Paros water quality: a literature review of water hardness and human health

Dorothy Filioti and Shenali Kalawana
Clean Blue Paros project
Common Seas C.I.C.

Sections

1. Introduction

Water hardness refers to the level of certain dissolved metallic ions in water, primarily calcium and magnesium, which can be present in several compound forms such as carbonates, sulphates, and chlorides (Kazemi, 2005)**.** Hard water exhibits the following properties:

- $CaCO_3$ equivalence of more than 120mg/l is considered 'hard', and more than 180mg/l is considered 'very hard' (WHO, 2011)
- When mixed with soap, hard water produces a 'scummy' or cloudy mixture. The mixture does not lather easily due to calcium and magnesium ions reacting with the soap compounds (Kazemi, 2005).
- Hard water often leaves a precipitate on pipes and surfaces with which it has had prolonged contact (WHO, 2011)
- Hard water can have a mineral taste (WHO, 2011)

The municipal drinking water in Paros that comes from the water supply is of a good quality and within international guidelines for potable water (DEYAP, 2019; Rickwood & Carr, 2007; WHO, 2017; EU, 1998; EPA, 2009). Municipal water in Paros can be classified as 'very hard' following widely used World Health Organisation (WHO, 2011) definitions, which state that $CaCO_3$ equivalent levels above 180mg/l constitute as "very hard".

While the official EU and WHO guidelines do not set an upper limit for water hardness, as it is not considered a health threat, local concerns about water safety are often raised as a reason for avoiding tap water (EU, 1998; WHO 2017; Common Seas, 2020). This may be in part due to the common sight of precipitate on pipes and appliances which people can imagine indicates some equivalent process of deposition internally. The aim of this research review is to address and clarify how hard water relates to health, in response to the common concerns in the local population of Paros that hard water can increase the risk of kidney stones, which is not supported by the literature as detailed in this review.

Methodology note:

The literature reviewed in this document was collected from articles on Pubmed, and Google Scholar, consisting of academic reports from established health organizations such as the WHO, national service providers, and scientific journals. Key search words included “hard water”, “health”, and “kidney stones”.

2. How does water become hard?

Rainwater is initially soft when it falls, gaining hardness as it collects minerals along its course, percolating through geological layers. Sedimentary or limestone rocks with a prevalence of ions available for absorption (mainly calcium and magnesium) are associated with greater hardness. In the case of Paros, the water absorbs minerals from Parian marble (consisting mainly of calcium carbonate) in addition to other bedrock such as gneiss and schist, depending on the area (Hannappel et al., 2005).

Hard water is common throughout the world, present in over a third of the United States (USEPA, 2005); almost half of Western Europe (Chopade & Nagarajan, 2000); over half of England (DWI, 2009); prevalent in Iran (Basiri, et al., 2011), Sri Lanka (Jayasumana et al., 2014) and Indonesia (Sulistyawati et al., 2016).

Water hardness is measured by the presence of calcium carbonate ($CaCO_3$) in the water. Table 1 shows the water hardness levels for the water zones of Paros (DEYAP, 2020). For context, there is no official upper limit to water hardness according to WHO (2011), and there are also no official European limits for water hardness (EU, 1998, DEYAP, 2020). An upper limit for daily intake of calcium is suggested at 2500mg/l, however this is many times above the level that may be ingested through tap water (Cotruvo & Bartram, 2009).

Table 1: *Levels of total, temporary, and permanent water hardness, calcium, and magnesium in different water zones of Paros (DEYAP, 2020), (see section 2.1 for more information on temporary and permanent hardness):*

Location	Date collected	Total Hardness (mg/l)	Temporary Hardness (mg/l)	Permanent Hardness (mg/l)	Ca (mg/l)	Mg (mg/l)
Paroikia	25/08/20	286	222	64	88	16
Naoussa	25/08/20	309	180	129	84	24
Marpissa	14/09/20	283	224	59	69	27
Kostos/ Lefkes	28/09/20	436	288	148	120	33
Drios	28/09/20	359	258	101	91	32
Archilochos	28/09/20	322	286	36	83	28
Aliki/Ageria	28/09/20	353	250	103	120	13

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2.1 Temporary hardness vs. Permanent hardness

Temporary hardness describes the short-term presence of calcium and magnesium in their carbonate form (calcium carbonate and magnesium carbonate). These compounds can be removed by boiling; thus, this hardness is considered temporary (Rubenowitz-Lundin & Hiscock, 2012). The carbonates precipitate in the form of scale on surrounding surfaces such as on a kettle (Boyd, 2015).

Permanent water hardness constitutes the presence of calcium and magnesium in their sulphate and chloride form (calcium sulphate, calcium chloride, magnesium sulphate and magnesium chloride), which remain in the water despite boiling. Such compounds require other treatment methods if they are to be removed (Boyd, 2015). These treatments are not explored in the context of this review.

Most of the hardness in Paros water is temporary (See table 1).

3. Links between water hardness and human health

Decades of research show that hard water is generally considered neutral or even beneficial for human health with respect to many conditions and bodily functions (WHO, 2011; Cotruvo & Bartram, 2009). Studies suggest a possible benefit of hard water minerals (particularly magnesium) for cardiovascular systems, cancer, gastrointestinal, kidney health, and bones, amongst other health areas (Sengupta 2013; Cotruvo & Bartram, 2009; Momeni et al., 2014). There are no mandated upper limits for water hardness in most international directives (EU, 1998; WHO, 2011), indicative of the lack of threat that water hardness poses to human health as research currently stands.

Soft water is in fact considered more of a health concern as inadequate intakes of calcium and magnesium are associated with a host of health issues (WHO, 2011). Soft water may also corrode pipes, releasing unwanted metals (Lahlou, 2002; Rubenowitz-Lundin & Hiscock, 2012). This report provides an overview of basic information and research on the health effects of hard water, as deemed relevant to the conditions in Paros.

3.1 Kidney Stones

The water hardness levels in Paros are subject to rumours linking drinking water and kidney stone formation. In this section we present the main research facts related to this topic and aim to address some key concerns.

Studies show that healthy individuals are protected from excess calcium intake from water, through kidney excretion. Even for people who have already had kidney stones the British Association of Urological Surgeons (BAUS) states that reducing the amount of calcium in the diet can increase the chance of recurrence of stones, and that an “intake of up to 1000mg per day is safe for calcium stone formers" (BAUS, 2017). We would have to drink many litres of water to reach that level of calcium intake (See table 1 for calcium content in Paros water). Calcium and magnesium present in water are highly absorbable by the body, at around 50% (WHO, 2011). Concern has been mentioned for patients with certain rare kidney diseases such as milk alkali syndrome and hypercalcaemia (WHO, 2011). We advise individuals with diseases that affect kidney function to seek additional medical guidance regarding water hardness.

Calcium in the diet is evidenced to be protective against kidney stone formation:

Calcium and magnesium absorbed through the diet have been found to protect against kidney stone formation (Cotruvo & Bartram, 2009). A study by Curhan et al. (1993) tracked the diet and occurrence of kidney stones in 45,619 men aged 40 - 75 over four years and found that dietary calcium was correlated with a lower risk of kidney stone formation. An equivalent study performed with women (Curhan et al., 1997), demonstrated similar results, that dietary calcium was inversely related to risk of kidney stone formation. In another study a high intake of calcium and magnesium rich water was found to be protective against stone formation compared to water with less mineral content (Rogers, 1998). The above evidence points to the protective effect of dietary calcium and water-based calcium against kidney stones, which is relevant as calcium is the main component of the water hardness in Paros.

Links between hard water and kidney stone incidence in populations are weak:

Epidemiological studies, observing trends in populations regarding kidney stones and water hardness, have for the most part found no significant patterns between stone formation and hard water.

- In the US, Schwartz (2002) examined local water hardness for 4,833 patients with calcium stones, finding no significant association between water hardness and lifetime stone formation.
- Shuster et al. (1982) cites the inverse relationship between kidney stone incidence and water hardness on the macrogeographical level in the US. Looking at the local level, Shuster compared 2,295 kidney stone patients' hard and soft water intake to a control group (hernia patients) and found no correlation between hardness and kidney stone incidence. An elevated risk was identified for private well water consumption.
- Mitra (2018) compared water quality and quantity consumed to kidney stone incidence with 1,266 kidney stone patients representing case areas, versus control areas with no stone incidence. Quantity of water rather than quality was identified as the most important factor relating to kidney stone risk, along with sedentary lifestyle. The hardness range in this study (up to 250mg/l $CaCO_3$) was mostly below the range found in Paros (173 - 393mg/l $CaCO_3$), which may limit its implications for the situation in Paros.

Two studies found some association between magnesium-to-calcium ratio in the water and kidney stone occurrence in populations.

- A study across 24 regions of Iran that examined kidney stone occurrence against water hardness factors found no relationship between hardness and stone incidence. Higher relative magnesium was linked to a mildly protective effect, and a low magnesium-to-calcium ratio was positively associated with kidney stone occurrence (Basiri et al., 2011).
- Kohri (1989) found a similar pattern in Japan, where low magnesium-to-calcium ratios in tap water were associated with greater frequencies of stone formation.

While several studies mentioned above show no relationship between kidney stones and water hardness, there is preliminary evidence that high magnesium to calcium ratios in water mineral content are related to kidney stone incidence.

<u>Research shows hard water increases calcium content in urine:</u>

Studies examining how the body processes calcium from water, and how this may relate to kidney stones reveal some inconsistent conclusions. Hard water has been found to increase calcium content in urine; however, the significance of this with regards to kidney stone formation is unclear (Schwartz, 2002). Some studies have found that higher calcium intake is suggested to protect against kidney stone formation due to its action of binding with oxalic acid, a common precursor to kidney stones present in foods (Caudarella et al., 1998; Siener & Hess, 2003). Milk intake (which is high in calcium) for instance, was found to be protective against kidney stone formation in one study (Moghaddas et al., 2015). Curhan et al. (1993), BAUS (2017), and Han et al. (2017) indeed state that limiting dietary calcium is found to be a risk factor for recurrent kidney stones.

On the other hand, several studies have found that individuals with a history of stone formation, have been observed to accumulate more urinary calcium compared to non-stone formers following hard water intake (Mirzazadeh, 2012), and recommend that stone-formers should consume softer water between meals, when there is no ingested oxalate for calcium to bind with (Belizzi et al., 1991; Coen et al., 2001). However, the British Association of Urological Surgeons warns against limiting calcium intake without consulting with a doctor (BAUS, 2017).

The available research on this topic indicates that there is inconclusive evidence to show the effect of urinary calcium on stone formation. High calcium water increases calcium in urine but can decrease oxalate, protecting against stone formation. Some studies suggest limiting calcium rich water ingestion between meals because of the lack of oxalate for the calcium to bind with. In general, limiting calcium intake is discouraged without consulting a doctor. Further research on this topic is required to provide a conclusive statement, and as stated by Schwartz (2002), the significance of urinary calcium on stone formation remains unclear.

<u>Other lifestyle factors are important for kidney stone risk:</u>

While studies of hard water and kidney stone formation reveal some mixed results, the conclusions of literature on lifestyle contributors to kidney stone formation are clear. Of primary importance is avoiding dehydration (Ackerman, 1990; Fink et al., 2009; Frassetto & Kohlstadt, 2011), which implies that the quantity of water is more important than the quality (Borghi et al., 1999; Mitra et al., 2018). People should drink enough water to keep urine as clear as possible according to BAUS (2017). Furthermore, animal protein intake, sodium intake, and sedentary lifestyle are recognized as increasing the risk for kidney stones (Boarin et al., 2018; Curhan et al., 1993; Han et al., 2017; Lopez & Hoppe, 2010). Following a Mediterranean diet is associated with a lower risk of kidney stone occurrence (Rodriguez et al., 2020), as is the ingestion of certain beverages in moderate quantities such as tea, coffee, beer, and wine (Curhan et al., 1996). Warm ambient temperatures with high sunlight exposure have also been associated with greater incidence of kidney stones (Soucie et al., 1996).

3.2 Other health considerations

The presence of bioavailable calcium and magnesium in hard water can supplement a human's daily intake of these minerals (WHO 2011). For instance, one liter of water containing 300mg of calcium is equivalent to one dairy serving (Cotruvo & Bartam, 2009). Soft water is of greater concern as it does not provide essential minerals and can leave populations at risk of a host of health problems associated with calcium and magnesium deficiencies (Koziec, 2005). The main research topics in health areas related to hard water and its potential mineral supplementation are listed below.

- Several studies have found a protective association between hard water and cardiovascular disease (Anderson et al., 1969; Hopps & Feder 1986; Lee et al., 2006; Yang et al., 1996), other studies have not found a conclusive association (Catling et al., 2008; Leurs et al., 2010; Morris et al., 2008; Nerbrand et al., 2003).

- Research on the relationship between water-based calcium and magnesium intake and several cancers (gastric, kidney, esophageal, ovarian, colon, hepatic) have found a protective effect to varying degrees (Chio et al., 2010; Sengupta, 2013; Yang et al., 1999; Yang et al., 1999).

- Magnesium deficiency is associated with diabetic onset, indicating that in the case of diabetes, hard water may decrease the risk of onset (Chaudhary et al., 2010).

- Magnesium-sulphate present in hard water is found to dramatically reduce the occurrence of eclampsia in pregnant women, while calcium is also recognised and recommended as protective against eclampsia (Omotayo 2018; Sengupta, 2013; Villar et al., 1983).

- According to Sengupta (2013) hard water is beneficial for the digestive tract, potentially alleviating constipation in 85% of cases.

- Water hardness has also been attributed to affect bone mineral density. Costi et al., (1999) demonstrated that, when comparing bone mineral density between elderly women in regions of hard and soft water, women living in hard water regions had higher bone mineral density. Researchers also state that a woman drinking 1L of water a day with 400mg of calcium content, would have the equivalent bone density of a woman drinking water with low calcium content that is 7 years younger (Aptel et al., 1999). High calcium mineral water intake was also found to protect bone mass in healthy young men, providing an extra source of calcium (Guilemant et al., 2000).

4. Conclusion

The relationship between hard water and kidney stone formation appears weak considering the mild and inconsistent patterns emerging from the literature. At the same time, perhaps counterintuitively, dietary calcium (from food or water) is repeatedly cited as a necessary part of protecting the body from stone formation, especially when ingested with food. WHO (2011) does not identify any known health concerns associated with hard water, and subsequently, such organisations have not proposed water hardness limits. Lifestyle factors, on the other hand, are well evidenced to influence stone formation, adequate hydration, reducing animal product and salt intake, and keeping active are the most protective factors against kidney stones (Boarin et al., 2018). Hard water has several known positive health effects including protecting against certain cancers, diabetic onset, and supporting healthy bone density, and digestion (Sengupta, 2003). Whilst healthy individuals are protected from excess calcium intake by kidney excretion, evidence does suggest that some groups with pre-existing conditions may have an increased risk of stone formation in relation to hard water ingestion (WHO, 2011), and should seek additional medical advice.

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