Volume 50(3-4):97-104, 2006
Acta Biologica Szegediensis
http://www.sci.u-szeged.hu/ABS

ARTICLE

Drinking water, the most essential and not replaceable foodstuff – legal situation and assessment

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ABSTRACT The availability of water on the globe shows great regional differences. Due to the vital importance of water, quality criteria have been developed for its human consumption. In Europe the Water Directive gives the frame for national legislation concerning public water supply. Lists with parameters and highest acceptable concentrations are given as well as control and management principles to guarantee the health supporting function of water. The occurrence of different pollutants like pathogenic microorganisms, pesticides, pharmaceuticals, heavy metals and persistent organic chemicals clearly shows that water has to be treated before usage. Basis for this is a positive list of compounds including impurities and allowed amounts of added substances as well as remaining concentrations after separation. One of the highest objectives is to come to a sustainable water management. Green production, ecological product design, and consumer information are promising aspects to reach that goal.
Acta Biol Szeged 50(3-4):97-104 (2006)

KEY WORDS

drinking water
microorganism
pesticides
quality

Water is the basis for life. It is the unique, most essential food stuff which cannot be substituted. There are great regional differences in the availability of water on the globe. It is obvious that in addition to the climatic situation the amount of available water is of highest importance for the standard of living of the population. The Food and Agricultural Organization (FAO) defines the necessary availability of water in countries to be 1000 m^3 per capita and year. Countries below that value suffer from water shortage. In many parts of Europe, the available amount of water is around 2000 m^3 per capita and year, whereas in arid zones only a few 100 m^3 are typical (UNESCO-WWAP 2003).

These values seem to be rather high in light of the two liters per day of drinking water which are necessary for the survival of a human being. However, it has to be kept in mind that for hygienic purposes and a well accepted standard of living the water demand is much higher and commonly between 100 and 200 liters per person per day in industrialized countries (BGW 1995). In addition, the virtual amount of water necessary for the production of goods of our daily life has to be taken into account, e. g. for 1 kg of bread on our table, the equivalent amount of 1 m^3 water is needed for growing the corn, harvesting, baking and distributing the product (Zehnder et al. 2003). Due to the importance of water for drinking purposes and irrigation, the quality criteria for human consumption are of vital importance and are subject to ordinances and technical guidelines.

Accepted Dec 15, 2006
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Raw water situation

Wherever possible, ground water is used as raw water for human consumption. The situation is reflected in the amounts of ground water used for public water supply in the European member states (Table 1).

The reason for the preferential usage of ground water is the high quality of water in aquifers which are well protected by the overlaying soil in which organic pollutants get trapped by adsorption and are biodegraded by microorganisms (討theß et al. 1992). In addition, the porous material of the aquifer has an efficient filter function for nonliving matter as well as organisms including pathogenic bacteria and viruses (Ward et al. 1985). As a consequence, favorable natural conditions and a circumspect management of the ground leads to the situation where ground water quality is good enough to allow a direct water consumption without any pre-treatment. This

Table 1. Relative amounts of ground water used for public water supply in Europe.

Country	Fraction of groundwater
Austria	99 %
Denmark	99 %
France	61 %
Germany	72 %
Italy	85 %
Netherlands	69 %
Norway	13 %
Spain	21 %
Sweden	24 %

Table 2. Contents of the annexes of the drinking water ordinance.

Annex No.	Content	Number of parameters
1.1	Microbiology	3
1.2	Microbiology	6
2.1	Chemistry (no change in distribution system)	14
2.2	Chemistry (change in distribution system expected)	12
3	Indicators	20
4	Scope and frequency of examinations	
5.1	Specific analytical methods	
5.2	Specific quality criteria for analytical methods	
6	Treatment Chemicals for Special Cases	3

has been the case even in general major cities of Germany like Berlin, Hamburg and München (Frimmel and Gordalla 1996). Well protected ground water with high hygienic, chemical and physical quality therefore has become a reference material for safe and good drinking water.

In regions where ground water of high quality is not available, cleaned surface water is used for consumption. In highly populated areas, drinking water is often also provided by means of pipelines from places were water resources are sufficiently available.

Surface waters normally are more prone to pollutants than ground water. A careful management of the aquatic system concerned including the watershed, and the availability of several ten meters of depth as zone of self purification makes lakes and reservoirs more favorable than rivers as resources for human consumption. In all cases, however, treatment processes have to be applied to guarantee the hygienic and other quality criteria for drinking water (Frimmel 1999). These quality criteria are given in official directives, rules and laws.

Legal situation

The global importance of drinking water quality is reflected in the "Guidelines for Drinking Water Quality" of the World Health Organization (WHO 1993). The parameter values given are an orientation for all nations. In the United States of America drinking water quality issues are addressed in several rules (e. g. lead and copper rule, disinfection byproduct rule etc.; Roberson 2003). In Europe, in 1992 a Directive of the council was issued concerning the "Quality of Water intended for human consumption" (Council Directive 98/83/EC). This directive had to be transferred into national law by the EU member states and was enforced on January 1, 2003 (Grohmann 2003). The following principles were applied:

The framework of the national law had to closely follow the EU Directive.

Wherever possible and in accordance with the Directive, national law should be used to maintain the high level of water quality given in a member state, *i. e.* better: yes, worse: no.

The responsibilities for meeting the quality criteria and for actions in case of transgression have to be exactly defined.

The overall aim of the law is to guarantee the availability of safe water for public consumption without any concerns. This means that the water has to be "clean", free of any unnecessary and unwanted pollution of microbial, chemical or other kind which can harm the health of the population.

Parameter values

The backbone of the resulting law consists of several lists of parameters and values to guarantee the protection of human health. In addition, rules for practical monitoring and remediation actions, information of consumers and reporting to the EU-Commission are given (Table 2).

The microbial parameters are given in detail in Table 3.

This is a fairly limited list, and it is questionable whether these parameters reflect all the important aspects of modern

Table 3. Microbial parameters of the Directive, their parametric values and specified methods for their determination. CM: check monitoring required; AM: audit monitoring.

Parameter	Monitoring	Protocol	Parametric value	
			Water from distribution network	water offered in bottles or containers
Escherichia coli (E. coli)	CM	ISO 9308-1	0/100 mL	0/250 mL
Enterococci	AM	ISO 7899-2	0/100 mL	0/250 mL
Pseudomonas aeruginosa	CM	prEN ISO 12780		0/250 mL
Colony count 22 °C	CM	prEN ISO 6222		100/mL
Colony count 37 °C	CM	prEN ISO 6222		20/mL
Clostridium perfringens [a)b)]	CM	Given in the Directive	0/100 mL	
Coliforms [b)]	CM	ISO 9308-1	0/100 mL	0/250 mL

[a)] only to be measured as an indicator parameter for waters originating from or influenced by surface water
[b)] indicator parameter

hygienic assessments. It has become clear that E. coli, though not necessarily pathogenic, is a very useful indicator for the recent contact of water with excrements of humans or warm-blooded animals. This bears the risk of infection and cannot be accepted according to the precautionary principle. Clostridium perfringens may indicate the non-vegetative forms of parasitic protozoa, e. g. cryptosporidium or giardia. As can be seen from Table 3, more stringent parametric values have to be applied for water distributed in bottles or containers, e. g. on ships.

The chemical parameters and their values given in Table 4 are set mostly beyond acute toxicological relevance to human beings. According to the precautionary principle, a lifelong (70 years) daily intake of drinking water shall not be injurious to the consumer's health. Some of the substances regulated neither are constituents of the raw water nor environmental water contaminants, but stem from materials used for treatment or distribution of water (Grohmann 2003). This applies also to the disinfection by products (DBP) bromate and trihalomethanes, to PAH and especially to Benzo(a)pyrene which may be set free from coal-tar lined water mains. The parameter values of epichlorohydrin, acrylamide or vinylchloride have to be seen as rest monomers based on the maximum deliberated amount from the respective polymer application. Nitrite is largely formed in the distribution system when chloramination is used as disinfection method. Its limit is considered in combination with nitrate. Furthermore, the limit at the consumer's tap is less stringent than the one at the water works exit.

The so-called indicator parameters (Table 5) are a seemingly unsystematic suite of properties. They mainly refer to aspects of aesthetics, treatment or corrosiveness of the water. Most of them are of minor health relevance, but non-compliance indicates that something with the water handling – watershed, catchment, treatment, distribution – is in disorder.

Compliance of the distributed water with the microbiological, chemical and indicative parametric values of the Directive is assumed to grant that drinking water is "wholesome and clean". The standards refer to substances likely to be present in raw water. Should water intended for human

Table 4. Chemical parameters, their parametric values and the minimum requirements for accuracy of applied analytical methods as specified in the Directive. Percentages refer to the parametric values. LOD: limit of detection, % of parametric value; CM: check monitoring required; AM: audit monitoring.

Parameter	Monitoring	Parametric value	Accuracy	Precision	LOD
Acrylamide	AM [0]	0.10 µg/L	– [a]	– [a]	– [a]
Antimony	AM [+]	5.0 µg/L	25 %	25 %	25 %
Arsenic	AM [+]	10 µg(L	10 %	10 %	10 %
Benzene	AM [0]	1.0 µg/L	25 %	25 %	25 %
Benzo(a)pyrene	AM [+]	0.01 µg/L	25 %	25 %	25 %
Boron	AM [0]	1.0 mg/L	10 %	10 %	10 %
Bromate	AM [0]	10 µg/L	25 %	25 %	25 %
Cadmium	AM [+]	5.0 µg/L	10 %	10 %	10 %
Chromium	AM [0]	50 µg/L	10 %	10 %	10 %
Copper	AM [+]	2.0 mg/L	10 %	10 %	10 %
Cyanide	AM [0]	50 µg/L	10 %	10 %	10 %
12-Dichloroethane	AM [0]	3.0 µg/L	25 %	25 %	10 %
Epichlorohydrin	AM [+]	0.10 µg/L	– [a]	– [a]	– [a]
Fluoride	AM [+]	1.5 mg/L	10 %	10 %	10 %
Lead	AM [+]	10 µg/L	10 %	10 %	10 %
Mercury	AM [0]	1.0 µg/L	20 %	10 %	20 %
Nickel	AM [+]	20 µg/L	10 %	10 %	10 %
Nitrate	AM [+]	50 mg/L	10 %	10 %	10 %
Nitrite	CM [c]	0.5 mg/L	10 %	10 %	10 %
Pestidices – individual	AM [0]	0.10 µg/L	25 %	25 %	25 %
Pesticides – total	AM [0]	0.5 µg/L			
Polycyclic aromatic hydrocarbons (PAH)	AM [+]	0.10 µg/L	25 %	25 %	25 %
Selenium	AM [0]	10 µg/L	10 %	10 %	10 %
Tetrachlorethene and trichlorethene	AM [0]	10 µg/L	25 %	25 %	10 %
Trihalomethanes (THM) – total	AM [+]	100 µg/L [G]	25 %	25 %	10 %
Vinylchloride	AM +)	0.50 µg/L	– [a]	– [a]	– [a]

[0] no changes expected after central treatment
[+] increase expected in distribution system
[a] to be controlled by product specification
[b] ρ(nitrate)/50 + ρ(nitrite)/3≤1 mg/L
[c] CM necessary only when chloramination is used as a disinfectant
[d] 0.10 mg/L at ex treatment works
[G] Germany: 50 µg/L

Table 5. Indicator parameters, their parametric values and the minimum requirements for accuracy of applied analytical methods if specified in the Directive. Percentages refer to the parametric values. LOD: limit of detection; CM: check monitoring required; AM: audit monitoring.

Parameter	Monitoring	Parametric value	Accuracy	Precision	LOD
Aluminium	CM [a)]	200 µg/L	10 %	10 %	10 %
Ammonium	CM	0.50 mg/L	10 %	10 %	10 %
Chloride	AM	250 mg/L	10 %	10 %	10 %
Clostridium perfringens [b)] including spores	CM	0/100 mL	Protocol given in the Directive		
Colour	CM	Acceptable to consumers and no abnormal change	-	-	-
Conductivity	CM	2500 µS/cm at 20 °C	10 %	10 %	10 %
Hydronium ion concentration	CM	6.5≤pH≤9.5	0.2	0.2	
Iron	CM [a)]	200 µg/L	10 %	10 %	10 %
Manganese	AM	50 µg/L	10 %	10 %	10 %
Odor	CM	Acceptable to consumers and no abnormal change	-	-	-
Oxidizability	AM	5.0 mg/L O_2	25 %	25 %	10 %
Sulfate	AM	250 mg/L	10 %	10 %	10 %
Sodium	AM	200 mg/L	10 %	10 %	10 %
Taste	CM	Acceptable to consumers and no abnormal change	-	-	-
Colony count 22 °C	CM c)	No abnormal change	prEN ISO 6222		
Coliform bacteria	CM	0/100 mL	ISO 9308-1		
Total organic carbon (TOC) [d)]	AM	No abnormal change	-	-	-
Turbidity	CM	Acceptable to consumers and no abnormal change [e)]	25 % [f)]	25 % [f)]	25 % [f)]
Tritium	- [g)]	100 Bq/L	- [g)]	- [g)]	- [g)]
Total indicative dose	- [g)]	0.10 mS/a	- [g)]	- [g)]	- [g)]

[a)] CM only when used as flocculant
[b)] only to be measured for waters originating from or influenced by surface water
[c)] CM only for waters offered in bottles or containers
[d)] need not to be measured for supplies less than 10000 m^3/d
[e] ≤ 1.0 NTU at ex treatment works should be striven for in case of surface water treatment
[f)] specifications must be met only for monitoring of treated surface water
[g)] frequency and methods are still to be fixed

consumption however be a human health risk because of other infectious, toxic or undesirable ingredients not mentioned in the Directive, it must also not be distributed to the consumer and, if necessary, the Member States must set values for other additional parameters.

Quality assurance of the data

The results of microbiological tests and of chemical and physical determinations depend strongly on the protocol and methods applied. The quantitative data therefore have to be obtained according to standardized methods like CEN or ISO protocols (Gordalla and Frimmel 2003). Examples for microbiological methods are given in Table 3. The minimum requirements of the data quality to be obtained for chemical and indicator parameters are given in the EU-Directive, and they are shown in Tables 4 and 5. The improvements of the methods applied, and the international standardization of the analytical methods belong to the most challenging fields of analytical sciences.

Frequency of assessment

Analytical data have to be representative. This includes the sampling strategy as well as the scope and frequency of the determined parameters. Samples have to be taken according to standardized methods at a point directly after the water treatment process and at different consumer taps, e. g. in households, schools or public buildings. The sampling campaign frequency depends on the size of the supply system (Table 6).

It is interesting to note that the EU Member States cannot be held responsible for the domestic distribution system nor for its maintenance. Nevertheless they have to inform the consumers about the water quality to enable them to chose appropriate pipe material and operation principles with respect to health and corrosion aspects.

Water treatment substances

If the microbiological and chemical parameter values of the Directive are not met by the raw water, technical treatment is necessary. The Member States have to regulate the use of substances or materials used for preparing water in a way that possible harmful effects on human health are avoided. These substances have to be applied in a manner that they do not remain in the finished water in concentrations higher than necessary for their use. This also implies minimization of DBPs.

In the Ordinances only for special cases, e. g. natural disasters, epidemics or war-like situations, defined substances and allowed concentrations are given (Table 7).

Substances for water treatment under ordinary conditions are regulated in § 11 of the Ordinance which states that chemicals for water treatment and methods for disinfection need to be declared in a list given by the Federal Ministry for Health and published in the Bundesgesundheitsblatt (Official Journal of Federal Healthcare). The list has to contain substance specific information on

- identity of material
- purity standards
- allowed maximum concentration of application
- allowed maximum concentration of remaining rest substances and reaction products after treatment.

In case of chlorine-based disinfection, minimum concentration of free chlorine after treatment is given. The necessary scope of analytical control of the treatment chemicals is also specified, and methods for disinfection and the conditions for their effective application are defined.

The German list of allowed substances gives 34 different aims for treatment processes and 90 substances at the moment. The list is organized and supplemented by the Environmental Protection Agency (Gordalla and Frimmel 2003). The dynamic character of the list (as non-internal part of the EU Directive and national Ordinance) guarantees its topicality. The permission of substances and materials depends on their technical effectiveness, and on the possible impact on health and environment. These aspects are evaluated by an expert group of representatives of the State, the army, the railway company, water supply specialists and authorities. Specific rules exist for substances and materials accepted in other EU Member by States or other international trade partners. The application of non-specifically allowed substances and methods is not permitted. Legal basis for all these regulations are the safety rules for foodstuff and consumer goods which have a good tradition in industrialized nations.

The aims for water treatment in detail are:

- elimination of unwanted substances from raw water
- alteration of the water constituents to guarantee a safe and technically perfect distribution of the water to the consumer. This can include corrosion aspects and hardness.

Inactivation or destruction of pathogenic agents of water

- in the treatment plant (primary disinfection)
- in the distribution pipes (secondary disinfection)
- in storage tanks (secondary disinfection).

Technical basis for these regulations is the broadly accepted technology. This allows a more generous approach than a state of technology based regulation. Of general importance is the so called 10% rule in combination with the minimization principle (MP). This means that the additional chemical load of drinking water caused by treatment chemicals has to be kept as low as possible. It refers to the added chemicals as well as to their reaction products. In any case chemical additions are not allowed to lead to more than a 10% increase of the original parameter value in the water. This implies of course that the original value is less than 90% of the maximum allowed concentration.

If possible, the control of chemical additions should be done continuously to avoid too high doses. This applies mainly to the additives which remain in the water like phosphate, silicates, chlorine, acids or bases and oxygen. The substances like flocculants and activated carbon which get eliminated after the treatment step are assessed as technically unavoidable compounds and have to be eliminated to technically irrelevant levels which show no adverse health, odor and taste effects. Based on the obligatory technical product quality, standard concentrations also can just be calculated using the manufacturer's product speciation, the amount of chemicals added and the volume of water treated. It is the aim of a dynamic positive list of treatment methods and chemicals to serve the minimization principle. Best of course would be if the raw water quality was good enough to make any addition of chemicals unnecessary.

An important part of the Directive also deals with the information policy of the water supply companies and the responsible authorities on the one hand and the EU Council and the consumers on the other hand. Each significant noncompliance has to be announced and assessed, and strategies of tackling the specific problems have to be supplied in due time.

Existing and emerging problems

There exists a number of actual problems in public water supply. Despite of a broad awareness of the importance of the hydrological cycle and the needs of raw water protection for the supply of people with the fundamental foodstuff water, there are numerous examples of severe problems in water quality. Some are addressed here:

The pollution of groundwater by pesticides and nitrate in many regions is caused by intense farming. Pesticides in their manifold chemical structures have a maximum allowed concentration in drinking water of 0.1 μg/L each which is often exceeded. Toxicologically relevant metabolites also have to be taken into account. The parameter value for nitrate in the Directive is 50 mg/L. We have learned that groundwater polluted with persistent chemicals can take decades to recover after the

Table 6. Frequency of sampling and analyses depending on the volume of water supplied from a distribution network.

Volume V of water distributed of produced each day within a supply zone	Check monitoring number of samples per year	Audit monitoring number of samples per year
V ≤ 100 m^3	Frequency to be decided by the Member State concerned	Frequency to be decided by the Member State concerned
100 m^3 ≤ V ≤ 1 000 m^3	4	1
1 000 m^3 ≤ V ≤ 10 000 m^3	4	1 +1 for each 3 300 m^3/d and part thereof of the total volume
10 000 m^3 ≤ V ≤ 100 000 m^3	+3 for each 1 000 m^3/d and part thereof of the total volume	3 +1 for each 10 000 m^3/d and part thereof of the total volume
> 100 000 m^3		+ 1 for each 25 000 m^3/d and part thereof of the total volume

pollution source has been eliminated (LfU 2003). This also underlines the importance of the metabolites of the pesticides. This situation asks for a powerful ground water protection and a ground water related enforcement of good farming practice. The dilemma is clear: we all want to have rich crops and enough meat for our nourishment, but we and the next generation also urgently need clean water as basis for our life. Recently, a biodegradable polymer (poly(ε)caprolactone) has been introduced as promising absorbant for pesticides which, mediated by the biodegradation, leads to a denitrification and cometabolic pesticide elimination. In polluted waters this can help to solve both problems at a time.

Another reason for concern lies in highly populated areas and their growing needs for water which is taken from poor aquifers. Taking more water out of an aquifer than the amount which is recharged leads to a lowering of the water table and finally to the use at lower water levels to overcome the shortage. The hydrogeology in the deeper underground offers water with higher salt content, higher hardness and in some regions higher arsenic concentrations (Bissen and Frimmel 2003). All these parameters can exceed the values given in the Directive.

Industrialization with uncontrolled left-overs and dumping areas have led to so called hot spots with high risk potential for the groundwater. Polycyclic aromatic hydrocarbons (PAHs) and other persistent pollutants as carcinogenic and mutagenic compounds are dominant. Benzo(a)pyrene with 10 ng/L is the lowest parameter value of the whole Directive. Amongst the different technical remediation techniques, natural attenuation methods have become most attractive for economic reasons (Förstner and Gerth 2001). However, in these cases thorough analytical control instead of complicated technical treatment facilities has to be installed.

An interesting emerging problem can be seen in the environmental occurrence of pharmaceuticals and their metabolites. Lipid regulators, anti epileptic drugs, contraceptives and even iodinated organic X-ray contrast media have found their way via waste water, rivers, lakes and the ground water to the water supply systems (Daughton and Ternes 1999, Drewes et al. 2003). These compounds so far have not been regulated by parameter values. Their subtle effects in water are less in the range of acute toxicity, but more in the field of chronic effects. Identification, quantifycation and assessment of pharmaceuticals in the aquatic environment are a challenge for the years to come.

DBPs are another important topic in water supply. There are only two parameter values, the THMs (with 100 µg/L) and bromate (with 10 µg/L) in the Directive so far. Far more than hundred of compounds have been identified up to now (Richardson 2003). Some of them like MX have turned out to be highly mutagenic (Barrett et al. 2000). A good part of the DBPs formed are still unidentified. In the past, especially the polar ones were difficult to be analyzed. The availability of high performance liquid chromatography (HPLC) coupled with tandem mass spectrometry (MS/MS) has recently

Table 7. Chemicals for treatment in special cases.

No.	Substances	EWG no.	Aim	Allowed concentration mg/L
1	Sodium carbonate Potassium dichloroisocyanurate		Disinfection	40 [1)]
2	Sodium carbonate Sodium bicarbonate Adipinic acid Sodium benzoate Polyoxymethylenpolyglycol waxes Sodium chloride Tartaric acid	500 500 500 335 E 211 E 334	Aid for tableting	
3	Sodium, Calcium, Magnesium hypochlorite	925	Oxidation Disinfection	200 [2)3)]

1) minimum amount: 33 mg/L
2) as active chlorine
3) minimum amount: 100 mg/L

opened the door to the analysis of the world of hydrophilic DBPs (Zwiener and Frimmel 2003).

The assessment of the biological effects of the suite of DBPs is still poor and has many open questions. The Directive addresses this situation with the recommendation to enlarge the chemical and microbiological analytical methods if necessary. The dilemma is again obvious: there is a choice of high hygienic safety which is achieved by a high dose of disinfectants and consequently a high amount of toxic and mutagenic DBPs or a low risk coming from the toxicity of DBPs which are minimized by low doses of disinfectants that have only a limited potential for the inactivation of microorganisms.

Finally, it is an urgent issue whether the classical way of assessing the hygienic quality of raw water and drinking water is efficient enough for a reliable health protection of the population. Direct information on parasites and viruses are missing in the Directive. In addition, the time span between sampling and availability of the final results which normally lies in the range of several days is too large to prevent epidemic outbreaks. Modern molecular biological testing and cell tests are promising to add precious information on microbiological pollution in a much shorter time (Grummt et al. 2004). Tailor-made bioassays can also help to bridge the gap between chemical analysis and biological effects which should be a major field for research and development in water hygiene.

Sustainable water shed management

The global water crisis seems to be evident. More and more people have to rely on the limited availability of water, the most essential resource for life. This asks for a convincing strategy to face the future. Sustainable water shed management based on ecological, economical and social aspects can show us the way. All parts of the hydrological cycle have to be seen in this sensitive magic triangle, and wise decisions on the system management have to be made to guarantee a safe water supply also for the next generations. Production-integrated environmental protection, green product design and consumption-integrated environmental protection as well as waste and waste water handling with minimized pollution of aquatic systems must be the key stones of our economic system. Precautionary principles and minimization principles for chemical addition in water treatment processes are essential. Biological, chemical and technical methods based on sustainability are promising to reach a water consumption orientated on natural processes as they are given in the hydrological cycle.

The EU has given a Directive for a framework for community action in the field of water policy (Council of the European Union 2001). It contains the ideas of a definition of safe drinking water which is orientated on a properly managed ground water without any major environmental pollutants. In short: it should be appetizing and it has to be colorless, clear and cool without any adverse odor, taste, or a significant amount of germs (DIN 2000 2000). Consequently, a concerted effort on a sustainable water management has to be undertaken by mankind to support its further existence.

Acknowledgements

This study was presented on the NATO Advanced Research Workshop on "Food Safety and Security" held between 13-15 September, 2004, at Lake Issyk-Kul, Kyrgyzstan. The workshop was funded by NAT0. Co-directors were Prof. Dr. A. Aldashev, National Academy of Sciences of the Kyrgyz Republic, and Prof. Dr. L. Erdei, University of Szeged, Szeged, Hungary.

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