Journal of
Water, Sanitation & Hygiene for Development

IWA PUBLISHING

Research Paper

Assessment of multiple boiling of potable water utilizing household kettles for consumption

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ABSTRACT

Boiling potable water utilizing 11 household/office electrical kettles for sterilization and aesthetic purposes is common among all age groups. However, the effect of continued boiling of the same water multiple times utilizing household electrical kettles on potable water quality has not been investigated previously; thus, the current study experimentally investigates the effect of reboiling potable water seven times on potable water quality. Kettle H (Dexon) recorded the highest concentration increase in Cl^- and SO_4^{2-} of 62.5 and 104%, respectively. In the case of cations, kettles I (Dexon Glass) and H (Dexon) recorded the highest concentration values for Na^+ (48.8 ppm) ion in comparison with Ca^{2+} (31.8 ppm; kettle K (Moulinex)) and Mg^{2+} (5.8 ppm; kettles I and H). Kettles A (Sharp) and E (Black + Decker) showed a total dissolved solids (TDS) value of 34 ppm and a pH value of 9.05, respectively, after the second boiling that is undesirable as per the permissible standards. It is observed that kettles with a water compartment made of stainless steel displayed values closer to the raw sample after one to two boils as per anions, pH and TDS analyses. Moulinex, Tokyo, Wansa and Bosch showed the best results in the case of various analyses.

Key words: boiling, drinking water, kettle, total dissolved solids

HIGHLIGHTS

- Impacts of reboiling of water in various kettles.
- Represented the physiochemical changes of water upon boiling.
- Compared the results with regulatory standards.
- Informed choice for the consumer in choosing kettles.

1. INTRODUCTION

Kuwait, an arid country, experiences hot summers with maximum temperatures up to 50 °C and scanty amounts of rainfall in the winters (Ahmed 2015). Having limited supplies of natural resources of water, Kuwait heavily depends on seawater desalination to meet the country's potable drinking demands. Multistage flash distillation and reverse osmosis are the main technologies for water production in Kuwait. The process ends with the blending of distilled water with certain percentages of brackish water to produce water whose quality meets the guidelines of WHO (Ahmed 2015). However, the water that reaches homes and other establishments has to pass through underground pipes and various storage facilities, which may not be regularly maintained. As a result, the tap water coming to homes may be contaminated.

WHO has referenced the requirement to boil water to inactivate enteric protozoa, microscopic organisms and infections in drinking water in their guidelines for drinking water quality (WHO 2011). Boiling is the most common household water treatment method, as it is being utilized by an estimated 1.2 billion people (Rosa & Clasen 2010; Brown & Sobsey 2012). Boiling is not highly environmentally friendly because of the combustion of solid fuels and black carbon emissions contributing to respiratory diseases and climate change (Cohen et al. 2015) The Carpenter Electric Organization of Chicago launched the first electrical kettle that uses electricity to boil water. The two most common types of electric kettle used are the one made of metallic fabric such as stainless steel, and another made of plastic material such as polypropylene (Gallego-Schmid et al. 2018). Nonetheless, the environmental impact of the electric kettles remains unidentified. Most kettles come with a standard

size of 1.5–2.0 L cordless kettles with 2,200–3,000 W of power rating (Murray *et al.* 2016). In this study, they have mentioned that over 90% of people in the UK use the kettle on a daily basis, with 40% using it more than five times each day. However, the fact is that there is more concern nowadays for the potential harm to human health caused by the reboiling of water in a kettle, concentrating certain undesirable chemicals in the water. Reboiling water in a kettle is assumed to be harmful to the body. The contents in water, i.e. the minerals, would get concentrated. Certain compounds, like nitrates, could turn into nitrosamines and become carcinogenic (Richardson 2020). Even the minerals, such as calcium salts that are good for us, can be harmful if their concentration reaches too high (Richardson 2020). But others have ridiculed this claim stating that the available water cannot contain harmful components unless it is taken from a non-trusted source and hence cannot concentrate minerals and harm the body.

A safe electrical kettle should be made of stainless steel or glass and never contain any plastic component. The bisphenol A in plastic can leach out into the water upon repeated contact with hot water (Electric Kettles Guide 2020). Studies on multiple boiling by Muller *et al.* (2015), of drinking water from kettles, have not yet been conducted to the best of our knowledge. The studies done by the release of heavy metals from coffee machines and electric kettles were investigated and it was found that Pb, Ni and Cu were found to be increased during the study. This increase was quantified within the working range based on specific release limits (SRL) by the Council of Europe (CoE) (EQDM 2013a, 2013b).

This paper aims to assess the effect of widely used household electrical kettles from the local market on the quality of reboiled potable water for hot drinks and baby formula, not for drinking water treatment purposes. This can be achieved by studying the physiochemical properties of drinking water after reboiling it several times (seven times in this study). Such properties are pH, total dissolved solids (TDS), cation and anion concentrations. The analysis of the cation and anion concentrations after each boiling stage is presented in this paper. The results are also compared with permissible standards by local authorities. Qualitative observations of potable water chemistry after each boiling stage are also presented for all selected kettles. We are hoping that this study will provide valuable information for the consumer to help him/her make the right decision with regard to boiling potable water utilizing such kettles.

2. MATERIALS AND METHODS

In this study, 11 household kettles of different materials and brands (Table 1) with volume ranges from 1.7 to 1.8 L were used for reboiling potable water seven times. Each kettle has an electrically powered heating element that is placed underneath a metallic water compartment. Figure 1(a) shows various kettles' brands used in the current work, and Figure 1(b) shows the main parts of the kettle after dismantling. Each kettle was filled up to 1.7 L with potable tap water (supplied by the ministry of electricity and water) collected from the local laboratory. The boiling of water started at the same time for all kettles with the help of other lab technicians. The water in each kettle was boiled until it shut off automatically and was left to cool off to room temperature. This procedure was repeated seven times for all kettles to cover the entire volume of water inside the kettle

Table 1 | Data of the kettles used

Representation	Brand	Model	Power consumption (W)	Capacity (L)	Heating base	Water compartment
A	Sharp	EKJ-176-3	1,850–2,200	1.7	Stainless steel	Plastic
B	Bosch	TWK6A833GB	2,600–3,100	1.7	Stainless steel	Stainless steel
C	Primera Delphi	PTK2100	1,500	1.8	Stainless steel	Stainless steel
D	Universal	Un-ss3501	1,800	1.8	Stainless steel	Stainless steel
E	Black + Decker	JC72-B5	2,000	1.7	Stainless steel	Plastic
F	Bravo	KEC-1799	1,850–2,000	1.7	Stainless steel	Plastic
G	Tokyo	TK-5007	1,500	1.8	Stainless steel	Stainless steel
H	Dexon	WK-1302WBK	1,850–2,200	1.7	Stainless steel	Plastic
I	Dexon Glass	WK-5801GLS	1,850–2,200	1.7	Stainless steel	Glass
J	Wansa	KE01301AGS	2,200	1.7	Stainless steel	Plastic
K	Moulinex	BY550*	2,000–2,400	1.7	Stainless steel	Stainless steel

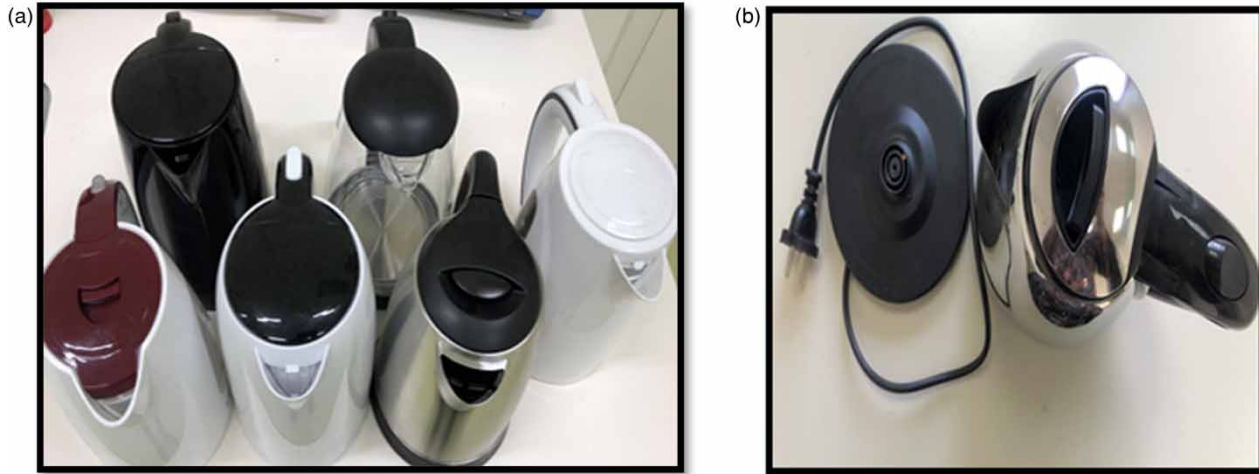*Note:* The studies were conducted in August 2020.

Figure 1 | (a) Various kettles used in the study and (b) kettle after dismantling.

(1.7 L). After each boiling stage, an amount of water equal to coffee/tea mug/cup was taken out for analysis after the sample cooled off. A kettle with a volume of 1.7–1.8 L is considered common for office and household use. Assuming the cups' volume is 240 mL (Wikipedia Contributors 2021; Guide to Buying an Electric Kettle), this kettle is enough for a maximum of seven tea or coffee cups/mugs as per the literature (Guide to Buying an Electric Kettle) to supply the same individual.

Cations in the water were analyzed using a microwave plasma-atomic absorption spectrometer (MP-AES Agilent:4100), anions were analyzed with ion chromatography-mass spectrometry (IC-MS Metrohm 850), and pH values were measured using Thermo Orion instruments. The measured values were then compared with Kuwait Public Environmental Authority (KUPEA) and other various regulatory standards (Table 2) (Alsulail *et al.* 2015), and also with the raw sample (R). Table 3 displays the composition of tap water/raw sample (R).

Table 2 | Regulatory standards provided by the various international and national (KUEPA) boards (Alsulail *et al.* 2015)

Parameters (ppm)	FDA (Food and Drug Administration)	WHO	WHO AESTHETIC	KUEPA
Ca^{2+}	–	–	200	200
Na^+	–	50	200	200
K^+	–	12	200	10
Mg^{2+}	–	50	–	150
Cl^-	250	–	200	250
SO_4^{2-}	250	–	250	250
pH	–	–	6.5–8.5	6.5–8.5
TDS	500	–	600	1,000
Pb (µg/L)	5		10	10
Ni (µg/L)	100	70	–	20
Cu (µg/L)	1,000	2,000	5,000	2,000
Al (µg/L)	200	100	100	200
Cd (µg/L)	5	–	3	3
Zn (µg/L)	5,000	50	4,000	3,000
Ba (µg/L)	2,000	700	–	700
Cr (µg/L)	100	50		50
Fe (µg/L)	300	–	300	300

Table 3 | Tap water composition (R)

Parameters	Levels (ppm)
Ca^{2+}	20.71
Na^+	26.23
K^+	4.56
Mg^{2+}	3.17
Cl^-	28.32
SO_4^{2-}	11.44
Pb	0.01
Ni	0.02
Cu	0.02
Al	0.02
Zn	0.04
Ba	0.05
Co	0.01
Fe	0
Cd	0.01
pH	7.75
TDS	187.3

3. RESULTS AND DISCUSSION

Potable water samples were analyzed for all ions dissolved in water (including heavy metals), TDS and pH after each boiling step.

3.1. Effect of reboiling of water on various anions

Figures 2 and 3 depict the concentration change of chloride (Cl^-) and sulfate (SO_4^{2-}) anions in potable water after seven boiling stages. The general trend shows that both anion concentration levels increase with the number of boiling attempts with kettle H (Dexon) measuring the highest values of Cl^- and SO_4^{2-} concentration of 47.3 and 21.3 ppm, respectively. The lowest final concentrations of the same anions were recorded by kettle G (Tokyo) for Cl^- and kettles F (Bravo) and J (Wansa) for SO_4^{2-} of 38.4 and 17.8 ppm, respectively. Kettle H recorded the highest concentration change in Cl^- and SO_4^{2-} of 62.5%
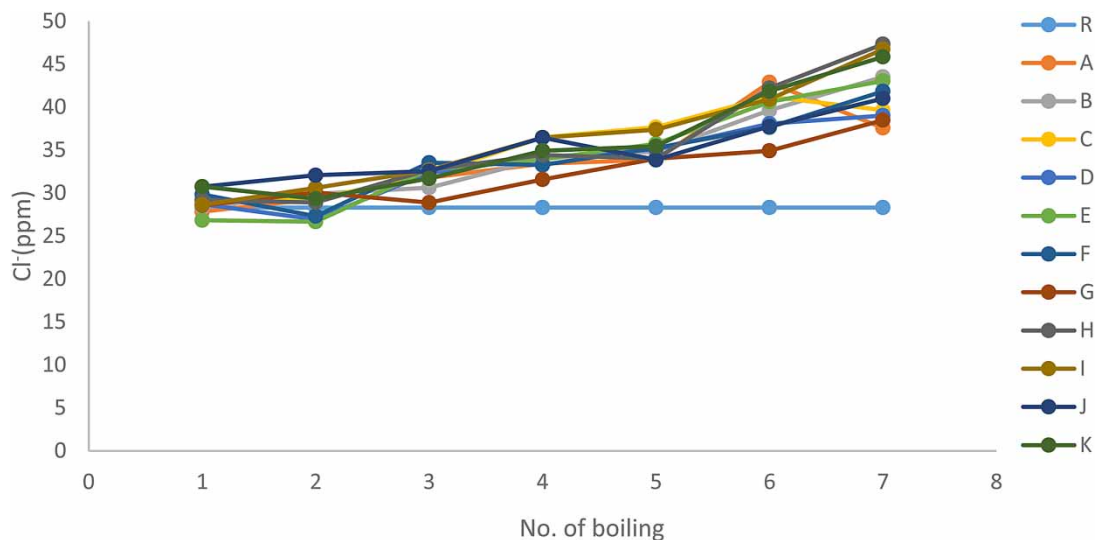
Figure 2 | Changes in the concentration of chloride throughout the boiling stages.
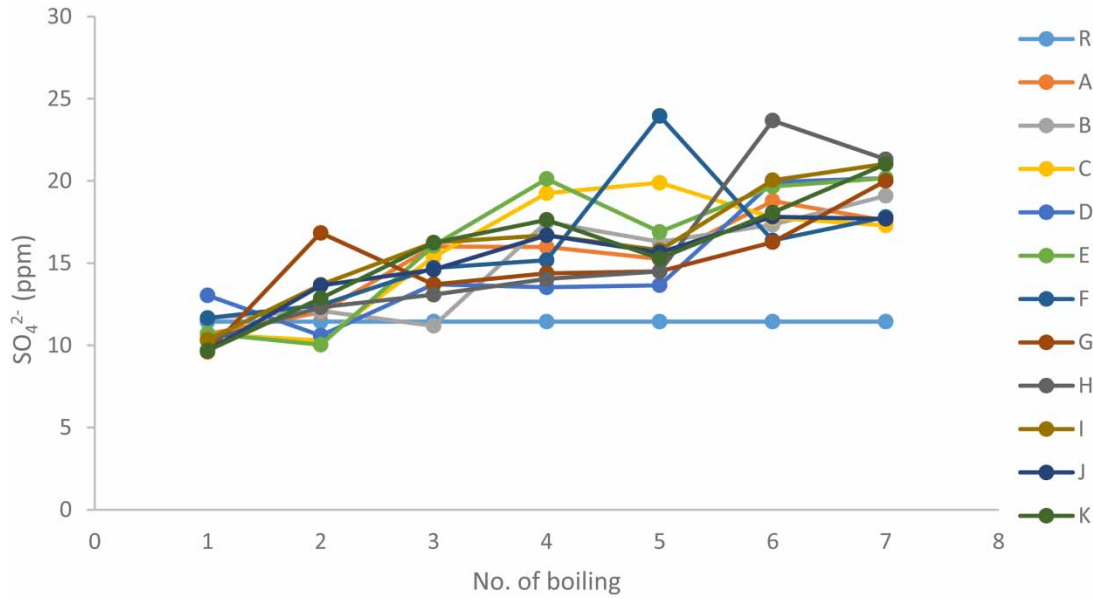
Figure 3 | Changes in the concentration of sulfate throughout the boiling stages.

(29.1–47.3 ppm) and 104% (10.29–21.0 ppm), respectively. The concentration change of these anions due to the remaining kettles varied between kettle H and kettles G, F and J. SO_4^{2-} showed more variations than that of Cl^- for all the kettles throughout the seven runs. Gailani et al. (2020) have reported that as the boiling continues, the chloride ion content and salinity increase with the volume of evaporated water.

3.2. Effect of reboiling of water on various cations

As shown in Figures 4–6, a similar trend was obtained for calcium, magnesium and sodium cations for all kettles during the seven boiling stages. The initial concentration of all the foregoing ions was lower than that of the raw tap water. Generally, the concentrations for the selected cations increased gradually for all kettles until the fourth boiling stage where all of the cations experienced a leap. Then the concentrations of the cations slightly decreased after the fifth reboiling stage and continued to
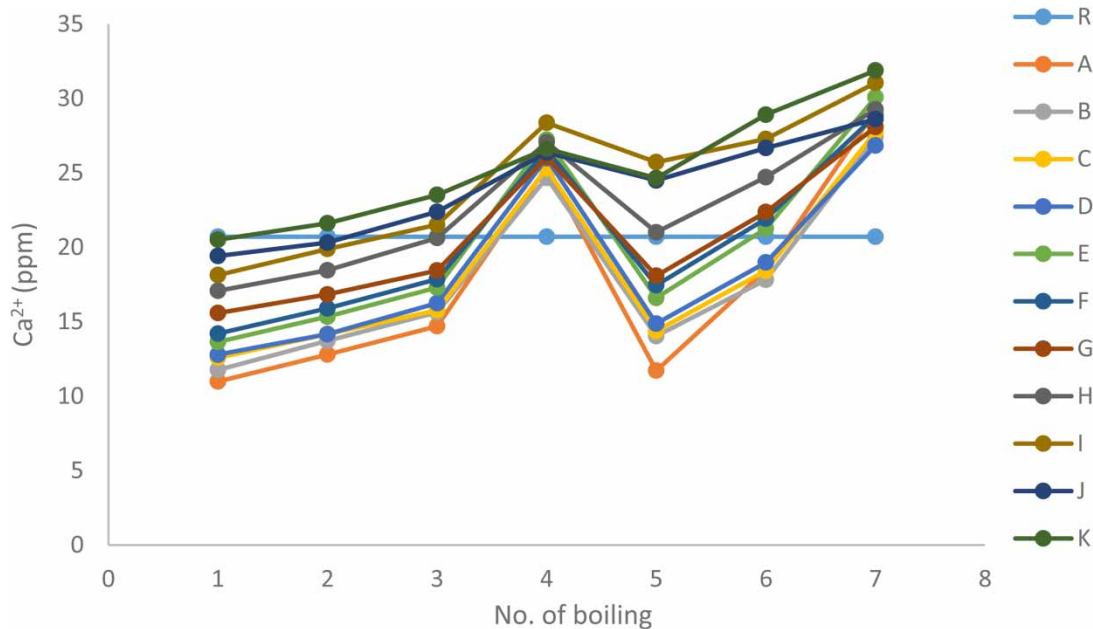

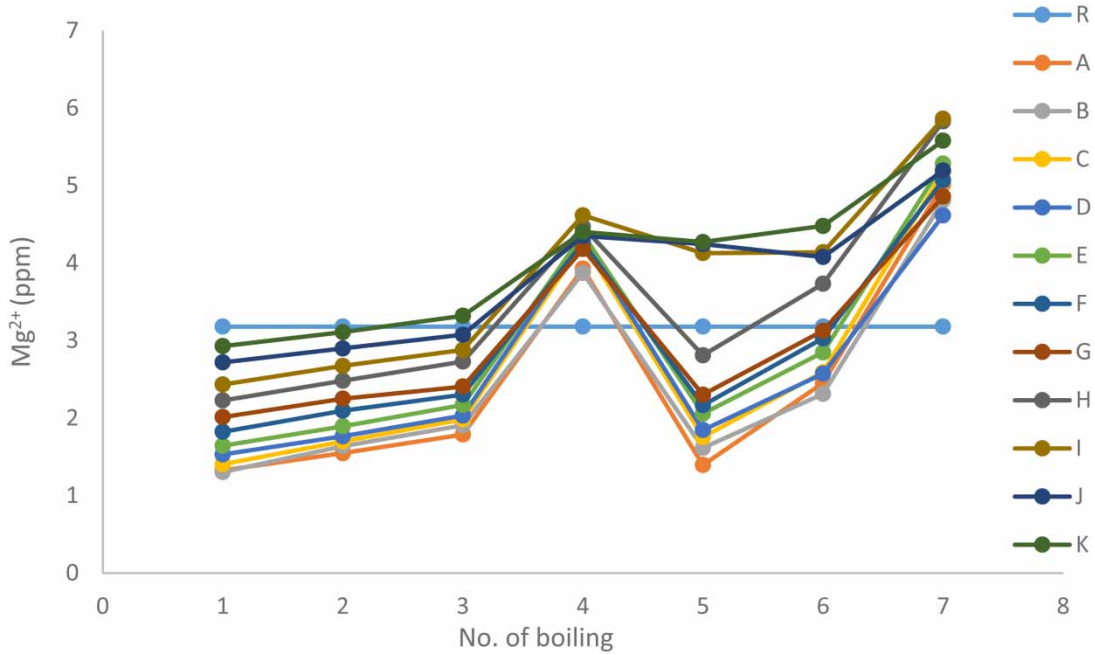**Figure 4** | Changes in the concentration of calcium throughout the boiling stages.

Figure 5 | Changes in the concentration of magnesium throughout the boiling stages.
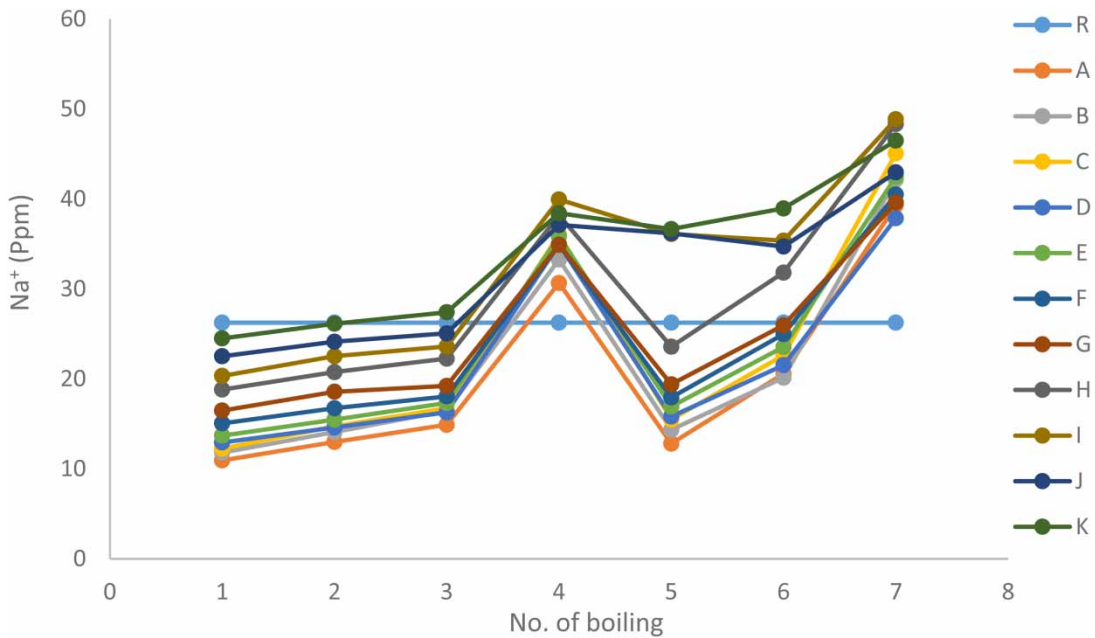

Figure 6 | Changes in the concentration of sodium throughout the boiling stages.

increase for the last two stages until they reached their maximum concentrations level (absolute maximum). On the contrary, the concentration of cations was reduced below the raw sample after the first and second boilings. This may be due to the removal of the hardness compounds (bicarbonates) dissolved in the water to form insoluble compounds such as $MgCO_3$ during the boiling stages. Out of the three cations, Na^+ recorded the highest concentration of 48.8 ppm by kettles I (Dexon glass) and H (Dexon) in comparison with Ca^{2+} (31.8 ppm; kettle K (Moulinex)) and Mg^{2+} (5.8 ppm; kettles I and H). The least incremental increase in the concentration of Ca^{2+} was observed for kettle K (Moulinex) of 55% (20.5–31.8 ppm) and the highest was observed for kettle A (Sharp) with 166.9% (10.9–29.1 ppm). Similarly, Mg^{2+} had the least change in the concentration of 89.6% (2.9–5.5 ppm) for kettle K and the highest for kettle A 285% (1.3–5.0 ppm). In the

case of Na$^+$, the highest increase in the concentration of Na$^+$ ions after all the boiling stages was observed for kettle C (Primera Delphi) 268.8% (12.2–45.0 ppm) and the least increase for kettle J (Wansa) 90.6% (22.5–42.9 ppm).

Thus on increasing the number of boiling stages, loss of water through evaporation operation can act as a thermodynamic driving force for the crystallization reaction resulting in the precipitation of insoluble salts (Gubbins 1997) onto the interior of the kettle (Figure 7). The continuous deposition of insoluble salts can reduce the heat transfer area and hence increases the power needed for the boiling operation (Gailani et al. 2020). Whelton et al. (2007) reported that the continuous deposition of mineral salts can affect the quality attributes of boiled water such as color and taste.

3.3. Effect of reboiling of water on pH and TDS

Upon boiling seven times in all kettles, it is noticed that the concentration values for the anions and cations are within the guidelines set by the KUEPA and WHO. However, the TDS and pH levels of water upon multiple boiling need to be considered to ensure the aesthetic aspects of drinking water. Figure 8 displays the change in the level of pH upon reboiling water utilizing the selected kettles. It can be observed that upon reboiling there is an increase in the level of pH from the raw sample after the first boiling stage and then it fluctuated until boiling stage 5 and decreased reaching a value of pH below the initial raw tap water for all kettles except kettle I (Dexon Glass). Gubbins (1997) reported a similar observation on the boiling of water where the dissociation of bicarbonates to carbonates occurs along with the release of carbon dioxide (CO$_2$) gas, resulting in the shifting of pH to higher values. Hence, the formation of scalants such as MgCO$_3$, Mg(OH)$_2$ and CaCO$_3$ can occur. According to WHO, the pH of drinking water should be between 6.5 and 8.5; however, as displayed in the below graph, kettle E (Black + Decker) showed a higher pH value (9.05) than that required by WHO after the second boiling stage. pH above 8.5 creates a soda-like taste for the water (SDWF 2017). The least variation was shown by kettles J (Wansa) and G (Tokyo).

The TDS level of drinking water should be below 500 ppm according to WHO. For all of the boiling stages, the obtained results showed (Figure 9) that TDS values were significantly lower than those of the tap water (187.3) for all kettles except kettle K (Moulinex) that recorded higher TDS values after the second boiling stage. It is evident that the TDS level of the boiled water reached its absolute minimum of 34 ppm after boiling stage 2 for kettle A (Sharp). It has been reported that a very low concentration of TDS can result in a flat taste which is undesirable to many people (SDWF 2017). However, kettles G (Tokyo), H (Dexon) and K (Moulinex) displayed TDS concentrations closer to the raw sample after all the boiling stages.

3.4. Effect of reboiling of potable water on heavy metals concentration

Table 4 illustrates the change in the concentration of Pb, Ni and Cu in the boiled water after each boiling stage. It is observed that there is no significant variation that can be detected for these heavy metals from the raw sample.

4. CONCLUSION

The present paper discusses the effect of seven reboiling stages on the physiochemical properties, TDS and pH of local potable water utilizing 11 household kettles. It is evident from this study that the water quality has been affected by the reboiling process, where the extent of the effect depends on the kettle type as well. Results showed that anions exhibited a gradual

Figure 7 | Mineral salt deposition inside the water compartment of a kettle.
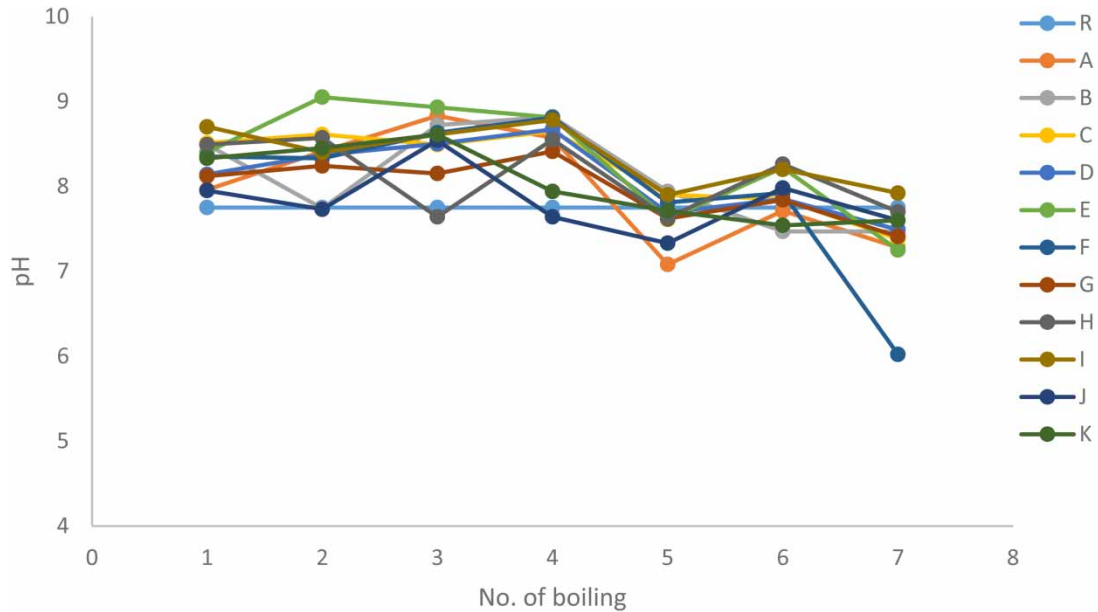
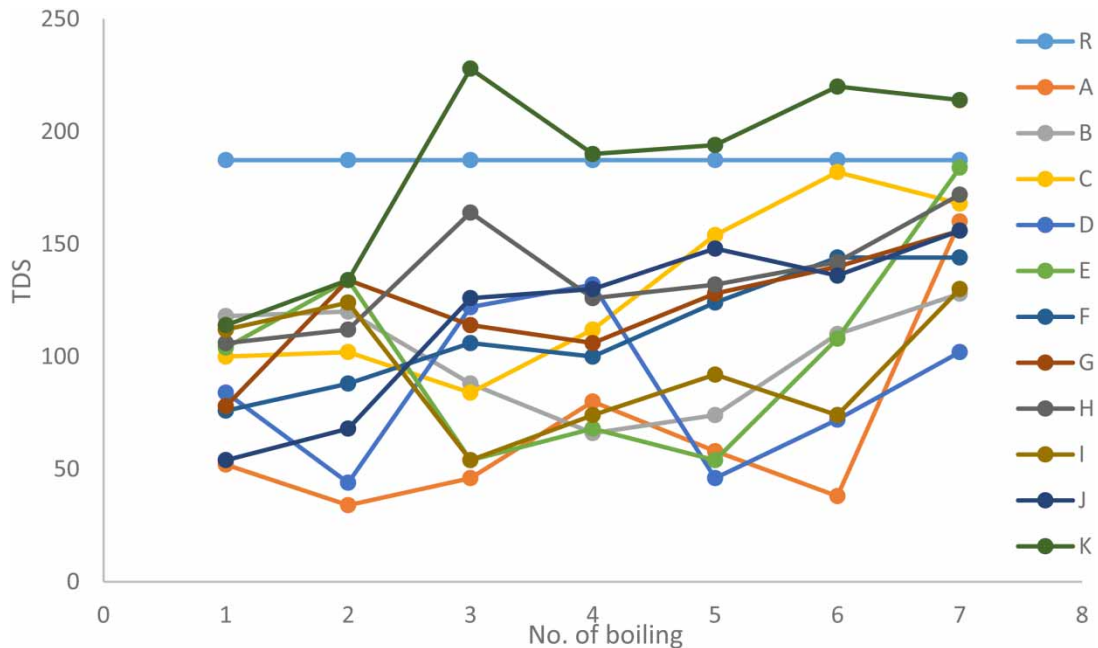**Figure 8** | Variations in pH upon boiling.

Figure 9 | Variations in TDS upon boiling.

increase trend throughout the seven runs with the highest Cl^- concentration of 47.3 ppm and SO_4^{2-} of 21.3 ppm for the same kettle (H). Based on the obtained results, it is preferable to limit the boiling stages to two before diluting or replacing the potable water. This is due to the fact that further boiling the same water increases/decreases the physical–chemical attributes of reboiled water from the raw sample as shown by the graphs of anions and cations. Cation concentrations such as Ca^{2+}, Mg^{2+} and Na^+ fluctuated with a distinct leap, above the raw water values, after boiling run number 4 and absolute maximum at the last run for all the runs and kettles. TDS, however, decreased significantly to values well below the raw water for all kettles except kettle K. Kettle A (Sharp) showed an absolute minimum of 34 ppm. This can create an undesirable taste in the boiled water. Kettle E (Black + Decker) displayed a pH value of 9.05 after the second boiling stage, which is higher than the allowable value (6.5–8.5). It can be noticed that the boiling effect is more pronounced for kettles with water compartments made of

Table 4 | Change in the concentration of various metal ions after each boiling

Kettle	Ni (ppm)							Pb (ppm)							Cu (ppm)						
A	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.01	0.02	0.02	0.02	0.02
B	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.01
D	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
E	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.02	0.01	0.02	0.01	0.02	0.02
F	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.02	0.02
G	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
H	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02
I	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02
J	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02
K	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02

plastic than those made of stainless steel as per anions, pH and TDS analyses. This study provides important information to the consumers on the impact of kettles and reboiling stages on the quality of potable water that may help their future practice in choosing the most appropriate kettle and reboiling stages.

ACKNOWLEDGEMENTS

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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