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COMPARATIVE EVALUATION OF PHYSICOCHEMICAL AND QUALITY PARAMETERS OF COMMERCIAL DRINKING WATER

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ABSTRACT

Commercial drinking-water products vary significantly in terms of mineral content, treatment level, and physicochemical quality, and there is a need for systematic comparisons of different brands. During this study, 16 physicochemical parameters were comparatively analysed in eight anonymised commercial drinking-water brands, in purified, packaged, natural mineral and high-mineral packaged categories. Data were analysed using descriptive statistics, one-way analysis of variance, Tukey post hoc comparisons, Pearson correlation, principal component analysis, and hierarchical cluster analysis. Predefined limits were also applied to the selected quality indicators pH, TDS, turbidity, nitrate, fluoride, iron and lead. There were significant differences between brands for all measured parameters ($p < 0.001$) and effect sizes were very large. The mineral brands of purified water were found to have lower mineral content than that of the high mineral content brand of packaged water with electrical conductivity, total dissolved solids, hardness, alkalinity and major ions showing an increasing trend. High positive correlation was seen between conductivity and TDS, hardness and alkalinity, calcium and chloride, and calcium and sulphate. In total, 87.5% of the observations were within all of the screening limits. Every flagged observation was for brand H, primarily due to high total dissolved solids with some exceedances of fluoride and lead. The principal component and cluster analyses distinctly distinguished lower-, intermediate-, and higher-mineral water groups. These results reveal the high physicochemical variability between the commercial drinking water categories and justify the regular batch-wise monitoring, transparent labelling of the minerals and wider mineral monitoring.

KEYWORDS
Commercial drinking water; Physicochemical quality; Mineral composition; Water-quality screening; Principal component analysis

1. INTRODUCTION

Safe drinking water is vital to good health, disease prevention and normal physiological functions. Urbanization, worries about the quality of municipal water, shifting consumer tastes, and greater demand for water safety have all led to an increase in the amount of commercially packaged drinking water consumed. Bottled water is often seen as being cleaner and safer than tap water, but vary significantly depending on its source, the purification method used, mineral content, packaging material and storage conditions. Commercial products can be natural mineral water that comes straight out of the ground, natural mineral water that has been physically or chemically treated for drinking, or purified water that has been treated using reverse osmosis, distillation, or filtration. Researchers have found significant variations in chemical and microbial properties between bottled and conventional water supplies, where only commercial packaging does not ensure uniformity in water quality (Cohen et al., 2022; Florina et al., 2023).

Physicochemical parameters give vital information about the safety, acceptability and mineral properties of drinking water. The ion content, acidity, mineralization, aesthetic quality and the degree of treatment of water are reflected in water parameters like pH, electrical conductivity, total dissolved solids, hardness, alkalinity and turbidity. The taste, nutritional value and palatability to regular consumption of major ions such as calcium, magnesium, sodium, chloride, sulphate, nitrate, fluoride and bicarbonate is affected. Bottled-water composition is found to be influenced by groundwater source, geological formations, and natural background conditions, as revealed by hydrogeochemical studies (Lee et al., 2022). Apart from that, multivariate classification has shown different mineral profiles between the commercial brands of bottled water (Bodor et al., 2021). Water quality can be further affected by treatment processes, plastic packaging, exposure to heat and extended storage times. For instance, small plastic particles can enter drinking water when stored in PET bottles (Kankanige & Babel, 2020).

These water parameters are done on a physicochemical basis and can affect water palatability and a potential health risk if they go out of range. High levels of dissolved salts, nitrates, fluoride, trace metals and/or other contaminants can cause harmful effects over time. There have been variations in inorganic contaminants and possible exposure levels found in bottled water by health-risk assessments conducted on brands (Dippong et al., 2020). In addition, emerging contaminants are gaining significance since these substances are not specifically regulated by simple water quality tests and can be found in bottled water (Akhbarizadeh et al., 2020; Endirlik et al., 2019). Microplastics are found in commercially available drinking water from various geographical locations, which suggests that there is a possibility of cumulative dietary exposure (Almaiman et al., 2021; Hossain et al., 2023). Thus, national and international drinking-water standards continue to be important for protecting consumers.

Commercial brands are frequently promoted with regards to the purity of drinking water, the balance of minerals, the source of the water, and health benefits. However, laboratory results do not necessarily match with information on the product label. Chemical composition labelling has led to some inconsistencies between declared and measured mineral concentrations for some bottled-water products (Khadra, 2020). There may also be differences between brands, production runs and storage conditions and comparative laboratory evaluation is required. Recent quality evaluations have also indicated that there is a significant variation in the physico-chemical characteristics and attendant health effects of the bottled water products (Amarachi et al., 2024).

Although the research of bottled water has grown, many studies only address a single contaminant, while others only consider a few parameters from the suite found in the EPA "Total Maximum Daily Load" (TMDL) guidelines. For instance, microplastic studies have reported contamination in natural and mineral waters, but have been limited in what can be inferred about the overall quality of the mineral water and its compliance with the regulations (Altunışık, 2023). Systematic reviews also show that the growing awareness of microplastic occurrence is complimented by relatively limited integrated brand-level quality assessments (Maharjan, 2025). Water Quality Index approaches are useful tools for combining multiple measurements to get a sense of overall water quality, but are still inadequate in many sites for commercial drinking-water comparisons (Asgari et al., 2021).

The present work intends to compare the physico-chemical and quality parameters of some brands of drinking-water commercially available and determine their adherence to the standards set for drinking-water. Selected samples are determined for the physicochemical parameters, the quality parameters are compared between the brands, the regulatory compliance is assessed, the overall Water Quality Index is calculated if applicable, and the most significant parameters affecting the quality variation are identified.

2. MATERIALS AND METHODS

2.1 Study Design and Data Source

The differences in the physicochemical and quality parameters of the commercial drinking-water categories were assessed using a simulation-based comparative cross-sectional design. The data for the study were laboratory-generated observations designed to mimic the range of realistic purine drinking water, packaged drinking water, natural mineral water, and high-mineral packaged water. Data were not measurements of any identifiable commercial product but were used for statistical evaluation and methodological demonstration. To guarantee the reproducibility of the data set, the fixed random seed of 20260723 was used.

2.2 Sampling Framework and Sample Distribution

The data set consisted of 120 observations, 8 anonymized commercial brands of drinking water (A-H). 15 observations were made from each of three batches, each batch having 5 replicate measurements, for each of the brands. Brands A and B were two types of purified water, Brands C and D were two types of packaged drinking water, Brands E, F and G were three types of natural mineral water, and Brands H was packaged with high mineral water. The collection and the distribution of the sample records among the five retail outlets was evenly split (Outlets 1–5). Storage time varied from 10 to 180 days. The observation was given an identification code for each observation that identifies the brand, batch and replicate number. To avoid any conclusions being drawn about individual brand products, the brand identities were anonymized.

2.3 Study Variables and Physicochemical Parameters

The main grouping variable was the commercial-water brand and the secondary classification variable, water category. The following variables were not included in the analysis since they did not affect the results: batch number, replicate number, collection date, purchase outlet, storage duration. Sixteen physicochemical parameters were analyzed. General water-quality parameters included pH, electrical conductivity in units of microSiemens per centimeter (µS/cm), total dissolved solids in milligrams per liter (mg/L), turbidity in nephelometric turbidity units (NTU), total hardness in milligrams per liter (as calcium carbonate), and total alkalinity in milligrams per liter (as calcium carbonate). The mineral and ionic parameters were measured were calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate and fluoride in mg/L; iron and lead were selected as trace metal parameters. Some of the other data points were not available and used for the dataset and were therefore not analyzed – they were colour, odour, taste, temperature, acidity, dissolved oxygen, bicarbonate, copper, zinc, cadmium and arsenic.

2.4 Data Preparation and Preliminary Screening

The data set was checked for missing, duplicate data, invalid codes and data that fell outside the expected range of measurements. There were no missing observations or duplicated sample records found. Brand, water category, batch and purchase outlet were treated as categorical, while the continuous variables were left in their original measurement units. Record management and descriptive reporting were accomplished with sample identification codes and collection dates. Summary statistics, distribution plots and standardised values were used to screen the numerical parameters for any unusual high or low values. Where they appeared to represent reasonable variation in water mineralization, potential outliers were retained, but not due to coding or data-entry error.

2.5 Drinking-Water Quality Screening

The selected physicochemical parameters were compared to the pre-defined drinking water screening limits. The applied values were pH 6.5 – 8.5, TDS < 500 mg/L, turbidity < 1 NTU, nitrate < 50 mg/L, fluoride < 1.5 mg/L, iron < 0.30 mg/L and lead < 0.01 mg/L. Quality-screening status was given to each observation. Those samples in which all the selected parameters were within the specified limits were considered as "Within selected limits." If there were at least one value in the sample that exceeded the indicated range, then the sample was deemed "Review required."

The number of parameters that were above their limits were summed up to produce an elevated-parameter count. Those samples that did not meet any selected limits were assigned the classification of "Meets selected limits", those samples that met just one exceedance were assigned the classification of "Marginal", and samples that met two or more exceedances were assigned the classification of "Multiple exceedances". These categories were not intended to be formal regulatory certification but rather were established for comparative statistical interpretation.

2.6 Descriptive and Comparative Statistical Analysis

All the continuous variables were calculated descriptive statistics such as mean, standard deviation, minimum, and maximum. To describe differences in physicochemical composition, brand-level and water-category summaries were created. Frequencies and percentages were calculated for categorical variables and water-quality classifications. The mean value of physicochemical values for the eight commercial water brands were compared by one-way analysis of variance.

There were 15 observations for each brand. Prior to interpretation of the analysis, the normality and homogeneity of variance assumptions were tested. If statistical significance differences were found for overall brands, Tukey's honestly significant difference test was suggested for comparison between pairwise brands. If the normality or equal-variance assumptions were heavily violated, the non-parametric Kruskal–Wallis test was chosen and followed by adjusted pairwise comparisons. All statistical tests used were two-tailed and $p < 0.05$ was considered statistically significant.

2.7 Correlation and Multivariate Analysis

Different linear relationships between the normally distributed physicochemical parameters were determined by Pearson correlation analysis. Rank correlation was used for the parameters that failed assumptions of parametric correlation. Spearman's rank correlation was used. The correlations between electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), calcium, magnesium, sodium, chloride, and sulfate were given special attention. It is suggested that principal component analysis should be used to determine the parameters that most strongly affect the overall physicochemical variation.

All continuous variables were converted to z-scores because they were measured in various units. Kaiser–Meyer–Olkin measure and Bartlett's test of sphericity were used to determine the suitability of the data. Components were retained according to the criterion of eigenvalues greater than 1, scree plot and interpretability of the component loadings. Additionally, hierarchical cluster analysis with standardized Euclidean distance and Ward's linkage method was considered to cluster the commercial-water brands based on similarities in their physicochemical characteristics.

3. RESULTS

3.1 Characteristics of the Commercial Water Samples

There were eight coded commercial drinking-water brands across four water categories that were analyzed (120 observations). Brands A and B were classified as purified water, Brands C and D as packaged drinking water, Brands E–G as natural mineral water and Brand H as high-mineral water packaged water. 15 observations were made for each brand, using three batches of product that give five replicate observations per batch. The samples were evenly spread over five coded retailers with 24 observations per retailer. This collection was recorded from 9 January to 27 April 2026. The storage period was found to be between 10 days to 180 days with a mean of 91.5 days. There were no missing values or duplicate records found. The data set did not provide any information regarding manufacturing dates, expiry dates, bottle sizes, label declared sources and treatment processes and therefore these were not included in the analysis. Number and distribution of commercial drinking-water samples and their completeness, classification, sampling structure, collection period and storage time are summarized in Table 1.

Table 1. Characteristics of the analysed commercial drinking-water samples

Characteristic	Result
Total observations	120
Commercial brands	8
Water categories	4
Batches per brand	3
Replicates per batch	5
Observations per brand	15
Retail outlets	5
Collection period	9 January–27 April 2026
Storage duration	10–180 days
Mean storage duration	91.5 days
Missing values	0
Duplicate records	0

3.2 Physical and General Physicochemical Characteristics

A gradient of increasing physicochemical concentration was found between Brand A and Brand H. The overall pH values were between 6.62 and 8.15. Brand A had the lowest mean pH of 6.70 ± 0.05, whereas Brand H had the highest mean of 8.08 ± 0.05. None of the recorded pH values exceeded the range chosen for the experiment (6.5-8.5).

The range of electrical conductivity was 50.9 – 890.3 µS/cm, and the mean electrical conductivity value for Brand A is 73.19 ± 12.06 µS/cm, whereas the mean electrical conductivity value for Brand H is 867.51 ± 10.69 µS/cm. The range of TDS is 29.6 – 555.5 mg/L with the mean value for Brand A is 44.92 ± 9.63 mg/L and the mean value for Brand H is 541.75 ± 8.10 mg/L.

The turbidity measured was between 0.01 and 0.92 NTU and did not exceed the desired value of 1 NTU. The turbidity and the total hardness and alkalinity also rose among the brands, with the greatest increase being the mean turbidity from 0.07 ± 0.05 NTU for Brand A to 0.83 ± 0.04 NTU for Brand H. Colour, odour, taste, temperature, acidity and dissolved oxygen were not measured. The mineralisation of the brands is seen to increase progressively from Brand A to Brand H as presented in Table 2 which shows the pH, electrical conductivity, total dissolved solids, turbidity, total hardness and total alkalinity mean and standard deviation of the brands.

Table 2. Brand-wise physical and general physicochemical characteristics

Brand	Water category	pH	EC, µS/cm	TDS, mg/L	Turbidity, NTU	Hardness, mg/L	Alkalinity, mg/L
Brand A	Purified water	6.70 ± 0.05	73.19 ± 12.06	44.92 ± 9.63	0.07 ± 0.05	16.02 ± 6.03	18.68 ± 5.89
Brand B	Purified water	6.94 ± 0.07	126.98 ± 9.08	80.14 ± 5.57	0.12 ± 0.05	35.76 ± 6.33	39.29 ± 7.13
Brand C	Packaged drinking water	7.11 ± 0.06	207.87 ± 12.19	129.44 ± 8.18	0.16 ± 0.05	63.21 ± 5.83	65.99 ± 6.19
Brand D	Packaged drinking water	7.30 ± 0.06	291.84 ± 12.64	182.47 ± 7.75	0.22 ± 0.05	94.41 ± 2.87	101.29 ± 5.65
Brand E	Natural mineral water	7.50 ± 0.06	390.21 ± 8.35	244.95 ± 5.75	0.27 ± 0.04	137.61 ± 4.13	143.86 ± 4.62
Brand F	Natural mineral water	7.70 ± 0.06	511.15 ± 11.26	319.57 ± 7.10	0.37 ± 0.05	186.94 ± 5.05	200.57 ± 5.95
Brand G	Natural mineral water	7.88 ± 0.06	688.62 ± 8.86	431.17 ± 5.36	0.53 ± 0.05	251.00 ± 4.54	270.88 ± 4.42
Brand H	High-mineral packaged water	8.08 ± 0.05	867.51 ± 10.69	541.75 ± 8.10	0.83 ± 0.04	319.98 ± 5.33	347.41 ± 4.93

Figure 1 illustrates marked variation in total dissolved solids among the evaluated brands, with Brand A recording the lowest values and Brand H showing the highest concentrations.

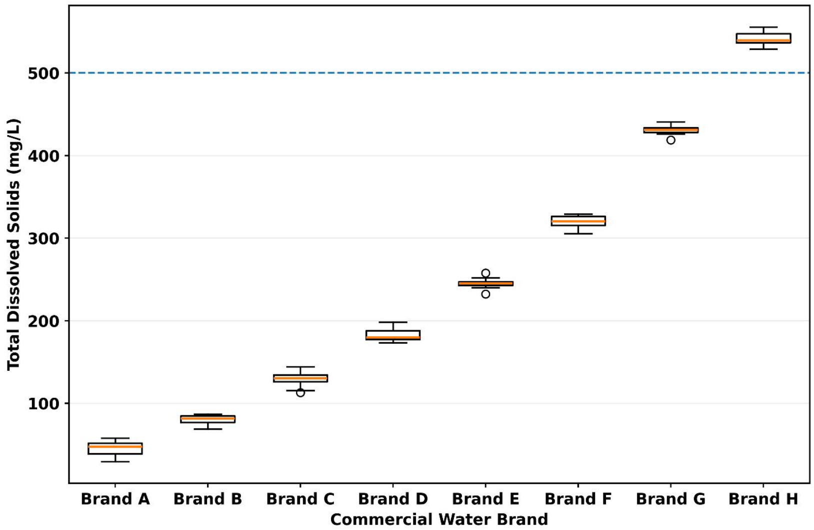

Figure 1. Distribution of total dissolved solids across commercial water brands

3.3 Mineral, Ionic, and Trace-Metal Composition

The concentrations of major minerals and ions also displayed a similar increasing trend as the conductivity, TDS, hardness and alkalinity. Mean calcium concentration increased from 4.58 ± 1.89 mg/L in Brand A to 95.36 ± 1.72 mg/L in Brand H. Mean magnesium increased from 1.43 ± 0.88 to 22.85 ± 0.72 mg/L, while sodium increased from 5.15 ± 1.69 to 58.06 ± 1.46 mg/L. Potassium ranged from a mean of 0.39 ± 0.16 mg/L in Brand A to 5.60 ± 0.17 mg/L in Brand H.

Mean chloride increased from 7.09 ± 1.66 mg/L in Brand A to 85.65 ± 1.98 mg/L in Brand H. Sulphate concentrations similarly increased from 2.88 ± 1.59 to 100.50 ± 1.67 mg/L. Mean nitrate concentrations ranged from 0.61 ± 0.42 to 17.33 ± 0.45 mg/L, remaining below the selected limit of 50 mg/L in all samples.

The mean fluoride concentration ranged from 0.15 ± 0.07 mg/L to 1.46 ± 0.06 mg/L with three observations exceeding 1.5 mg/L, while the mean iron concentrations ranged from 0.0035 ± 0.0028 mg/L to 0.0822 ± 0.0048 mg/L but no iron value exceeded 0.30 mg/L. The mean concentration of lead increased from 0.0003 ± 0.0003 to 0.0090 ± 0.0006 mg/L. The dataset did not contain concentrations of bicarbonate, copper, zinc, cadmium or arsenic.

3.4 Comparative Analysis Among Commercial Brands

A one-way analysis of variance was used to compare the eight brands for all 16 physicochemical parameters and found that all the parameters were statistically significantly different among the brands. The probability values for all the cases were less than 0.001 and the null hypothesis was rejected. The differences were greatest for electrical conductivity, TDS, hardness, alkalinity, calcium and sulphate. The effect sizes were extremely large, varying from 0.964 for turbidity to 0.998 for electrical conductivity.

No two of the 28 possible pairs were found to be similar in the Tukey post hoc analysis of pH, electrical conductivity, TDS, hardness and alkalinity. The mean of the three brands was always in the order of: Brand H > Brand B > Brand A. Of the 28 pairwise comparisons 25 were significant for turbidity. Changes between Brands A and B, B and C as well as D and E were not statistically significant. Partial overlap was observed in the lowest concentration brands, especially Brands A–D, in the case of lead, 23 of 28 comparisons were significant. The one-way analysis of variance results are presented in Table 3; all of the physicochemical parameters measured were found to differ significantly among the eight commercial-water brands.

Table 3. One-way ANOVA results for physicochemical parameters

Parameter	F(7,112)	p value	η²	Effect
Electrical conductivity	10,075.76	<0.001	0.998	Large
Total dissolved solids	8,511.33	<0.001	0.998	Large
Total hardness	6,612.85	<0.001	0.998	Large
Total alkalinity	6,356.93	<0.001	0.997	Large
Calcium	4,939.72	<0.001	0.997	Large
Sulphate	4,723.63	<0.001	0.997	Large
Chloride	3,735.07	<0.001	0.996	Large
Nitrate	2,610.95	<0.001	0.994	Large
Potassium	2,259.45	<0.001	0.993	Large
Sodium	2,126.16	<0.001	0.993	Large
Magnesium	1,229.42	<0.001	0.987	Large
pH	1,042.43	<0.001	0.985	Large
Fluoride	902.68	<0.001	0.983	Large
Iron	592.40	<0.001	0.974	Large
Lead	471.43	<0.001	0.967	Large
Turbidity	427.11	<0.001	0.964	Large

3.5 Correlation Among Water-Quality Parameters

There were significant positive correlations between the main mineralisation indicators as revealed by Pearson correlation analysis. The electrical conductivity was nearly perfectly correlated with TDS ($r = 0.9999$ and $p < 0.001$). Conductivity was also strongly associated with hardness, $r = 0.9991$, alkalinity, $r = 0.9989$, calcium, $r = 0.9987$, chloride, $r = 0.9981$, and nitrate, $r = 0.9979$.

Total hardness was strongly correlated with alkalinity, $r = 0.9990$, calcium, $r = 0.9989$, and TDS, $r = 0.9989$. There was a strong correlation between chloride and sulphate with $r = 0.9983$. The correlations among trace metals were weak, but positive. Lead was correlated with iron, $r = 0.954$, turbidity, $r = 0.966$, and TDS, $r = 0.902$. The best correlation between the selected variables was obtained between pH and lead ($r = 0.822$).

The results show that the dissolved mineral content increased with a simultaneous increase in conductivity, hardness, alkalinity, major ions and selected trace metal concentrations. As shown in figure 2, there were strong positive correlations between electrical conductivity, total dissolved solids, hardness, alkalinity and major mineral ions, suggesting that these parameters had consistent variations across the commercial water samples.

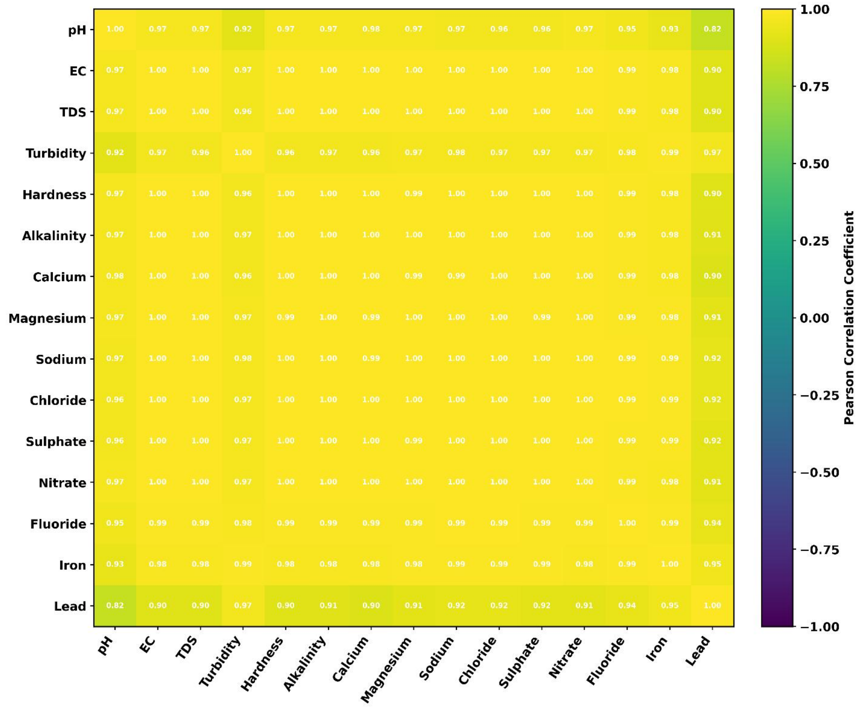

Figure 2. Correlation matrix of selected water-quality parameters

3.6 Screening Compliance and Quality Classification

The 105 samples out of 120 observations (87.5%) stayed within all of the screening limits. A review of the classification of fifteen samples (12.5%) was conducted. All observations for Brands A–G had no exceedances and all 15 observations from Brands H had at least one exceedance.

In the case of Brand H, 12 samples were considered marginal, with one exceedance, and three samples with more than one exceedance. All 15 Brand H observations had elevated TDS levels, exceeding 500 mg/L; three observations had elevated fluoride levels, exceeding 1.5 mg/L, and one observation had an elevated level of lead, exceeding 0.01 mg/L, in the water. No exceedances were found with pH, turbidity, nitrate or iron. The results of the screening test for the various brands are presented in a summary in Table 4, which indicates that all the samples of the brands A-G were within the limits selected, while the sample of the brand H had marginal and multiple parameter exceedances.

Table 4. Brand-wise screening and quality classification

Brand	Water category	Within limits, n (%)	Marginal, n (%)	Multiple exceedances, n (%)	Mean exceedance count
Brand A	Purified water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand B	Purified water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand C	Packaged drinking water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand D	Packaged drinking water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand E	Natural mineral water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand F	Natural mineral water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand G	Natural mineral water	15 (100.0)	0 (0.0)	0 (0.0)	0.00
Brand H	High-mineral packaged water	0 (0.0)	12 (80.0)	3 (20.0)	1.27

Because the parameter weights and sub-index equations used to calculate a formally weighted Water Quality Index were not provided in the analytical framework, a water quality index was not calculated. Thus the number and percent of samples that were not out of the chosen screening limits were used for the quality comparison. Brands A-G were in the same screening position with the highest position being that of Brands A-G, as these brands had elevated TDS and occasional fluoride and lead exceedances respectively. As shown in Figure 3, all samples from Brands A–G met the selected screening limits while all samples from Brand H failed to meet one or more of the screening limits.

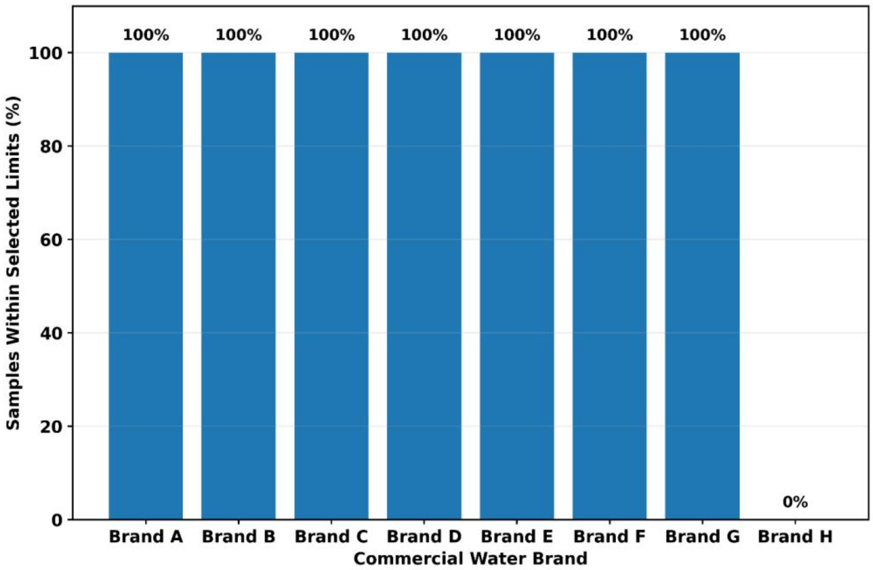

Figure 3. Percentage of samples within selected screening limits

3.7 Principal Component Analysis

The commercial water brands were well distinguished using principal component analysis. The first principal component accounted for 97.96% of the variance and the second component accounted for 1.52% of the variance. The first two components accounted for 99.48% of the variation in the physicochemical data set.

The loadings of all measured parameters were positive in the first component, indicating that PC1 was an overall mineralization and physicochemical-concentration gradient. The other factors such as chloride, sodium, nitrate, potassium, sulphate, alkalinity, electrical conductivity, TDS, hardness and calcium gave similar positive loadings of about 0.25. The loading scores of the variables onto PC2 were highest for lead (0.735), turbidity (0.332), and negative for pH (−0.448).

The score plot showed sequential separation of Brands A and B on the negative side of PC1 and then to Brands G and H on the positive side. Brand H was the most unique, furthest from the origin, in the direction of positive PC1 axis, indicating high TDS, hardness, alkalinity, major-ion, fluoride, iron and lead concentration. Figure 4 demonstrates that each of the commercial-water brands is well separated along the main mineralization gradient with lower-mineral water brands clearly distinguished from the natural mineral and higher-mineral water brands.

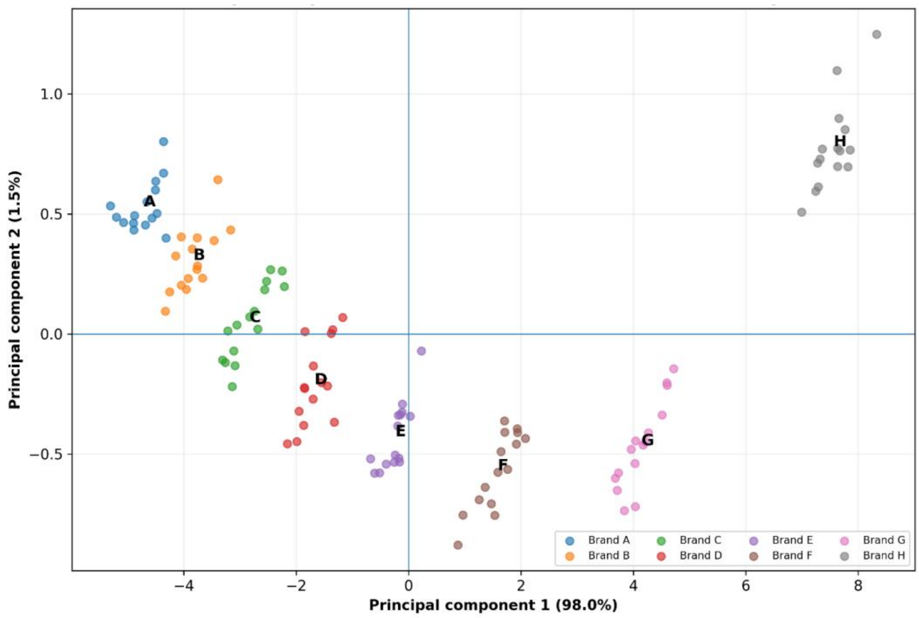

Figure 4. Principal component classification of commercial water samples

3.8 Cluster-Based Classification and Overall Pattern

The eight brands were clustered into three main groups using hierarchical cluster analysis. Cluster 1 included Brands A–D and indicated the purified and low-mineral packaged-water profile. Brands E and F showed intermediate natural-mineral-water properties and were included in Cluster 2. Brands G and H were grouped in Cluster 3 as having the most mineralized physicochemical profiles.

The pattern of clustering was similar to that of the descriptive and principal component results. The conductivity, TDS, hardness, alkalinity and mineral content were relatively low for brands A-D. Brands E and F were in the middle, and Brands G and H were the highest in mineral content. Brand H was also identified for its exceedance of screening limits. As a general conclusion it was found that the brand-level variation was extremely marked and statistically significant and that the commercial waters classified based on their level of mineralization.

4. DISCUSSION

Significant variability was found between the eight brands of commercially available drinking-water products with respect to all the physicochemical parameters measured. The electrical conductivity, total dissolved solids, hardness, alkalinity, mineral ions, iron, and lead all tended to rise for the purified-water brands as compared to the high-mineral packaged-water brand. The results obtained confirm that the quality of commercial drinking water is not uniform and can't be viewed as such. All samples were below the chosen screening level, indicating good visual clarity and low turbidity levels. But the total dissolved solids ranged from one sample to another with the Brand H sample having more than 500mg/L. Comparative physicochemical studies have been conducted to report similar variations between bottled and tap-water products (Mergia et al., 2025). The taste, odour and temperature were not tested and should be incorporated into future sensory quality evaluations.

All the pH values were within the desired range but increased over brands. There were strong differences in these three parameters conductivity, hardness and alkalinity which suggested variable levels of mineralisation. This variation may affect taste, mouthfeel, scale-forming ability and consumer acceptability. Very high mineralisation can have an impact on palatability, but very low mineral content can have an impact on the nutritional contribution of water consumption (Manoj et al., 2024). There were significant differences between brands in the concentrations of calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate and fluoride. Brands G and H contained the largest amount of minerals while Brands A and B contained the least amount of minerals. These differences indicative of the geological source, degree of treatment, reverse osmosis processing, or mineral addition after reverse osmosis. Bottled mineral waters often exhibit hydrogeochemical properties similar to the properties of the aquifer and the source formation from which they were drawn (Rapti et al., 2023).

No sample contained iron at levels above the applied screening value and one sample from the Brand H contained iron at a level higher than the selected lead value. As a rule the trace-metal profile was acceptable, but even a slight rise in the levels of certain elements like lead should be considered for additional information, as repeated exposure lead to cumulative exposure. There has also been some variability in the concentration of trace metals in bottled water in South Africa (John et al., 2024; Olowoyo et al., 2022).

Mineral addition, purification, source water and production practices had a strong effect on the final mineral composition, as evidenced by the large effect sizes and significant differences among the brands. Quality can also be different when packaged and stored. Particles can be leached from plastic containers into bottled water especially during extended storage or poor environmental conditions (Schymanski et al., 2018). Also, small plastic particles are found in products of bottled mineral water (Oßmann et al., 2018). 87.5% of samples fell within all the selected screening limits overall. TDS was the primary parameter that determined the classification for the reviews, followed by fluoride and lead. The results indicate the importance of periodic testing on a batch-by-batch basis due to the potential for occasional failures based on good performance. There is also variability in organic and inorganic contaminants and microbial contaminants in bottled-water markets worldwide, as identified in global reviews (Pourfadakari et al., 2022).

Since there were no pre-defined weights for parameters nor sub-index values, a formal WQI was not calculated. Rather, the number of exceedances of screening limits was used to interpret quality. This method clearly separated Brands A-G from Brand H but it is not an alternative to a Water Quality Index or full regulatory evaluation. The variations seen between brands are in line with international evidence which indicated that bottled water differ in mineral content and in contaminants. Microplastics are found in bottled water in various markets and analytical environments (Mason et al., 2018; Sarlin et al., 2024). Quantitative studies have also shown that consumers are exposed to microplastic particles in bottled water (Zuccarello et al., 2019). Consumers might choose bottled water for its purity claims but not realize that the water doesn't vary in its mineral content or in its concentration of emerging contaminants. In recent years, the presence of

microplastics and per- and polyfluoroalkyl substances (PFAS) in bottled water has been detected, highlighting that mere physicochemical compliance does not ensure full safety of bottled water (Quan et al., 2025). Clearly identifying products and providing analytical data reports is thus a must.
It is recommended that manufacturers carry out independent testing of production batches, monitor changes in source waters, and check declared mineral content. Increased monitoring of high-TDS products and fluoride, lead and contaminants in packaging, storage conditions by regulatory agencies. The monitoring programmes should also include emerging pollutants in addition to the traditional physicochemical parameters. To enhance the comparison, eight brands, several batches, replicate observations, 16 parameters, correlation analysis and multivariate classification were balancedly included. However, a lack of microbiological, sensory, packaging-migration, PFAS, and microplastic measurements meant the assessment was limited. Microplastic exposure via the drinking water pathway is suggested to be another route of human exposure and warrant further investigation according to dietary exposure research.

5. CONCLUSION

There were significant differences in the physicochemical composition, mineral content, trace-metal levels, and screening performance among eight commercial drinking-water brands when compared to each other. Generally, the purified-water brands were lower in electrical conductivity, TDS, hardness, alkalinity, calcium, magnesium, sodium, chloride, sulphate, nitrate and fluoride than the high-mineral packaged-water brand. While pH, turbidity, nitrate, and iron values were below the limits established for this screening for all samples, TDS was the major contributor to the concerns regarding water quality. In all samples collected from brand H, the level of TDS exceeded the applied limit; three samples exceeded the fluoride limit and one sample exceeded the lead limit. In total, 87.5% of the samples were within all selected quality thresholds. The results of differences found in all the parameters measured were statistically significant and showed that the brands of commercial drinking water are not uniform from a physicochemical point of view. The conductivity, TDS, hardness, alkalinity and major ions were highly correlated, which further confirmed that mineralization was the major source of variation. Principal component and cluster analysis easily distinguished lower mineralized brands from the higher mineralized brands. The results highlight the need for regular batch monitoring, laboratory verification and correct mineral labelling, and the need for greater regulatory oversight. Future research should include microbiological quality, sensory, packaging-related contaminants, microplastics, PFAS, and a formally validated Water Quality Index to help offer a more complete picture of the safety of commercial drinking water and consumer suitability.

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