QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

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Summary

Access to clean water is a basic need, which is still not within the grasp of a huge population in the developing world. As international efforts are reaching a decisive momentum to provide clean water to these deprived populations, the estimated rise in use of water will increase sixfold over the next four decades. An assessment of quantity with minimum quality requirements will therefore be important so that the intended benefits of better water supplies can be achieved at lower costs. Quantity of water to be supplied to a community depends on primary and secondary needs of a community that has to be correctly assessed before embarking on a water supply scheme. Technologies for treatment of water to achieve required quality levels are available, the selection of which requires careful evaluation, to suit the local needs.

1. Introduction

Water is essential for human life. Its quantity and quality are equally crucial. However, natural waters are, in most cases, not aesthetically and hygienically fit to be consumed directly, thus calling for some kind of treatment. The plight of over two-thirds of the world's population that lives in developing countries due to exposure to the dangers of unsafe water supply was highlighted during the United Nations International Drinking Water and Sanitation Decade, 1981–1990. Providing access to clean water and sanitation would not eradicate all of such dangers to health, though it would be the single most effective means of alleviating human distress. It has been estimated that domestic water use in developing countries will rise sixfold over the next four decades. Such an increase will demand assessment of quantities of water required and its quality, by different communities, so that safe water can be made available in adequate quantities at reasonable costs. This article describes various factors that are to be considered in assessing quantities of water in schemes for drinking water supply and provides an overview of national and international standards and guidelines on the quality aspects of water used for drinking and other domestic purposes, briefly outlining the treatment technologies to achieve this quality requirement.

2. Assessment of Water Quantity

The basic factors to be considered in the assessment of quantity for a water supply scheme are:

- area and population to be served;
- water demand;
- design period;
- selection of water source
- treatment requirements;
- nature and extent of water transmission and distribution.

Water Demand

Water consumption is commonly referred as the amount of water taken from distribution systems; however, little of it is actually consumed and most of it is discharged as wastewater. The water demand of a community depends on:

- climate;
- standard of living;
- type of water supply system;
- type and extend of sewerage system used;
- water pricing;
- availability of private supply;
- method of distribution.

Depending on the climate and workload, the human body needs about 3 to 10 L of water per day for normal functioning (IRC 1981). While a minimum of 70 to 100 L per capita per day may be considered adequate for the domestic needs of urban communities, the non-domestic needs of urban communities would significantly push this figure up. The non-domestic needs basically depend on standard of living of the community.

Table 1 presents domestic water usage in developing countries for different types of water supply systems indicating the variation in quantity consumed by type of supply. Table 2 presents the design water consumption rates used by various agencies of a developed country (Australia) for comparison.

Table 1. Domestic water supply type and consumption rates.

Table 2. Design consumption rates in Australia.

In assessing per capita demand, one needs to know domestic and small industry needs, institutional and major industry needs, municipal and fire-fighting needs, requirements for live stock, and percentage of wastes among all users. Typical values of various water requirements in developing countries are presented in Table 3. In assessing these needs, attention should be paid to the local needs, habits of the people, and their living standards, and industrial and commercial importance of the area. In the absence of specific data, a preliminary estimation of 1.5 Ls^{-1} (or more) per 1000 people can be assumed for small community water supply schemes.

Table 3. Non-domestic water requirements in developing countries.

An allowance of about 20% for water losses and wastes is also normally included. To allow for future population growth and higher use of water per capita (or per household), a community water supply system must also have sufficient surplus capacity.

In any water supply project, the design period is fixed to compute the design population and thus the design demand. Generally, different components in the system are designed for different periods, as given in Table 4.

Table 4. Design periods of different components of water supply schemes.

3. Assessment of Water Quality

Public, in general, judges the quality of water supplied based on its appearance, taste and odor at the point of its use. Although appearance, taste, odor etc., are useful indicators of the quality of drinking water, their presence may not necessarily make water unsafe to drink. In the same way, the absence of any unpleasant qualities does not guarantee water to be safe for consumption. True that drinking water should be aesthetically pleasing, ideally looking clear, colorless and well aerated with no unpalatable taste and odor. However, suitability in terms of public health is determined by microbiological, physical, chemical and radiological characteristics. Of these, the most important is microbiological quality. Also a number of chemical contaminants (both organic and inorganic) are found in water. These cause health problems in the long run and, therefore, detailed analyses are warranted. The drinking water, thus, should be:

- Free from pathogenic (disease causing) organisms.
- Clear (with low turbidity and little color).
- Not saline (salty in taste).
- Free from offensive taste or smell.
- Free from compounds that may have adverse effects on health or harmful in long term.
- Free from chemicals that may cause corrosion of water supply system or stain clothes washed using it.

Although in small community water supplies (especially in developing countries), the water quality problems are mainly due to bacteriological contamination, a significant number of very serious problems may occur as a result of chemical contamination of water resources. To ensure safe drinking water, detailed quality standards for physical, chemical, microbiological and radiological characteristics of water have been proposed by different countries and international organizations. These guidelines provide the following information for water authorities, health officials, and consumers:

- Day-to-day operational value to ensure that the supplied water does not carry any significant risk to the consumer.
- A basis for planning and designing water supply schemes.
- Assessment of long-term trends of the performance of the system.

Physical Parameters

Important physical quality parameters include turbidity, color, odor, pH and taste. The water quality standards/guideline values for physical parameters are mainly to ensure aesthetic quality of water supplied and as such there is no data or information to set these values based on health considerations. As per the current knowledge, the values of physical characteristics that would threaten health are well beyond the acceptable range.

High turbidity and/or color impart an aesthetically unpleasant appearance to water. The turbidity in surface waters results from the presence of colloidal material (such as clay and silt), plankton, and microorganisms. Apart from aesthetics, turbidity provides adsorption sites for chemicals that may be harmful or cause undesirable taste and odor. It also provides adsorption sites for biological organisms and interferes with disinfection. Color in water can also be due to natural organics such as humic substances or dissolved inorganics such as iron and manganese. When water is disinfected with chlorine, the color-causing organics will produce chlorinated organics that are carcinogenic. Odor problems in water are mainly due to the presence of organic substances. Water supplied to consumers should be free of objectionable taste and odor.

Factors that are normally taken into account for determining guidelines for physical quality parameters include:

- taste and odor thresholds;
- concentrations that would produce noticeable stains on laundry or corrosion and scaling of pipes or fittings;
- concentrations that would be just noticeable in a glass of water.

Table 5 compares the physical quality standards/guidelines adopted in various industrialized countries with that of World Health Organization (WHO).

Table 5. Standards/guidelines for physical quality of water.

Chemical Parameters

Chemical components that are present in drinking water may be either of inorganic or organic origin. Inorganic chemicals occur in drinking water, usually in dissolved form as salts such as carbonates, chlorides, etc., attached to suspended materials such as clay particles, or as complexes with naturally occurring organic compounds. Their presence may be as a result of:

- *Natural leaching from mineral deposits due to geological weathering into water sources.* Prominent examples are iron, manganese, arsenic, nitrates, and fluoride in water. Both iron and manganese at higher concentrations cause stains in laundry and plumbing fixtures, and impart undesirable growth of iron bacteria in water distribution system that can block pipes. Arsenic at concentrations above 0.05 mg/L leads to adverse health effects. Fluoride levels above 1.5 mg/L have been reported to cause mottling of teeth enamel. High levels of nitrates (>10 mg/L) are found to cause methemoglobanaemia in infants.
- *Catchment land use activities leading to exacerbation of natural processes such as salt mobilization.* Industrial and agricultural activities discharge wastes containing chemicals such as chromium, cadmium, lead, mercury, pesticides, etc., that reach water sources. Cadmium, chromium, lead and mercury can be toxic even at low concentrations.
- *Carry over of small amounts of chemicals used in water treatment.* Aluminum compounds are used in water treatment plants as coagulant. Water containing 0.2 mg/L of aluminum (or more) is not suitable for use by kidney dialysis patients.
- *Addition of chemicals such as chlorine and fluoride.* Chlorine is added to water during treatment for disinfection purposes.
- *Corrosion and leaching of pipes and fittings.* Lead and cast iron pipe fittings may corrode and introduce these chemicals in water.

The water quality standards for chemicals present in water are for both inorganic and organic origin. They may or may not directly affect health. For example, inorganic chemicals like arsenic, barium, cadmium, chromium, lead, and mercury, and organic chemicals such as trihalomethanes, pesticides, and polycyclic aromatic hydrocarbons will directly affect human health. Inorganic chemicals like aluminum, copper, iron, manganese, etc., are not directly health related. Out of more than 600 organic substances identified in drinking water, several were found to be carcinogenic and a number of them have been shown to be mutagenic. However, these organics represent only a small fraction of the total organic matter present in drinking water. Table 6 and Table 7 summarize various standards for organic and inorganic chemicals that are both health related and non-health related.

Table 6. Standards/guidelines for inorganic chemicals (non-health related) in water.

Table 7. Standards/guidelines for organic chemicals (health related) in water.

Microbiological Parameters

The most important parameter indicating drinking water quality is the microbiological quality, that is, the presence or otherwise of microorganisms that can cause disease (pathogens). Where drinking water sources and supply systems are not adequately protected, and outbreaks of infectious disease, such as diarrhea, dysentery, etc., are frequently encountered. Diseases are not the only effects caused by the presence of microorganisms in drinking water. Certain cyanobacteria (blue-green algae), for instance, can produce toxins, which affect humans and which may remain in water even when the algae responsible have been removed. There are also a number of ‘nuisance’ microorganisms that occasionally occur in large numbers in drinking water. While such microorganisms do not prejudice health, may cause problems of taste, odor, color and staining of laundry.

Ideally, drinking water should not contain any **pathogens**. However, microbial pathogens that may be found in water include salmonellas, shigellas, pathogenic vibrios, enteroviruses, diagnostic forms of pathogenic protozoa such as cysts of *Giardia lamblia*, as well as certain opportunistic (bacterial) pathogens. Factors that contribute to increase in the number of microorganisms in water may include the organic and microbiological load of the water, sediments, biofilms, system parameters (such as loss of residual chlorine), and physical parameters such as temperature. Only a small percentage of total organic load is available as organic matter for utilization by microorganisms within the aqueous phase. The remaining large macromolecules provide a conditioning film and concentrated nutrient source for subsequent biofilm development. High levels of organic matter affect disinfection creating a high chlorine demand and potential for formation of trihalomethanes (THMs).

High **turbidity** levels of water are usually associated with increased numbers of microorganisms. Turbidity in a water source might be made up of suspended matter such as clay, silt, inorganic and organic matter, planktons, and microscopic organisms. This turbidity will add to sediments in areas of slow flows and dead ends in the treatment and distribution systems. The presence of turbidity also decreases the chlorination efficiency.

A **biofilm** is an organic or inorganic surface deposit consisting of microorganisms, microbial products, and detritus. Biofilms comprise microorganisms and extracellular products. In a distribution or transmission network, the constant removal of biofilm from the pipe surface back into the aqueous phase will contribute to the deterioration of drinking water quality.

The microbiological quality standards/guidelines seek to ensure that water delivered to consumers contains no pathogens. They are based on:

- Ensuring that a number of barriers are developed and placed to prevent contamination of water and to minimize the transmission of microorganisms through the water supply systems.
- Testing the water samples in adequate numbers (based on population served)
- Ensuring that if fecal contamination is detected or suspected, immediate action is taken to rectify the situation and/or advise health authorities.
- Ensuring that the performance of water supply system is evaluated over time to determine the need for further improvement of barriers.

It is not practical to test water for all microorganisms that it might possibly contain. So water is examined for a specific type of bacteria that originates in large numbers from human and animal excreta and whose presence in water is indicative of fecal contamination. Such indicative bacteria must be specifically fecal and not free-living. An indicator organism should always:

- be present when the pathogenic organisms of concern is present, and absent in clean, uncontaminated water;
- be present in fecal material in large numbers;
- be able to respond to natural environmental conditions and to treatment processes in a manner similar to the pathogens of interest;
- be easy to isolate, identify, and enumerate;
- have a high ratio of indicator/pathogen;
- come from the same source as pathogens.

Total coliforms, fecal coliforms, *Escherichia coli*, fecal streptococci, enterococci are some of the microorganisms selected to be indicators. However, total coliforms and fecal coliforms are the most commonly used indicators. Total coliforms are defined as all aerobic and facultative, gram-negative, non-spore forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35 ° C. The definition includes *E.coli* plus species of enterobacter, klebsiella, and citrobacter. Fecal coliforms are a subgroup of total coliforms and can be distinguished in the laboratory through elevated temperature tests (43 to 45 ° C). A comparison of microbiological water quality parameters of WHO and some other countries are presented in Table 8.

Table 8. Guidelines for microbiological quality.

Related Chapters

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Glossary

Biofilm **:** An organic or inorganic deposit consisting of microorganisms, microbial products and detritus on the pipelines.

Microbiological parameters : Microorganisms that indicate water quality deterioration due to human and animal fecal wastes and hence the presence of pathogens.

Pathogens : The microorganisms that causes the water borne diseases.

Physico-chemical parameters : Impurities in water that cause quality deterioration either due to their physical presence or chemical composition, or both.

Water demand : The quantity of water required to supply all the private and public consumption of a community, considered during the design of a water supply system.

Water quality : The quality of water required to drinking purpose.

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Biographical Sketches

S. Vigneswaran is currently a Professor and a Head of Environmental Engineering Group in Faculty of Engineering, University of Technology, Sydney, Australia. He has been working on water and wastewater research since 1976. He has published over 175 technical papers and authored two books (both through CRC press, USA). He has established research links with the leading laboratories in France, Korea, Thailand and the USA. Also, he has been involved in number of consulting activities in this field in Australia, Indonesia, France, Korea and Thailand through various national and international agencies. Presently, Dr. Vigneswaran is coordinating the university key research strengths on "water and waste management in small communities", one of the six key research centers funded by the university on competitive basis. His research in solid liquid separation processes in water and wastewater treatment namely filtration, adsorption is recognized internationally and widely referred.

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EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Types of water supply	Typical consumption (Litres/capita/day)	Range (Litres/capita/day)
1. Communal standpipe (walking distance <250 m)	30	20–50
2. Yard connection (tap placed in house-yard)	40	20–80
3. House connection		
Single tap	50	30–60
Multiple tap	150	70–250

Source: IRC (1981), Small community water supplies, International Reference Center for Community Water Supply and Sanitation, The Hague, Netherlands

Table 1. Domestic water supply type and consumption rates.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Agency	Average daily demand (Litres/capita/day)
Department of Public Works (PWD)	
Coastal and Table lands	275
Western	340
Water Board	
Total system	550
Sydney	517
South Coast	1000
National Capital Development Corporation (NCDC) average	1700

Table 2. Design consumption rates in Australia.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Category	Typical water use
Schools	
Day schools	15–30 L/day per pupil
Boarding schools	90–140 L/day per pupil
Hospitals (with laundry facilities)	220–300 L/day per bed
Hostels	80–120 L/day per resident
Restaurants	65–90 L/day per seat
Cinema Houses, Concert Halls	10–15 L/day per seat
Offices	25–40 L/day per seat
Railway and Bus Stations	15–20 L/day per user
Livestock	
Cattle	25–35 L/day per animal
Horses and mules	20–25 L/day per animal
Sheep	15–25 L/day per animal
Pigs	10–15 L/day per animal
Poultry- Chicken	15–25 L/day per bird

Source: IRC (1981), *Small Community Water Supplies*, International Reference Center for Community Water Supply and Sanitation, The Hague, Netherlands

Table 3. Non-domestic water requirements in developing countries.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Component of water supply	Design period in years
1. Storage by dams	50
2. Infiltration works	30
3. Pump sets	
- all prime movers except electric motors	30
- electric motors and pumps	15
4. Small community water treatment units	15
5. Pipe connection to the several treatment units and other small appurtenances	30
6. Raw water and clear water conveying mains	30
7. Clear water reservoirs at the head works, balancing tanks, and service reservoirs (overhead or ground level)	15
8. Distribution system	30

Source: *Manual on Water Supply and Treatment*, 3rd edition, 1991, Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, Government of India

Table 4. Design periods of different components of water supply schemes.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Characteristics	WHO	Australia	Canada	EEC	US
Turbidity (NTU)	<5	5	5	0–4	1–5
Color (TCU)	15	15	15	20 mg PtCo/L	15
Odor (TON)	NS	No objectionable odor	ND	0–2 dilution numbers at 12 ° C	3
pH	6.5–8.0	6.5–8.5	6.5–8.5	6.5–8.5	6.5–8.5
Taste	ND	ND	ND	2 dilution numbers at 12 ° C	ND

ND: No data available
NS: No Standard
Sources: NHMRC-AWRC (1987), Sayre (1988), WHO (1993)

Table 5. Standards/guidelines for physical quality of water.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Characteristics	WHO	Australia	Canada	EEC	US
Aluminum	0.2	0.2	0.2	NS	NS
Chloride	25	250	400	250	250
Copper	0.1	2.0	1	1	1
Hardness (as $CaCO_3$)	NS	500	500	NS	NS
Total dissolved solids	NS	1000	NS	500	500
Iron (as Fe)	0.3	0.3	0.3	0.3	0.3
Manganese (as Mn)	0.05	0.1	0.02	0.05	0.05
Cyanide	NS	0.05	NS	NS	NS

NS: Not specified or not available
Sources: NHMRC (1987); Sayre (1998); WHO (1993)

Table 6. Standards/guidelines for inorganic chemicals (non-health related) in water.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Characteristics	WHO	Australia	Canada	EEC	US
Trihalomethane precursors, mg/L	0.03	0.2	0.35	0.001	0.1
Pesticides, mg/L	a	NS	0.1	0.005 b	NS
2,4 D, mg/L	0.1	0.1	0.1	NS	0.1
Endrin, mg/L	NS	NS	0.0002	NS	0.0002
Lindane, mg/L	0.002	0.1	0.004	NS	0.0004
Methoxychlor, mg/L	0.02	NS	0.1	NS	0.1
PAHs, μ g/L	NA	0.01	NA	0.2	NA

a: Guidelines are given in Table A.2.2.C of WHO, 1993
b : 0.001 mg/L for each pesticides and 0.005 mg/L for the total amount of pesticides present in drinking water
NA: Not available
NS: Not specified
Sources: NHMRC (1987); Sayre (1998); WHO (1993)

Table 7. Standards/guidelines for organic chemicals (health related) in water.

EOLSS-QUANTITY AND QUALITY OF DRINKING WATER SUPPLIES

Country	Guidelines
WHO[a]	1. All water intended for drinking: *E.coli* or thermotolerant coliform bacterial 0 per 100 mL 2. Treated water entering the distribution system; *E.coli* or themortolerant coliform bacteria, total coliform bacteria 0 per 100 mL. 3. Treated water in the distribution system: *E.coli* or thermotolerant coliform bacteria, total coliform bacteria 0 per 100 mL. For large water supplies, where sufficient samples are examined, must not be present in 95% of samples taken through any 12 month period
United States[b]	Number of coliform bacteria as determined by membrane filter test shall not exceed 1 per 100 mL as the arithmetic mean of all samples examined per month. When 10 mL fermentation tubes are used, coliform bacteria shall not be present in not more than 10% of the portions in any month. When 100 mL tubes are used, coliform shall not be present in more than 60% of portions in any month.
European Community (1992) [c]	The number of total coliforms, fecal coliforms and fecal streptococci determined by the membrane filter method should be 0. When determined by multiple tube method, the Most Probable Number (MPN) should be less than 1.
China[d]	Total colony count not more than 100 per mL; *E.coli* not more than 3 per mL.
India (1973) [e]	Coliform = 0 to 1.0 per 100 mL permissible; 10 to 100 per 100 mL excessive but tolerable in absence of alternative, better source; 8 to 10 per 100 mL acceptable only if not in successive samples; 10% of monthly samples can exceed 1 per 100 mL.
India (1975)[e] recommended	*E.coli* = 0 per 100 mL. Coliforms = 10 per 100 mL in any sample, but not detectable in 100 mL of any two consecutive samples or more than 50% of samples collected for the year.
Philippines (1963) [e]	Coliforms: Not more than 10% of 10 mL portions examined shall be positive in any month. Three or more positive 10 mL portions shall not be allowed in two consecutive samples; in more than one sample per month when less than 20 samples examined; or in more than 5% of the samples when 20 are examined per month.
Qatar[e]	Coliforms = 0 per 100 mL if present in two successive 100 mL samples is considered as grounds for rejection of supply.

Tanzania (temporary– 1974) [f]	Non-chlorinated pipe supplies: 0 per 100 mL of coliforms, classified as excellent; 1 to 3 per 100 mL coliforms, classified as satisfactory; 4 to 10 per mL coliform, classified suspicious; 10 per 100 mL coliforms, classified unsatisfactory; one or more *E.coli* per 100 mL classified as unsatisfactory. Other supplies: as per WHO guidelines.
Thailand[e]	Coliforms = 2.2 per 100 mL. *E.coli* = 0 per 100 mL

Note: The data before 1980 are presented to enable comparison with current standards

Sources: [a] WHO, 1993;

[b] Pontius, 1992;

[c] AQUA, 1992;

[d] IDRC, 1981;

[e] Schulz and Okun, 1984;

[f] National Environmental Board, 1989.

Table 8. Guidelines for microbiological quality.