion of population using an improved drinking water source (WHO 2010) [4].

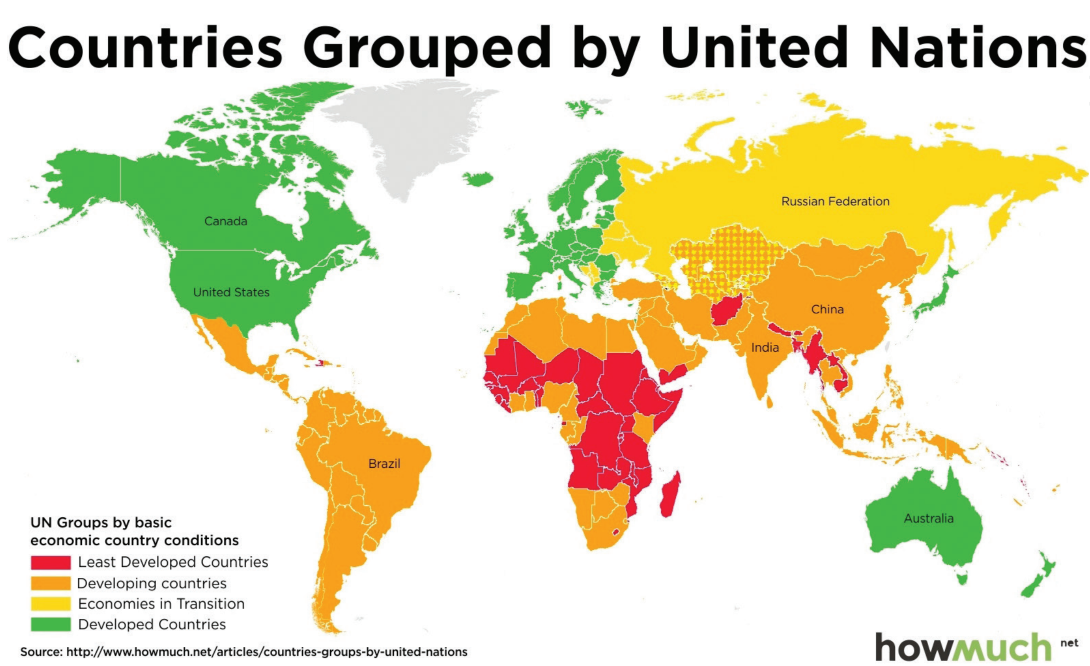

Figure 2.
Global representation of developing countries (WHO/UNICEF Joint Monitoring Programme [4]).

for sanitation and hygiene in the 'water development report 2015' emphasises cost as one of the key challenges for future water needs [6].

2. The importance of treating water

As well as accounting for the lack of physical water accessibility due to drought, 'distance from a water supply' and polluted water can all affect drinking water accessibility. Water quality issues due to anthropogenic and natural pollution can affect the amount of water available for use. Both surface and groundwater can be contaminated by both anthropogenic and natural contaminations. Microbiology and chemical contaminants in drinking water can cause acute and chronic health effects. Contamination can also affect the aesthetic properties of water systems. The contaminants include:

- Pathogens—disease-causing organisms that include bacteria, amoebas, viruses and eggs and larvae of parasitic worms [6].

- Harmful chemicals from human activities and industrial wastes such as pesticides and fertilisers [7].

- Chemicals and minerals from the natural environment, such as arsenic, common salts and fluorides. In Bangladesh, for example, 1.4 million tube wells have high levels of naturally occurring arsenic [8].

- Some non-harmful contaminants may influence the taste, smell, colour and turbidity of water and make it unacceptable to the consumer; its examples include zinc, iron, particulate matter and humic material [9].

The physiochemical properties of contaminants of water that can impact its toxicology in water include size, density compared to water, charge, solubility, volatility, polarity, hydrophobic, hydrophilic, boiling point, chemical reactivity and biodegradability [10].

2.1 From source to consumer and the multi-barrier approach

When deciding on the water supply for drinking water purposes an understanding of the stresses on the water source is important. Seasonal variation of the water source is also important to understand in areas such as water level and water table levels and sanitation contamination trends [11]. Throughout this chapter emphasis on the multi-barrier approach to maintain clean water will be described. All parts of the multi-barrier approach, including source selection, treatment type, transport to consumer and storage if necessary are all important to control, to minimise the risk of contamination. The water safety plans (WSPs) manual published in 2009 by the World Health Organization (WHO) guides the multi-barrier approach for the maintenance of good quality drinking water [12, 13]. When deciding on the drinking water supply and subsequence treatment, the WHO safety plan manual encourages people to think of the best treatment taking into consideration local factors. In the International Water Association (IWA), Bonn Charter emphasises the 'provision of clean safe drinking water which has the trust of consumers' as a focal point [14] (**Figure 3**).

The multi-barrier approach examines water in detail from source to tap and aids in maintaining the quality of water at each stage. The lesser the number of steps in treatment, the cleaner the water source and the nearer the consumer is to the source are challenges in drinking water management. Other variables to consider include

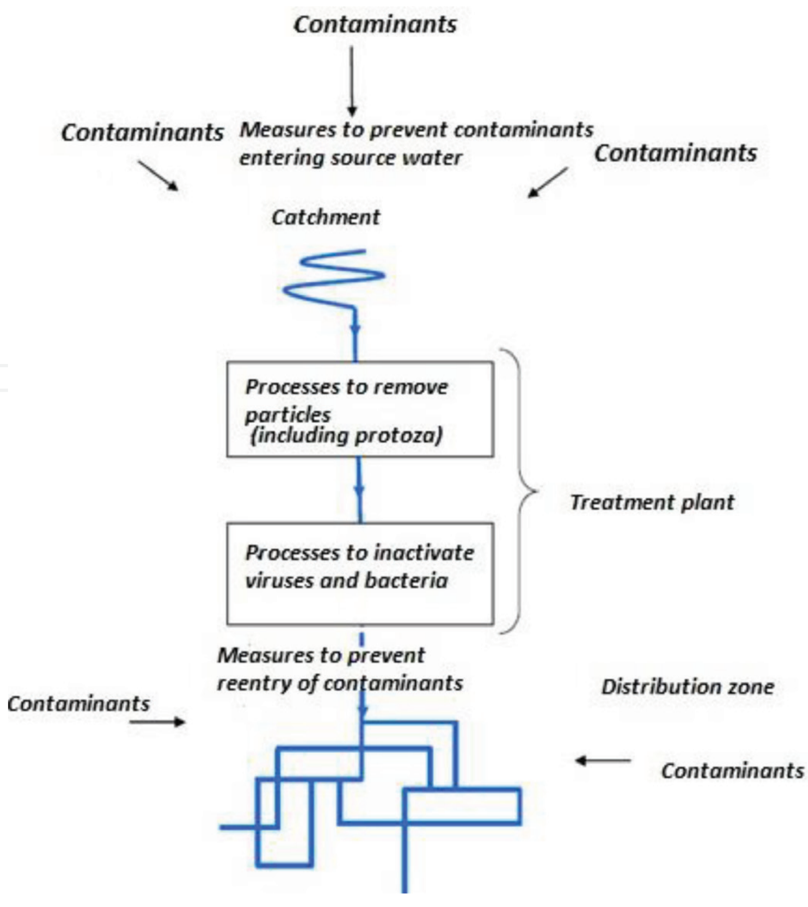

Figure 3.
The multi-barrier approach [15].

prevention of reentering of contaminants at storage and distribution stages of the process [16]. Indicator parameter studies of facial coliforms have been used in Rangoon Burma of Southeast Asia for storage and distribution control management [16].

2.2 Abstraction points

The source supply is known as the abstraction point. A large priority of water management in developing countries is to supply water from a source that requires little or no treatment rather than a source that requires treatment. Risk management to ensure that the source is protected from pollution is also a priority [17]. The baseline of the water source physiochemical, organic and inorganic composition and its monitoring is a challenge [18]. Supply provision of water source under different conditions such as seasonal factors is important to understand. The types of water abstraction points consist of boreholes, open wells, surface water river and lakes, saline waters and brackish waters. An example of the range of drinking water abstraction types utilised in developing countries can be seen in **Table 1** [19].

Abstraction water point in certain areas will change at different times of the year corresponding with the dry season and the wet season. Boreholes where citizens dig down to find water would be popular in dry seasons and river water sampling, and the use would be popular in wet season. This is common in areas such as Francistown, Botswana, in South Africa. The Shashe river is used readily in the wet season as stated by a sister of the Cross and Passion order working in the Francistown area. Another source of water for future investigation would be bottled water; bottled water can be bought in from other countries. Bottled water can be classified as natural mineral water, and water source bottled from an underground aquifer still or aerated protected from pollution has no treatment [20]. Issues with

Source type	Drinking water % use	Domestic water % use	Irrigation % use
Shallow well	68.6	75.4	82.3
Borehole	11.0	4.3	6.5
River	0.7	0.7	1.6
Spring	0.7	0.7	1.6
Wetlands	0	0	1.6
A combinations of above Due to seasonal factors	9.7	9.4	1.6

Table 1.
Abstraction drinking water supply and % use from case study Ndola [19].

confidence in quality, shelf life, storage including refrigeration and transportation to consumer can be a challenge. The cost of transporting bottled water can be costly.

2.3 Rainwater (water harvesting)

Rainwater harvesting can be considered a free source of water. Rainwater precipitation can be very large in certain parts of the globe. Global precipitation climatology, for the period 1979–2017 in millimetres/day, can be visually seen in **Figure 4** [21]. This data represents the precipitation estimate from version 2.3 global precipitation climatology project (GPCP) SSAI/NASA GSFC project data [21].

Different technologies can be used for rainwater harvesting such as roof water which can be collected through gutters and pipes into storage tanks [22]. Other water harvesting systems that have been developed include farm ponds, community ponds, wells, recharge pits micro-irrigation sprinklers and check dams' low cost water harvest systems [23]. The advantage of farm ponds and check dams is that water can be stored in the rainy season which can be utilized during the dry season. Recharge pit systems can be used to recharge groundwater aquifers in the rainy season. The Vidarbha region of India has successfully deployed farm pond and pit macro-irrigation systems. Positive outcomes of these technologies include crop irrigation improvements and raised water tables, subsequently increasing the availability of drinking water sources. [23].

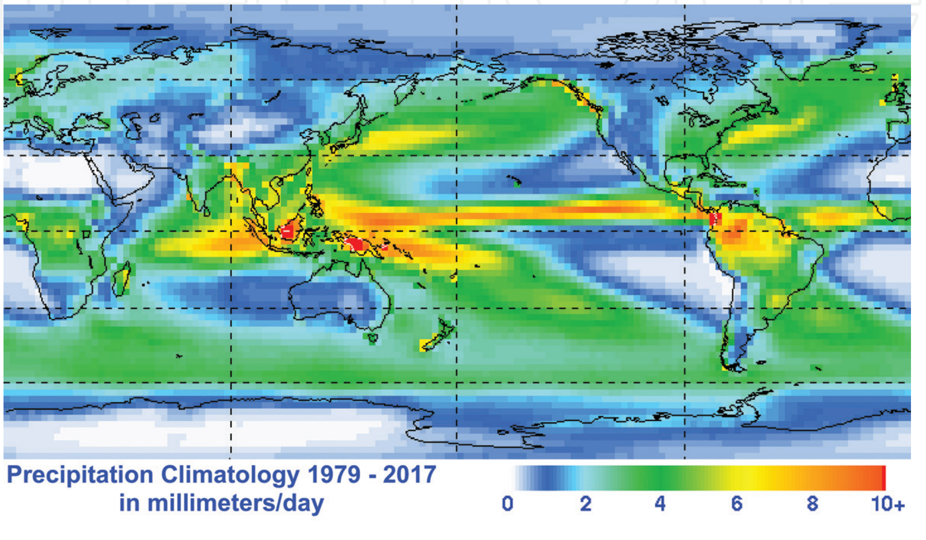

Figure 4.
Global precipitation image provided by David Bolvin (SSAI/NASA GSFA [21]).

From **Figure 4**, one can see that the estimated rainfall in Africa, Asia and South America is in the range of 4–10 millimetres/day, which can be utilised for water harvesting for the purpose of drinking water, irrigation and washing and cooking. The data in **Figure 4** is based on a combination of passive microwave and active radar sensors.

Rainwater can be a significant source of water for an individual, a family or a community. Rainwater harvesting is widely practised in Maldives, India and Sri Lanka [24]. It is very beneficial for tsunami-affected regions where piped water infrastructures are severely damaged [25].

Other areas where rainwater harvesting has been developed include Bhutan and Bangladesh as an alternative source due to the high levels of naturally occurring arsenic in groundwaters [26]. The advantage of using rainwater as a water source is a great benefit to a community if distance from a water supply in rural areas makes water inaccessible.

Rainwater harvesting can levitate issues with storm water and minimise diffuse sources of pollution due to storm water. Harvested rainwater is a water source during the drought season if stored correctly. The treatment of the rainwater if needed would involve point-of-use (POU) treatment technologies which will be discussed later in this chapter.

Globally, sub-Saharan Africa has the largest number of water-scarce countries [27]. Unfortunately, these countries also do not have a large availability of clean drinking water due to urbanisation and industrialisation impact on water quality [27]. Most of the African continent relies on rainfall and surface water for their drinking water supply. Experts estimate that between 75 and 250 million people will live in water-stressed areas of Africa by 2030 [28]. Pollution of rainwater can be due to the transboundary pollution and anthropogenic and naturally occurring pollution such as bird droppings [29]. The key benefits of using rainwater include local water security and reduced central treatment infrastructure needs for water supplies.

2.4 Desalination

Processes such as distillation and evaporation can be used as a means of desalination [30]. Other processes include freeze distillation and reverse osmosis. Freezing salt makes crystals of fresh water form and grow leaving a concentrated brine solution behind [31]. Reverse osmosis involves movement of water from a high concentration to a low concentration. Membrane systems can also be used [32]. The major advantage of desalination is that when chlorination is used as a disinfectant, there is a lower risk of forming disinfectant by-products as the water has a lower organic content [32]. Many developing countries have coastal areas which enable sea water and brackish water following desalination to be used as a drinking water source. The largest challenge to the use of desalination technologies is the cost of the technologies used [33]. Research has shown that cost of desalination can be minimised by using solar and wind energy as an energy supply for reverse osmosis [34].

3. Pollution and abstraction point

The minimising of pollution must be linked with point and diffuse sources of pollution. Categories of pollution risk include point sources and diffuse sources of pollution. Diffuse source of pollution is harder to control and monitor. Diffuse sources of pollution include dry and wet atmospheric deposition. Storm water infiltration from waste storage and septic tanks is also a major concern [35].

Watershed protection refers to the activities preformed on a topographical and hydrological water area in order to protect water quality within a catchment. As an example for drinking water the topography of the watershed basin is studied linking with surface water runoff entering a river or stream. Soil types should be investigated in terms of soil characteristics and water permeability and sand silt and clay composition [36]. Water-permeable soil can impact on the movement of surface water downwards to groundwater causing a transfer of pollution (**Figure 5**).

Aquifer protection groundwater quality is dependent on the geology of the subsurface material of which water is drawn. Also, understanding the transport and fate of contaminants requires a study of groundwater geology if any aquifer protection zone treatment is in place. Soil horizon characteristics should also be reviewed. Arsenic is a common naturally occurring metal problem in developing countries as can be seen in **Figure 6**. Hydraulic pump control to prevent intrusion of sea water is an important variable to control in coastal areas in terms of fresh water aquifer use [38].

Waste disposal and lack of proper sanitation practices can affect the quality of surface waters and groundwaters. The principle component analysis (PCA) and factor analysis (FA) can be used to minimise the risk of water pollution. The PCA and FA create an inventory of variables that can be an impact on water quality [39]. **Figure 7** shows the PCA and FA flow approach in relation to surface water management [40]. Point and diffuse sources and source-receptor mechanisms are also important to understand. Source-receptor mechanisms are important to control and understand, linking to the physical, chemical and biological characteristics of the pollutants that may be natural or anthropogenic [41].

The types of waste issues to monitor relate to the pharmaceutical and agricultural industries, oil refining, textile industry, leather industry, fine chemical manufacture, animal and human solid and liquid waste and sediment issues linked with floods and the construction industry.

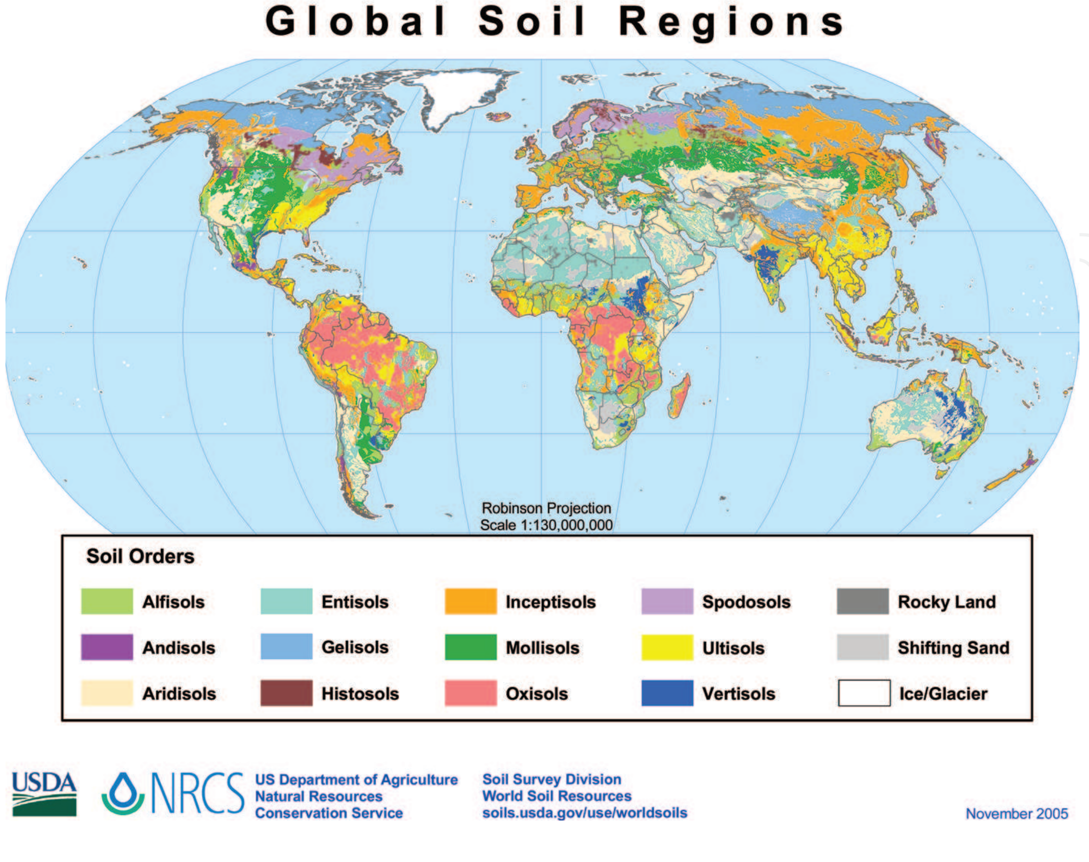

Figure 5.
Soil types globally [37].

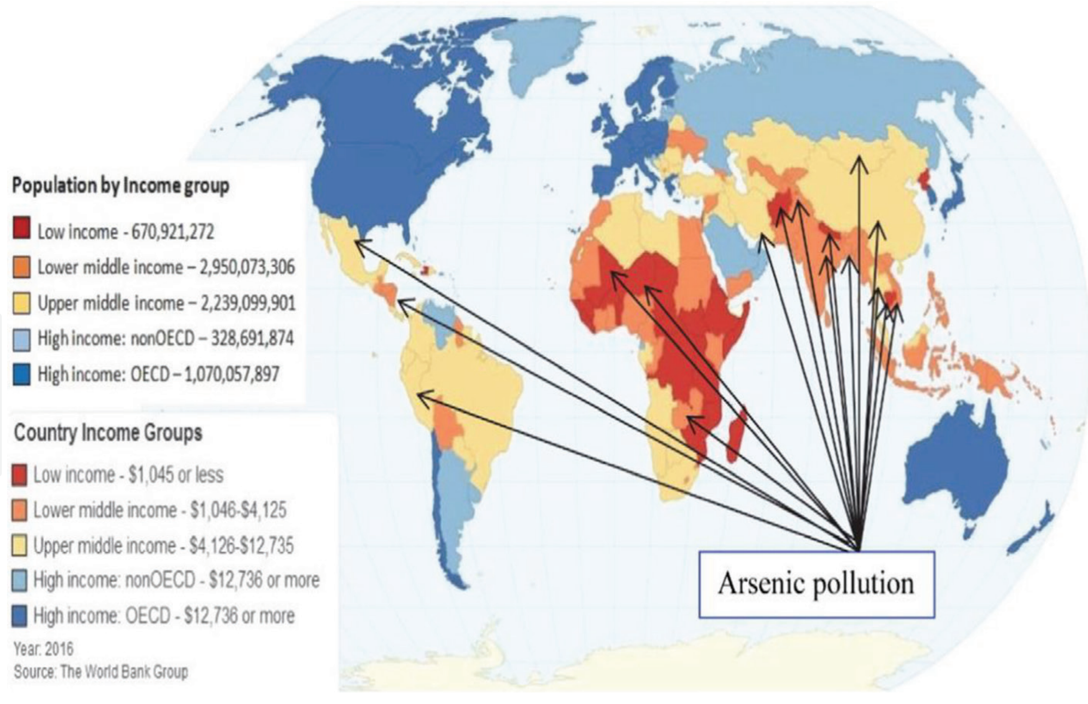

Figure 6.
Naturally occurring arsenic in a global perspective [1].

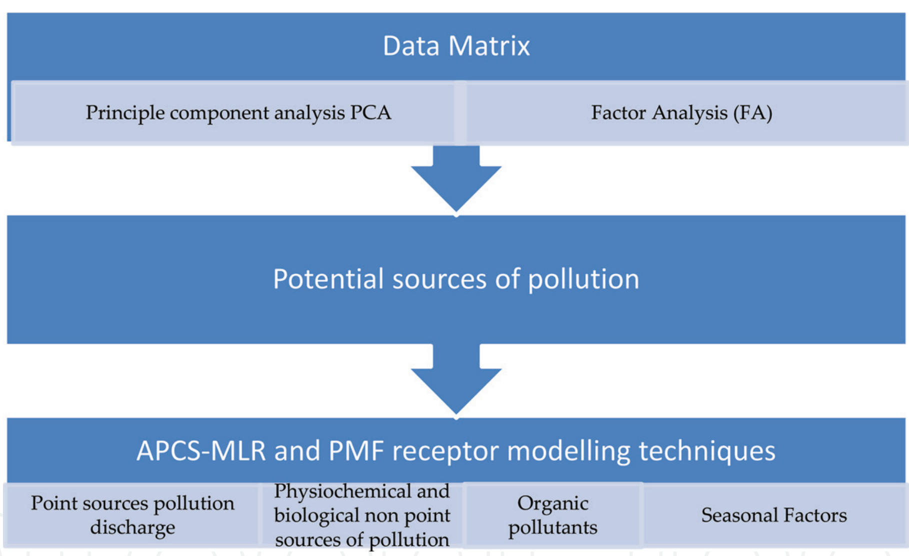

Figure 7.
Point and diffuse sources and seasonal factors and pollution control linking with PCA and FA [40].

4. Treatment technologies

Any drinking water treatment technology focuses on source supply, treatment type, storage and transportation to customers. Conventional treatment methods in developed countries can be applied to developing countries. The basic drinking water treatment steps can be seen in **Figure 8**.

The first stage of treatment to produce drinking water involves screening the abstraction point water and passing through coarse filters. The water can then be kept in a storage tank where natural sedimentation occurs and natural ultraviolet light can break down pathogens. The next stage is the pre-chemical stage which can involve aeration, use of activated carbon and use of aluminium salts or iron salts. Aluminium salts are the more commonly used. The simplest coagulant is aluminium

Figure 8.
Drinking water treatment [42].

sulphate $Al_2(SO_4)_3.14H_2O$ known as alum. Aluminium sulphate salt is converted to an aluminium hydroxide complex in the water which is known as a polynuclear species $Al_{13}O_4(OH)_{24}{}^{7+}$ and in the presence of polyelectrolytes aids in the coagulation process [43]. The traditional view of coagulation is that it facilitates agglomeration of small colloidal particles into large particles of a size that can be physically removed. Dirt, chemicals and pathogens in the water attach to the aluminium hydroxide during the coagulation process. Dual coagulants, a hydrolysed metal salt and a low concentration of polyelectrolyte, can be used. The most common polyelectrolytes in water treatment consist of polydiallydimethyl ammonium chloride (polyDADMAC) and epichlorohydrin dimethylamine (epiDMA) [43]. Coagulation/flocculation technologies can also remove total organic carbon (TOC). High-charge-density cationic polymers bridge particles of the primary coagulations to form a floc to initiate the flocculation process. Sedimentation and decanting of the water occur at this stage, and the floc can fall out of the water phase. The gravity sedimentation removal of particles from water follows the coagulation/flocculation process. High-rate gravity sedimentation involves blasting flocculation using polymers. This process is commercially known as ACTIFLO process, microsand 70–100 μm is dosed together with the polymer forming a lamella [44]. The lamella settles out of the water clarifying the water [45]. In the dissolved air flotation (DAF) technique, part of the treated water is recycled under pressure to dissolve air in the water as part of the aeration process. The floc attaches to the air bubbles, moves to the top of the water and can be removed [45].

The next stage of the treatment is sand filtration; enhanced filtration systems such as granular media filtration and disinfectant membranes are also readily used. The filtration process can remove excess pathogens and chemicals from the water [46].

The post-chemical stage involves disinfection of the water; disinfectants used include hypochlorous acid, ozone and chloride dioxide [47]. Many water utilities have moved to the use of multiple disinfectant rather than just chlorination. Advanced technology with the use of ultraviolet light to create free radicals which can break down pathogens can also be used.

The most common disinfectant used is chlorine (Cl_2) which reacts with water forming.

$$Cl_2 + H_2O \ = \ HCl + HOCl \tag{1}$$

Hypochlorous acid which is a weak acid can dissociate into hydrogen ion, H^+ and hypochlorite ion OCl^-:

$$HOCl \rightleftharpoons H^+ + OCl^- \quad (2)$$

Both HOCl and OCl^- can act as disinfectants [47].

Chlorine dosing is the best disinfectant as it can leave a residual in the water to aid disinfection. Ozone and ultraviolet light do not give a residual disinfectant in the water. Post-chemical treatment can also involve pH control. Fluorination can also be used as a post-chemical treatment in certain countries such as Ireland [47].

The water is then stored in reservoirs before being used. Residual disinfection in the storage facility is important to prevent contamination of the storage space. The network management is also very important, and residual disinfection is important to maintain water safety. Microbial slimes in the distribution system pipes can cause the development of waterborne viruses and bacteria and invertebrate grazing in the pipe systems [48]. Lead piping is also an issue in the European countries [49]. Breaks in pipe systems are concerns in terms of society's water footprint and overall sustainability. Infiltration and leakages in pipe systems are other issues. Excessive particulate matter in pipe systems can also give rise to microorganism build-up [48]. Stagnation in the pipes can also give rise to microbial slimes [48].

Certain privately owned ground water supplies and group schemes incorporate treatments such as aeration and disinfectant using chlorination and ultraviolet light disinfectant [47].

For conventional drinking water treatment, sufficient time for each step of the process, maintenance and energy use is important to management in terms of moving in the direction of an eco-label for water treatment.

4.1 Water treatment in developing countries

In developing countries, the priority is to obtain biologically safe water. Waterborne diseases is a large issue globally especially in tropical countries with poor water supplies [17]. The chemical and physical characteristics of water should not be overlooked, but emphases on the biological quality treatment should be salient.

The treatment that is utilised in developing countries shall now be discussed.

The two treatment systems include:

a. Central source treatment systems

b. Point-of-use (POU) treatment

Central source systems involve water treatment in a central location followed by distribution to the consumer. This is known as medium- or large-scale treatment. The treatment is similar to conventional treatment used in developed countries. This type of treatment can be suitable for urban areas in developing countries. Challenges of network contamination and maintenance of the infrastructure are a large concern [48]. The treated water can be transported by tanker to rural areas, if piped networks are not present in a particular area.

Point-of-use (POU) treatment involves 'informal sources' treated at source which are also known as small-scale treatment. Risk management in terms of pollution of informal sources such as rainwater, shallow boreholes and small streams treated per household is a large concern [50]. When deciding on which type of POU treatment variables to consider, it should include ease of use, price, time for treatment and volume of water treated.

A selection of point-of-use (POU) treatment commercial systems and small-scale technologies that can be utilised can be seen in **Table 2**.

Some interesting point-of-use (POU) treatments will be discussed below.

4.1.1 Chlorination

Chlorination was initially used to disinfect public water supplies since the early 1900s, in cities in Europe and the United States of America. In developing countries, a common method for treating water at source involves using a sodium hypochlorite solution placed in a bottle with directions for use. The user adds one full bottle cap volume of the solution to clear water (or two cups volumes for turbid water) to a standard-sized storage container. The user shakes the container and then waits 30 minutes before drinking. The reason that chlorination is so popular is because it leaves a residual in the water matrix [57].

One of the large challenges of chlorination is the presence of high organic composition that can give rise to the formation of disinfectant-by-products which are considered carcinogenic.

4.1.2 Chlorination and flocculation

Hybrid water treatment technologies are commonly used such as a combination of chlorination and flocculation. An example of the combined technologies involves a small sachet containing both a powdered ferrous sulphate (a flocculant) and calcium hypochlorite (a disinfectant). A commercial design of this approach is known as Pu-R. To use Pu-R, users open the sachet and then add the contents to an open bucket containing 10 litres of water maximum. The bucket contents are stirred for 5 minutes, and the solids in the water will then settle to the bottom of the bucket [56, 57].

The water is then strained through a cotton cloth into a second container; the user then waits 20 minutes for the hypochlorite to inactivate the microorganisms. This technique has been shown to remove bacteria, viruses and protozoa, even in highly turbid waters [58].

Chlorination and flocculation can eliminate the formation of disinfectant by-products as the flocculation process can remove organics from the water.

4.1.3 Filtration

Filtration and innovations in filtration are a growing interest in the water industry. Basic filtration involved the use of porous stones, and a variety of other natural materials have been used to filter visible contaminants from the water for hundreds of years. Filters are an attractive option for household treatment [59]. A number of interrelated removal mechanisms within the filter media are relied upon to achieve

Commercial name	Information reference
Biosand filter and ceramic water purifier	[51]
Kanchan™ Arsenic filter (KAF)	[52]
AquaEst RainPC®	[53]
Solar disinfection (SODIS)	[54]
LifeStraw®	[55]
PUR Purifier of Water™	[56]

Table 2.
Selection of point-of-use (POU) treatments and small-scale treatment.

high removal efficiencies. These removal mechanisms include the following processes: (1) sedimentation on media (sieve effect), (2) adsorption, (3) absorption, (4) biological action, and (5) straining [60].

There are many porous materials which are locally available and inexpensive options for filtering water. They are simple and easy to use, and the filtering material has a long lifetime. However, filtration has its drawbacks due to maintenance issues such as back flushing of filters and lack of residual effects with regard to disinfection. Again, hybrid water treatment technologies involving basic filtration have been investigated. An interesting membrane hybrid system combining trickling filtration filter and a thin layer of biomass biosand to reduce organic matter can be seen in the literature [61]. Other membrane designs that can be utilised include disc and tubular design, microfiltration, ultrafiltration, nanofiltration and reverse osmosis. The scope for the removal of contaminants by filtration processes can be seen in **Figure 9**.

4.1.4 Filtration and biosolids

More advanced filtration methods using biosolids have been developed. The biosand filter (BSF) is a slow sand filter which can be adapted for use at home. When the water pours over the filter, a shallow water layer is formed which allows a bioactive layer to grow on top of the sand, which breaks down pathogens in the water. A plate protector prevents the water layer from being disturbed when more water is passed through the filter. In the literature it can be shown that the BSF has high efficiency to remove bacteria and protozoa from the water [63, 64].

An interesting study to remove arsenic from the water in the presence of iron can be seen in the literature in Nigeria using a sand filter. The filter immobilises arsenic (As) via co-oxidation with Fe(11) and sorption to or co-precipitation with the formed Fe(111) to the filter surface [65].

One of the problems with the prolonged use of filters is the potential build-up of biofouling on the surface of the filter [66].

4.1.5 Filtration and chlorination

A combination of filtration and chlorination systems is also regularly used [67]. Ceramic and slow sand filtration lack a residual disinfectant protection of water, to compensate for this filtration followed by chlorination can be used [68, 69].

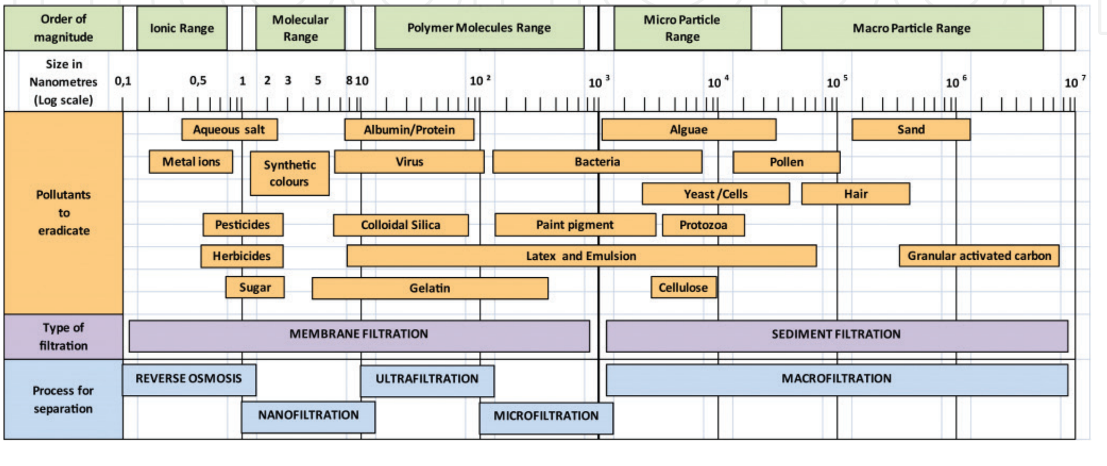

Figure 9.
Filter/membrane particle sizes and what contamination can be removed [62].

4.1.6 Innovative solid materials

To remove arsenic (As) metal and its metalloids from drinking water, metal absorption phases have been utilised including iron oxide-coated sand, ferrihydrite red mud, activated alumina, TiO_2, $FePO_4$ (amorphous), MnO_2, MnO_2-loaded resin, natural zeolites (such as clinoptilolite), iron oxide and iron-loaded chelating resin [70]. The use of the biosand iron oxide-coated sand filters to remove viruses from water can be seen in literature. The method consists of electrostatic adsorption of negatively charged virion to sand particles with positively charged iron oxides [71].

4.1.7 Solar disinfectant

The role of natural sunlight to disinfect water has much potential in developing countries. A common method in use is known as the solar disinfection (SODIS) method. Solar disinfection (SODIS) method was initially developed to inexpensively disinfect water used for oral rehydration solutions [72]. The SODIS method involves filling 0.3–2.0 litres of plastic soda bottles with low-turbidity water, followed by shaking to oxygenate the water. The bottles are left for 6 hours in sunny conditions and 2 days if weather is cloudy [73]. Studies have shown that the SODIS method inactivates bacteria and viruses; the protozoa cryptosporidium and giardia are also sensitive to solar irradiation [74]. Other innovations using ultraviolet light can be seen in the literature [75–78]. One of the major advantages of ultraviolet light technology is its cheapness. One of the challenges is designing the technology for max trapping of the ultraviolet light. Seasonal factors can affect the intensity of the ultraviolet light. Small volumes and length of time to treat the water can be a concern. If water has high turbidity, it is recommended to pretreat with flocculation or filtration before ultraviolet light treatment. Presently, the container type is plastic.

4.1.8 Innovative technologies and nanotechnologies

Photocatalysts based on nanocatalysts such as the TiO_2 catalyst harness ultraviolet radiation from the sunlight and use the energy to break down substances such as microbes, pesticides, dyes, crude oils and organic acids [79]. Pilot projects for drinking water purification in developing countries have only begun involving TiO_2 immobilised on plastic which is activated by ultraviolet light to disinfect the water [80]. Other nanotechnologies are at developing stage [81, 82].

5. Challenges

Challenges to the drinking water supply in developing countries include the natural scarcity of water source in certain areas. Floods can create more siltation problems in river systems as well as the contamination of rivers and large dams giving rise to source-receptor issues. Climate change and water scarcity are also some of the concerns [83, 84]. Stratification problems in lake abstraction points and aeration of abstraction point to break down the thermocline layer are needed which requires much energy.

Poor access to water and poor water resource management must be addressed. Poor water productivity in the agricultural sector can impact on water quality [85]. Water affordability issues and the challenges of investing in water infrastructure need to be addressed [86, 87]. Storage and confidence in storage facility container to prevent contamination entail education and awareness of cross-contamination [67].

Figure 10.
Variables to consider in integrated water management [88].

To maintain clean drinking water, an integrated approach is needed in developing countries. Proper management of solid waste and waste water can enhance the quality of our drinking waters [88, 89].

Private companies' management of water treatment systems is an interesting debate in developing countries [90]. Water conservation and future issues of water recycling have been discussed in developed countries and can also be applied to developing countries.

Large-scale and small-scale technologies are important to review in terms of maintenance and monitoring [91]. Energy and water treatment needs are a concern [92]. Most developing countries are located in regions of the world which have the most droughts and seasonal changes in precipitation and evaporation which challenges the source of the water at different times of the year [93] (**Figure 10**).

Natural disasters such as storms and earthquakes can affect infrastructure of large-scale system and small-scale systems; point-of-use (POU) treatments are needed to compensate for these issues. Education on the use of point-of-use (POU) treatment in local communities must be encouraged [76]. At different times of the year, the water source availability varies for examples rivers are used during the wet season and bore well water sources are used during the dry season.

6. Conclusion

Access to safe drinking water is also considered to be a human right, not a privilege, for every man, woman and child (World Bank, 2018).

The World Health Organization emphasizes that 'the introduction of water treatment technology without consideration of the socio-cultural aspects of the community and without behavioural, motivational, educational and participatory activities within the community, is unlikely to be successful or sustainable' [94]. Research, development and deployment (R&D&D) of clean water technologies for developing countries are important to nurture. All these initiatives can help move in the direction of the challenge by the Millennium Development Goals (MDGs) to halve the proportion of the people without access to safe water by 2015 [95]. Clean water is only as clean as waste water management and treatment linking with global waters and the practically closed loop [96]. Performance management framework surrounding drinking water must be nurtured [97]. Private companies organising treatment systems must be properly introduced [98].

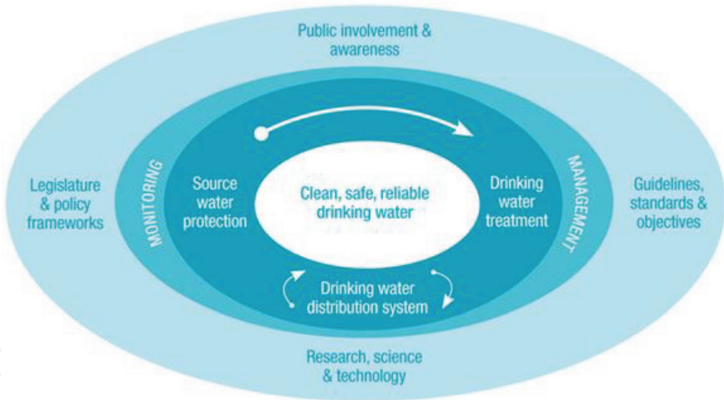

Figure 11.
Drinking water sustainability [113].

Certain water sources used for different applications challenge our water resources such as industrialisation needs of developing countries. Transport costs and informal sources are important to develop [99]. The human carrying capacity and population increase and water use are important to monitor [100].

Legislation and risk management audits and awareness in terms of water conservation issues and human behaviour towards water are important to address [101, 102].

Informal water supply involving point-of-use (POU) treatment will need to be continuously integrated with central supply systems (CSS) as CSS will not facilitate all water demands [50, 103–105]. Cost issues for integration need to be addressed [106].

Two key indicators highlighted by the World Bank are 'annual freshwater withdrawals' and 'improved water source' [107, 108]. Linked with these two key indicators are performance management, public awareness and conservation issues of central treatment systems and point-of-use (POU) treatment [109, 110].

Waterborne diseases will always be researched in the future [111]. Industrial regulation and waste management especially when industrialisation is occurring at a rapid rate in developing countries are important issues in the future. Good waste management practice will always be embedded in achieving clean drinking water supplies [112] (**Figure 11**).

The full multi-barrier approach from the source to the tap linking with policy should be a future strategy [113]. Network maintenance and provisions for same are salient within the strategy [114, 115]. A harmonisation approach to water sustainability should be embedded in future water planning [116, 117]. The harmonisation approach would involve common arrangements, simple procedures and sharing of information and standards [118]. Developing countries should nurture the opportunity to learn from developed countries about their successes and failures. Sustainability and water security will also be embedded in the future of water management. Informed education, information sharing and simplified production are important to ensure good water quality [119]. Health and water are fundamentally interlinked and need to be constantly researched in terms of global development [120–123].

Acknowledgements

I wish to acknowledge the Limerick Institute of Technology for facilitating easy access to journals and ordering of interlibrary loans. I wish to thank David

Bowlin, of 'Laboratory of Atmospheres, NASA/GSFC. Greenbelt M.D. USA.; Science Systems and Application, Inc Lanham M.D. USA', for producing the map of global precipitation. I also wish to acknowledge a sister of the Cross and Passion order who ministered in Francistown South Africa for her insight into the drinking water source during the wet and dry season. I also wish to thank the EPA Ireland for giving me an Image from their *Drinking water report Public supplies* 2017.

Conflict of interest

None.

Author details

Josephine Treacy
Department of Applied Science, Limerick Institute of Technology, Limerick City, Ireland

*Address all correspondence to: josephine.treacy@lit.ie

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