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UROLITHIASIS

What kind of water should I advise my kidney stone patient to drink: the Dutch experience

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Introduction To compare the mineral content of commercially available water (tap and bottled) in the Netherlands and to evaluate which type of water should be recommended for kidney stone patients.
Material and methods All Dutch water supply companies were contacted to request water analysis reports of tap water. Bottled still and sparkling water available in the 5 main supermarket chains in the Netherlands were also included. Information regarding the mineral composition of bottled waters was read from the manufacturers' ingredient label on the bottles. Data regarding sodium, potassium, bicarbonate, calcium, magnesium, and sulphate content were evaluated.
Results All Dutch water supply companies, consisting of 179 production locations, were included. Twenty-one bottled still waters and 25 bottled sparkling waters were included. There was a wide range of results for the evaluated minerals. Sodium levels were highest in tap water (134.0 mg/l), whereas potassium concentrations were highest in bottled water (18.0 mg/l). Bicarbonate, calcium, and sulphate concentrations were highest in bottled still water (432.0 mg/l, 240.0 mg/l, and 400.0 mg/l, respectively). Magnesium levels were highest in bottled sparkling water (51.4 mg/l).
Conclusions Commercially available water (bottled and tap) in the Netherlands is safe to use for KSD patients. However, specific bottled waters can be described as calcium and magnesium rich. Therefore, it remains important for KSD patients and their physicians to realise that the mineral composition of drinking water may vary, and its consumption might require alterations of their diet.

Key Words: bottled water ‹› kidney stone disease ‹› mineral content ‹› mineral composition ‹› tap water ‹› urolithiasis

INTRODUCTION

Urolithiasis is one of the most common urological disorders, which, due to its high costs and increasing prevalence worldwide, represents a significant burden of disease. The overall prevalence of kidney stone disease (KSD) is currently estimated to be around 8.8% in North America and approximately 5–10% in Europe, and these numbers keep rising [1, 2].

One of the most recognised strategies to prevent crystal-forming elements such as oxalate and calcium precipitating within the urinary tract is dilution of urine and prevention of stasis. The underlying mechanism of diluting the urine results in reduction of the saturation state of kidney stone promoters. In addition, the upper meta-stability limit for nucleation of calcium-oxalate increases in the event of higher urinary volume [3]. Earlier research has shown that a high water intake resulting in a minimum of 2 litres of urine per day significantly reduces stone recurrence rates in calcium stone formers [4, 5]. The risk of kidney stone development is reduced by 50% in individuals with a fluid intake of 2.3 l/day compared to those with a fluid intake of 1.2 l/day [6]. On top of this, a regime with high water intake prolonged the interval between stone episodes [4, 5]. Therefore, nowadays the recommended fluid intake for KSD patients is 2.5–3 l/day to achieve a diuresis of 2–2.5 l/day [7].

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Although sufficient water intake is crucial as a preventive measure against stone formation, physicians must realise that the mineral composition of water may differ regionally or between commercial water brands. Previous studies have demonstrated the broad range in the mineral composition of bottled water around the world [8–10].

For physicians and KSD patients it is important to acknowledge these differences in mineral content because drinking water contains minerals known to promote stone formation, like calcium. Contrarily, other minerals might have a preventive effect on stone formation, like bicarbonate and magnesium. Therefore, a common question in the daily practice of urologists is which water (tap, bottled still, or bottled sparkling water) KSD patients should drink.

Because stone formation might be influenced by the type of water consumed and the range of minerals in water has been found to be so broad, this study aims to compare the mineral content of commercially available waters in the Netherlands to discover which type of water should be recommended for KSD patients.

MATERIAL AND METHODS

Study design

This descriptive study aims to analyse the mineral content of commercially available water (tap and bottled) in the Netherlands to enhance the understanding of the variabilities of mineral content of drinking water. Moreover, this study evaluates whether the differences in mineral content could negatively influence stone formation, and which water is safest for KSD patients.

All water supply companies across the Netherlands were contacted to request water analysis reports from collected water samples. Because some supply companies publish these reports online, the selected reports for those companies could be downloaded from the website. The remaining water companies were requested to send their reports by e-mail. However, some water companies provided us with data summarising a single month, half a year, or even a whole year because the data for the requested period were not separately available.

The ingredient labels on water bottles available in the 5 main supermarket chains in the Netherlands were read for information regarding mineral composition. According to a market study performed by NielsenIQ, these 5 supermarket chains (Albert Heijn, Jumbo, Plus, Lidl, and Aldi) are good for a market share of 79.4% [11]. Data collection was performed in December 2022.

Data regarding sodium, potassium, bicarbonate, calcium, magnesium, and sulphate content were extracted.

Statistical analysis

The software Statistical Package for Social Sciences (SPSS) Statistics, version 28, (IBM Corp., Armonk, New York, USA) was used for statistical analysis. All data are expressed as median (interquartile range [IQR]). To provide a graphic representation of the data and to compare the distribution of our data, simple boxplots were used. Within the boxplots, outliers (1.5 × IQR) are displayed as circles and extreme values are displayed as asterisks (3 × IQR).

RESULTS

Tap water

All water supply companies in the Netherlands (Brabant Water, Dunea, Evides, Oasen, PWN, Vitens, Waterbedrijf Drenthe, Waterbedrijf Groningen, Waternet, and WML) were included. Each company consists of several production locations spread throughout their service area, where water is purified to produce tap water. The mineral content of drinking water derived from 179 production locations was analysed. Four of the included water supply companies (Dunea, Evides, Oasen, and PWN) did not report data on potassium levels. The reports from Oasen did not include data regarding calcium and magnesium levels.

Figure 1 visualises the distribution of sodium, potassium, bicarbonate, calcium, magnesium, and sulphate concentrations in tap water in comparison with the concentrations in bottled still and sparkling water. Sodium levels in Dutch tap water varied the most in comparison to bottled waters, with a range between 0.8 mg/l and 134.0 mg/l (median 19.0 mg/l [IQR: 11.5–42.0]). Potassium concentration had the smallest range, from 0.6 mg/l to 8.2 mg/l (median 2.4 mg/l [IQR: 1.3–3.6]). Bicarbonate ranged from 49.0 mg/l to 276.0 mg/l (median 153.0 mg/l [IQR: 124.0–190.0]). Calcium levels of tap water ranged from 15.2 mg/l to 96.5 mg/l (median 44.0 mg/l [IQR: 37.2–51.0]). Magnesium concentrations were between 1.1 mg/l and 13.2 mg/l (median 6.0 mg/l [IQR: 4.1–7.9]). Finally, sulphate levels varied between 0.5 mg/l and 90.0 mg/l (median 21.1 mg/l [IQR: 6.3–38.0]). An overview of all data is available in Table 1.

Bottled still water

All commercially available bottled still water brands in the 5 largest supermarket chains in the Netherlands

(Albert Heijn, Jumbo, Lidl, PLUS, and Aldi) were included in this study. In total, 21 different bottled still waters were analysed (Acqua Panna, Albert Heijn, Albert Heijn Basic, Bar le Duc, Chaudfontaine, Cristaline, Dalphin, Evian, G'woon, Jumbo, Just Water, Montcalm, Natural Cool, PLUS, Quellbrunn, Saskia, Solan de Cabra, Sourcy, Spa, Tavina Elegantia, and Vittel).
Figure 1 visualises the distribution of sodium, potassium, bicarbonate, calcium, magnesium, and sulphate concentrations of these bottled still waters in comparison with the concentrations in tap and bottled sparkling water. Sodium levels in Dutch bottled still water varied between 0.0 mg/l and 50.4 mg/l (median 8.3 mg/l [IQR: 4.0–31.8]). Potassium varied from 0.4 mg/l to 18.0 mg/l (median 2.0 mg/l [IQR: 0.8–3.5]). The range 0.3–432.0 mg/l (median 190.0 mg/l [IQR: 71.3–332.5]) in bicarbonate levels was highest in bottled still waters when compared to tap and bottled sparkling waters. Calcium levels of bottled still

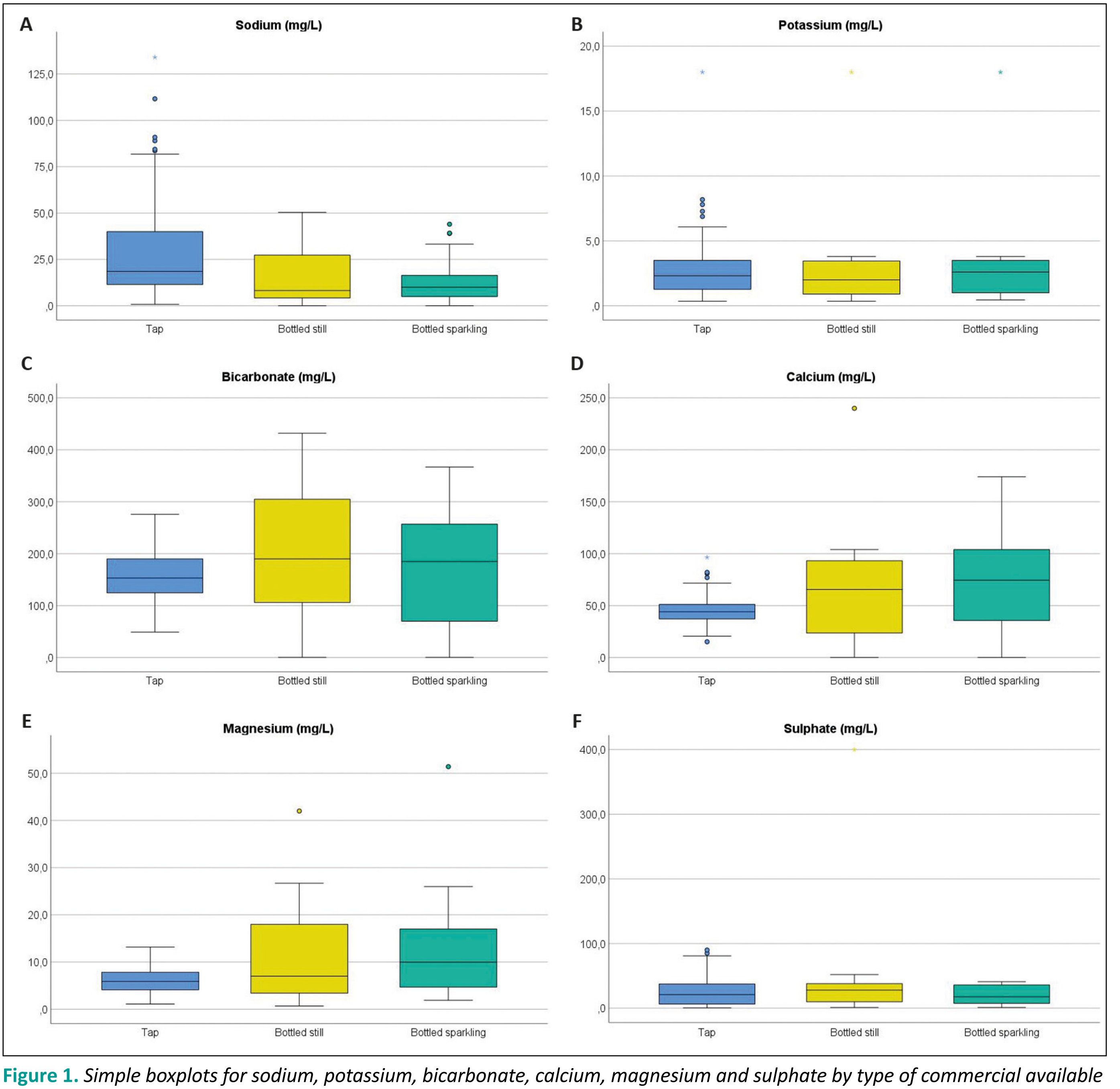

Figure 1. *Simple boxplots for sodium, potassium, bicarbonate, calcium, magnesium and sulphate by type of commercial available water.*

Table 1. *Overview of mineral content in tap water*

		Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Brabant Water	Bergen op Zoom	183.3	61	3.3	2.6	16	26
	Budel	170	36	5.9	4.15	12.5	5.5
	Dorst	240	57	6.6	5	16	2.6
	Eindhoven	160	35	4.85	3.1	11.67	6.3
	Genderen	260	58	5.9	3.8	22	<1
	Haaren	180	40	3.8	5	11	<5
	Helmond	210	61	6	1.7	12	20
	Lieshout	210.77	37.15	9.89	4.1	19	<5
	Lith	126.67	44.62	8.68	3	16	44
	Loosbroek	245	41	9.55	5.9	49	<5
	Luyksgestel	89	34.67	1.1	1.1	6.4	22
	Nuland	231.67	56.15	8.56	4.7	62	18
	Oirschot	170	27	6.2	7.8	16	<5
	Oosterhout	188.33	44.25	7.22	4.25	11.67	<5
	Prinsenbosch	220	58	4.9	2	5.9	<1
	Schijndel	250	46	7.5	5.7	30	<5
	Seppe	172.86	44.62	6.08	2.31	11.86	<5
	Someren	210	45	7.8	2.5	15	<1
	Son	220	50	5.8	3.4	14	<5
	Tilburg	145.71	45.31	6.72	3.59	8.69	29.14
	Veghel	217.14	35.15	9.82	5.69	55.71	<5
	Vessem	140	62.33	5.8	1.97	15.13	71.33
	Vlierden	270	54	11	4.9	28	<1
	Vlijmen	160	42	5.1	4.6	15	25
	Welschap	150	33	5.9	3.1	11	<5
	Wouw	197.14	45.85	6.37	4.96	14.71	<5
Dunea	Katwijk	174	44	8.1		63	51
	Monster	171	45	8.4		60	55
	Scheveningen	175	43	8.2		63	52
	Katwijk	179	46	8.1		54	48
	Monster	173	46	8.2		51	50
	Scheveningen	176	44	8.3		57	48
Evides	Baanhoek	160	46	7.1		43	40
	Berenplaat	130	45	6.8		42	48
	Braakman	120	45	6.9		44	65
	Haamstede	200	77	8.4		44	55
	Halsteren	170	50	3.7		20	26
	Huijbergen	210	52	3.8		40	21
	Kralingen	130	46	6.7		40	48
	Midden Zeeland (Huij-bergen-Ossendrecht)	210	52	3.8		40	21
	Ouddorp	250	82	9.7		40	32
Oasen	Alblasserdam	165.7				44.73	41.2
	De Hooge Boom	227.78				111.62	60.8
	De Laak	126.38				32.23	31.1

Table 1. *Continued*

		Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Oasen	De Steeg	138.54				44.12	36.19
	Reijerwaard	103.11				48.8	21.05
	Rodenhuis	157.3				78	52.3
	Schuwacht	131.77				32.01	25.32
PWN	Andijk	141	34	13		134	85
	Bergen	145	45	7.3		62	38
	Laren	145	50	4		19	24
	Leiduin	161	38	9		73	50
	Mensink	148	41	11		89	54
	Weesperkarspel	198	46	7		52	10
Vitens	Amersfoort Berg	98	36.9	4.35	1.6	17.6	22
	Amersfoort Hogeweg	119	33.5	2.76	1.18	11.4	4
	Amersfoortseweg	101	38.7	2.61	1.12	12.3	22
	Archemerberg	152	53.9	6.16	2.91	0.828	37
	Beerschoten	114	35.8	4.6	3.02	26.6	18
	Bremerberg	120	50.3	4.34	1.68	32.4	41
	Bilthoven	119	39.8	3.69	0.7	8	12
	Bunnik	147	44	8.64	1.64	11.8	20
	Buren	148	37.1	8.72	4.76	29.6	12
	Ceintuurbaan	175	59.1	10.4	7.28	84.4	<2
	Corle	195	41.5	7.91	2.99	79.2	90
	Cothen	184	47.1	7.93	1.14	12.6	<2
	Culemborg	276	71.6	5.39	1.27	21.4	<2
	De Meern	177	49.2	3.32	0.78	10.9	<2
	De Haere	80	24.5	2.06	0.84	15.6	14
	Diepenveen	155	43.9	5.88	4.58	70	<2
	Dinxperlo	163	54.5	5.8	5.09	37.5	65
	Doorn	81	36.4	6.08	2.1	18.4	35
	Driebergen	95	37.6	4.41	1.01	21	26
	Druten	202	34.8	12.8	4	90.9	49
	Eemdijk	153	40.2	3.16	1.38	11.6	<2
	Eerbeek	127	37.8	3.16	1.56	7.64	5
	Edesebos	97	41.6	3.42	0.74	13	26
	Ellekom	86	32	2.97	1.4	11.9	23
	Engelse Werk	145	48.9	5.57	2.78	30.3	30
	Epe	78	15.2	2.4	1.34	25	22
	Espelo	187	34.4	7.91	3.88	58.1	48
	Fikkersdries	125	39.6	3.38	0.61	6.54	8
	Fledite	92	28.5	2.35	0.86	8.09	8
	Goor	186	38.1	7.64	4.64	60	55
	Groenekan	170	64.4	4.58	1.14	22.5	24
	Hammerflier	169	58.2	5.48	2.58	23.4	28
	Harderbroek	85	26.5	2.16	0.78	6.08	8
	Harderwijk	98	35.4	2.57	0.76	7.66	15

Table 1. *Continued*

		Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Vitens	Hasselo	149	53.8	5.66	2.38	21.2	40
	Havelterberg	159	46.4	4.82	2.05	25.4	21
	Hengelo ,t Klooster	226	38.9	8.7	2.91	69.3	62
	Herikerberg	199	65.9	8.26	3.2	32.4	66
	Heumensoord	134	56.3	6.44	2.79	16.8	46
	Hoenderloo	129	40.9	4.54	2.01	11.2	14
	Hoge Hexel	141	66.5	5.87	2.64	14.1	67
	Hollum	124	33.7	5.7	4.16	19.4	7
	Holk	137	37.4	2.87	1.1	11.2	2
	Ir. Sijmons	234	70	8.38	8.18	18.6	16
	Kolff	244	26.6	10.2	3.18	71.5	21
	LaCabine	100	37.2	3.29	0.9	9.18	14
	Laren	174	54.9	3.61	1.24	21.6	12
	Leersum	69	33.6	3.39	1.68	10.2	26
	Leidsche Rijn	175	49.9	3.55	0.72	10.8	2
	Linschoten	176	48.6	4.01	1.18	13.3	<2
	Loosdrecht	125	38.9	2.27	0.84	13.8	11
	Manderveen	104	28	6.37	3.76	51.9	79
	Muntberg	65	27.5	5.29	0.88	15.8	36
	Nieuwegein	159	37.4	6.44	0.98	11	3
	Nijverdal	74	29.9	2.88	1.18	10.8	24
	Noord-Bergum	136	51.7	9.83	2.48	42.4	6
	Olde Eibergen	189	41.8	8.28	3.45	65	76
	Oldeholtpade	190	43.6	5.09	1.96	37.7	9
	Oosterbeek	114	38.6	4.13	0.8	7.78	14
	Pinkenberg	74	24.6	2.31	0.66	6.64	10
	Putten	100	42.5	3.7	4.5	10.5	29
	Rhenen	108	41.7	4.1	1.28	9.46	34
	Rodenmors	213	59.9	4.15	1.68	30.7	12
	Schalterberg	84	31.7	2.01	0.78	10.8	16
	Schiermonnikoog	136	38.3	5.97	2.3	19.5	4
	Sint Jansklooster	131	45.6	6.59	3.37	20.8	22
	Soestduinen	108	40.6	4.13	1.05	10.6	22
	Spannenburg	272	31.6	9.85	2.06	75	<2
	Terschelling	121	36.7	4.44	1.56	25	3
	Terwisscha	142	43.8	4.93	1.11	10.6	12
	Tull en 't Waal	168	41.2	5.87	1.18	12.6	<2
	Twello	150	32.2	5.01	4.48	53.5	5
	Van Heek Montferland	101	36.9	5.44	1.5	18.2	36
	Vechterweerd	126	44.5	3.48	2.95	25.8	30
	Veenendaal	162	37.2	7.69	5.32	19.8	4
	Velddriel	274	28	10.3	2.96	81.8	26
	Vlieland	114	41	5.96	3.6	42.8	19
	Vorden	240	34.8	10.4	3.05	83.6	66

Table 1. *Continued*

		Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Vitens	Wageningseberg	93	29.6	2.34	0.58	5.64	9
	Weerselo	217	96.5	8.89	3.36	19.6	78
	Weerseloseweg	145	44.5	6.41	2.6	29.4	48
	W.G. Boele Wezep	113	40.3	2.83	1.35	10.8	17
	Wierden	175	50.5	9.12	4.13	47.1	81
	Witharen	138	51.2	4.35	2.26	17.8	29
	Woudenberg	143	32.6	5.98	3.75	10.1	<2
	Zeist	71	30.8	5.16	1.55	18.1	36
	Zoelen	238	68.2	8.4	2.8	11	11
	Zutphenseweg	178	45.7	8.69	6.88	77.2	<2
Waterbedrijf Drenthe	Annen	180	51	4.2		12	6.2
	Assen	190	50	6.9		19	1.1
	Beilen	220	70	6.5		14	23
	Dalen	110	56	8.8	4.2		
	Gasselte	130	47	5.4			
	Hoogeveen	170	43	8.3		19	<0.5
	Kruidhaars	150	59	4.3		14	38
	Leggeloo	150	50	3.9			
	Noordbargeres	110	52	7			
	Ruinerwold	220	62	6.3	1.2	9.8	3.4
	Valtherbos	110	44	3.9	1.5	16	35
	Zuidwolde	190	57	6.1			
Waterbedrijf Groningen	De Groeve	190	62	5.7			
	De Punt	140	50	5.7	2.7	26	22
	Nietap	190	50	6.7		13	4.2
	Onnen	230	81	7	1.6	29	19
	Sellingen	140	35	4.3			
Waternet	Leiduin	175	39.7	9.3	4.03	69.7	47
	Weesperkarspel	196	44.3	6.58	2.89	51.7	9.7
WML	Beegden	129.09	49.73	1.95	1.53	6.3	31
	Bergen	129.09	49.73	1.95	1.54	6.3	31
	Breehei	195	55.75	6.95	3.03	16.25	29.75
	de Beitel- Heerlen	195.93	21.76	7.54	1.6	77	76.75
	Groote Heide – Venlo	159.57	48.26	5.38	1.73	9.53	20
	Grubbenvorst	147.5	53.25	6.48	2.65	35.5	39.75
	Hanik	137.5	50.25	10.38	3.85	28	15.25
	Heel	196.25	66.69	7.52	2.71	24	50.08
	Hoogveld- Sittard	216.88	60.13	8.5	2.1	7.6	20.75
	Hunsel	193.15	31.98	11.85	6.08	16.5	6.25
	Ijzeren Kuilen- -Maastricht	123.14	50.56	13.19	2.6	18.5	51.25
	Inkoop Vlodorp	158	44	7.3	1.3	6.3	19
	Inkoop Meinweg	147.5	52	6.55	3.25	11	34.5
	Inkoop Pannesheide – Kerkrade	49	20.58	3.23	1.51	11.5	22.83

Table 1. *Continued*

		Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
WML	Inkoop Rothenbach – Herkenbosch	215	62	13	5.5	17	40
	Inkoop Waldfeucht – Maria Hoop	107.5	41	7	2.2	11	39
	Ospel	182.96	45.18	9.66	3.2	21	25.5
	Pey – Echt	167.14	42.62	5.43	1.55	6.25	6.65
	Plasmolen	109.11	34.23	4.9	2.5	7.63	16.75
	Schinveld	109.3	35.78	1.73	1.18	4.3	12.73
	Susteren	120.7	37.57	4.73	2.28	11.85	21

water ranged from 0.1 to 240.0 mg/l (median 65.5 mg/l [IQR: 19.3–95.1]). Magnesium concentrations were between 0.7 mg/l and 42.0 mg/l (median 7.0 mg/l [IQR: 2.9–22.0]). Finally, sulphate levels varied the most in bottled still water with a range between 1.0 mg/l and 400.0 mg/l (median 28.0 mg/l [IQR: 10.0–39.0]) when compared to tap and bottled sparkling waters. An overview of all data is available as supplemental data (Table 2).

Bottled sparkling water

All bottled sparkling water brands that were available in the 5 largest supermarket chains in the Netherlands (Albert Heijn, Jumbo, Lidl, PLUS, and Aldi) were included in this study. This resulted in 25 different commercial bottled sparkling waters (Albert Heijn, Albert Heijn Basic, Bar le Duc, Chaudfontaine, Cristaline, Dalphin, Gerolsteiner Medium, G'woon slightly sparkling, G'woon, Hébron, Jumbo, Jumbo slightly sparkling, Natural Cool, Perrier, PLUS, PLUS slightly sparkling, Quellbrunn, Saskia, Saskia slightly sparkling, San Celestino, San Pelligrino, Sourcy, Spa Finesse, Spa Intense, and Tavina Elegantia Vivace). Figure 1 visualises the distribution of sodium, potassium, bicarbonate, calcium, magnesium, and sulphate concentrations of these bottled still waters in comparison with the concentrations in tap and bottled

Table 2. *Overview of mineral content in still bottled water*

	Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Acqua Panna	106	32.2	6.5	0.8	6.4	22
Albert Heijn	360			2.7	5	
Albert Heijn Basic	280	104	3.7	1.8	3.7	52
Bar le Duc	170	47	3.4	0.6	10.6	1
Chaudfontaine	305	65	18	2.5	44	40
Cristaline	432	66	26	18	50	34
Dalphin	219	78	7	3.8	39	36
Evian	360	80	26	1	6.5	14
Jumbo	190	97	10.8	3.4	18.5	
Just Water		15	2.35	0.35	50.4	35
Montcalm	5.2	3	0.7	0.6	2,.2	10
Natural Cool		89.5		3.6	36.2	
Solan de Cabra	284	60	26.7	1	4.8	
Sourcy	180	49	6	1	10	10
Spa	17	5	2	0.5	3	4
Tavina Elegantia	36.5	7.86	2.46			
PLUS koolzuurvrij		104		3.5	16.4	
G'woon koolzuurvrij		104		3.5	16.4	

Table 3. *Overview of mineral content in sparkling bottled water*

	Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]	Sodium [mg/l]	Sulphates [mg/l]
Albert Heijn	360			2.7	5	
Albert Heijn Basic	257	98	2	0.6	3,1	33
Bar le Duc	170	47	3.4	0.6	10.6	1
Chaudfontaine	305	65	18	2.5	44	40
Cristaline		66	26	18	50	
Dalphin	219	78	7	3.8	39	36
Gerolsteiner Medium	181.6	34.8	10.8	1.1	11.8	3.8
G'woon licht koolzuurhoudend		104		3.5	16,4	
G'woon koolzuurhoudend		104		3.5	16,4	
Hébron	360	105	16	3	6	41
Jumbo	190	97	10.8	3.4	18.5	
Jumbo slightly sparkling	367	142	20	3	6	
Natural Cool		89.2		3.6	39.2	
Perrier	420	150	3.9	<1	9,6	25.3
PLUS koolzuurhoudend		104		3.5	16,4	
PLUS licht koolzuurhoudend		104		3.5	16.4	
San Pelligrino		174	51.4	2.2	33.3	
Sourcy	180	49	6	1	10	10
Spa Finesse	70	11	5.5	1	9	8,5
Spa Intense	18	5.5	1.9	0,5	5	7.5
Tavina Elegantia Vivace	36.5	7.86	2.46			

sparkling water. Sodium levels in Dutch bottled sparkling water varied the least in comparison to tap and bottled still waters, with a range between 0.0 mg/l and 50.0 mg/l (median 10.3 mg/l [IQR: 5.0–18.0]). Potassium concentrations had the smallest range, starting at 0.5 mg/l and reaching 18.0 mg/l (median 2.6 mg/l [IQR: 1.0–3.5]). Bicarbonate ranged from 0.3 mg/l to 367.0 mg/l (median 185.0 mg/l [IQR: 53.3–281.0]). Calcium levels of bottled sparkling water ranged from 0.1 mg/l to 174.0 mg/l (median 74.5 mg/l [IQR: 35.2–104.0]). Magnesium concentrations had the highest range when compared to tap and bottled still water, varying between 1.9 mg/l and 51.4 mg/l (median 10.0 mg/l [IQR: 3.9–18.0]). Finally, sulphate levels had the smallest variety when compared to tap and bottled still waters, with a range between 1.0 mg/l and 41.0 mg/l (median 17.7 mg/l [IQR: 6.6–37.0]). An overview of all data is available in Table 3.

DISCUSSION

This study evaluates the mineral content (sodium, potassium, bicarbonate, calcium, magnesium and sulphate) of tap water purified by all Dutch water supply companies (179 production locations), as well as bottled drinking water available in the 5 largest supermarket chains.

Water is an important source of fluid intake worldwide. A survey among the Dutch population showed that on average 549 ml of water (excluding tea and coffee) is consumed daily per person, representing 27% of the daily fluid intake. Eighty-seven per cent of the total water intake consisted of tap water, which is the equivalent of 476 ml/day. In contrast, only 72 ml of bottled water is consumed daily, which demonstrates the preference for tap water by the majority of the population [12, 13]. However, the consumption of bottled water in Europe keeps rising, even though most Europeans have access to safe and cheap tap water [14]. Multiple reasons have been assigned to this rise, such as fashion, convenience, and the image of being safer, healthier, and tastier than tap water [14]. Interestingly, European tap water must meet strict European and, depending on the country, and local regulations regarding minerals and other biochemical substances, whereas bottled waters need not [15–17]. This leads to a broader range in mineral content in bottled waters compared to tap water – a potential risk for KSD patients.

This study shows that Dutch tap water had the smallest range in potassium, bicarbonate, calcium, and magnesium content. Bottled sparkling water had the lowest range in sodium and sulphate concentration. The fact that potassium, bicarbonate, calcium, and magnesium in tap water does not vary as much as in bottled water might be explained by the fact that Dutch drinking water must meet strict requirements by law [17]. Even the maximal concentrations of sodium and sulphate found were still below the thresholds to define tap water as sodium-rich (>200 mg/l) or sulphate-rich (>200 mg/l) [16]. The maximal bicarbonate levels of bottled waters were also below the threshold of bicarbonate-rich water (<600 mg/l) [16]. A study performed by Karagülle et al. demonstrated that drinking 1.5 l of bicarbonate-rich water (2673 mg/l) increases urinary pH to a metaphylactic level [18]. However, such levels can only be reached by drinking 6.5 l of commercially available water with the highest bicarbonate content (Cristaline 432 mg/l). Therefore, the bicarbonate levels found in this study will unlikely influence stone formation.

As stated, calcium is a stone promotor, especially in calcium-dependent calcium oxalate stone formers [16]. Calcium binds to oxalate, preventing reabsorption in the bloodstream and release in the urine, reducing the risk of stone formation [15, 16, 19, 20].

Two brands, one sparkling (S. Pellegrino, 174 mg/l) and one still (Vittel, 240 mg/l), had a calcium concentration above 150 mg/l, defining them as calcium-rich waters. They contain significant levels to possibly influence stone formation when drinking the recommended 2.5–3 l of water per day. For all the other tap and bottled waters studied, drinking 3 l will not fulfil the recommended daily calcium intake, but most importantly, it will not result in excessive calcium intake. Although patients were initially prescribed a low-calcium diet, nowadays patients are advised to consume a normal-calcium diet (800–1200 mg), because low (oxalate-dependent calcium oxalate stones) and high (calcium-dependent calcium oxalate stones) calcium intake are related to a higher risk of stone formation [20, 21]. Previous studies have demonstrated that the calcium content of drinking water varies greatly, with calcium levels reaching 579 mg/l [8–10]. If water is not recognised as a potential source of calcium, water intake could unintentionally lead to an overconsumption of calcium resulting in a higher risk of stone formation. Because water can be a calcium source, just like yoghurt, cheese, or milk, the amount of calcium consumed through these sources should be adjusted to water intake and calcium content.

Magnesium is important for KSD patients because it diminishes urinary oxalate excretion by reducing the intestinal reabsorption. Secondly, it keeps calcium dissolved in the bloodstream, preventing release into the urine and hypercalciuria. Both effects lower the risk of stone formation. The daily recommended magnesium intake is 300–320 mg for women and 400–420 mg for men [19, 22–24]. None of the examined waters, expect one (S. Pellegrino, 51.4 mg/l), could be defined as magnesium rich (>50 mg/l).

The findings of our study are in favour of tap water. Even though there is a broad range in mineral content, tap water is one of the most controlled nutrients. As a result, independent of where they live, KSD patients can safely drink tap water.

Seven previous studies have investigated the mineral content of tap water in the US, Canada, Egypt, Japan, Bangladesh, Spain, Malaysia, Belgium, and the UK (Table 4) [15, 25–30]. None of those countries had sodium-rich, magnesium-rich, or bicarbonate-rich tap waters. Calcium-rich tap water, however, can be found in specific regions in Spain (160 mg/l) and Belgium (157 mg/l) [15, 25]. However, these values only just surpass the threshold of 150 mg/l. Therefore, one might conclude that tap water is safest for KSD patients because the variation in mineral content in tap water is smaller than in bottled water due to the strict regulations imposed for tap water [15–17].

This is the first study to provide an overview of the mineral content of commercially available water in the Netherlands and to evaluate the safety from a KSD perspective. However, our study has some limitations. Unfortunately, the water analysis reports provided by the water supply companies did not include water samples collected in the same period. Possibly, measurements could have been influenced by seasonal changes in weather or other natural processes affecting water quality. Furthermore, we relied on information given by the water supply companies and the manufacturers rather than on independent laboratory measurements. Although our aim was to check whether commercially available water is safe to drink for KSD patients, it would be interesting to investigate whether water with different mineral compositions affects the incidence of urolithiasis. However, due to the complex nature of kidney stone formation and its multifactorial aetiology, it would be a challenge to examine the sole effect of the mineral composition of drinking water on kidney stone formation.

CONCLUSIONS

Commercially available water in the Netherlands is safe to use for KSD patients. However, specific bottled waters can be defined as calcium and magne-

Table 4. *Comparison between mineral content of tap water in the Netherlands and data found in the literature describing mineral concentrations in tap water in other countries*

#	Author (year)	Journal	Year	Title	Country	Sodium [mg/l]	Potassium [mg/l]	Bicarbonate [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Sulphate [mg/l]
					the Netherlands (NL) (range)	0.8–134.0	0.6–8.2	49.0–276.0	15.2–96.5	1.1–13.2	0.5–90.0
1	Azoulay et al. [28]	Journal of General Internal Medicine	2001	Comparison of the mineral content of tap water and bottled waters	United States (US) (range)	2.0–85.0	1.0–48.0	NR	3.0–195.0	NR	NR
2	Azoulay et al. [28]	Journal of General Internal Medicine	2001	Comparison of the mineral content of tap water and bottled waters	Canada (CA) (range)	2.0–40.0	0.0–8.0	NR	0.0–12.0	NR	NR
3	Saleh et al. [29]	Journal of Food Composition and Analysis	2001	Chemical Evaluation of Commercial Bottled Drinking Water from Egypt	Egypt (EG) (range)	30.5–37.2	11.7–16.2	NR	33.7–36.0	5.58–6.09	NR
4	Chiba et al. [30]	Journal of Radioanalytical and Nuclear Chemistry	2006	Drinking water quality from the aspect of element concentrations	Japan (JP) (range)	21.0–22.2	4.8–5.6	NR	9.0–9.8	2.0–2.2	NR
5	Chiba et al. [30]	Journal of Radioanalytical and Nuclear Chemistry	2006	Drinking water quality from the aspect of element concentrations	Bangladesh (BD) (range)	10.2–148.0	4.3–40.4	NR	4.3–65.5	1.1–4.5	NR
6	Rodriguez et al.	Actas Urologicas Espanolas	2009	Spanish bottled and tap water analysis and their relation with urinary lithiasis	Spain (ES) (range)	2.9–160.0	NR	NR	NR	NR	NR
7	Azlan et al. [27]	Scientific World Journal	2012	Evaluation of minerals content of drinking water in Malaysia	Malaysia (MY) (range)	0.5–23.1	0.1–4.1	NR	1.2–15.3	0.9–6.6	1.1–31.2
8	Henderickx et al. [15]	Acta Chirurgica Belgica	2021	Could the region you live in prevent or precipitate kidney stone formation due to mineral intake through tap water? An analysis of 9 distribution regions in Flanders	Belgium (BE) (range)	6.8–126.6		NR	16.1–157.0	2.7–31.8	3.0–218.5
9	Michael and Somani [26]	Journal of Clinical Medicine	2022	Variation in Tap Water Mineral Content in the United Kingdom: Is It Relevant for Kidney Stone Disease?	United Kingdom (GB) (range)	3.0–57.8		16.0–331.5	5.4–128.0	0.6–31.8	2.9–112.4

sium rich. Therefore, it remains important for KSD patients and their physicians to realise that the mineral composition of drinking water may vary, and its consumption might require alterations of the diet. Due to the strict regulations imposed on tap water, the variation in its mineral content is unlikely to influence kidney stone formation when the recommended amount of 2.5–3 l/day is consumed.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

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