CLASSIFICATION OF WATER QUALITY STANDARDS

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Contents

Summary

Water is used for various purposes: for daily life, agriculture, industry and fisheries. Water in chemically pure form rarely occurs in nature; it is commonly found to host a wide variety of constituents derived from both the natural and human environments. It is therefore necessary to establish water quality standards to assess and to manage water from the viewpoint of water use as well as the resource availability.

Water quality standards must be developed from scientific evidence that of adverse effects on ecological system including human beings and their water usage. This article deals the types of water quality standards and the basic concepts of development of the standards according to the target of water environment.

1. Introduction

Environmental management of various kinds of contaminants should be developed from scientific evidence that shows adverse effects on ecosystems, including human beings and their water usage. The goals should be established by providing a regulatory standard of quality at the virtually safe level, i.e. a level safe enough for the effects of the substances to be ignored. Needless to say, the goals of environmental protection depend on the technological feasibility of substitution of chemical substances, which influence the environment in whatever ways, the feasibility of the applied technologies, and the feasibility of measurement. The role of the science and technology is to accurately establish the goals of the environmental management and to increase the feasibility of achieving those goals.

There are various water quality standards, but the basic procedures for development of water quality standards can be by followed by examining drinking water quality standards.

2. Drinking water quality standards

The science which clarifies whether an environmental factor has an influence on the health of human beings started as epidemiology. In 1855, John Snow showed statistically that in the region where water supply with sand filtration was used, the incidence of cholera was smaller than in other regions. The epidemiological method was developed with the aim of clarifying the causes of diseases with high incident rate, such as cholera, and occupational diseases, or diseases with different incidences between populations. Medical science has now greatly advanced, not only in clinical medicine but also in statistical and mathematical methods that have flourished with the development of computers. Consequently, cohort research and experimental epidemiological methods have developed with the advancement of computer science. The epidemiological method is a very useful tool to set the goal of environmental management for protecting public health from pathogenic organisms, and chemical and physical factors This corresponds to WHO criteria: EHC (Environmental Health Criteria).

When WHO sets its drinking water quality guidelines, it puts an emphasis on the results of clinical studies or epidemiological studies involving effects on human beings. However, epidemiological data does not exist for all the factors in the environment, and epidemiology is a science which concentrates on phenomena that already exist in the environment. It therefore has limitations when trying to examine newly generated synthetic and/or unintentionally produced chemicals.

When there is not enough data on human beings, the results from animal testing are used. Only results from mammal are useful, since they allow more accurate application to human beings. EHC states that the results of animal testing on more than two different species of mammals, over two generations, are valid to improve the accuracy of application to human beings. There are various kinds of adverse effects such as cancers caused by genotoxicity of chemicals, cancers of somatic cells, and endocrine disrupting by chemicals. Various diseases occur when the self-protecting capability of the body is exceeded, and the adverse effects may be reversible or irreversible. In addition, it is obvious that environmental factors affect human bodies in all sorts of different ways. It is therefore necessary to adopt the method by applying the results of animal testing as accurately as possible to live animals, including human beings, and to use those results in order to remove such influences, while recognizing the scientific limitation. Put another way, we should reduce as many uncertainty factors as possible when applying animal testing results to human beings.

As a result, the tolerable daily amount of exposure, as the goal of environmental management, was derived so that the life-time risk of developing cancer from the genotoxicity of an environmental factor should be around 10^{-5}. When extrapolating from animal testing, an uncertainty factor (not a safety factor) is applied for intra- and interspecies variance, as well as allowances for the accuracy of the toxicological data and the severity of the effect.

Since human society exists in the natural/man made water metabolic system, human beings are affected not only by physical properties and chemical impurities, but also by infectious microorganisms, which co-exist with human beings and animals, and toxic algae. Urban water metabolic systems such as water supply and sanitation have been developed with countermeasures against communicable diseases caused by biological vectors. In Japan in the 1960s, more than 30 000 people a year were infected either by water- or food-born diseases such as dysentery, typhoid, and poliomyelitis. Today the number has been decreased greatly and opportunistic microorganisms are responsible for the main infectious diseases. This is evidence of how water supply and sanitation systems have improved public health. But, new emergent and re-emergent infectious diseases, which are not so familiar, have been recognized, e.g. diseases caused by *E-coli.* O-157, *Cryptosporidium,* and *Giardia*. These 'new' diseases are partly attributable to international human migration and food distribution.

Infectious microorganisms exist in suspended form (not dissolved in water), and eventually settle to the bottom of water bodies or tanks, unlike chemical substances. In addition, many infectious microorganisms have different levels of infection according to the stage of their life cycle. It is therefore a complex matter to calculate the risk that a pathogenic microorganism will have an effect on human health. Diseases caused by infectious microorganisms are, unlike cancer, generally curable, thanks to the development of medical treatment. Today, the risk of contracting an infectious disease is quantified as a yearly incidence. Since some infectious diseases are caused by food, it is appropriate to accept an annual risk of 10^{-4} for diseases transmitted by water. Group infection is defined as a situation where two or more people get infected by the same species of infectious microorganism. Though water-borne infectious diseases may commonly occur in big cities, they are often overlooked because of the confusion with food-borne diseases, or because their low incidence. As a result, the incidence rate of water-borne infectious diseases should be socially acceptable.

Regulatory standards should also include monitoring to verify if the water quality meets the standard. If it does not meet the standard, some kind of countermeasures must be taken to reach the standard. 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 Guideline is a typical example of such a guideline.

3. Ambient water quality standards

Ambient water bodies are categorized into three types: rivers, lakes, and coastal waters. These contribute to domestic and industrial water supplies, agricultural practices and fisheries, as well as supporting natural biota. Therefore, their water quality should be managed so as not to cause any adverse effect, including the conservation of aquatic ecosystems. The ambient water quality standards are registered for protecting water bodies, having regard to their type and water usage in many countries. The control of pollutant from point sources such as domestic sewage and industrial waste water treatment plants should be implemented by setting the effluents standard, taking into account the dilution factor and the natural purification capacity of the receiving water bodies. In other words, the ambient water quality standard is a basic tool for every water quality management activity. Here, the outline of Japanese ambient water quality standards is described in order to illustrate the concept of the ambient water quality standards.

3.1. Water quality standards for rivers

Water quality standards for river are shown in Table1. There are five water quality parameters: pH, biological oxygen demand (BOD), suspended solids (SS), dissolved oxygen (DO), and total coliform bacteria. Six water use classes from AA to E were established for rivers. Reservoirs with less than ten million cubic meter capacities are regarded as rivers rather than lakes. All standards are defined on the basis of daily averages.

	Water use	**Standards [1]**				
		pH	**BOD**	**SS**	**DO**	**CG**
AA	Water supply class I; conservation of natural environment, and uses listed in A-E	6.5 to 8.5	1	25	7.5	50
A	Water supply class 2; fishery class I; bathing and uses listed in B-E	6.5 to 8.5	2	25	7.5	1000
B	Water supply class 3; fishery class II, and uses listed in C-E	6.5 to 8.5	3	25	5	5000
C	Fishery class III; industrial water class I, and uses listed in D-E	6.5 to 8.5	5	50	2	NA
D	Industrial water class II; agricultural water; and uses listed in E	6.5 to 8.5	8	100	2	NA
E	Industrial water class III; conservation of living environment	6.0 to 8.5	10	*	2	NA

* no floating matters like garbage

Notes:

1. The standards are based on daily average values.
2. At the intake for irrigation water, pH shall be between 6.0 and 7.5 and DO shall be more than 5 mg L^{-1}.
3. Water supply Class I: can be treated by a simple purification process such as filtration. Water supply Class II: can be treated by conventional purification processes such as sedimentation and filtration. Water supply Class III: can be treated by advanced water purification processes with pretreatment.
4. Fishery Class I: suitable for fish such as trout and bull trout inhabiting oligosaprobic water, and those of fishery Class II and Class III. Fishery Class II: suitable for fish such as the salmon family and ayu (sweet fish) inhabiting oligosaprobic water and those of fishery Class III. Fishery Class III: suitable for fish such as carp and crucian carp inhabiting β-mesosaprobic water.
5. Industrial water Class I: can be treated by conventional processes such as sedimentation. Industrial water Class II: can be treated by advanced purification processes with chemicals. Industrial water Class III: can be treated by special purification processes.

6. Conservation of living environment: no unpleasant odor at riverside.

Table 1. Environmental quality standards related to the human environment. (1). Rivers.

Descriptions of each variable for which standards were established are described as follows:

1) pH. Generally, the pH of rivers in Japan is around 7, except in estuaries. At most intake facilities the pH is around 7.0. If the pH is more than 8.5, it affects the chlorination process in the treatment plant. To ensure corrosion prevention in the treatment plant and distribution system, maintaining pH between 6.5 and 8.5 is desirable. If pH is outside that range, it may cause irritation of eyes and adversely affect the growth of plants and marine organisms. Low pH at the roots of rice plants severely affects the plants due to the dissolution of salts, while high pH causes discoloration of leaves. Generally speaking, the optimum pH range for proper plant growth is between 6.5 and 7.5, therefore the pH standard for agricultural use is set as 6.5 to 7.5.

2) BOD. The self-purification capacity of rivers was given strong consideration when BOD standards were established. Waters with BOD of less than 1 mg L^{-1} can be subject to minimum human impact and are primary candidates for conservation. About 31.4%, 29.9% and 13.8% of drinking water sources in Japan, have BOD values less than 1 mg L^{-1}, 2 mg L^{-1} and 3 mg L^{-1}, respectively. If BOD exceeds 3 mg L^{-1}, it affects coagulation and rapid sand-filtration processes in conventional water treatment plants, requiring expensive advanced water treatment. Therefore, BOD standards are set at 2 and 3 mg L^{-1}, respectively, for Class I and II waters.

For Class I fisheries, BOD is set at less than 1 mg L^{-1}, since oligosaprobic fish such as salmon and smelt require water with BOD less than 2 mg L^{-1}. For Class II fisheries, BOD is set at less than 2 mg L^{-1}, since mesoprobic fish such as carp require water with a BOD less than 3 mg L^{-1}. For Class III fisheries, BOD is set at less than 3 mg L^{-1}, since Class III fisheries require water with BOD less than 5 mg L^{-1}. For Class E, conservation of environment, BOD is set at less than 10 mg L^{-1} to prevent odor caused by the anaerobic decomposition of organic matter.

3) Suspended solids (SS). Generally SS should be less than 25 mg L^{-1} to prevent any harmful effect to the aquatic environment. SS concentration of more than 50 mg L^{-1} affects the proper functioning of fish gills. Turbidity exceeding 30 Nephelometric Turbidity Units (NTU), equivalent to 30 mg L^{-1} SS, adversely affects slow sand-filtration systems. Therefore SS standards of 50 mg L^{-1} and 25 mg L^{-1} were adopted for fisheries and water supply use, respectively.

Suspended solids are also significant for agricultural water use, because high SS decreases soil pore size and causes a decrease in permeability. Field results indicate that 3 cm deposition of SS remains permissible, so the SS standard for agricultural water was set at 100 mg L^{-1}. No SS limitations were provided for environmental conservation, but there should be neither solid refuse nor floating solids that produce undesirable aesthetic conditions.

4) Dissolved oxygen (DO). The DO standards were formulated using fisheries criteria. Relatively good water bodies have more than 7.5 mg L^{-1}. For fisheries, hatching of salmon and trout rearing, more than 7 mg L^{-1} DO is required. Other general aquatic organisms also require more than 6 mg L^{-1}. In Ohio State, USA, the DO standard for fisheries is 5 mg L^{-1}, and the Japanese standard for Class III fisheries is established at the same level. Dissolved oxygen should be more than 5 mg L^{-1} for agricultural use, because DO less than this interferes with root growth. The DO level for the conservation of the environment should be at least 2 mg L^{-1} to prevent anaerobic conditions that cause bad odors.

5) Coliforms. Fecal coliform bacteria themselves are usually harmless to humans, but they are used as indicators for pathogenic bacteria. Coliform organisms should be non-existent in drinking water, and the most probable number (MPN) should not exceed one per 100 ml considering the normal expected efficiency of 98% kills during chlorination. Therefore, the safety limit to control for chlorination is 50 MPN per 100 ml.

The Council on the Living Environment in the Japanese Ministry of Health and Welfare reports that the removal rate of coliforms is around 99% and 95% in slow and rapid sand filtration, respectively. The removal rate in rapid sand filtration can be improved to around 98 to 99% with very careful maintenance. The standard was set as 1000 MPN per 100 ml for Class II water supply in which rapid sand filtration systems is operated with standard maintenance, considering that follow up with chlorination can safely function at 50 MPN per 100 ml level. For Class III water supplies in which high-level maintenance can be expected, the limit is around 2500 to 5000 MPN per 100 ml. Therefore, the standard was set at 5000 MPN per 100 ml. For bathing, 1000 MPN per 100 ml was established as the standard.

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Bibliography

WHO (1996). *Guidelines for drinking-water quality*, Second Edition, Volume 2, Health criteria and other supporting information, 973 pp. Geneva: World Health Organization. [This explains how the guideline value for drinking-water contaminants should be used, defines the criteria used to select the various chemical, physical, microbiological, and radiological contaminants included in the report, describes the approaches used in deriving guideline values, and presents brief summary statements either supporting the guideline values recommended or explaining why no health-based guideline value is required at the present time.]

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 since 1984 for the Department of Sanitary Engineering, then Department of Water Supply Engineering. He also 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 the Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. Meanwhile he performs international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As for academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of Japan Society on Water Environment.

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