Bottled Water: Global Impacts and Potential

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Abstract This chapter discusses the rationale beyond global expansion of bottled water, components of bottled water industry, and problems associated with bottled water production and consumption; energy demand; health concerns; and plastic pollution. From technology perspective, bottled water can be considered a decentralized water system which distributes water for human consumption via a portable container instead of a pipeline which is a required component for transporting water via conventional water supply infrastructure. It is concluded that the current bottled water industry is not a part of a sustainable solution for the overall challenge of providing safe drinking water worldwide. However, bottled water can be a part of an overall solution to global lack of safe drinking water and community development if innovative water treatment technologies, renewable energy use, and biodegradable plastic (or similar materials) are incorporated into bottled water production and infrastructure system design.

Keywords Decentralized water system • Health impacts • Plastic pollution • Energy consumption • Sustainability

1 Introduction

Early civilizations used various types of vessel, made from animal skin or clay, to carry water from its source for consumption in royal palaces, peasant households, war zones, and other locations [1, 2]. In modern times, the synonym "bottled water" refers to various sizes of containers (10 oz to 20 L or larger) that provide water to consumers in various situations and environments.

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The modern water bottling industry was launched in 1960s simultaneous with plastic invention. However, the industry mostly flourished in 1990s when polyethylene terephthalate (PET) plastic became available. PET plastic, because of its light weight and strength, is highly advantageous for packaging and transportation of bottled water. As a result, in 1990s, bottled water production grew worldwide from $115 million to $4 billion industry [3]. Today bottled water is a major global commodity, a $22 billion industry that ranges from very small local bottling operations to giant international corporations [3, 4]. According to the International Bottled Water Association (IBWA), world's top 10 bottled water consumer countries are United States, Mexico, China, Brazil, Italy, Indonesia, Germany, France, Thailand, and Spain (2009 data) [5]. In terms of per capita consumption, the top 10 countries are Mexico (234 L/capita), Italy, United Arab Emirates, Belgium-Luxembourg, Germany, France, Lebanon, Spain, Hungary, and the United States (105 L/capita) [6].

Several factors have contributed to high consumption of bottled water. First, high consumption of bottled water is attributed to consumer preferences and perception [7–11]. Consumer preference for bottled water consumption appears to be due to its ease of transportability but most importantly due to public perception about quality of public water (tap water). Many consumers perceive bottled water as "cleaner" and/or "healthier" than tap water, and some prefer the taste of bottled water to that of tap water. Current literature supports the rationale of consumer perception about the quality of tap water. For example, recent literature cites the presence of emerging pathogens such as *Legionella spp*., *Mycobacterium spp*., *Aeromonas spp*., and other opportunistic pathogens in drinking water distribution pipes and home plumbing systems [12].

Second, bottled water availability is considered a necessity in many rural and isolated communities of the developed countries as well as in rural and suburban communities of most developing countries [13]. Reasons for bottled water demand in these areas include lack of confidence in quality of public water as noted above and low quality of private water supplies such as household wells and privately owned small water supply systems. Furthermore, bottled water availability in these areas is justified due to high cost of extending centralized public water distribution pipelines to areas of low-density population and/or extreme topographic features. Third, around the world, bottled water is considered an absolute necessity during emergency conditions when public water supplies are disrupted, at least temporarily, due to natural disasters or man-made events.

2 Water Bottling Industry

Major components of a water bottling industry include plastic bottle production, water source development, water treatment technology, bottled water packaging, and bottled water transport and distribution to markets.

2.1 Plastic Bottle

Plastic bottles are mostly produced elsewhere and transported to the water bottling plants for packaging. As stated earlier, PET plastic is the most common type of material used in water bottling industry. PET plastic, a polymer resin derived from petroleum hydrocarbons, consists of a chain of repeating organic molecules with high molecular weight. A comprehensive discussion of PET plastic production is beyond the scope of this chapter. For details, the curious reader is referred to polymer chemistry publications; for example, see Speight and Lange [14].

2.2 Water Source and Treatment

Worldwide, depending on geography, all types of water—surface water, groundwater, spring water, and salt water are used to produce bottled water. Most water bottling plants are installed in the proximity of an available water source.

Selection of water treatment process to produce bottled water depends on quality of water source, scale of water bottling plant, and available financial resources. In general, water treatment processes in large bottled water industries are identical to those implemented in conventional and/or advanced public water treatment plants. Water treatment process at very small water bottling plants which mostly use spring water or groundwater is sometimes limited only to disinfection. Details of water treatment process are provided in Sect. 3.3 of this chapter.

2.3 Bottled Water Packaging

Bottled water packaging is a mechanical operation. Bottles are filled with water of acceptable quality and packaged appropriately for transportation and delivery to consumers. Important packaging considerations include quality control of bottled water, meeting various regulatory requirements, and cost-effectiveness of operation. For quality control purposes, bottled water packaging is regulated in accordance with established standards and regulations. Bottled water regulations are discussed in Sect. 4.1 of this chapter.

2.4 Transportation and Marketing

Bottled water transportation to markets and marketing strategies are critical parameters that influence energy consumption and bottled water cost. The impacts of transportation mode and market distance on energy consumption are discussed in Sect. 3.4 of this chapter.

Consumer preference for increased bottled water consumption noted earlier indicates industry's successful marketing strategies. However, in recent years, in some European countries and the United States, high bottled water consumption has instigated a debate over necessity, appropriateness, cost, and negative environmental impacts of bottled water consumption. To combat the anti-bottled water movement, major bottled water industries have shifted marketing strategies promoting green technologies and ethical bottled water production [15, 16]. For example, Fiji Company has launched a campaign to market carbon neutral bottled water [17], and CocaCola Company markets Dasani bottled water which claims reduced bottle size and promotes recycling [18]. These marketing strategies exploit consumers' willingness, particularly in developed countries, to consume bottled water in an ethical manner for the sake of environmental protection, and therefore justify imposing additional cost to bottled water consumers.

3 Energy Demand

Energy demand is a significant factor in producing bottled water and its transport and distribution to markets and ultimately determines bottled water cost. An overview of energy consumption in various components of bottled water industry is provided below.

3.1 PET Bottle Production

At present, bottled water industry depends largely on fusel fuels to meet its energy needs. O'Connor [19] estimated that in the United States about 2.4 million kL of fossil fuel is used for PET bottle production. According to Woods [20], worldwide, the amount of fossil fuel used for PET bottle production is about 48 million kL.

Gleick and Cooley [21, 22] have cited two comprehensive studies on energy demand for producing PET plastic and PET bottles. According to those studies [23, 24], energy required to produce PET resin is approximately 70–83 megajoules (MJ)/kg of PET resin. An additional 20 MJ/kg of PET is required to produce a finished PET bottle. It is estimated that approximately 300 billion MJ of energy is used for producing PET bottles in order to satisfy global bottled water demand [21].

3.2 Water Source Development

Energy is used to pump and transport water from water source to water bottling plant. Energy demand depends on the proximity of source water to bottling plant. Therefore, energy use is determined by the depth of groundwater aquifer, proximity of bottling plant to surface water, and landscape topography. In general, energy requirement for water source development in water bottling industry is similar to energy requirement for public water systems and can be estimated from existing publications; for example, see Larsen [25].

3.3 Water Treatment

Similar to public water, major factors that affect energy use for water treatment of bottled water include chemical and biological characteristics of water source and type of water treatment technology. As noted earlier, potential sources of water include various freshwater sources and saltwater with different degrees of treatment requirement. For example, energy demand for treatment of brackish and seawater is 4.0 kWh/1.0 m^3 to 10 kWh/1.0 m^3, several times higher than energy need to treat freshwater using reverse osmosis technology [26]. Table 1 shows estimated energy needs for various water treatment technologies for public water which are also applicable to bottled water [21].

The major energy use in a small decentralized packaged water treatment system is attributed to a pump that operates the water treatment unit. For these packaged treatment systems energy usage is in the range of 3.0 kWh/1.0 m^3 to 3.5 kWh/1.0 m^3 depending on water quality [30].

3.4 Bottled Water Transportation

As noted earlier, bottled water transportation mode and distance to markets are major factors affecting energy use and ultimately cost of bottled water. Weber and Matthews [31] estimated average short travel distance for delivery to retailer and total lifecycle transportation travel distance as 330 km and 1,200 km, respectively. Furthermore, fuel consumption for 330 km and 1,200 km transport was estimated as 0.891 MJ/kg (844 BTU/kg) and 3.24 MJ/kg (3,073 BTU/kg), respectively.

Dettore [32] used lifecycle assessment (LCA) technique to quantify lifecycle energy need for plastic bottled water. The study concluded that more than 70 % of total energy demand in water bottling industry can be attributed to plastic bottle production if bottled water is produced and marketed locally, i.e., short travel distance. However, transportation energy needs will be the dominant factor if bottled water is transported long distances, for example, to national and overseas

Table 1 Energy requirements for various water treatment technologies [21]

Treatment technique	Energy use (kWh/ million L)	Data source
Ozone		
Pre-oxidation (pretreatment)	30	SBW Consulting 2006 [27]
Disinfection	100	SBW Consulting 2006
Ultraviolet radiation		
Bacteria	10	SBW Consulting 2006
Viruses	10–50	SBW Consulting 2006
Microfiltration/ultrafiltration	70–100	SBW Consulting 2006
Nanofiltration (source TDS = 500–1,000 ppm)	660	AWWA 1999 [28]
Reverse osmosis		
Source TDS = 500 ppm	660	AWWA 1999
Source TDS = 1,000 ppm	790	AWWA 1999
Source TDS = 2,000 ppm	1,060	AWWA 1999
Source TDS = 4,000 ppm	1,590	AWWA 1999
Seawater Desalination (RO)	2,500–7,000	NRC 2008 [29]

Table 2 Impact of transportation mode and travel distance on energy use [21, 22]

Scenario	Medium truck (km)	Heavy truck (km)	Railroad (km)	Cargo ship (km)	Energy use (MJ/L)
Local production	200 (local delivery)	0	0	0	1.4
Spring water form Fiji	100 (local delivery)	0	0	8,900 (Fiji to Long Beach, U.S.)	4.0
Spring water from France	100 (local delivery)	600 (Evian to Le Havre, France)	3,950 (New York to Los Angles)	5,670 (Le Havre to New York)	5.8

markets. As an example, Table 2 shows possible impact of transport mode and travel distance on bottled water energy use [21, 22].

4 Health and Environmental Impacts

Noted areas of health and environmental concerns related to bottled water production and consumption include inadequacy of regulation and/or lack of regulatory enforcement, potential contaminant leakage from plastic bottle to bottled water, plastic pollution due to indiscriminate disposal of used plastic bottles, potential air pollution due to incineration of used plastic bottles, and atmospheric CO_2 emission due to high energy consumption attributed to bottled water production and transportation [33].

4.1 Bottled Water Regulation

Worldwide, bottled water regulations are developed to ensure safety of bottled water. In general, the World Health Organization (WHO) Guidelines for public drinking water systems are applicable to bottled water industry. Details about global drinking water standards and regulations are provided in Chap. 1 of this book. Below is an overview of typical bottled water regulations in several countries.

In the United States, bottled water production is regulated by the U.S. Food and Drug Administration (FDA) as a packaged commodity [U.S. Code of Federal Regulations (CFR), Title 21, Part 129 and Part 165.110(b)]. The FDA's bottled water standard of quality regulations generally follow national primary drinking water regulations for public water supplies (tap water) which is authorized by the Safe Drinking Water Act and regulated by the U.S. Environmental Protection Agency (EPA). Therefore, water quality standards for contaminants in bottled water are identical to the allowed Maximum Contaminant Levels (MCLs) in public drinking water supplies. Bottled water is labeled in accordance with type of source water based on the EPA classifications [34].

In Canada, similar to the United States., bottled water is regulated as a food package, and therefore, it must comply with Canada's Food and Drugs Act and Regulations [35]. Canadian regulations include specific microbiological standards, acceptable water treatment processes, and labeling requirements.

In most European countries bottled water production is regulated by the European Communities Regulations (e.g., FSAI [36]). These regulations provide the definition of mineral water, spring water and "other water," water source exploitation, water treatment, microbiological criteria, chemical contaminants, and bottled water labeling and packaging.

In China, bottled water industries use a variety of drinking water standards. These include national standards, local government standards, and standards developed by water bottling industries. However, according to China National Center for Food Safety Risk Assessment, unified national standards for regulating water bottling industry will be published in the near future [37].

In Japan, bottled water is usually referred to as "mineral water" and is regulated under the Consumer Product Safety Law [38]. Japanese regulations for bottled water cover safety, bottled water labeling, disposal of used containers, and importation of bottled water.

4.2 Regulation Inadequacies

Regulation enforcement and inadequacies are noted areas of concern related to safety of bottled water. Discussion below focuses on bottled water regulation in the United States as a typical example.

As noted above, in the United States, bottled water is regulated as packaged food. Investigators have identified the following problems with bottled water being regulated as packaged food: (1) the FDA requires only once a year testing for bottled water quality, while in comparison, the EPA mandates daily water quality testing and frequent monitoring of public drinking water supplies for contaminants; (2) the FDA does not have the specific statutory authority to require bottled water industry to use certified laboratories for water quality tests or to report test results, even if violations of the standards are found; and (3) the FDA's bottled water labeling requirements are similar to labeling requirements for other foods, but the information provided to consumers is less than what EPA requires of public water supplies under the Safe Drinking Water Act (GAO [39]).

The Natural Resources Defense Council (NRDC) conducted a comprehensive study of bottled water quality [40]. The investigation was based on published and unpublished data, surveys, expert interviews, and "snapshot" water testing of more than 1,000 bottles of water sold under 103 brand names. The NRDC study found that, in most cases, water treatment technologies for bottled water are similar to public drinking water supplies and reported some problems. For example, it was found that detected contaminants exceed established bottled water guidelines and standards in one-third of bottled water brands. It is noted that unlike public water supplies, bottled water is not packaged with a residual disinfectant such as chlorine. There is increased risk for bacterial growth since bottled water is often stored at relatively warm (room) temperatures in markets and elsewhere for extended periods of time. Studies show that during storage substantial growth of certain types of bacteria, such as *heterotrophic-plate-count-bacteria* and *Pseudomonas*, can occur in bottled water [40]. Even when there are relatively low levels of bacteria in finished bottled water, total bacteria counts in bottled water one week after storage can increase by 1,000-fold or more [41].

A study based on survey of 173 bottled water brands found that overall, 18 % of bottled waters producers fail to list the location of source water, and 32 % do not disclose water treatment process or water quality information [42]. Furthermore, the study noted that labels of nine of the ten top-selling domestic brands in the United States do not identify specific water source or water treatment process and do not provide contact information for consumers seeking additional information on water quality.

4.3 Potential Contaminant Leakage

The mechanism of contaminant leakage from plastic bottle to bottled water is not well understood. However, existing scientific literature presents a snapshot of potential contamination and implications of chemical leakage to bottled water. For example, Ceretti et al. [43] have noted leakage of acetaldehyde and formaldehyde. These two compounds are used in plastic bottle production and are contaminants with possible mutagenic or carcinogenic properties. The International Agency for Research on Cancer (IARC) has cited acetaldehyde as a possible human carcinogen that is genotoxic in many biological systems [44]. Formaldehyde has been identified as a genotoxic chemical that has demonstrated DNA and chromosomal damage to a number of organisms [45].

Bisphenol A (BPA), an organic compound, is also cited as a contaminant of concern in bottled water. A Japanese study found BPA concentrations of 0.24–3.5 μg/L in commercial bottled waters [46]. Additionally, antimony, a potentially harmful substance, has been observed to leak through plastic water bottles in both high temperature and long-term storage settings [47, 48].

4.4 Plastic Waste Pollution and Management

Around the world, plastic waste pollution of inland waters and oceans caused by disposal of used plastic bottles and similar products is major threat to protecting water quality and ecosystems (e.g., NRDC [49]). Therefore, implementing appropriate management practices for disposal of used plastic bottles is a critical global issue. Current management practices for disposal of used plastic bottles include landfill disposal (underground burial), incineration, and recycling.

4.4.1 Landfill Disposal

At present, landfill disposal is the most common practice for disposal of plastic bottles. For example, in the United States about 80 % of used plastic water bottles are disposed in landfills [3, 39]. However, landfill disposal is considered an environmental dilemma due to potential for chemical leachate from disposed plastic to soil and groundwater systems. It is estimated that it will take more than 1,000 years for a plastic bottle to decompose and be regarded environmentally safe [50]. In addition, land requirement for landfills is a major limitation particularly in urban areas and is expected to become more limited as the global urban population continues to rise. Significant amounts of used plastic bottles to be disposed of are transported to landfills away from urban centers, spreading plastic pollution to rural and isolated areas and increasing the energy footprint of the plastic bottle life cycle.

4.4.2 Incineration

Incineration or combustion of plastic bottles is practiced worldwide as a part of incineration processes for other types of wastes generated in municipal areas. Incineration of plastic waste has been a common practice in some Asian countries since 1990s [51], and in recent years it is practiced in the United States as well. In 2011, the United States disposed of 29.3 million tons of waste by combustion process [52]. However, it is unknown how much of this waste specifically originates from PET plastics. It is estimated that rubber tires make up the majority of combustion programs in the United States.

Several studies show the impact of incineration on air pollution due to release of harmful gases [53]. However, energy generation and capture of heat during the consumption process are considered a positive outcome of incineration [54, 55]. Environmental friendly alternatives for thermal processing of plastic wastes, such as pyrolysis and gasification, are currently investigated through pilot projects and commercial scale research [55]. These new technologies show promise for safe disposal of used PET bottles in the future.

4.4.3 Recycling

At present, recycling is considered the most appropriate management option for used plastic bottles. Recycling of used plastic bottles facilitates significant environmental benefits such as saving landfill space and less atmospheric pollution caused by incineration. However, worldwide, recycling of plastic bottles is not yet a common practice. For example, in the United States only about 28 % of used PET bottles are recycled [5]. Furthermore, there are limitations for implementing a successful recycling program. These include economic viability, capacity, distribution, and energy demand [51, 56, 57]. Ferrier [57] noted limited impact of recycling on energy conservation. It was estimated that increasing PET bottle recycling rate from 0 % to 100 % decreased energy use from 5.9 GJ/1,000 L to 4.1 GJ/1,000 L.

4.5 Atmospheric Pollution

Factors that contribute to atmospheric pollution include incineration of used plastic bottles noted earlier and dependency on fusel fuel consumption for bottled water production and transportation. Several studies show the impact of burning plastic and releasing of harmful particles such as CO_xNO_x, SO_x, and polycyclic aromatic hydrocarbons to atmosphere [53]. High fusel fuel consumption can lead to atmospheric CO_2 emission, a major contributor to global warming and climate change. However, atmospheric pollution concerns noted above are not unique to bottled water industry and are a component of the overall plastic use and industrial activity in our modern society.

5 Bottled Water: A Decentralized System

As stated earlier, a major benefit of the bottled water is its practicality for providing safe drinking water to communities where extending public water distribution pipelines can be cost prohibitive. In these areas, small packaged water treatment bottling plants that use available local water sources can be installed to provide safe drinking water to affected communities.

Advances in small-scale and packaged water treatment technologies allow integration of these technologies into small-scale bottled water production as a decentralized system at the local level. A typical small-scale advanced water treatment package with a water treatment capacity of up to 50,000 L/day can be a unit that is 1.2 m long, 1.0 m wide, and 2.1 m high and can easily fit and operate in a small room [30]. The advanced water treatment package can provide multi-process purification of water with capability to remove a broad range of contaminants including arsenic, pesticides, and metals from any source water. Furthermore, the water bottling system can be equipped with a programmable logic control (PLC) component which facilitates automated operation of the system. The system allows for easy operator training and enables the operator to run the system without supervision.

Packaged water treatment bottling plants illustrated above are installed in several suburban Mexican communities using groundwater or other local water source to provide safe drinking water to needy communities [30]. In some communities, the bottled water plant owner provides 20 L bottled water to each household. Water consumers return empty plastic container to the bottling plant where it is rinsed and refilled for next use. Small volume (half-liter) bottled water is also produced for sale in the local markets and other nearby communities. This approach advances a secondary goal of bottled water production industry as a vehicle for creating small business and jobs at the local level. There are many other cases like this where small-scale micro-entrepreneurs in the water business are striving to provide clean water while also creating a stable income generation source for themselves and their families [58].

6 Conclusions

At present, in many areas, the cost of 1 L of typical bottled water is equivalent or higher than the cost of 1 L of gasoline and several hundred times higher than municipal tap water. As described in this chapter, disadvantages of bottled water consumption include health concerns, inadequate regulations, plastic pollution, and significant energy demand for bottled water production and transportation. An understandable argument is made that the use of reliable public water supplies should not be replaced by more expensive, energy-intensive, and environmentally problematic bottled water. In the United States and a few other countries there is a movement to ban or restrict bottled water use and encourage more use of public water supplies. This movement is evidenced through numerous municipalities banning the use of funds to purchase bottled water, universities instituting a ban on bottled water in vending machines [59, 60], and some cities removing bottled water from market shelves [61], as well as several other instances of various approaches to control consumption of bottled water.

However, despite these concerns, bottled water consumption will continue to rise globally even though some countries for example Spain and Italy show decreasing trends of bottled water consumption [62]. Aside from its convenience of transportability, from health perspective, many consumers consider bottled water an alternative to high sugar content soft drinks. Furthermore, the huge plastic market which is not limited to plastic bottles is developing biodegradable plastic products. And there is strong momentum toward recycling of used plastic bottles. Industrial energy use efficiency and possible use of renewable energy resources for industrial production and commodity transport to the market are expected to alleviate the concern related to high energy consumption and atmospheric pollution due to production of bottled water.

Technically, bottled water production can be categorized as a decentralized water supply system. It facilitates drinking water distribution via bottles to consumers instead of constructing a high-cost conventional water supply infrastructure. Proper implementation of small decentralized water systems such as integrated bottled water and local water sources such as rainwater harvesting systems is expected to alleviate global scarcity of safe drinking water and improve human health and environment [63]. Therefore, with appropriate investment and improved regulation, there is a significant opportunity to incorporate bottled water production as a decentralized water system for community development and job creation in low-income areas as well as in affluent island resort areas where freshwater resources are limited and the island economy and water consumption significantly depend on seasonal tourists.

As the world population continues to climb past seven billion people and the demand for safe drinking water grows, it is critical to incorporate innovative procedures that will enable policy and decision-makers to make bold intellectual and financial investments that will result in providing safe drinking water to large unserved communities throughout the world. Bottled water can be a part of an overall solution to global lack of safe drinking water if innovative water treatment technologies, renewable energy use, and biodegradable plastic (or similar material) production are incorporated into bottled water production and infrastructure system design. Further advances in new and innovative water treatment technologies or using renewable energy sources such as solar and wind energy for water treatment are expected to reduce energy use and increase energy use efficiency for small decentralized water treatment systems including bottled water production.

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