WATER QUALITY STANDARDS AND MONITORING

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Contents

Summary

Water quality standards indicate the levels that do not cause a hazard to the human body and do not limit uses of water. Each standard varies depending on the natural, social, cultural and economic situation in each region. A reasonable standard reflects the latest scientific information, and it should be evaluated periodically and revised when necessary.

WHO drinking water quality guidelines are widely used to establish national standards for drinking water in many countries. Emphasis is put on clinical and epidemiological studies in establishing guidelines but animal testing can substitute for or supplement data when human-based data are inadequate.

A major concern for irrigation water is to prevent salinization. Highly saline water inhibits absorption of water from soil. Salinity also disperses soil aggregates and influences the infiltration and porosity of the soil. Water for aquaculture in important because the marine products must be safe for consumption. The toxicity of chemicals to fish is evaluated by LC50 or LD50. Wastewater is reused for various purposes, either after treatment or without treatment. Public health is the major concern in ensuring safe use of wastewater.

Ambient water contributes to various activities and uses as well as the conservation of natural ecosystems. The ambient water quality standards are classified by types and water usages. The control of pollutants from point sources is implemented through effluent standards.

Monitoring is conducted to examine compliance with the standards. Both frequency and choice of site are very important in quality monitoring. Water quality must be evaluated comprehensively, using various data taken from several sampling points.

1. Introduction

Water is used for various purposes—for daily life, agriculture, industry, fishery, etc. Water is supplied from the ocean to the atmosphere through evaporation and comes back to the ground surface as rainfall. It supports various human activities and natural ecosystems. As water flows over and through the ground surface and becomes available as a water resource in rivers, lakes/marshes, underground water, and coastal water, it captures inorganic substances from the soil, and organic substances and microorganisms generated by human activities and natural ecosystems.

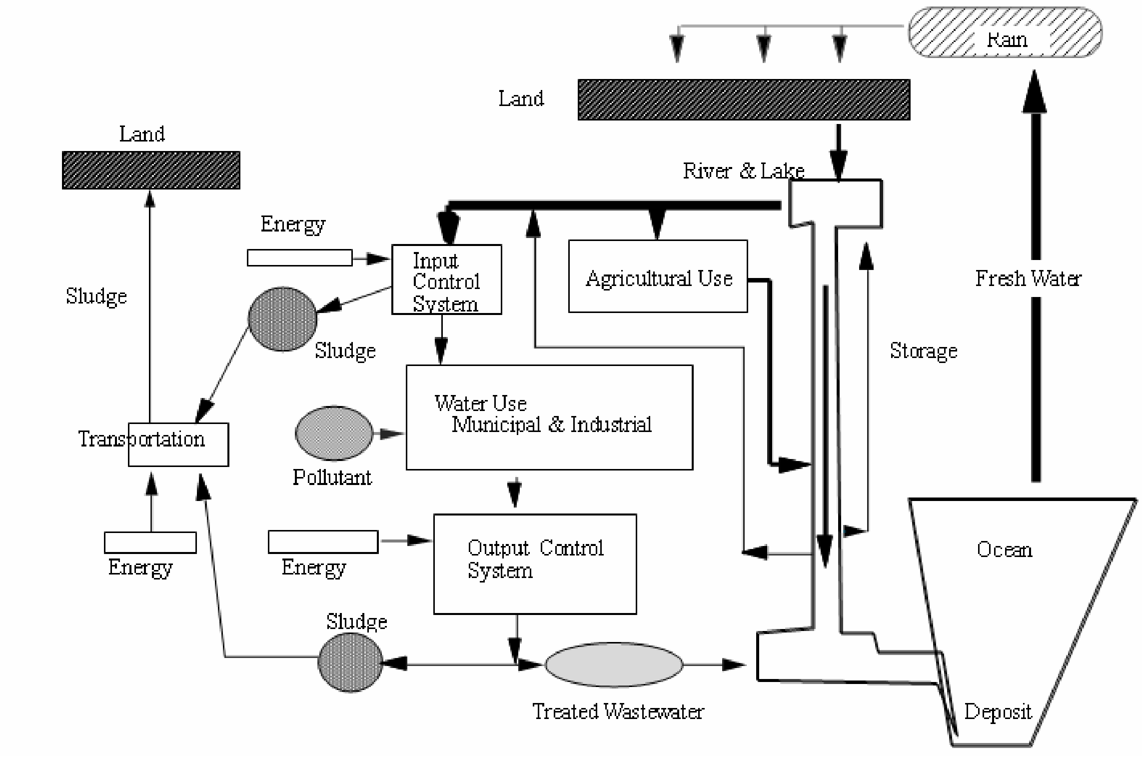

Figure 1. Water cycle and water uses

Chemically pure water rarely occurs in nature. Water is commonly found to host a wide variety of constituents, derived from both the natural and living environment, as shown in Figure 1. The input control system shown in Figure 1 corresponds to the water treatment system. The output control system is a man-made system to control the pollutants from the living environment and to measure the impact of the discharge upon the receiving water. Unless these systems are suited to human community activities, serious problems can result, such as water shortages, outbreaks of epidemic diseases, deterioration of homeostasis of aquatic ecosystems, and decrease of the value of water resources as a result of water pollution.

Materials present in water include not only essential substances necessary for supporting life, such as nitrogen, phosphorus and iron, but also hazardous substances such as arsenic and mercury, which are not just unnecessary for living creatures but cause health problems. Also, parasites and other infectious microorganisms and chemical substances such as agricultural chemicals are often found in water. Further, some substances, which do not cause any hazard to humans or living creatures but disturb the proper use of water, such as silt and sand which make water turbid, are also subject to consideration. Impurities in water can be classified according to the sources and the effects. Water quality standards should be established for these impurities, referring to their properties, the behavior and the effect on the ecological system, including human beings.

Once a standard has been established, it is necessary to check whether the standard is properly enforced. Temporary and continuous monitoring is needed to assure compliance. The results of such monitoring may sometimes require the standard itself to be reviewed, such as when a hazard is recognized even if the standard is being met. It will then be necessary to take measures including new regulations to bring the new standard into effect and enforce it.

Water quality standards show the levels that do not cause any hazard, either to the human body or to uses of water, according to the purpose of water usage. Accordingly, there are various levels of water quality standards, e.g. safety of drinking water, acceptability of water quality for industrial use such as cooling water for boilers, water used for agriculture, fish farming or fishery, and for sustaining aquatic ecosystems. Therefore, scientific examination of the safety and availability of water for each purpose of use is required in setting water quality standards. Affordability of technologies to analyze the concentration of the substances in question, or to treat water to remove the substances to a level below the standard values, and affordability of costs necessary for these technologies, are all essential issues in establishing the standards. Therefore, each standard varies depending on the natural, social, cultural and economic situation in each region; in other words, the standard should be developed not only from the viewpoint of preventing adverse effects of contaminants but also the feasibility of technical countermeasures and the achievability of analytical work in routine laboratories.

A reasonable standard is one which corresponds to the latest scientific information. Therefore, the standard should be evaluated periodically, on a scientific basis, and should be revised if necessary.

2. Drinking water quality standards and their development

The branch of science that examines the environmental factors that influence human health is called epidemiology. In 1855, John Snow proved statistically that in districts where water treatment with sand filtration was used, the incidence of cholera was lower than elsewhere. The epidemiological method has developed with an aim of explaining cases with high incident rate, such as infectious diseases like cholera and occupational diseases, or cases that are easy to distinguish from other populations. Medical science, including clinical medicine, has advanced, and the statistical approach and mathematical methods, have also been improved with the availability and power of computers. Consequently, cohort research and experimental epidemiological method have developed rapidly. The epidemiological method is a very useful tool in setting goals of environmental management for protecting public health from environmental organisms, and chemical and physical factors. This corresponds to WHO's EHC (Environmental Health Criteria).

Since human society exists in the natural/man made water metabolic system, human are not just affected not by physical properties and chemical impurities of water, but also by infectious microorganisms which co-exist with human beings and animals. The urban water metabolic system, which includes water supply and sanitation, has been established as a countermeasure against communicable diseases caused by pathogenic microorganisms. In Japan in the 1960s, more than 30 000 people were infected either by water or food-borne diseases such as dysentery or typhoid every year. However, today the number has decreased significantly and opportunistic microorganisms cause the main infectious diseases. This indicates how safe water supply and sanitation have improved public health conditions, but, unfortunately, new emergent and re-emergent infectious diseases, which are not so familiar, have become increasingly serious problems, mainly as a consequence of increased international travel and food distribution. These diseases include *E-coli* O-157, *Cryptosporidium* and *Giardia*.

2.1. WHO drinking water quality guidelines

Regulatory standards should include mandatory monitoring to verify whether the water quality meets the standard. If it does not meet the standard, some kind of countermeasures must be taken so that the standard can be achieved. On the other hand, unlike these regulatory standards, there is a guideline, which serves just as a reference when the goal or the standard for the desired water quality is provided. The WHO Drinking Water Quality Guidelines (DWQG) is a typical example of such a guideline.

The WHO DWQG is used as a reference in development of national drinking water quality standards in many countries. The WHO DWQG was recently revised following review of the latest scientific information (see Tables 1 to 3). The process of developing the DWQG provides one of the most appropriate examples to illustrate the development of rational standards.

Chemical	**Guideline value**	**Remarks**
Naturally occurring chemicals (mg L^{-1})		
Arsenic	0.01 (P)	
Barium	0.7	
Boron	0.5 (T)	
Chromium	0.05 (P)	For total chromium
Fluoride	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Manganese	0.4 (C)	
Molybdenum	0.07	
Selenium	0.01	
Uranium	0.015 (P, T)	Only chemical aspects of uranium addressed
Chemicals from industrial and human dwellings(μg L^{-1})		
Cadmium	3	
Cyanide	70	
Mercury	1	For total mercury (inorganic plus organic)
Benzene	10^b	
Carbon tetrachloride	4	
Di(2-ethylhexyl)phthalate	8	
Dichlorobenzene, 1,2-	1000 (C)	
Dichlorobenzene, 1,4-	300 (C)	
Dichloroethane, 1,2-	30^b	
Dichloroethene, 1,1-	30	
Dichloroethene, 1,2-	50	
Dichloromethane	20	
Edetic acid (EDTA)	600	Applies to the free acid
Ethylbenzene	300 (C)	
Hexachlorobutadiene	0.6	
Nitrilotriacetic acid (NTA)	200	
Pentachlorophenol	9^b (P)	
Styrene	20 (C)	
Tetrachloroethene	40	
Toluene	700 (C)	
Trichloroethene	70 (P)	
Xylenes	500 (C)	
Chemicals from agricultural activities(μg L^{-1})		
Nitrate (as NO_3^-)	$50x10^3$	Short-term exposure
Nitrite (as NO_2^-)	$3x10^3$	Short-term exposure
	200 (P)	Long-term exposure
Alachlor	20^b	
Aldicarb	10	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.03	For combined aldrin plus dieldrin

Atrazine	2	
Carbofuran	7	
Chlordane	0.2	
Chlorotoluron	30	
Cyanazine	0.6	
2,4-dichlorophenoxyacetic acid	30	Applies to free acid
2,4-DB	90	
1,2-Dibromo-3-chloropropane	1^b	
1,2-Dibromoethane	0.4^b (P)	
1,2-Dichloropropane	40 (P)	
1,3-Dichloropropene	20^b	
Dichlorprop	100	
Dimethoate	6	
Endrin	0.6	
Fenoprop	9	
Isoproturon	9	
Lindane	2	
MCPA	2	
Mecoprop	10	
Methoxychlor	20	
Metolachlor	10	
Molinate	6	
Pendimethalin	20	
Simazine	2	
2,4,5-T	9	
Terbuthylazine	7	
Trifluralin	20	
Chemicals used in water treatment and materials in contqact with water($\mu g\ L^{-1}$)		
Chlorine	$5x10^3$ (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥0.5 mg/litre after at least 30 min contact time at pH <8.0
Monochloramine	$3x10^3$	
Bromate	10^b (A, T)	
Bromodichloromethane	60^b	
Bromoform	100	
Chloral hydrate	10 (P)	
Chlorate	700 (D)	
Chlorite	700 (D)	
Chloroform	200	
Cyanogen chloride	70	For cyanide as total cyanogenic compounds
Dibromoacetonitrile	70	
Dibromochloromethane	100	
Dichloroacetate	50 (T, D)	
Dichloroacetonitrile	20 (P)	
Formaldehyde	900	
Monochloroacetate	20	

Trichloroacetate	200	
Trichlorophenol, 2,4,6-	200^b (C)	
Trihalomethanes		The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Acrylamide	0.5^b	
Epichlorohydrin	0.4 (P)	
Antimony	20	
Benzo[*a*]pyrene	0.7^b	
Copper	2000	Staining of laundry and sanitary ware may occur below guideline value
Lead	10	
Nickel	20 (P)	
Vinyl chloride	0.3^b	
Pesticides used for public health purposes(μg L^{-1})		
Chlorpyrifos	30	
DDT and metabolites	1	
Pyriproxyfen	300	
Cyanotoxins produced by algae(μg L^{-1})		
Microcystin-LR	1 (P)	For total microcystin-LR (free plus cell-bound)

Table 1 WHO drinking water quality guidelines: health related chemicals

Type of water	**Organisms**	**Guideline value**
All water directly intended for drinking	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Treated water entering the distribution system	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Treated water in the distribution system	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample

Table 2 WHO drinking water quality guidelines: microbiological aspects

Chemical	**Guideline value**	**Remarks**
Chemically derived contaminants (mg L^{-1})		
Aluminium	0.1–0.2	discoloration
Ammonia	1.5	odour
Chloride	250	taste
Chlorin	0.6 - 1.0	taste
Chlorophenols	10-300	taste
Colour	15 TCU	color
Copper	5	taste/color
Dichlorobenzenes	1-6	taste
Ethylbenzene	2-130	taste

Hardness	500	taste
Hydrogen sulfide	0.1	taste/color
Iron	0.3	discoloration
Manganese	0.1	discoloration
Monochloramine	5	odour
Monochlorobenzene	0.04-0.12	odour
pH and corrosion	6.5-8	corrosivity
Sodium	200	taste
Styrene	2.6	odour
Sulfate	250	taste
Toluene	0.025-0.170	odour
Total dissolved solids	1000	taste
Trichlorobenzenes	0.005	odour
Turbidity	5CTU	color
Xylenes	300	odour
Zinc	5	discoloration

Table 3 WHO drinking water quality guidelines: acceptability aspects

When WHO develops its drinking water quality guidelines, it puts great emphasis on the results of clinical studies or epidemiological studies of human populations. However, it has limitation when trying to examine newly generated synthetic and/or unintentionally produced chemicals—epidemiological data is not available for all environmental factors. Epidemiology can only examine phenomena which already exist in the environment.

When human data is insufficient, the results of animal testing are used. Results from animal testing using mammals are preferable for evaluation, since they are more applicable to human beings than other animal groups. EHC states that the results of animal testing on more than two different species of mammals over two generations are valid in order to improve the accuracy of application to humans. Chemicals cause various kinds of adverse effects, such as cancers caused by gene toxicity, cancer initiation in injured cells, and endocrine disruption. The virulence of diseases depends on the strength of the immune response in the human body, and may result in either reversible or irreversible adverse effects. In addition, it is obvious that environmental factors affect internal organs, and different problems occur in response to each environmental factor. It is therefore necessary to apply to humans the results of animal testing as accurately as possible, and to use these results in order to remove such influences, while recognizing the scientific limitations.

The guideline value is basically calculated using the approach known as tolerable daily intake (TDI). This is the level below which there is no observed adverse effect (NOAEL), and LOAE) is the level at which the lowest observed adverse effect occurs. In addition to the TDI approach, each contaminant is evaluated for carcinogenicity according to a similar classification adopted by the International Agency for Research on Cancer (IARC). In the case of substances considered to be genotoxic carcinogens, evaluation values are determined using mathematical model.

2.2. Health related chemicals

2.2.1. Threshold chemicals

For most toxicity, it is believed that there is a dose below which no adverse effect will occur. For chemicals that give rise to such toxic effects, a tolerable daily intake (TDI) should be derived using the most sensitive end-point in the most relevant study, preferably involving administration in drinking water.

The TDI is an estimate of the amount of a substance in food and drinking water, expressed on a body weight basis (mg kg^{-1} or µg kg^{-1} of body weight), which can be ingested over a lifetime without appreciable health risk. Over many years, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and the WHO/FAO Joint Meeting on Pesticide Residues (JMPR) developed certain principles in the derivation of acceptable daily intakes (ADIs). These principles have been adopted where appropriate in the derivation of TDIs used in developing guideline values for drinking-water quality.

The NOAEL is defined as the highest dose or concentration of a chemical in a single study, found by experiment or observation that causes no detectable adverse health effect. Wherever possible, the NOAEL is based on long-term studies, preferably of ingestion in drinking water. However, NOAELs obtained from short-term studies and studies using other sources of exposure (e.g. food, air) may also be used. If a NOAEL is not available, a LOAEL may be used, which is the lowest observed dose or concentration of a substance at which there is a detectable adverse health effect. When a LOAEL is used instead of a NOAEL, an additional uncertainty factor is normally applied.

The application of uncertainty (or safety) factors has been widely used in the derivation of ADIs and TDIs for food additives, pesticides and environmental contaminants. The derivation of these factors requires expert judgment and careful consideration of the available scientific evidence.

In relation to exposure to human beings, the NOAEL for the critical effect in animals is normally divided by an uncertainty factor of 100. This comprises two 10-fold factors, one for inter-species differences and one for inter-individual variability in humans. Extra uncertainty factors may be incorporated to allow for database deficiencies (1-10) and for the severity and irreversibility (1-10) of effects.

The selection and application of uncertainty factors are important in the derivation of guideline values for chemicals, as they can make a considerable difference in the values set. For contaminants for which there is sufficient confidence in the database, the guideline value is derived using a smaller uncertainty factor. For most contaminants, however, there is greater scientific uncertainty, and a relatively large uncertainty factor is used.

Drinking water is not usually the sole source of human exposure to the substances for which guideline values have been set. In many cases, the intake of chemical contaminants from drinking water is small in comparison with the intake from other sources, such as food and air. Guideline values derived using the TDI approach take into account exposures from all sources by apportioning a percentage of the TDI to drinking water. Wherever possible, data concerning the proportion of total intake normally ingested in drinking water (based on mean levels in food, air and drinking water), or intakes estimated on the basis of consideration of physical and chemical properties, are used in the derivation of the guideline values. Where such information is not available, an arbitrary (default) value of 10% for drinking water is used. A daily consumption of two liters by a person weighing 60 kg is generally assumed.

2.2.2. Non-threshold chemicals

In the case of compounds considered to be genotoxic carcinogens, guideline values were normally determined using a mathematical model. Although several models exist, the linearized multistage model was generally adopted. Other models were considered more appropriate in a few cases. Guideline values presented are the concentrations in drinking-water associated with an estimated upper-bound excess lifetime cancer risk of 10^{-5} (or one additional cancer per 100 000 of the population ingesting drinking water containing the substance at the guideline value for 70 years).

The guideline values for carcinogenic substances have been computed from hypothetical mathematical models that cannot be verified experimentally. These models do not usually take into account a number of biologically important considerations, such as pharmacokinetics, DNA repair or protection by the immune system. They also assume the validity of a linear extrapolation of very high dose exposures in test animals to very low dose exposures in humans. As a consequence, the models used are conservative (i.e. err on the side of caution). The guideline values derived using these models should be interpreted differently from TDI-based values because of the lack of precision of the models.

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Biographical Sketch

Yasumoto Magara is Professor of Engineering at Hokkaido University, where he has been on faculty since 1997. He was admitted to Hokkaido University in 1960 and received the degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for four years, he moved to the National Institute of Public Health in 1970. He served as Director of the Institute from 1984 for Department of Sanitary Engineering, then Department of Water Supply Engineering. Meanwhile he obtained a Ph.D. in Engineering from Hokkaido University in 1979 and was conferred an Honorary Doctoral Degree in Engineering from Chiangmai University in 1994. Since 1964, his research subjects have been in environmental engineering and have included advanced water purification for drinking water, control of hazardous chemicals in drinking water, planning and treatment of domestic waste including human excreta, management of ambient water quality, and mechanisms of biological wastewater treatment system performance. He has also been a member of governmental deliberation councils of several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He performs international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As regards academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of the Japan Society on Water Environment.

Professor Magara has written and edited books on analysis and assessment of drinking water. He is the author or co-author of more than 100 research articles.