TASTI QUALITY OF MINERALIZED WATER

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TASTI

THE taste of water is affected by the common dissolved minerals: calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride, nitrate, and sulfate. Collectively these constituents make up most of the dissolved minerals in water. The purpose of the present research was to collect data which would for the first time objectively describe the relationship between mineral content and the general taste quality of water. Such data will contribute basic knowledge regarding mineral taste in water and it will be of substantial use in establishing standards which regulate the potability of domestic water.

The USPHS [1] has a recommended limit of 500 mg/l for total dissolved solids (TDS) in drinking water. There are no records to indicate any scientific basis for the USPHS standard. Many communities now use water containing TDS above 500 mg/l, some above 1,000 mg/l, without apparent ill effects or noticeable deleterious physiological reactions.[2] However, consumers may strongly dislike the taste of more highly mineralized waters. In addition to freedom from danger to health, water served the public should be fully acceptable for daily drinking. Therefore, objective standards for mineral content are need to ensure potability for all consumers, and this need is particularly acute in rapidly developing semiarid regions of the United States where water is often highly mineralized.

A common approach to taste and odor problems in domestic water has involved the determination of detection thresholds.[3,4] A limit for the constituent producing taste or odor is then set at a value that would prevent its detection by most or all consumers. The detection threshold approach is unnecessarily and unreasonably restrictive for common minerals in domestic water, and therefore an alternative method has been developed which allows for assessment of the general taste quality of mineralized water by methods of psychometric scaling. A full rationale for the scaling approach has been given in an earlier paper.[5] The research has two major components, taste panel evaluations and consumer attitude surveys. The purpose of the present report is to present results from two taste panel studies in which panel members rated the general taste quality of natural water samples. The panel data, along with results from consumer surveys which will be reported separately, can be used to establish standards which govern total mineral content in domestic water.

Method

Study I. Samples for the first taste panel study were collected from eleven community water systems located in the central California coastal area, carefully selected for range of mineral levels and absence of possible interfering taste- and odor-producing substances. On-site hot and cold odor threshold tests [6] for water samples collected from each source supplying each system showed that none contained perceptible odor. Further, no system had any history of complaints regarding odor nor any record of taste problems other than those attributable to common minerals. With the exception of one system, all sources were wells and these waters were not chlorinated or otherwise treated. The one exception, a surface water system, was carefully checked to be sure that the chlorine residual produced no perceptible taste or odor in the delivered water, and this was supported by the odor threshold tests. None of the samples taken from the sources supplying each system contained iron or manganese in amounts exceeding 0.1 mg/l. Finally, the level of total mineralization had been relatively constant over sources and seasons for each system for the past several years. Water samples for the taste panel work, one from each system, were collected in Sep. 1966. Chemical analysis data for each sample appears in Table 1.

The 27 subjects who voluntarily served in Study I, eighteen males and nine females, were all employees of the State of California Department of Public Health and residents of the San Francisco Bay area. The domestic water supplied all subjects was low in total mineral content (TDS <250 mg/l). Although many of the subjects had prior experience in water taste studies, none was highly experienced in sensory evaluation procedures. Study I was conducted during Nov. 1966.

Each subject took part in three rating sessions separated by an interval of 1 week. All eleven samples were rated on two nine-point scales during each session. Rating was performed alone in a small, quiet, air conditioned room whose temperature was maintained at 70° ± 2°F. Water samples were served at room temperature since earlier research had revealed that sample temperature ranging from 40°–72°F had little systematic effect on ratings of taste quality obtained using

TABLE 1

Chemical Data for Samples Used in Study I—mg/l

Sample Number	TDS	Ca	Mg	Na	HCO_3	Cl	NO_3	SO_4	Sample Number in Study II
1	50	8	1	2	17	2		2	1
2	119	5	5	17	32	26	9	3	5
3	358	58	13	36	194	16		91	
4	452	31	35	69	278	49	14	63	14
5	644	68	33	58	91	71	144	141	15
6	654	93	45	43	339	44	26	144	16
7	1,011	140	53	80	266	45	12	438	23
8	1,063	144	54	93	257	53	16	470	27
9	1,163	168	73	58	294	129	12	387	
10	1,188	162	63	95	331	76	22	471	28
11	2,250	314	140	124	287	164	18	1,121	29

Tests were conducted to determine mineral content levels in drinking water as they affect the taste. Based on test results, a grading schedule is offered which codifies water taste acceptability as a factor of mineral content.

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methods similar to those employed in the present study. Samples were presented in letter-coded 100-ml beakers filled to the 75-ml level. Subjects tasted each sample three times, recorded the rating for each scale, rinsed thoroughly with Berkeley tap water (85 mg/l TDS), and rested for 1 min before proceeding to the next sample. Sample order was randomly arranged before each individual rating session. A different coding system was used for each of the three weeks of the study.

One of the nine-point scales was comprised of quality (Q) statements (Table 2) referring directly to the taste of water in general good-bad terms, while the other was comprised of action tendency (AT) statements (Table 3) referring to predicted behavior regarding the water for daily drinking. Scores on the Q scale could range from 1.16 to 10.67, and those on the AT scale could range from 1.05 to 9.96. The number 6.00 on each scale represents the neutral point. Scores below 6.00 indicate increasingly negative ratings, and scores above 6.00 indicate increasingly positive ratings. Units on each rating scale were designed to represent equal distances on the continuum and results are reported to the second decimal place as a matter of convention.[7] A full description of the rating scales and a discussion of their reliability and validity is available.[8]

Study II. Samples for the second taste panel study were collected in May, 1968, from 29 community water systems scattered throughout the state of California. Samples were taken from 9 of the 11 systems covered in Study I as indicated in the extreme right column of Table 4 which lists chemical analysis data for Study II samples. Criteria for system selection were the same as for Study I. As in Study I, only one system was a treated surface water; all other systems were supplied by wells whose waters were not chlorinated or otherwise treated. Consumer surveys, the results of which will be reported separately as noted earlier, have very recently been completed for all 29 systems.

TABLE 2

Quality (Q) Scale

Statement	Scale Value
1. This water has an excellent taste	10.67
2. This water has a very good taste	9.79
3. This water has a good taste	8.45
4. This water has a slightly good taste	7.16
5. This water has a neutral taste	6.00
6. This water has a slightly bad taste	4.61
7. This water has a bad taste	2.95
8. This water has a very bad taste	2.05
9. This water has a horrible taste	1.16

TABLE 3

Action Tendency (AT) Scale

Statement	Scale Value
1. I would be very happy to accept this water as my everyday drinking water	9.96
2. I would be happy to accept this water as my everyday drinking water	9.20
3. I am sure that I could accept this water as my everyday drinking water	8.07
4. I could accept this water as my everyday drinking water	7.35
5. Maybe I could accept this water as my everyday drinking water	5.64
6. I don't think I could accept this water as my everyday drinking water	4.21
7. I could not accept this water as my everyday drinking water	2.65
8. I could never drink this water	1.27
9. I can't stand this water in my mouth and I could never drink it	1.05

Twenty of the 27 subjects participating in Study I served as panel members in Study II, which was conducted during Jul. 1968. Thirteen of the Study II subjects were males and seven were females.

Each subject took part in nine rating sessions, one per day, conducted during a 2-week period. Ten samples were rated during sessions 1, 2, 4, 5, 7, and 8; while nine samples were rated during sessions 3, 6, and 9. Code numbers representing the 29 samples were randomly arranged separately for each subject. The first ten samples in the random order constituted session 1; the second ten, session 2; and the remining nine, session 3. The remaining sessions were set up for each subject in the same way using new code numbers. In this manner each subject rated each sample three times during the entire course of the study.

A paper presented on Oct. 24, 1968, at the California Section Meeting, Anaheim, Calif., by William H. Bruvold, Assoc. Research Scientist, School of Public Health, Univ. of Calif., Berkeley, Calif., and Henry J. Ongerth (Active Member, AWWA), Asst., Bur. of San. Eng., Calif. State Dept. of Public Health, Berkeley, Calif. [Q]

TABLE 4

Chemical Data for Samples Used in Study II—mg/l

Sample Number	TDS	Ca	Mg	Na	Cl	HCO_3	NO_3	SO_4	Sample Number in Study II
1	53	9	1	3	4	33	1	1	1
2	78	5	1	4	2	34	1	1	
3	96	14	3	6	2	73	2	1	
4	103	9	4	7	2	62	1	1	
5	118	5	5	18	25	39	10	5	3
6	192	17	3	37	5	139	1	14	
7	209	11	9	29	12	126	5	6	
8	277	50	9	30	14	210	3	39	
9	359	55	13	48	31	222	5	67	
10	376	48	14	57	68	244	3	13	
11	401	71	15	38	37	235	6	69	
12	418	77	17	37	41	248	6	76	
13	452	93	21	14	34	250	81	45	
14	584	38	41	88	66	288	16	113	4
15	617	69	34	59	63	137	150	134	5
16	677	95	41	56	68	276	77	145	6
17	778	111	27	103	116	296	21	195	
18	796	101	44	78	129	222	89	170	
19	808	45	9	184	62	84	10	394	
20	877	116	31	109	112	224	12	298	
21	930	121	35	125	114	383	121	142	
22	956	75	61	139	134	217	12	335	
23	957	138	43	80	42	240	9	416	7
24	1,020	68	12	271	334	196	4	149	
25	1,030	113	56	135	171	299	22	287	
26	1,038	147	52	79	51	232	11	459	
27	1,072	144	49	98	34	232	17	508	8
28	1,120	170	68	64	128	306	9	400	10
29	2,236	305	130	134	159	260	20	1,104	11

Rating was performed in a large laboratory room with each subject at his own bench with sink. Room temperature was maintained at 70° ± 4°F. Rating procedures were the same as those employed in Study I. Scale ratings for Q and AT were obtained for each sample as in Study I.

Results

Study I. The three ratings given each water sample in Study I by a single subject on a particular scale were averaged to yield eleven mean scores for each subject and scale. Table 5 shows Q and AT means and standard deviations. Each entry in Table 5 is based upon 27 individual mean ratings. The lines best fitting TDS values and Q and AT means are presented in Fig. 1, along with related correlation coefficients and standard errors of estimation.[9] Stepwise multiple regression analyses [10] employing all ions, except for potassium and carbonate whose concentrations were negligible, were performed with Q and AT ratings. Results showed the correlation coefficient for the best single ionic predictor of individual mean Q ratings—calcium—to be −0.53, while the multiple correlation coefficient for the seven ions, a necessarily nonnegative value, was 0.54. Analogous results were obtained for AT ratings with coefficients of −0.44 and 0.45, respectively, for calcium and for the seven ions.

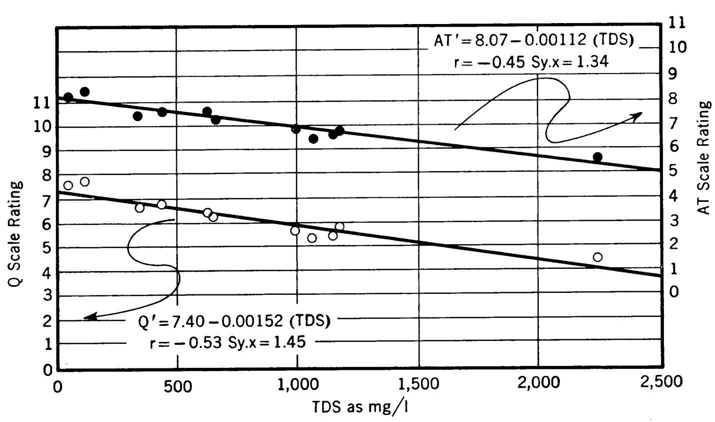

Fig. 1. Lines of Best Fit for Study I Ratings

Both this figure and Fig. 2 show a clear distaste for water containing much more than 1,000 TDS, the authors construct their suggested potability grade scale (Table 7) with this area as his boundary between palatable and unpalatable water.

Study II. The three ratings given each water sample in Study II by a single subject on a scale were averaged to yield 29 individual mean scores for each subject and scale. Study II means and standard deviations for the Q and AT scales are shown in Table 6. Each entry in Table 6 is based upon 20 individual mean ratings. The lines best fitting the Q and AT means and the TDS values of Study II are presented in Fig. 2 with the associated correlation coefficients and standard errors of estimation. Stepwise multiple regression analyses were also performed upon Study II results employing the seven ions listed in Table 4. The best single predictor of Study II Q ratings was calcium with a correlation coefficient of −0.49. The multiple correlation coefficient for Q ratings as predicted by a linear combination of all seven ions was 0.59. Analogous results for AT ratings of Study II were −0.42 for calcium and 0.48 for the seven ions.

Discussion

The results clearly show that there was an inverse linear relationship between general taste quality and total mineral content for the waters here studied. Results from multiple regression analyses involving major ionic constituents as predictor variables show only a small increase in percentage of variance accounted for when compared to the linear TDS functions. This statistical finding is illustrated by Fig. 1 and 2 where it may be seen that all means fell near their respective lines of best fit. The reliability of the inverse linear relationship between taste ratings and total mineral content is attested to by the similarity of all four regression equations. The smaller slope for AT ratings is due to panel members' expressed willingness to consume waters that had a slightly bad mineral taste. In spite of this differ-

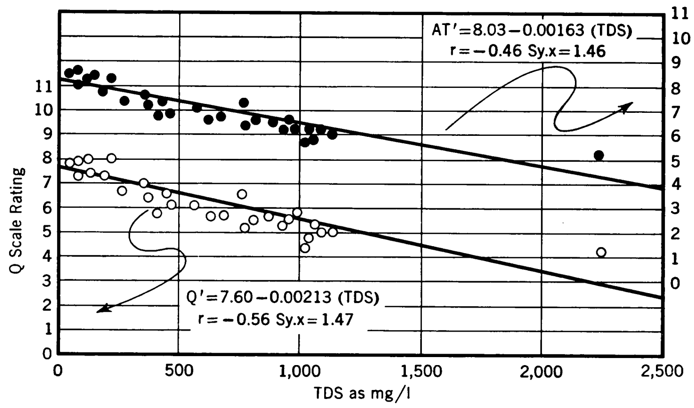

Fig. 2. Lines of Best Fit for Study II Ratings

The slighter slope of the action tendency (AT) line than of the quality (Q) line reflects the willingness of panel members to accept worse tasting water than they really like.

ence, the slopes and intercepts of all four lines, and the associated correlation coefficients and standard errors of estimation were, as noted, similar in value.

What are the implications of these findings for standards which seek to ensure the potability of mineralized water? Taking only the taste panel data, water could be graded on the basis of the linear TDS functions, functions which accounted for the major portion of the explainable variance in rating scale scores. It should be noted that the slopes of the linear functions were gradual, that a rating of 6.00 always represented the neutral point, and that there was a distribution of ratings above and below each of the means for each scale. The substance of the latter finding is shown by the standard deviations of Tables 5 and 6 and by the reported standard errors of estimation.

Considering the three points noted, it would immediately appear to follow that the limit for mineral content should be the highest TDS value resulting in no dissatisfaction with mineral taste in the water. For the present situation this would be the highest TDS value associated only with scores of 6.00 or higher. However, the results shown in Tables 5 and 6, and a consideration of the size of the four standard errors of estimation, reveal this to be an unreasonable approach since some dissatisfaction with the water's taste occurs even at the lowest levels of mineralization. Thus, a value judgment is needed to decide what degree of dissatisfaction with mineral taste in water can be accepted. Since the slope of the linear relationship is gradual, no single cut-off point is immediately obvious. Perhaps the best solution to the problem would be to establish multiple cut-off points referring to grades of water. One such solution is suggested in Table 7 using AT ratings for the 29 waters as an example. The TDS values associated with each grade of water were estimated using the standard error of estimation and assuming a normal distribution around the line of best fit.

Conclusion

Some final comments are in order regarding Table 7 and the scope of the research here reported. The grades of potability by TDS levels shown in Table 7 represent but one solution to the problem of recommending limits for mineral content in domestic water. Other solutions could be developed for the present data employing alternative regression equations listed above or results from the multiple regression analyses. Further, it must be strongly emphasized that the research reported here is the first of what should become a comprehensive set of studies dealing with the general taste quality of mineralized water. When results from consumer surveys on these and additional waters become available, standards for mineral content can be established with confidence. Obstacles which in the past have blocked establishment of these standards have been considerably lessened now that it has been demonstrated that reliable assessment of the general taste quality of mineralized water can be obtained by methods of psychometric scaling.

TABLE 5

Means and Standard Deviations for Study I Ratings

Sample Number	Q Scale		AT Scale	
	Mean	Standard Deviation	Mean	Standard Deviation
1	7.60	1.53	8.19	1.18
2	7.75	1.09	8.37	0.65
3	6.70	1.36	7.44	1.24
4	6.90	1.08	7.66	1.04
5	6.26	1.61	7.25	1.33
6	6.10	1.67	7.15	1.30
7	5.74	1.35	6.96	1.26
8	5.14	1.59	6.43	1.58
9	5.52	1.61	6.65	1.68
10	5.63	1.29	6.76	1.41
11	4.47	1.51	5.87	1.68

Acknowledgments

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TABLE 6

Means and Standard Deviations for Study II Ratings

Sample Number	Q Scale		AT Scale	
	Mean	Standard Deviation	Mean	Standard Deviation
1	7.99	1.42	8.25	0.97
2	7.97	1.33	8.32	1.33
3	7.63	1.49	8.02	1.27
4	7.98	1.21	8.14	1.06
5	7.86	1.43	8.21	1.23
6	7.40	1.25	7.84	1.15
7	8.01	1.57	8.25	1.27
8	6.73	1.44	7.38	1.44
9	7.07	1.38	7.60	1.36
10	6.66	1.66	7.44	1.41
11	5.97	1.32	6.90	1.38
12	6.71	1.64	7.26	1.38
13	6.14	1.46	6.90	1.40
14	6.19	1.53	7.16	1.28
15	5.71	1.58	6.62	1.38
16	5.75	1.33	6.71	1.41
17	6.69	1.46	7.31	1.35
18	5.41	1.06	6.45	1.25
19	5.47	1.72	6.59	1.69
20	5.85	1.32	6.65	1.51
21	5.33	1.16	6.21	1.31
22	5.46	1.21	6.44	1.71
23	5.64	1.49	6.43	1.75
24	4.50	1.24	5.70	1.72
25	4.82	1.27	5.85	1.60
26	5.40	1.53	6.32	1.75
27	5.18	1.47	6.18	1.62
28	5.01	1.62	6.02	1.81
29	4.20	1.12	5.35	1.71

TABLE 7

Suggested Potability Grades by TDS as Defined by Estimated Percentage of Testers Dissatisfied With the Water's Taste, Based on AT Ratings from Study II

Potability	Excellent	Good	Fair	Poor	Unacceptable
Grade	A	B	C	D	F
Estimated % scoring below 6	0–15	16–25	26–35	36–45	46–100
TDS—*mg/l*	≤313	314–638	639–896	897–1,129	≥1,130
Rounded TDS values—*mg/l*	≤300	301–600	601–900	901–1,100	≥1,101

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Snowpack Monitoring from Space?

Mark F. Meier wrote in the January 1969 Journal about the vast reserves of fresh water that might someday be tapped from packed snow, in the form of glaciers, scattered throughout America's Northwest. Now Dr. Meier, who is a research glaciologist with the USGS Water Resources Division in Tacoma, Wash., has turned his attention to fresher snowfall and, with William J. Campbell, a USGS research meteorologist, is conducting tests at Crater Lake, Ore., to determine the feasibility of eventually monitoring the amount of snow on the ground, and its location, from earth-orbiting satellites. The test project involves the operation of truck-mounted microwave radiometers in the mountain snow areas of the West in an attempt to find out if these remote sensing techniques can help analyze snow-water resources.

"Snow surveying on the ground," Meier and Campbell explain, "is a laborious and costly task. If the microwave systems prove capable of making the proper measurements, they can eventually be used from aircraft and satellites to survey the snowpacks of large drainage basins to aid in regional management of the water resources."

The 2-year project is related to a number of studies being conducted by the USGS in cooperation with NASA, to define specific objectives of the proposed Earth Resources Observation Satellite (EROS) program.