The need for guidelines to bridge the gap between ideal drinking-water quality and that quality which is practically achievable and acceptable

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Abstract

Classically a distinct boundary is made between ideal and non-ideal water. Such a distinct boundary is not in keeping with resource water quality conditions, especially in a semi-arid climate. To facilitate the decision processes around the supply of quality drinking water, a classification system was devised to give a clearer picture of expected effects on the domestic user. The classification system, which divides water quality into four classes from 0 (ideal) to III (unsuitable for use as drinking water without prior treatment), is based on the 2nd, 1996 edition, of the *South African Water Quality Guidelines for Domestic Use*. The classification, however, differs in several respects from the latter: (i) The definition of the user as drinking water for human use, rather than the wider definition for domestic water; (ii) the concept that non-ideal water may be used for short periods only rather than for a lifetime without significant ill effects, as in Class II; and (iii) the emphasis on health effects from drinking-water use, especially in sensitive individuals, such as bottle-fed infants. In the selection of constituents the classification is biased towards those constituents that commonly are of concern in borehole water in rural areas where there is little or no pollution from heavy industry. The present constituent list is not nearly as extensive as that contained in the 2nd edition of the *South African Water Quality Guidelines for Domestic Use*.

Introduction

The evolution of water quality guidelines has seen the emphasis usually on a single cut-off value, such as the guideline value (WHO,1984; WHO, 1993) with, on occasion, a second non-ideal, but still acceptable limit, such as the maximum allowable limit (SABS,1984). As early as 1985, a third limit was introduced, viz. the crisis limit (Kempster and Smith, 1985) implying clearly unsuitable water quality, and indicating that urgent measures needed to be introduced to rectify the quality of the water supply concerned. In all these historical approaches there has been no departure from an intended identification of the ideal or recommended limit as being that which should be aimed at and achieved in practice if at all possible. Clearly, it is not desirable to drink water less fit than the ideal.

Consideration of the philosophy of the development of water quality guidelines, however, reveals that the target guideline value (DWAF,1996) or the guideline value (WHO,1993) invariably contains a built-in safety factor, of a magnitude dictated by the knowledge of the toxicology of the given constituent, such as revealed in tests on experimental animals, or from a study of actual effects on the user as established by epidemiology. In the case of the synthetic organic pesticides, this safety factor can be several orders of magnitude, especially when there are limited toxicological data, and to allow for uncertainty in extrapolation of animal data to man.

Recently there has been a growing realisation that exposure to concentrations of a constituent at levels greater than the target, recommended or guideline value need not necessarily lead to any detrimental health effects, particularly where the exposure to the elevated concentration is of short duration only. This insight has arisen as a consequence of actual supplies not consistently meeting the ideal guidelines, in, for example epidemiological studies. Realisation that the boundary between the no-effect level and the threshold for the initial appearance of undesirable effects is not a sharp one, but rather a gradual transition, is also reflected in the definition of water quality guideline limits for less than lifetime exposure, e.g. in the one-day, ten-day and long-term (7-year) health advisory limits issued by the United States Environmental Protection Agency (1994). It is notable that these shorter than lifetime health advisories still contain a margin of safety.

This development in guideline definition to cater for short- to medium-term deviations of a constituent's concentration above the ideal value reflects a recognition of the real life situation where the quality of the raw water sources, and often the treated water likewise fluctuates, and is influenced by hydrological cycles and events. Not all drinking-water sources are of ideal quality. In a semi-arid country such as South Africa, a major problem in many groundwaters is that of elevated salinity levels. Coupled to this are often elevated levels of nitrate and fluoride. Installation of treatment technology to render such valuable groundwater supplies palatable is both financially demanding and also requires a trained operator infrastructure to maintain and operate such treatment units. There is a pressing need in the vast arid areas of South Africa for a structured water quality guideline evaluation process, whereby management decisions can be facilitated and day-to-day decisions made in terms of treating water to render it fit-for-use. Compliance with the ideal at all times, especially on small-scale plants, is neither practically nor economically feasible. The development of a hierarchical guideline system in order to facilitate evaluation of where the water quality lies in the grey zone between ideally fit-for-use, and the threshold for definitely unfit-for-use would thus considerably ease the decision-making processes of water quality managers in charge of the supply of water to rural communities.

In the revised (2nd edn.) of the *South African Water Quality Guidelines for Domestic Use* (DWAF,1996), a tiered approach

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was adopted, with an indication of what effects on the user can be expected when the concentration of a constituent exceeds the ideal limit, i.e. the upper limit of the target water quality range. In these revised guidelines, however, explicit guidance in terms of use of water exceeding the target water quality limit is not given. The revised guidelines consequently do not lend themselves to quick decisions on water quality suitability by the engineer or operator in the field. An initiative was therefore developed to make the tier or hierarchical approach used in the guidelines more user-friendly, in terms of defining class limits indicating the suitability of the water for drinking-water use. This initiative was undertaken as a joint co-operative venture between the Department of Water Affairs and Forestry, and the Department of Health (1996). The basis of this further development of the tier system for evaluating water quality was the definition of four classes of water quality in terms of suitability for use, ranging from the ideal, Class 0, to Class III, which is unsuitable for use without treatment. The philosophy of this tiered class approach is discussed in this paper.

Classification system

The classification system distinguishes between four classes of water quality as follows:

- ***Class 0***
  This is ideal water quality, suitable for lifetime use, with no adverse health effects on the user. This class is essentially the same as the target water quality range in the 2nd edn., of the *South African Water Quality Guidelines for Domestic Use* (DWAF,1996).

- ***Class I***
  Water in this class is safe for lifetime use, but falls short of the ideal water quality in that there may be rare instances of adverse health effects, but these are usually mild, and overt health effects are almost always subclinical and difficult to demonstrate. Water in Class I does not cause health effects under normal circumstances. Aesthetic effects may, however, be apparent.

- ***Class II***
  Water in this class is defined as that where adverse health effects are unusual for limited short-term period use. Adverse health effects may become more common particularly with prolonged use over many years, or with lifetime use. This class represents water suitable for short-term or emergency use only, but not necessarily suitable for continuous use over a lifetime.

- ***Class III***
  This water has constiuents in a concentration range where serious health effects might be anticipated, particularly in infants or elderly people with short-term use, and even more so with longer term use. The water in this class is not suitable for use as drinking water without adequate treatment to shift the water into a lower and safer class.

Classification

Using the classification principles described above, in conjunction with the health effects for constituents as given in the revised *South African Water Quality Guidelines for Domestic Use* (DWAF,1996), class limits for 16 representative constituents were defined (Kempster, 1996) as shown in Table 1.

Discussion

The class ranges for each of the constituents given in Table 1 are discussed below:

Total dissolved salts (TDS)

TDS refers to the summation of the concentrations of the individual ions from a full macro analysis. TDS may be estimated from the electrical conductivity where the conversion factor for the given water type is known. A typical conversion factor is 6.5 mg/ℓ·(mS/m)$^{-1}$. TDS and total dissolved solids, the latter determined gravimetrically after evaporation, are usually interchangeable in practice, unless an unusually high concentration of non-ionic substances is present, such as for example dissolved sugars.

The TDS limit of 450 mg/ℓ for Class 0 is based on taste considerations. No salty taste will be detectable below this concentration.

The upper cutoff limit of 1 000 mg/ℓ for Class I is based on taste considerations (WHO, 1993). The upper limit of 2 450 mg/ℓ for Class II is based on health considerations. At this concentration of salts, overloading of the renal salt excretion mechanism can occur, especially in individuals with impaired renal function, or with immature kidneys, such as infants. Water with a TDS of 2 450 mg/ℓ will taste unpleasantly salty and will not slake thirst.

The isotonic concentration of salt in serum in the human body is around 0.9% i.e., 9 000 mg/ℓ. This provides a physiological ceiling for ingested TDS, above which water will not be absorbed by the body, but will lead to dehydration and increased thirst.

Electrical conductivity

The class limits for electrical conductivity are analogous to those for the TDS, using the approximate conversion ratio of electrical conductivity at 25°C to TDS of 6.5 mg/ℓ·(mS/m)$^{-1}$.

Nitrate plus nitrite as N

The nitrate/nitrite class limits are based on the observed incidence of methaemoglobinaemia (blue baby syndrome due to nitrate/nitrite poisoning). The risk group is bottle-fed infants. The condition never occurs at nitrate concentrations below 6 mg/ℓ as N, thus the selection of this concentration as the upper cut-off concentration for the ideal or target water quality range of Class 0.

Class I water could pose a very slight risk of methaemoglobinaemia in bottle-fed infants, where associated predisposing factors are simultaneously present, i.e.:

- bottle-fed infant;
- with iron deficiency anaemia;
- insufficient vitamin C intake;
- achlorhydria (high stomach pH);
- presence of nitrate-reducing flora in the stomach and/or intestine; and
- presence of elevated nitrate concentrations in the drinking water.

Because the required simultaneous presence of the predisposing factors rarely occurs, the condition is in practice only very rarely if ever observed at nitrate concentrations of below 10 mg/ℓ(as N).

TABLE 1
PROPOSED CLASSIFICATION OF DRINKING-WATER QUALITY.
IDEAL (CLASS 0); SUITABLE FOR LIFETIME USE (CLASS I); INTERIM USE (CLASS II); AND UNFIT FOR USE WITHOUT SUITABLE TREATMENT (CLASS III). CONCENTRATIONS IN mg/ℓ UNLESS OTHERWISE STATED

Constituent	Class 0	Class I	Class II	Class III
Total dissolved salts	0 - 450	450 - 1 000	1 000 - 2 450	>2 450
Electrical conductivity (mS/m)	0 - 70	70 - 150	150 - 370	>370
Nitrate plus nitrite as N	0 - 6	6 - 10	10 - 20	>20
Fluoride	0 - 1.0	1.0 - 1.5	1.5 - 3.5	>3.5
Sulphate	0 - 200	200 - 400	400 - 600	>600
Magnesium	0 - 30	30 - 70	70 - 100	>100
Sodium	0 - 100	100 - 200	200 - 400	>400
Chloride	0 - 100	100 - 200	200 - 600	>600
pH (pH units)	6.0 - 9.0	5 - 6 or 9 - 9.5	4 - 5 or 9.5 - 10	<4 or >10
Iron	0 - 0.1	0.1 - 0.2	0.2 - 2.0	>2.0
Manganese	0 - 0.05	0.05 - 0.1	0.1 - 1.0	>1.0
Zinc	0 - 3.0	3.0 - 5.0	5.0 - 10.0	>10.0
Arsenic	0 - 0.010	0.010 - 0.050	0.050- 0.2	>0.2
Cadmium	0 - 0.005	0.005-0.010	0.010 - 0.020	>0.02
Faecal coliforms (counts/100 mℓ)	0	0 - 1	1 - 10	>10
Ammonia (as N)	0 - 1	1 - 2	2 - 10	>10

In the concentration range of 10 to 20 mg/ℓ (as N) of nitrate plus nitrite, there is a definite possibility of methaemoglobinaemia in bottle-fed infants, while above 20 mg/ℓ (as N), the water is definitely unfit for use by infants.

Fluoride

The target water quality range for fluoride of 0 to 1.0 mg/ℓ used as the basis of the limits for the ideal Class 0 range, is based on the fact that mottling of the tooth enamel is not observed at below 1.0 mg/ℓ fluoride under normal dietary conditions. The upper cut-off limit of 1.5 mg/ℓ of Class I is based on the fact that while some tooth mottling or staining may be observed in sensitive individuals or during hot climatic conditions with excessive water intake, the mottling is only mild and does not usually lead to pitting of the tooth enamel with consequent erosion and loss of teeth.

In the fluoride range 1.5 to 3.5 mg/ℓ (Class II), staining or mottling of the teeth may become quite severe, and be associated with erosion and loss of teeth, as the enamel in the mottled areas is pitted. Thus dental mottling is not just an aesthetic effect. The detrimental damage to the teeth will be most noted when the fluoride-containing water is drunk during early childhood, during the process of tooth formation. Water with a fluoride concentration of >3.5 mg/ℓ (Class III) is not suitable for use as there is a real danger of skeletal damage with sustained consumption for prolonged periods.

Sulphate

Sulphate is commonly found at elevated concentrations, particularly in areas containing pyrite deposits, which have been disturbed by mining activities, thus exposing the iron sulphide to oxidation to sulphate. Elevated sulphate in drinking water can result in diarrhoea. At moderate concentrations of sulphate the diarrhoea is only transient and adaptation occurs with continued intake of the water ("travellers diarrhoea"). However, if the sulphate concentration is very high, then adaptation may be only partial and diarrhoea is likely to be persistent.

In the concentration range 0 to 200 mg/ℓ (Class 0) sulphate, no adverse health effects from sulphate are anticipated, and no sulphate-induced diarrhoea will be observed, even in sensitive individuals.

In the concentration range 200 to 400 mg/ℓ (Class I), diarrhoea may rarely occur in sensitive individuals, but adaptation will occur with persistent use. In the concentration range 400 to 600 mg/ℓ (Class II) sulphate, an unpleasant bitter taste may be discernible and the water will cause transient diarrhoea in most non-adapted individuals. With persistent use adaptation is, however, anticipated in all but the most sensitive users (infants). Above 600 mg/ℓ sulphate (Class III), the water is not suitable for drinking, particularly by infants who may experience life-threatening diarrhoea.

Magnesium

From a health and aesthetic viewpoint magnesium concentrations of below 70 mg/ℓ do not have any undesirable health or aesthetic effects. The ideal limit for Class 0 of 30 mg/ℓ is based on the absence of scaling problems and no impairment of the lathering of soap. In the range 30 to 70 mg/ℓ (Class I) mild scaling may be observed in e.g., kettles, but no health or aesthetic effects are anticipated.

In the concentration range 70 to 100 mg/ℓ (Class II), a bitter taste will be noticeable, and diarrhoea may occur in sensitive individuals, such as infants. Above 100 mg/ℓ magnesium (Class III) the bitter taste will be increasingly noticeable, and diarrhoea may be expected, particularly in sensitive users.

Sodium

No adverse health effects are apparent at sodium concentrations of below 200 mg/ℓ (upper limit of Class I). A slight taste may be apparent above 100 mg/ℓ (Class 0), depending on the associated anion.

In the concentration range 200 to 400 mg/ℓ (Class II) the effect is usually aesthetic (salty taste), except with individuals on a salt-restricted diet (e.g. those with congestive heart failure or with hypertension due to salt retention, or those with immature kidneys i.e. infants). Above 400 mg/ℓ sodium (Class III) water is unsuitable for use especially by infants.

Chloride

At concentrations of below 200 mg/ℓ chloride has no undesirable health effects. Increase in the corrosion rate of domestic appliances may, however, be anticipated above 100 mg/ℓ. Above 200 mg/ℓ chloride the water will taste distinctly salty. Concentrations above 600 mg/ℓ will not slake thirst.

pH

The target water quality range (Class 0) is a pH range of 6.0 to 9.0. No adverse health effects are expected in this range. In the pH range 5.0 to 6.0, increased corrosion of metals in distribution systems and appliances may occur and caution should be exercised in this pH range. As the pH decreases, the possibility of, and rate of corrosion tends to increase with an associated increase in the danger of ingesting toxic corrosion products, such as cadmium impurities in galvanising, for example. At the alkaline end of the pH scale, the possibility of irritation of mucous membranes arises with an increase in the pH above especially pH 10.

Iron

Iron in solution, in the concentration range 0 to 0.2 mg/ℓ (Class 0 & I) has no health implications and aesthetic effects only may occur, such as brown discolouration of fixtures. In the concentration range 0.2 to 2.0 mg/ℓ (Class II) the aesthetic effects gradually increase but no adverse health effects are expected, except in rare individuals with a hypersensitivity to iron due to inadequate functioning of the uptake enzyme mucosal block control, with long-term intake. Above 2.0 mg/ℓ (Class III) negative health effects may occur, particularly in infants.

Manganese

The reason for the inclusion of manganese as a constituent is due to the severe aesthetic effects and staining problems encountered when manganese concentrations are elevated. Adverse health effects do not occur at manganese concentrations of below 1.0 mg/ℓ.

Zinc

Zinc is not toxic at concentrations of below 10 mg/ℓ. However, zinc causes a bitter taste at concentrations of >5 mg/ℓ. Toxicity may occur at concentrations exceeding 10 mg/ℓ.

Arsenic

The ideal concentration (Class 0) range of 0 to 0.010 mg/ℓ is based on the absence of any significant adverse health effects from arsenic after lifetime exposure. In the concentration range 0.010 to 0.050 mg/ℓ (Class I) there is the possibility of rare instances of mild skin lesions after lifetime exposure. In the concentration range 0.050 to 0.2 mg/ℓ (Class II) there is an increasing risk of skin lesions with long-term exposure but no systemic toxicity. At concentrations of above 0.2 mg/ℓ (Class III) there is an increased risk of skin cancer. The possibility of mortality from chronic arsenic poisoning arises when concentrations exceeding 1.0 mg/ℓ are ingested over a prolonged period.

Cadmium

Adverse health effects due to cadmium exposure generally do not occur below concentrations of 0.010 mg/ℓ. In the concentration range 0.010 to 0.020 mg/ℓ (Class II) there is a danger of adverse health effects with continuous exposure over a prolonged period. Kidney damage may be anticipated in concentrations exceeding 0.020 mg/ℓ (Class III).

Faecal coliforms

If faecal coliforms are undetectable (0 counts /100 mℓ), there is a negligible risk of microbial infection. In the range 0 to 1 count/100 mℓ there is a very slight but insignificant risk. In the range 1 to 10 counts/100 mℓ there is a slight risk of infection with continuous exposure. At concentrations of above 10 counts/ 100 mℓ, there is an increasing risk of disease transmission.

Ammonia nitrogen

The presence of elevated ammonia levels tends to be associated with taste and odour problems (WHO,1993). Ammonia in drinking water should ideally be less than 1 mg/ℓ as N (Class 0), although levels of up to 2 mg/ℓ are quite acceptable (Class I). Between 2 and 10 mg/ℓ as N (Class II), marked taste and odour problems are likely to be encountered. While ammonia nitrogen *per se* is relatively non-toxic, high concentrations may give rise to significant levels of nitrite under anaerobic conditions. It is consequently not advisable to drink water with an ammonia nitrogen concentration in excess of 10 mg/ℓ as N (Class III).

Duration of exposure

If it is assumed, for the sake of argument, that there is an inverse linear relationship between dosage and time of exposure leading to undesirable effects, then, as the upper limit of Class II water is 3 to 20 times higher than the ideal limit in most cases, the tolerable time of exposure to Class II water is 3 to 23 years (taking a lifetime as 70 years). This excludes such constituents as the faecal coliforms, where the ideal is zero, and pH, which is a non-linear scale of measurement. The geometric mean of 3 and 23 years is around 8 years, which is similar to one of the interim period exposures proposed by the EPA of 7 years. Obviously the inverse linear dose-time response relationship assumption can be criticised, and is probably unique for each constituent.

From a practical point of view the safe time of exposure to Class II water would be closely dependent on whether the constituent concerned is by its nature a toxic substance or merely a substance of aesthetic concern at the concentration of exposure. In the case of arsenic or fluoride, for example, long-term exposure to elevated concentrations has well-documented toxic effects and, consequently, it would be wise not to expose a population to Class II water any longer than is necessary, i.e. until adequate treatment or an alternative and safer class water can be supplied. If, however, the constituent has only aesthetic effects at the concentrations normally encountered in water, e.g. in the case of iron or manganese, then prolonged periods of exposure to Class II water can be tolerated without the risk of causing any serious damage to the health of the exposed population.

Conclusion

The definition of less-than-ideal water quality criteria used for limited periods of exposure is a relatively new trend in water quality criteria and fills a very necessary bridging role in narrowing the gap between the ideal target water quality and the non-ideal raw source water with which water suppliers usually are confronted. While it is relatively easy to establish treatment plants for large water supplies, treating a large number of isolated groundwater supplies in a rural area, for example, is a major challenge. Priorities which will assist in identifying the supplies to be treated, need to be established. The tier system of water quality classification in terms of suitability for drinking-water use simplifies the decision-making process.

Recommendations

The tier classification system for drinking-water quality is still in an early phase of development. Further refining of the approach is needed, particularly the systematic extension of the concept to cover a broader range of water quality constituents. In the extension and further refinement of the classification system it is envisaged that comment and input will be elicited from the major role players in the water quality field. To date in South Africa there has been a plethora of water quality guidelines, each developed and utilised by a different role player in the field. This is in part due to the differing user requirements of the various role players, as well as the inherent complexity of the domestic water quality supply situation in the country. The time is ripe for common ground to be sought among the various sets of water quality guidelines in order to define a more integrated set of criteria, which will come closer to the ideal of addressing the multiple constraints and requirements of the various role players.

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