Investigation of the Potential of Dolomite and Calcite Rocks for Improving Drinking Water Alkalinity

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Abstract - Groundwater remains a major source of drinking water in many developing countries; however, its quality is often compromised by low pH, poor buffering capacity, and undesirable sensory characteristics that limit consumer acceptance. This study evaluated the potential of calcite and dolomite minerals as natural, low-cost amendments for improving the chemical stability and organoleptic quality of groundwater over residence periods of 30, 60, and 90 days and application rate of 5 g/L. Untreated groundwater served as the control, while treated samples were analyzed for pH, total alkalinity, and sensory attributes including taste, odor, and color. Data were subjected to one-way analysis of variance (ANOVA), and treatment means were separated using Duncan Multiple Range Test (DMRT) at $p < 0.05$. Results indicated a significant increase in pH for mineral-treated water compared with the control across all residence periods. Calcite treatment produced the highest pH values, increasing from 7.32 at 30 days to 7.82 at 90 days, while dolomite increased pH from 7.05 to 7.71 over the same period. Total alkalinity also increased significantly, with dolomite exhibiting a stronger long-term buffering effect, reaching 121.40 mg/L after 90 days. Organoleptic evaluation conducted by 15 panelists showed that treated water samples recorded significantly higher preference scores for taste, odor, and color than the untreated control. Calcite-treated water consistently showed slightly increased sensory scores, though both minerals performed comparably. The ANOVA and DMRT results confirmed that mineral type and residence time significantly influenced groundwater quality parameters. The study demonstrates that calcite and dolomite are effective and sustainable materials for improving groundwater alkalinity and sensory acceptability, offering a practical solution for decentralized drinking water treatment in resource-limited settings.

Keywords: Desalination, Organoleptic, Alkalinity, Buffering.

I. INTRODUCTION

Magnesium (Mg) in drinking water is essential for human health, with low concentrations in drinking water being reported to be correlated with poor cardiovascular health outcomes (Jiang *et al.,* 2016). Due to the omnipresence of magnesium in ground and surface waters, low levels of magnesium in drinking water are primarily a concern in locations dependent on desalination; commercial. desalination processes, such as seawater reverse osmosis (SWRO) and Multi-Stage Flash (MSF) deliver water with low overall total dissolved solids content (TDS), to which calcium, hydrogen carbonate, and sodium are the only major ions typically added in post-treatment (Shemer *et al,* 2015). A large epidemiological study studying populations before and after connection to desalinated water supplies strongly suggest negative effects on cardiovascular health which can be linked to magnesium deficiency (Rosen *et al.,* 2018). The majority of water used for domestic and industrial purposes is produced from desalinated seawater, with approximately half coming from SWRO and half coming from thermal desalination processes, predominantly MSF.

This product water is typically treated with limestone dissolved with carbonic acid, to meet the Langelier Saturation Index values required to avoid corrosion of transmission and delivery systems and meet World Health Organization (WHO) recommendations for calcium (Shemer *et al.,* 2015). Based on the reported health issues regarding magnesium in drinking water and suggestions that the WHO would soon announce guidelines for minimum Mg content of drinking water, the SWA announced specifications in October 2020 setting an aspirational Mg target in product water for new seawater desalination projects in KSA of 15–25 ppm (Fellows *et al.,* 2023). We have recently reviewed the different options for magnesium supplementation in terms of relative cost and feasibility (Fellows *et al.,* 2023) and reported on an initiative to achieve 20 ppm target levels using multi-stage nano-filtration of desalination brine. It is most likely that the WHO guideline will target 5 ppm, rather than 15–25 ppm, which is a less costly target to achieve. In advance of this guideline, in 2024 KSA adopted a 5ppm minimum standard for magnesium in potable water from seawater desalination (Al-Hamzah *et al.,* 2025). Replacing a proportion of the calcium carbonate in the post-treatment process with dolomite ($Ca.Mg.(CO_3)_2$) is one possible pathway to approach this goal. However, under equivalent conditions dolomite dissolves significantly more slowly than calcite (by a factor of approximately 2–4 between 20 and 40 °C) (Pokrovsky *et al.,* 2009).

It has been advised to avoid limestones with elevated amounts of dolomite for post-treatment of desalinated water (Ruggieri et al., 2008). The lower solubility of dolomite has been addressed in experimental trials by using an excess of acid, leading to a reduced pH in the treated water which then needs to be adjusted with base to give a reasonable pH and LSI (Greiserman *et al.,* 2016). The high costs and increased solids loading resulting from such a treatment has led to discount dolomite addition as a credible alternative for increasing magnesium content of product water (Lahav *et al.,* 2018). More recently pre-treated micronized dolomite has been found to dissolve at rates that are compatible with desalination plant operations, consistent with the observation that most reported values of dissolution rate constants of minerals arise from physical rather than chemical processes (Fellows *et al.,* 2020). Micronized dolomite has however a significantly higher cost than the current food-grade limestone used in desalination post-treatment. If the goal of supplementation is a relatively low level of magnesium in remineralized water (5 ppm), then partial replacement of calcite with dolomite in existing limestone contactor infrastructure may be sufficient to meet targets without incurring significant increase in post-treatment cost. An additional benefit of dolomite compared to competing options where magnesium is added with a chloride or sulfate counter-ion is that the carbonate will contribute positively to the corrosion resistance of transmission and distribution systems, rather than negatively (Withers, 2005).

Talman et al. (1990) and Zhang et al. (2007) investigated calcite and dolomite dissolution, respectively, in the H_2O–CO_2 system up to 210–250 °C and demonstrated the applicability of dissolution kinetic model. However, in both studies the solution pH was not assessed although it is known to be the main controlling parameter of carbonates dissolution far from equilibrium. Calcite precipitation at high pCO_2 (55 atm to supercritical) was studied at 30–90 °C but the reacted fluid was not sampled in the course of reaction (Montes-Hernandez et al., 2007). The recent application of in-situ pH measurements in carbonate systems at $pCO_2 > 10$ atm, has made possible precise modeling of carbonate reactivity at high pCO_2 and temperature (Pokrovsky et al., 2005). Advanced drinking water treatment often produces low-alkalinity water deficient in calcium and magnesium, which may contribute to corrosive water chemistry and reduced intake of essential minerals linked to cardiovascular and bone health. In the Netherlands, the production and supply of drinking water should comply with the Dutch Drinking Water Directive (Staatsblad van het Koninkrijk der Nederlanden, 2011). The directive states that drinking water should contain a hardness (i.e. calcium and magnesium concentration) of at least 1 mol per liter and 60 mg per liter bicarbonate as a minimum concentration. Hence, a method to design and operate calcite contactors for the purpose of drinking water production or, more generally, conditioning of desalinated water, is relevant to ensure optimal operation and reduce costs related to finding an optimal design. Costs for calcite dissolution are estimated at 0.05 to 0.10 $\$/m^3$ (Shemer et al., 2015). The combination of reverse osmosis (RO) and post-treatment by the application of calcite contactors could be an economic feasible approach for the production of potable water for regions where there is brackish groundwater as e.g. in the Mediterranean countries or the Middle East region (Afonso et al., 2004).

Despite the wealth of information on the effectiveness of implementing a calcite contactor to increase the pH of desalinated ground water and its ability to adsorb divalent metallic cations on its surface (Haddad et al., 2019), to the best of our knowledge, such experimental investigation by means of dolomite and calcite contactor has not been addressed in the scientific literature. In this perspective, this study investigates the potential of dolomite and calcite rocks as natural materials for enhancing drinking water alkalinity and mineral content. The study is significant in promoting chemically stable drinking water while supporting dietary calcium and magnesium supply, thereby contributing to improved public health. The objective is to evaluate and compare the alkalinity enhancement and mineral release from dolomite and calcite for safe and sustainable drinking water treatment.

II. MATERIALS AND METHODS

2.1 Study area and groundwater source

The study was conducted at the National Institute of Construction Technology and Management, Uromi, Edo State Nigeria, using groundwater collected from a routinely used campus borehole. The borehole was flushed for 5 min prior to sampling to obtain representative aquifer water. Samples were collected in pre-cleaned high-density polyethylene containers and taken to the laboratory for pH and alkalinity analysis.

2.2 Preparation and characterization of calcite and dolomite

Naturally occurring calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$] rocks were sourced locally from Ikpeshi quarry Edo State Nigeria, washed, air-dried, crushed, and bore milled using a jaw crusher, disc mill, and bore milling machine. The crushed rock materials were sieved to obtain a particle size range of 75–250 µm, selected to enhance mineral dissolution while minimizing turbidity. The mineralogical composition of each rock sample was determined using X-ray diffraction (XRD) approach, while elemental composition was determined by X-ray fluorescence (XRF) approach to quantify major oxides, particularly CaO and MgO.

2.3.1 Experimental design and application rate

A completely randomized design was adopted with three treatments, a control experiment (untreated groundwater), calcite-treated groundwater and dolomite-treated groundwater. A single application rate of 5 g/L for rock sample with a total of 25Litres of water sample were adopted for both control and treated ground water samples. The chemical parameters of the control, calcite, and dolomite treated water were evaluated at residence period Day1 and Day 90, with all treatments conducted in triplicate.

2.4 Residence time and contact conditions

The rock mineral and water mixtures were maintained in a plastic reservoir and under a static conditions at ambient laboratory temperature (25 – 28°C). Samples were gently agitated manually every two days (48hrs) to improve contact and mineral dissolution. During sample collection, samples were filtered prior to laboratory analysis of water sample.

2.5 Water quality analysis

The pH of each experimental setup was measured using a calibrated digital pH meter, while total alkalinity was determined using standard titrimetric methods and expressed as mg/L $CaCO_3$.

2.6 Organoleptic evaluation of ground water and rock treated water

The organoleptic assessment was performed to evaluate the taste, odor, and color of the treated groundwater samples, using a structured sensory panel in accordance with ISO 8586:2012 standards. A total of 15 trained panelists (8 males and 7 females, aged 25–40 years) were recruited from staff and students of the National Institute of Construction Technology and Management, Uromi Edo State Nigeria. All panelists were screened for sensory acuity and familiarity with drinking water evaluation. Tests were conducted in a well-ventilated sensory laboratory under controlled lighting, at room temperature (25 ± 2.0 °C). Samples were coded with random three-digit numbers to ensure blinding. The assessment was based on taste with a 5-point hedonic scale score (1 = extremely unpleasant, 5 = extremely pleasant). Odor with a 5-point hedonic scale score (1 = extremely unpleasant, 5 = extremely pleasant), and color with a 5-point visual acceptability scale score (1 = highly unacceptable, 5 = highly acceptable). The panelists were instructed to rinse their mouths with distilled water between samples to minimize carry-over effects. Each panelist evaluated all three water treatments in randomized order.

2.6 Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA), and treatment means were separated using Duncan Multiple Range Test (DMRT) with consideration to $p < 0.05$. The results on the organoleptic assessment of the study in percentage was represented with bar chart.

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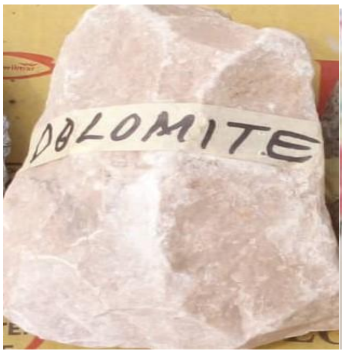

Plate1. Dolomite sample

Plate2. Crushed rock

Plate3. Treatment reservoirs

Plate4. Water sample

III. RESULTS AND DISCUSSION

3.1 Effect of calcite and dolomite on groundwater pH

The initial pH of the collected water sample at Day1 was evaluated in the laboratory as 6.40. The untreated groundwater (control) exhibited slightly acidic to near-neutral pH values (6.40 – 6.47) across all residence time (Table 1), indicating limited and insignificant natural buffering capacity. In contrast, both calcite and dolomite treatments produced significant increases in pH values relative to the control ($p < 0.05$). At 30 days, calcite-treated water showed a moderate rise in pH (6.40 - 7.32) due to the dissolution of calcium carbonate (Calugaru *et al.,* 2024; Holtman *et al.,* 2022), while dolomite produced a slightly slower response, attributed to its lower solubility and the presence of magnesium (6.40 – 7.05). By Day 60, both minerals resulted in further pH stabilization within the neutral to slightly alkaline range with calcite (7.68) and dolomite (7.52). At 90 days, pH values of calcite and dolomite approached equilibrium, with calcite showing marginally increased pH (7.82) than dolomite (7.71). These findings align with the dissolution kinetics theory, where calcite dissolves more rapidly than dolomite (Moral *et al.,* 2008), releasing carbonate species that neutralize acidity and increase buffering capacity. The World Health Organization (WHO) recommended the pH range of 6.5 – 8.5 for water that is meant for drinking. The value of the ground water for the control was evaluated to be slightly below the WHO standards while the values of other treatments are within the recommended range (FAO, 2012).

Table 1. Effect of Calcite and Dolomite Minerals on Groundwater pH for Different Residence Periods

Treatment	pH (30 days)	pH (60 days)	pH (90 days)
Control	6.42 ± 0.05^{c}	6.45 ± 0.04^{c}	6.47 ± 0.06^{c}
Calcite	7.32 ± 0.06^{a}	7.68 ± 0.05^{a}	7.82 ± 0.04^{a}
Dolomite	7.05 ± 0.07^{b}	7.52 ± 0.06^{b}	7.71 ± 0.05^{b}

Values are mean ± standard deviation (n = 3). Means within a column followed by different superscript letters differ significantly at $p < 0.05$ (DMRT).

3.2 Changes in total alkalinity (mg/L)

Total alkalinity of the ground water increased significantly in both mineral-treated waters compared to the control. The initial alkalinity of the untreated water at Day 1 was evaluated in the laboratory to be 38.10 mg/L. The calcite treatment resulted in a rapid increase in alkalinity at 30 days (38.10 – 86.70 mg/L), reflecting efficient release of bicarbonate ions (Hedin *et al.,* 1994). Dolomite treatment revealed a more gradual but sustained increase, particularly at Day 60 (108.50 mg/L) and Day 90 (121.40 mg/L). According to Table 2, the progressive rise in the alkalinity of the treated water with respect to residence time indicates continued mineral dissolution and enhanced buffering capacity. At Day 90, dolomite-treated water exhibited comparable or slightly higher alkalinity than calcite-treated water, likely due to sustained release of both calcium and magnesium carbonates.

Table 2. Effect of Calcite and Dolomite Minerals on Total Alkalinity of Groundwater (mg/L)

Treatment	Alkalinity (30 days)	Alkalinity (60 days)	Alkalinity (90 days)
Control	38.40 ± 2.1^{c}	38.40 ± 1.8^{c}	39.70 ± 2.0^{c}
Calcite	86.70 ± 3.4^{a}	104.20 ± 4.1^{b}	112.60 ± 3.8^{b}
Dolomite	72.90 ± 3.1^{b}	108.50 ± 3.6^{a}	121.40 ± 4.2^{a}

Values are mean ± standard deviation (n = 3). Means within a column followed by different superscript letters differ significantly at $p < 0.05$ (DMRT).

3.3 Influence of rock minerals residence time in drinking water

Residence time played a critical role in the alkalinity improvement of the ground water (Zhang *et al.,* 2020). Short residence period of 30 days was sufficient to improve the groundwater pH, while longer residence periods of 60 and 90 days were necessary to achieve stable alkalinity levels suitable for drinking-water buffering. This trend highlights the importance of adequate contact time in mineral-based post-treatment systems. The low-alkalinity drinking water is often corrosive and may contribute to the leaching of metals from distribution systems, posing potential health risks (Tam *et al.,* 2009). The use of calcite and dolomite rock minerals significantly improved pH and alkalinity (Calugaru *et al.,* 2024; Hedin *et al.,* 1994; Holtman *et al.,* 2022), thereby improving water stability and reducing corrosivity. Additionally, dolomite treatment contributed magnesium ions, an essential dietary mineral linked to cardiovascular and metabolic health (Varonese and Calder, 2023; Zhang et al., 2016). The observed alkalinity enhancement aligns with the international drinking-water recommendations that emphasize adequate buffering capacity for safe and palatable water. According to Table 1 and Table 2, calcite was more effective for rapid pH correction while dolomite provided longer-term alkalinity stabilization. This suggests that the combination or sequential use of both minerals could be beneficial for groundwater post-treatment systems in similar hydrogeological settings. The findings demonstrate that locally sourced calcite and dolomite rocks can serve as low-cost, sustainable materials for improving drinking-water quality. The approach is particularly suitable for decentralized water treatment systems in developing regions.

3.4 Organoleptic Assessment

3.4.1 Taste

From Table 3, calcite-treated groundwater received the highest average taste score (4.10 ± 0.30), which was significantly higher than the control ($p < 0.05$). Dolomite treatment also improved taste (3.95 ± 0.35) relative to the control, but the difference between calcite and dolomite was not statistically significant ($p > 0.05$).

3.4.2 Odour

A similar trend was observed for odor. Calcite-treated water had a mean odor score of 4.05 ± 0.28, significantly higher than the control (3.00 ± 0.35, $p < 0.05$). Dolomite-treated water scored 3.90 ± 0.33, which was also significantly higher than the control ($p < 0.05$).

3.4.3 Colour

Both calcite and dolomite treatments improved visual acceptability of the water (Table 3). Calcite-treated water had a mean color score of 4.00 ± 0.32, while dolomite-treated water scored 3.95 ± 0.30. Both treatments have improved visibility which is also significant than the control (3.10 ± 0.37, $p < 0.05$), with no significant difference between the two mineral treatments ($p > 0.05$).

Table 3. Organoleptic results on the treated and untreated ground water with rock minerals

Treatment	Taste	Odor	Color
Control	3.20 ± 0.42^a	3.00 ± 0.35^a	3.10 ± 0.37^a
Calcite	4.10 ± 0.30^b	4.05 ± 0.28^b	4.00 ± 0.32^b
Dolomite	3.95 ± 0.35^b	3.90 ± 0.33^b	3.95 ± 0.30^b

Values are mean ± standard deviation (n = 3). Means within a column followed by different superscript letters differ significantly at p < 0.05 (DMRT).Each value in the table represents the mean scores across the 15panelists

3.4.5 Organoleptical interpretation of the experimental data (%)

Figure 1 shows that mineral treatment significantly improved the organoleptic quality of groundwater compared with the untreated control. Across all sensory attributes (color, odor, and taste), the control recorded the lowest preference scores (27.40–28.44%), indicating insignificant variation in the typical quality of untreated groundwater. Both calcite and dolomite treatments significantly improved sensory acceptability. According to the panelist assessments, treated water achieved higher scores (calcite: 36.20%; dolomite: 35.75%) for color, suggesting improved clarity due to increased alkalinity and precipitation of color-causing constituents. A similar trend was observed for odor, where calcite (36.98%) and dolomite (35.62%) reduced objectionable smells relative to the control (27.40%). Taste followed the same pattern, with calcite (36.44%) and dolomite (35.12%) outperforming untreated water (28.44%), likely due to pH stabilization and enrichment with calcium and magnesium ions. Both minerals effectively improved drinking water acceptability, with calcite showing a slight but consistent advantage over dolomite. These results support the use of calcite and dolomite as low-cost, locally available materials for enhancing the sensory quality of groundwater for potable use.

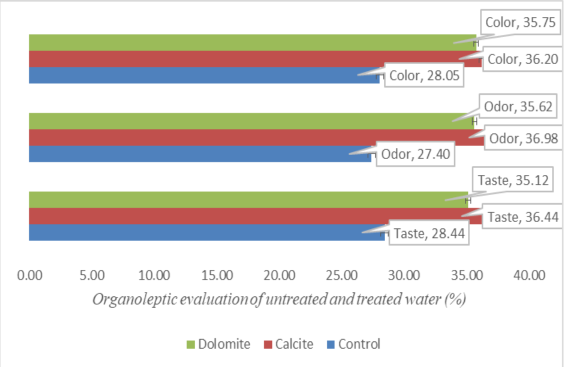

Fig 1: Trend of organoleptic assessment for experimental variables (%)

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V. CONCLUSION

This study demonstrates that calcite and dolomite minerals significantly enhance groundwater quality by improving pH, alkalinity, and organoleptic characteristics. Both treatments effectively neutralized acidic groundwater, with calcite producing a faster and slightly higher pH adjustment, while dolomite contributed greater long-term alkalinity enrichment. Sensory evaluation confirmed that treated water was more acceptable in terms of taste, odor, and color compared to untreated groundwater, highlighting the importance of mineral treatment in improving user compliance and drinking water acceptability. The findings are significant for public health and water management, particularly in low-resource and rural settings, as they confirm the potential of locally available carbonate minerals as sustainable alternatives to conventional chemical additives. Future research should focus on long-term field-scale applications, optimization of mineral dosage and contact time, and assessment of trace metal behavior and microbiological safety to further support large-scale adoption of mineral-based groundwater treatment systems.

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