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Indices of Drinking Water Concerned with Taste and Health

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Using the results of a sensory test of drinking water and some findings from the literature, we examined the requisites for tasty and healthy water. It was found that calcium, potassium and silica were correlated to the good taste of water and sulfate and magnesium were factors making water unsavory. We also found that the concentration difference between calcium and sodium was closely correlated to the death rate due to apoplexy and, consequently, the span of life in Japan. From these findings, we derived two equations for indicators of tasty water and healthy water. They were named the O index and K index, respectively, and were expressed as follows;

$$\text{O index}=\frac{Ca+K+SiO_2}{Mg+SO_4} \qquad (mg/l)$$

$$\text{K index}=Ca-0.87\ Na \qquad (mg/l)$$

It has become apparent that tasty water was an O index of over 2.0 and healthy water was a K index of over 5.2.

O and K indices were estimated Japanese waters, including representative drinking water, 218 river waters, and famous river waters selected by the Environmental Agency, and these waters were classified as tasty and/or healthy according to the results. This classification seems to be rational because the findings are consistent with everyday experience.

Public concern over the quality of drinking water, including its taste, odor, mutagenicity, and health-effect, has increased recently because of the pollution of water resourses. In particular the taste of water has been discussed widely[1-4] and the society for the study of tasty water sponsored by the Ministry of Public Welfare has presented the requisites for tasty water.[5]

The relationship between drinking water quality and human health, however, has been less extensively studied in spite of its importance. Nose[6] pointed out that the death rate caused by geriatric diseases including apoplexy, cancer of the stomach and so on, was correlated with the characteristics of both soil and water quality in a place of residence.

This report first presents an index of the taste for drinking water in terms of chemical components selected by a sensory test of drinking water. Secondly, an index of healthy water (drinking water which will lengthen lifespan and/or to prevent geriatric diseases such as apoplexy) is derived, using the quality of the drinking water in the prefecture in Japan with the lowest death rate due to apoplexy. Finally, these indices are estimated for Japanese river waters and popular drinking waters, which are classified accordingly as healthy and/or tasty.

Materials and Methods

Index of water taste

Water samples Samples used in the sensory test were selected from among various Japanese drinking waters appraised as tasty, and their principal components were analyzed according to the "Standard Method".[7] Test samples were also prepared by dissolving various chemical reagents in deionized water (specific resistance, $500\times10^4\ \Omega\cdot cm$) to give the same

Table 1. Chemical composition of representative drinking waters in Japan.

Sample \ Component	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	SO_4 mg/l	Cl mg/l	SiO_2 mg/l
Aomori	3.16	2.58	2.25	7.08	5.0	11.4	37.5
Akita	4.44	1.56	1.38	5.07	8.7	11.8	4.0
Kyoto	9.93	2.18	1.88	4.84	13.3	10.8	1.1
Nunobiki, Kobe	6.79	1.08	0.63	7.06	12.7	9.6	11.6
Kobe	13.93	1.70	2.25	8.06	21.5	16.3	3.0
Kumamoto	11.89	4.20	6.88	13.20	7.5	18.4	48.5
Kagoshima	11.65	1.80	5.50	10.00	17.9	15.4	64.0
Oita	17.65	2.41	4.78	6.50	51.7	12.9	44.8
Miyazaki	10.81	1.22	2.52	9.88	42.5	11.5	17.2
Nigatsu-do, Nara	8.84	4.83	3.46	7.60	3.5	8.4	75.9
Miya-mizu, Hyogo	26.81	4.18	12.78	25.16	38.0	38.1	25.4
Suizenji, Kumamoto	21.82	2.27	6.50	7.56	23.5	10.1	45.0
Evian, France	42.11	15.98	1.68	5.44	24.5	75.4	12.4

compositions as the analyzed waters. This had two purposes: to allow all samples for the sensory test to be prepared simultaneously, and to establish procedures for making artificial mineral water for the many islands of Japan lacking water resourses. Samples tested were tap waters from the cities of Aomori, Kumamoto (both cities are famous for the delicious water), Akita, Kyoto, Kobe, Oita, Miyazaki, and Kagoshima, drinking water from Nunobiki Water Works, Kobe (Nunobiki water), well waters from Nigatsu-do, Nara, and Suizenji, Kumamoto, groundwater known as Miya-mizu in Nishinomiya, Hyogo, and Evian water as an example of commercial mineral water. The chemical compositions of these samples are shown in Table 1.

Chemical reagents used in the experiment were of commercial reagent grade. On dissolving these chemicals, silicate was first dissolved in deionized water with sodium bicarbonate, then the other chemicals were added. Finally, pH of prepared water was adjusted with either phosphoric acid or carbonic acid.

Sensory test method Sixteen samples including deionized water, and boiled and unboiled city water from the tap in the laboratory were divided into two groups, which were used sequentially in a sensory test.[8] Eight samples cooled to 13°C were served at one time in order to each of ten panelists, who were asked to give marks of one to eight to all samples in order of deliciousness. The total number of marks given to each water by the ten panelists were calculated, and the three lowest-scoring samples were selected. The remaining eight samples were then tested similarly and the top four samples were selected. The seven selected samples were tested again in the same manner, and the most delicious water was chosen.

Results and Discussion

Results of sensory test of drinking water Tap waters of Oita and Kumamoto, and Evian mineral water were selected from the first group (the five rejected samples were; tap waters of Akita, Kyoto, and Aomori, Miya-mizu ground water and boiled tap water). The four samples selected from the second group were tap waters of Kagoshima and Kobe, and the well waters of Suizenji and Nigatsu-do (the four rejected samples were; tap waters of Miyazaki and Nunobiki, deionized water and city water in the laboratory). These seven selected samples were again tested and the results are shown in Table 2, where T_j is the sum of the marks given by the ten panelists. The smaller the value of T_j is, the more delicious the water is. Thus the three tastiest water are, in order, well water of Suizenji, Kumamoto, tap water of Kumamoto city and well water of Nigatsu-do, Nara.

Significance was tested by calculating the coefficient of concordance, W, and the ratio of variance, F, according to the following procedures.[8]

The sum of squares of T_j values, S, was calculated by Eq. (1).

Table 2. Sensory test of drinking waters.

Sample name	T_j
Suizenji, Kumamoto	18
Kumamoto	26
Nigatsu-do, Nara	28
Evian, France	32
Oita	37
Kagoshima	40
Kobe	43

$k=7$, $n=8$, $\bar{T}=32$; $S=458$, $W=0.26$, $F=2.46$, $f_1=5.75$, $f_2=40.3$, $F(5.40, 0.05)=2.45<2.46$ (5% level of significance)

$$S=\sum_{j=1}^{n}(T_j-\bar{T})^2 \qquad (1)$$

where $\bar{T}$ is the mean value of T_j, $[\bar{T}=(\Sigma T_j)/k]$ and k is the number of samples.

The coefficient of concordance was calculated by Eq. (2).

$$W=\frac{12S}{n^2(k^3-k)} \qquad (2)$$

where n is the number of panelists. The range of W values is $0\leqq W\leqq 1$. If the same order of water taste is given by all panelists, the value of W reaches one.

Significance was tested by comparing the calculated F value from Eq. (3) with the value in the F table.[8]

$$F=\frac{(n-1)W}{1-W} \qquad (3)$$

where F value is subject to F distribution which has number of degrees of freedom of (f_1, f_2). The values of f_1 and f_2 were calculated as follows;

$$f_1=k-1-2/n,\ f_2=(n-1)f_1 \qquad (4)$$

From these procedures, the value of W was calculated as 0.26 and the sensory test was proved to be reliable at the 5% level of significance.

Relationship between water taste and minerals Since it was clear what water were concerned with taste, the coefficients of correlation between T_j values and chemical composition (Ca, Mg, Na, K, Cl, SO_4, SiO_2) were calculated as shown in Table 3, where a high, negative correlation coefficient indicates involvement with good taste.

Calcium has been pointed out to be the most important component concerned with the taste of water.[2-5] Potassium is also important in giving water a good taste, but makes water taste salty if present in too high a concentration.[4] Silica has been reported by the society for the study of tasty water to have almost no effect on water taste.[5] However, Minagawa[4] reported that water that had soaked through a silica or clay layer has long been said to be delicious in Japan. The high, negative correlation coefficient between T_j and silica in Table 3 indicates that silica makes water taste delicious. We thus concluded that Ca, K and SiO_2 among the chemical components tested made water taste delicious.

Magnesium, on the other hand, which, like calcium, contributes to the hardness of water, is a principal component adding rough and bitter taste to water. Sulfate also makes water unsavory by decreasing the concentration of calcium, which is the most important component of tasty water. We also concluded that magnesium and sulfate made water unsavory.

It was thought that sodium and chloride had no effects on water taste because their coefficients of correlation were positive and/or low.

Index of tasty water From the above findings, O index, which reflects the chemical composition or mineral balances of water, was proposed as an index of water taste.

$$\text{O index}=\frac{Ca+K+SiO_2}{Mg+SO_4} \qquad (5)$$

Table 3. Correlation between T_j and chemical component.

Chemical component	Ca	Mg	Na	K	Cl	SO_4	SiO_2
Coefficient of correlation	−0.32	−0.23	−0.11	−0.48	0.16	−0.05	−0.51

Table 4. O index of representative drinking waters in Japan.

Sample	O index
Aomori	5.66
Akita	0.96
Kyoto	0.83
Nunobiki, Kobe	1.38
Kobe	0.83
Kumamoto	5.75
Kagoshima	4.11
Oita	1.24
Miyazaki	0.70
Nigatsu-do, Nara	10.59
Miya-mizu, Hyogo	1.54
Suizenji, Kumamoto	2.84
Evian, France	1.39

$$\text{O index}=\frac{Ca+K+SiO_2}{Mg+SO_4}$$

where the unit of concentration is mg/*l*.

The O index of thirteen samples used in a sensory test were calculated and are summarized in Table 4. Most drinking waters which were evaluated as tasty (Table 2) showed high values of O index. The O index of tap water of Aomori city was also high, even though the sample was eliminated in the sensory test. Miya-mizu and Nunobiki water have also high values of O index. Tap waters of Aomori city, Miya-mizu, and Nunobiki water have good reputations for taste, so the high values of O index would be expected.

We conclude that the taste of water can be evaluated by using the O index shown in Eq. (5). Generally, the higher the value of the O index is, the more delicious the water is. It is convenient, however, to decide a critical value of the O index for tasty water. Hence, we propose that water with an O index of more than 2 will be regarded as tasty water. It is evident from Table 4 that most of waters evaluated as tasty have an O index above this value. That is:

For tasty water, O index

$$=(Ca+K+SiO_2)/(Mg+SO_4)\geqq 2 \quad (6)$$

where concentrations are expressed as mg/*l*.

Index of healthy water

Requisites of healthy water Water plays important physiological roles in transportation and excretion of waste matters, maintenance of body heat and so on. Various minerals are absorbed from drinking water and accumulated in the body, and these may influence various human organs and ultimately the death rate, as was reported by Nose.[6]

Ueno[9,10] reported that the modified death

Table 5. Modified death rate* due to apoplexy in Japan, 1950.[9,10]

Order	Prefecture	Death rate	Order	Prefecture	Death rate
1	Akita	232.1	37	Fukui	95.6
2	Iwate	192.5	38	Nagasaki	95.4
3	Yamagata	184.6	39	Osaka	93.7
4	Aomori	167.6	40	Hiroshima	93.0
5	Niigata	156.5	41	Kagawa	92.6
6	Miyagi	152.2	42	Wakayama	91.3
7	Fukushima	150.8	43	Kyoto	85.7
8	Ibaragi	145.7	44	Tokushima	85.7
9	Tochigi	143.5	45	Ehime	85.0
10	Nagano	135.8	46	Hyogo	82.1

mean death rate in Japan = 118.2

* modified death rate = {sum total of (death rate of each age × population of each age) ÷ total population of 1950} × 100,000

Rate was expressed as number per 100,000 persons.

The table shows the ten prefectures with the highest rates and the ten with the lowest.

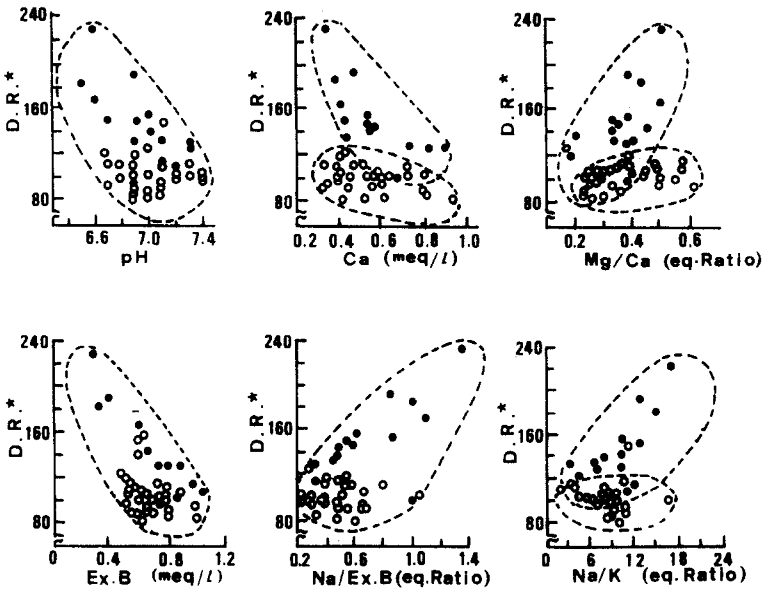

Fig. 1. Relationship between the modified death rate in 1950 and chemical compositions of river waters in Japan. (Cited from Ueno[9,10])
● : North-eastern Japan
○ : South-western Japan
* : Modified death rate, *i.e.*, mean death rate of 1947–1950 with respect to the population of 1950, expressed as per 100,000 persons.
Ex.B. $= Ca + Mg + K + Na - (Cl + SO_4) \fallingdotseq CO_3$

rate due to apoplexy in 1950 was correlated closely with the chemical composition of river waters as shown in Fig. 1, where excess base (Ex. B) is shown as $Ca+Mg+K+Na-(Cl+SO_4)=CO_3$. Table 5 shows that the modified death rate due to apoplexy in 1950 varied widely across the prefectures of Japan. In 1950, apoplexy was the major cause of death in Japan. This suggests that the drinking water or river water in the prefecture with the lowest death rate due to apoplexy can be regarded as healthy water, namely, water which, when drunk for many years, lengthens the span of life and/or prevents the geriatric diseases like apoplexy. Based on this hypothesis, chemical composition of healthy water was estimated by the following procedure: the regression equation between the modified death rate of apoplexy and the chemical composition of river water (*i.e.*, Ca, Mg/Ca, Ex. B., Na/Ex. B. or Na/K) was determined using the data shown in Fig. 1; the lowest prefectural death rate of 82.1, in Hyogo, was substituted into the regression equation to determine the concentrations of Ca, Mg, Na, and K. The calculated concentrations were: Ca, 0.56 (meq/l); Mg, 0.18 (meq/l); Na, 0.30 (meq/l); and K, 0.03 (meq/l).

Index of healthy water Kitagawa[11] and Nose *et al.*[12] reported that the concentration difference (expressed as meq/l) between calcium and sodium, (Ca-Na), was correlated with the concentrations of various other chemical components of river waters. Calcium and sodium are also said to be more closely related to human health than other mineral components of water. Moreover, the value of (Ca-Na) is higher than the concentrations of other chemical components of water, and thus the concentration difference between Ca and Na was proposed as an index of healthy water, termed the K index.

K index

$= Ca - Na$ (expressed as meq/l)

$= Ca - 0.87Na$ (expressed as mg/l) (7)

Table 6. Classification of water quality by O and K indices.

Ranges of indices	Category of water	Water quality
O index≧2.0; K index≧5.2	1	Healthy and tasty
O index≧2.0; K index<5.2	2	Tasty
O index<2.0; K index<5.2	3	Neither healthy nor tasty
O index<2.0; K index≧5.2	4	Healthy

Ishihara[13] reported that the values of (Ca−Na) for drinking water in a region of long life expectancy were usually higher than a region of lower life expectancy. Our proposal is consistent with this.

The value of (Ca−Na) of river water in the prefecture with the lowest death rate due to apoplexy is calculated to be 0.26 (meq/l), using the resulting concentrations of Ca (=0.56) and Na (=0.30). Therefore, the higher the calcium content and the lower the sodium content of water are, the more healthy it is. Water with a K index of more than 0.26 was regarded as healthy. That is:

For healthy water,

$$\text{K index} = \text{Ca} - \text{Na}\ (\text{meq}/l) \geqq 0.26$$

or

$$\text{K index} = \text{Ca} - 0.87\text{Na}\ (\text{mg}/l) \geqq 5.2 \quad (8)$$

Application of O and K indices to Japanese waters

Representative drinking water Since it was difficult to express both tasty and healthy water with an overall index combining O index and K index, the drinking waters were classified into four categories as shown in Table 6. Figure 2 shows a plot of O and K indices for seven tap waters and six mineral waters (including well water, groundwater and spa water) in addition to the waters shown in Table 1. Most tap waters were located near the healthy line (K line; line of 5.2 of K index) but below the tasty line (O line; line of 2.0 of O index): the exceptions were Kumamoto, Aomori, Kagoshima, and Shimamoto (Osaka). On the other hand, many of the mineral waters were over the tasty line, most were left of the healthy line. Only three samples, O mineral water, well water of Suizenji, and tap water of Shimamoto, were put into the category of healthy and tasty water. If the criteria of healthy and tasty waters are relaxed slightly, Evian water, tap water of Kagoshima and well water of Nigatsu-do can be also put into the category of healthy and tasty water. If an appropriate amount of calcium is added to waters of Omi spa and Dogo spa and groundwater of C Recreation Ground, Takarazuka, Hyogo, they will also fall into the category of healthy and tasty water.

Concentrations of potassium and silica are

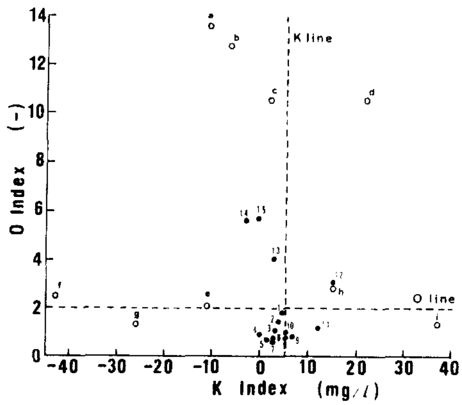

Fig. 2. Distribution of O index and K index for representative Japanese drinking waters.

●: Representative tap waters
1, Fukuoka; 2, Nara; 3, Okayama; 4, Akita; 5, Miyazaki; 6, Matsuyama; 7, Osaka; 8, Kyoto; 9, Kobe; 10, Otsu; 11, Oita; 12, Shimamoto; 13, Kagoshima; 14, Aomori; 15, Kumamoto.

○: Mineral waters including ground and well waters
a, well water of R Hotel, Nara; b, well water of Kaburaiji, Kobe; c, Nigatsu-do, Nara; d, O mineral water, Okayama; e, groundwater of C Recreation Ground, Takarazuka, Hyogo; f, groundwater of Omi spa, Shiga; g, groundwater of Dogo spa, Matsuyama, Ehime; h, Suizenji, Kumamoto; i, Evian, France.

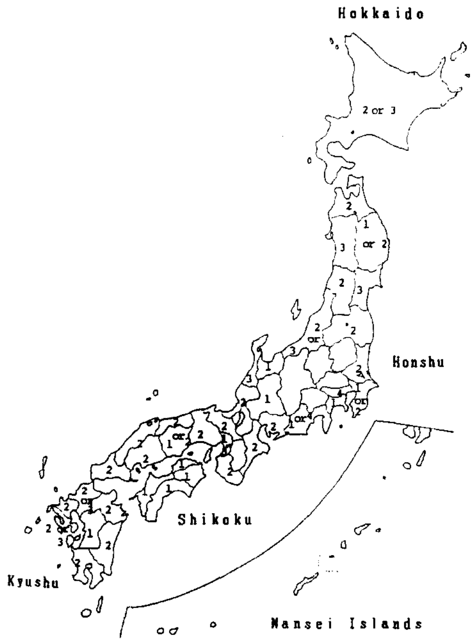

Fig. 3. Category of river water quality in each Japanese prefecture.

closely related to the requisites of tasty water, so waters which were classified as healthy water may be put into the category of healthy and tasty water by the appropriate addition of potassium and silica. This idea will be applied to make drinking water healthy and/or tasty.

River water The values of O and K indices of 218 Japanese river waters were calculated from the analytical data reported by Kobayashi,[14] and these waters were classified into the four categories as shown in Table 6. The representative category number for each prefecture was then determined using the distribution of category numbers of all rivers located in that prefecture, and the results are mapped in Fig. 3. In Aomori prefecture, for example, seven rivers were listed, five of them in category 2 and two in category 3, and therefore Aomori prefecture was classified into category 2. Classification as category 1 or 2 indicates almost equal numbers of rivers of category 1 and category 2 in a prefecture. Of all prefectures, 27% were classified as category 1, 52% as category 2, 14% as category 3,

Table 7. Classification of Japanese river waters by O and K indices.

Category	218 Japanese rivers[14]		Famous Japanese rivers	
	Rivers	%	Rivers	%
Category 1	49	23	5	25
Category 2	115	53	12	60
Category 3	40	18	2	10
Category 4	14	6	1	5
Total	218	100	20	100

* Rivers related to the 100 famous waters selected by the Environmental Agency.[15]

4% as category 4. In other words, 79% of all Japanese prefectures are classed as having tasty water and 31% are classed as having healthy water. All four prefectures in Shikoku fall into category 1, suggesting that the river waters of Shikoku are affected by the same geological properties.

In this classification, most prefectures belong to the category of tasty water. This is consistent with people's perceptions of drinking water, except in Tokyo or Osaka, where the resevoirs of drinking water have been polluted.

Figure 2 also suggests that the findings in Table 5 are consistent with the results of this classification, since many prefectures in north-eastern Japan belong to category 2 or 3 and many in south-western Japan belong to category 1 or 2. This may depend mainly on the calcium concentration of river waters.

Famous waters Yagi[15] listed 21 rivers which are related to the 100 famous waters (including river, spring, well water, and groundwater) selected by the Environmental Agency. The O and K indices of twenty of these rivers were calculated from the analytical data reported by Kobayasi,[14] and the rivers were classified into the four categories. These are shown in Table 7, together with the 218 Japanese rivers. The two groups of rivers were distributed similarly into the four categories, suggesting that 20 rivers selected by the Environmental Agency might be regarded as representative rivers of Japan. This finding is consistent with our daily experience.

We conclude that the two indices of tasty and healthy water should be of use for evaluating water quality from the viewpoint of an advanced water purification method or an advanced water supply system. These indices can be applied immediately as standards of drinking water quality for people in the desert regions or on solitary islands, who make the drinking water from sea water or moisture in the air.

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