Indian Journal of Environmental Sciences 22(1) 2018, pp.1-15. ISSN 0971-8958
Green Earth Foundation

REVIEW ON CHEMICAL AND BIOLOGICAL ASPECTS OF HARDNESS IN WATER

Kamlesh and M.K. Kidwai*
Department of Energy and Environmental Sciences, Chaudhary Devi Lal University, Sirsa
***Corresponding Author**

ABSTRACT

Water is one of the most essential natural resource for existence of life on this planet. With increasing human population and rapid development, the global water consumption demand have been increased many folds and physico-chemical and microbiological parameters of large proportion of the water sources have been altered due to anthropogenic activities. Physico-chemical parameters are influenced by both geogenic and anthropogenic agents. Hardness of water is one of them. Hardness is an essential parameter for drinking water from both aesthetic and quality aspects. A common source of natural pollutants in groundwater is the dissolution of minerals in some aquifers under certain physical conditions. Water having very high amount of minerals is reported to be detrimental to human health. Several epidemiological investigations have demonstrated the relation between hardness of drinking water and risk for cardiovascular disease, cancer, growth retardation, reproductive failure, and other health problems. It is therefore requisite to assess drinking water quality parameters at regular interval for preventing diseases and improving quality of life. This review is an attempt to explore the causes and effects of its constituents (calcium and magnesium) on humans and animals.

Key words: Hardness, calcium, magnesium, cardiovascular, drinking water, health

INTRODUCTION

Water quality assessment is of vital concern as it is directly linked to human welfare and the definition of water quality depends on the desired use of water (Kirda 1997, Jain et al. 2009).Consumption of deterioting water quality affects livelihoods at risk (Leelavathi et al. 2016). Groundwater quality is affected by both geogenic and anthropogenic agents (Sheikhy et al. 2014).About 70% of Earth's surface is covered by water of which 97.5%is salty and 2.5% is freshwater. Less than 1% of this 2.5% amount of freshwater is accessible (Mishra and Dubey 2015).Groundwater accounts for about 98% of global freshwater on the Earth (Kibona et al. 2009, Cassardo and Jones 2011, Lui et al. 2011) which is used by approximately 2.5 billion people worldwide for their daily needs (Margat 2008, Margat and van der Gun 2013).Total global population is reported to be 7.6 billion, out of which 1.1 billion people in the world, or 15 % of the global population lack access to safe drinking water (Sobsey 2006). Chemical characteristics of the groundwater are influenced by rock-water interactions and several anthropogenic factors (Alfy et al. 2017). A common source of natural pollutants in groundwater is the dissolution of minerals in some aquifers under certain pH and redox conditions (Rasool et al. 2015, Singh and Mukherjee 2015).The dominant factors in controlling the groundwater hydro geochemistry are chiefly evaporation and weathering (Ghalib 2017).Furthermore, increased use of chemical fertilizers to improve agricultural yields enhanced groundwater pollution (Bouzourra et al. 2015, Milhome et al. 2015, El Alfy and Faraj 2016).

One of the major causes of health issues in the developing countries is largely due to lack of safe drinking water (Cairncross and Valdmani 2006). Due to expansion in human population, intensive industrialization, excessive use of fertilizers in the agriculture and other human activity water is highly polluted with harmful contaminants (Patil et al. 2012, Nag and Lahiri 2012).The groundwater is reported to be comparatively clean and free from pollutants than surface water but prolonged discharge of industrial effluents such as glass and porcelain industries, enamel industries, steel industries, domestic sewage and solid waste dump caused groundwater pollution and raised human health issues (Raja et al. 2002). Those water sources that do not conform the national standard result in human health problem in long time exposure (Alemu et al. 2015). It is necessary that the quality of drinking water should be checked at regular time interval because due to use of contaminated drinking water, human population suffers from varied water borne diseases (cholera, typhoid, diarrhea etc.).

Water is essential for life. But water having very high degrees of hardness is reported to be harmful to human health (Ramya et al. 2015). Hardness is the property of water which prevents lather formation with soap and increases the boiling point of water (Khan and Khan 1985).Total hardness is one of the most important properties of drinking water. It is a measure of the quantity of divalent ions (salts with two positive charges) such as calcium (Ca), magnesium (Mg) and/or iron (Fe) in water. These ions enter in water supply by leaching and dissolution of minerals from rocks and soil. Calcium contributes to the hardness of water within the bicarbonate (HCO_3^-) forming temporal carbonate hardness while sulphate (SO_4^{2-}), chloride (Cl^-) and nitrate (NO_3^-) forming permanent or non-carbonate hardness (Twort and Dickson 1994). Water with higher hardness is considered to be unsuitable for domestic and industrial purposes (Sarath et al. 2012, Gopinath et al. 2015).

Table 1. Carbonated and non-carbonated hardness

Compounds responsible for carbonated hardness	References
Calcium carbonate ($CaCO_3$)	Amor et al. 2004, Ahnet al. 2018
Magnesium carbonate ($MgCO_3$)	Sengupta 2013, Ahnet al. 2018
Calcium hydroxide [Ca $(OH)_2$]	Kabayet al. 2002, Gunten 2003
Magnesium hydroxide [Mg $(OH)_2$]	Entezari&Tahmasbi 2009, Sengupta 2013
Calcium bicarbonate [Ca $(HCO_3)_2$]	Kabayet al. 2002, Amor et al. 2004
Magnesium bicarbonate [Mg $(HCO_3)_2$]	Entezari&Tahmasbi 2009, Gumashtaet al. 2012
Compounds responsible for non-carbonated hardness	**References**
Calcium chloride ($CaCl_2$)	Kabayet al. 2002, Sengupta 2013
Magnesium chloride ($MgCl_2$)	Sengupta 2013, Ahnet al. 2018
Calcium sulfate ($CaSO_4$)	Gumashtaet al. 2012, Ahnet al. 2018
Magnesium sulfate ($MgSO_4$)	Kabayet al. 2002, Sengupta 2013

Table 2. Classification of water hardness (WHO 1996, APHA 2012)

Hardness	$CaCO_3$ (mg/L)
Soft	0-75
Medium hard	75-150
Hard	150-300
Very hard	300-500
Need treatment	500 and above

Earlier researchers have reported various chemical compounds to cause carbonated hardness and non-carbonated hardness (Table 1).

Causes of hardness in water

The principal natural source of hardness in water are dissolved polyvalent metallic ions from sedimentary rocks, seepage and runoff from soils (WHO 2010). The presence of dissolved minerals coupled with special characteristics of groundwater as compared to surface water makes it a preferred choice for many purposes (Rajanka et al. 2009). Chemical composition of water depends to a great extent on the chemical composition of geological substrata. The principal processes that influence the quality of water in an aquifer are physical, geochemical, hydrogeochemical and biochemical. The quality of groundwater depends on the source, the degree to which it has been evaporated, the composition of recharge water, the interaction between the water and the soil, the soil-gas, the rock with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer (Caj and Postma 2005). It has been reported that chemical characteristics of the groundwater are majorly influenced by rock-water interactions (dissolution/precipitation, ion exchange processes, oxidation, and reduction) and anthropogenic factors (Freeze and Cherry 1979, Matthess 1982, Kumar et al.2006, Liu et al. 2008, Zhu and Schwartz 2011, Rajesh et al. 2012, Alfy et al. 2017).

The most common source responsible for hardness in water are calcium-containing limestone ($CaCO_3$) and magnesium-containing dolomite ($CaMg(CO_3)_2$). Therefore, groundwater obtained from deep tube wells usually has a greater hardness than does surface water (Prepas et al. 2001, Khound et al. 2012, Ahn et al. 2018).

Elementary calcium reacts with water at room temperature, according to the following reaction mechanism:

$$Ca\,(s) + 2H_2O \rightarrow Ca(OH)_{2\,(aq)} + H_2\,(g)$$

This reaction forms calcium hydroxide that dissolves in water as a soda ($NaHCO_3$), and hydrogen gas. Other important calcium reaction mechanisms are erosion reactions which usually occur when carbon dioxide is present. Under normal conditions calcium carbonate is water insoluble. In the presence of carbon dioxide carbonic acid (H_2CO_3) is formed, affecting calcium compounds. The reaction mechanism for carbon weathering is

$H_2O + CO_2 \rightarrow H_2CO_3$

$CaCO_3 + H_2CO_3 \rightarrow Ca\ (HCO_3)_2$

$CaCO_3\,(s) + CO_2\,(g) + 2H_2O\ (l) \rightarrow Ca^{2+}(aq) + 2\ HCO_3^-\ (aq)$

Hardness, a physico-chemical property of water, is a measure of calcium (Ca) and magnesium (Mg) ions in water. However, hardness can be caused by several other dissolved metals, those forms divalent or multivalent cations including aluminum (Al), barium (Ba), strontium (Sr), iron (Fe), zinc (Zn), and manganese (Mn). However, they are generally present in very low concentrations (Sengupta 2013). The types of anion present in these salts distinguish between two types of hardness i.e carbonate hardness and non-carbonate hardness. Carbonate hardness is known as temporary hardness because it can be removed by boiling of water to expel the CO_2, as indicated by the following equations:

$Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

$Mg(HCO_3)_2 \rightarrow MgCO_3 + CO_2\uparrow + H_2O$

$MgCO_3 + H_2O \rightarrow Mg(OH)_2\downarrow + CO_2\uparrow$

Whereas non-carbonate hardness cannot be broken down by boiling the water as it contains either calcium or magnesium sulfates ($CaSO_4$ or $MgSO_4$) as well as other salts that are not precipitated by boiling, known as permanent hardness. Permanent hard water may only be softened by the use of chemical softeners (Skipton and Dvorak 2014). Hardness is expressed in terms of equivalent quantity of $CaCO_3$. The water containing excess hardness is not desirable for domestic purpose as it forms scales on water heater and utensils when used for cooking and consume more soap during washing of clothes (Gupta et al. 2009, Ranjeeta et al. 2011). Lime scale is insoluble calcium carbonate that precipitated during thermal decomposition of calcium bicarbonate $Ca(HCO_3)_2$ as:

$Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

Hard water containing calcium (Ca) or magnesium (Mg) ions react with thesodium stearate (soap). The soluble calcium and magnesium ions combine with stearate ions in the soap to form insoluble calcium and magnesium stearates. These compounds are the insoluble scum that floats on the water, for example, with calcium ions (Brown 1997, Itsadanont et al. 2014).

Calcium ions + stearate ions → scum

(in solution) (in solution) (insoluble solid)

$Ca^{2+}_{(aq)} + 2C_{17}H_{35}CO_{2(aq)} \rightarrow Ca\ (C_{17}H_{35}CO_2)_{2(s)}$

Ions in water combine with soap to form insoluble precipitates, prevents lather formation during washing clothes can therefore be used to estimate the hardness of water.

Significance of calcium and magnesium in water

Water calcium and magnesium result from decomposition of calcium and magnesium aluminosilicates and, at higher concentrations, from dissolution of limestone ($CaCO_3$), magnesium limestone ($CaMg(CO_3)_2$), magnesite ($MgCO_3$), gypsum ($CaSO_4 .\ 2H_2O$) and other minerals. The acceptable limits of Ca^{2+} and Mg^{2+} in water for domestic use are 75 and 30 mg/L respectively (BIS 2012). In case of non-availability of alternate source of water, Ca^{2+}& Mg^{2+} limit can be extended upto 200 and 100 mg/L. The readily observable adverse effect of magnesium in drinking water is the laxative effect, particularly with magnesium sulphate at concentrations above 700 mg/L (Arabi et al. 2013).

The ratio of calcium and magnesium in water is also a crucial factor to cause several hard water related health problems. The reduction in Mg: Ca ratio is associated with increasing risk for mortality from ischemic heart disease (IHD) and acute myocardial infarction (AMI) (Itokawa 1991, Rubenowitz et al. 1996) while the increase in Mg : Ca ratio is associated with increasing risk for gastric cancer (Sakamoto et al. 1997). Durlach's recommended that the Mg to Ca total intake ratio should be 1 to 2 (Durlach 1989) as required for the best Mg absorption.

Table 3.Drinking water quality standards for hardness (mg/L)

Parameters	BIS (2012)		WHO (1996)
	Acceptable limit	Permissible limit in the absence of alternate source	
Total hardness	200	600	100
Calcium	75	200	75
Magnesium	30	100	50

Human health issues of excess hardness in water

Although hard water pose serious problem in industrial settings and hardness is monitored to avoid breakdown in expensive equipment, hard water is generally said to be not harmful to health. According to World Health Organization "there does not appear to be any convincing evidence that water hardness causes adverse health effects in humans" (WHO 2003).Water hardness has no known adverse effects, however, some studies indicates its correlation with heart diseases (Schroeder 1960, Park and Park 1980). Hardness is also reported to cause Urolithiasis (urinary stone formation) (Chari and Lavanya 1994).

According to BIS acceptable limit of total hardness i.e. 200 mg/L and permissible limit in the absence of alternate source is 600 mg/L. Hardness of 150- 300 mg/L and above is reported

Table 4. Earlier studies of various human health issues associated with hardness

S.No	Study	Conclusion	Author
1	Potential health impacts of hard water	Hardness influenced cardiovascular mortality, growth retardation, reproductive failure	Sengupta 2013
2	Effect of water hardness on non-communicable diseases, including chronic kidney disease of multifactorial origin (CKDmfo/CKDuo)	Consumption of hard water associated with chronic dehydration with urinary stones	Wimalawansa 2016
3	Urolithiasis, urinary cancer, and home drinking water source in the United States territory of Guam, 2006–2010	Deep well water having high calcium carbonate may be at increased risk for urolithiasis as compared to surface water	Haddock et al. 2016
4	Hydrogeochemistry and groundwater quality of Singhari river basin, district Chatarpur (M.P)	High hardness in water may cause kidney stone and heart diseases in human	Jain 1996
5	Domestic water hardness and prevalence of atopic eczema in Castellon (Spain) school children.	correlated domestic hard water usage with increased eczema in children	Arnedo-Pena 2007

Table 5. Earlier studies of animal health issues associated with hardness

S. No	Study	Conclusion	Author
1	Water quality management in aquaculture, In: Course Manual of summer school on development of sustainable aquaculture technology in fresh and saline waters, CCS Haryana Agricultural, Hisar (India)	hardness values less than 20ppm causes stress, 75-150ppm is optimum for fish culture and >300ppm is lethal to fish life as it increases pH, resulting in non-availability of nutrients.	Bhatnagar et al. 2004
2	Effect of water hardness on egg hatchability and larval viability of Angelfish (*Pterophyllum scalare* (Schultze 1823)	too soft water (10 mg/L $CaCO_3$) and too hard water (300 mg/L $CaCO_3$) are not suitable for *Pterophyllum scalare* incubation and larval rearing	Kasiri et al. 2011
3	Low water hardness and pH affect growth and survival of silver catfish juveniles	Juveniles kept at zero water hardness presented higher mortality at pH 7.0 and 8.0 than those submitted to other treatments	Copatti et al. 2011
4	Effects of water hardness and Cu and Zn on LC_{50} in *Gambusia holbrooki*	Water hardness had a much smaller effect upon the acute toxicity of Cu than that of Zn.	Pourkhabbaz et al. 2011
5	Effects of total hardness and Ca: Mg ratio of water during early stages of rare Minnows (*Gobio cyprisrarus*)	an imbalance between Ca^{2+} and Mg^{2+} in water is toxic to *Gobio cyprisrarus*	Luo et al. 2016

to cause kidney problems and kidney stone formation(Jain 1998). However, there is no guideline value for total hardness in drinking water from World Health Organization (WHO 2003).

Effect of hardness on cardiovascular system

Water hardness and human health issues were surfaced in the late 1950's. The relationship between water hardness and the incidence of vascular diseases was first described by a Japanese chemist Kobayashi (Kobayashi 1957) as he concluded, based on epidemiological analysis, higher mortality rates from cerebrovascular diseases (stroke) in the areas of Japanese rivers with more acid (i.e. softer) water compared to those with more alkaline (i.e. harder) water used for drinking purposes.

Table 6. Human health aspects of calcium and magnesium

Parameter	Calcium	Reference	Magnesium	Reference
Significance	Essential for bone and teeth, reducing the risk for preterm birth and low birth weight	Yang et al. 1996, 2002	Essential for metabolism, cell permeability, bone	Ebel and Gunther 1980, Lipkin and Newmark 1985, Furihata et al. 1989, Nishikawa et al. 1992
Deficiency	Increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity	Kohri et al., 1989, 1993, Chari and Lavanya 1994, Floyd 2004	risk of motor neuron disease, hypo magnesaemia	Mildred 1989, Altura and Altura 1991, Iwami et al. 1994, Nadler and Rude 1995
Toxicity	Calcium can interact with iron, zinc, magnesium, and phosphorus within the intestine, thereby reducing the absorption, Hypercalcimia	Sengupta 2013	Hyper magnesemia, renal insufficiency associated with a significantly decreased ability to excrete magnesium, diarrhea, laxative effect	Swaminathan 1998, Chandra et al. 2013

The effect of hardness of water on human health is still controversial(Crawford and Crawford 1967, Heyden 1976, Hall and Jungner 1993). Some studies concluded that the higher the hardness of water, the lower the incidence of cardiovascular diseases (CVD) (Malpas et al. 1973, Masironi et al. 1979, Leoni et al. 1985) but many other studies do not corroborate this finding (Mackinnon and Taylor 1980, Morris et al. 2008). Schroeder (1960) demonstrated correlation between mortality from CVD in males aged 45-64 years and water hardness in 163 large cities of the USA.

Crawford et al. (1971) studied variations in mortality from CVD depending on water hardness

in 11 British cities between 1950 and 1960 and found hardness in water increased in five cities and decreased in six cities. Water hardness exhibited protective effect against CVD (Yang et al, 1996). In Asia, several studies have suggested an inverse association between water hardness or magnesium and CVD mortality. A low dietary magnesium intake was associated with a higher risk of coronary artery disease in north India (Singh et al. 1996). Inverse association between magnesium levels in drinking water with mortality due to CHD in the age group of 15–64years in 12 South African districts has also been reported (Anne 2011). Human population studies exhibit that populations with less than 3–6ppm magnesium drinking water have very high rates of mortality from heart disease, and that rate goes down as the magnesium concentration of their water goes up, the higher the better(Calderon et al. 2009).

Effect of hardness on the development of cancer diseases

Several epidemiological studies were carried out in the late 1990's in Taiwan to focus on relationships between drinking water hardness and mortality from various diseases showing significant geographical variation. Water hardness showed protective effect against cancer of oesophagus (Yang et al. 1999c), pancreas (Yang et al. 1999d), rectum (Yang et al. 1999e) and breast (Yang et al. 2000).

Hardness in drinking water has also been suspected to be associated with stomach cancer (Turner 1962, Malnasi et al. 1976, Zemla 1980). Animal studies indicate that salt-induced damage to the gastric mucosa might be inhibited by increased intake of calcium (Lipkin and Newmark 1985, Furihata et al. 1989, Nishikawa et al. 1992). Yang et al. (1998) studied possible association between the risk of esophageal cancer and hardness levels in drinking water from municipal supplies in Taiwan and reported 42% excess risk of mortality from esophageal cancer in relation to the use of soft water. Magnesium may protect against deaths from cancer (Durlach et al. 1986, Van Rensburg et al. 1986).However, in a more recent study, it was found that magnesium did not show any protective effect on the risk of esophageal cancer (Hashemian et al. 2015). Calcium in drinking water protects against colorectal cancer (Yang et al. 1997) and gastric cancer (Yang et al. 1998). However, an increased risk of esophageal cancer has been attributed to diets high in calcium (Graham et al. 1990, Chen et al. 1992, Rogers et al. 1993). Magnesium is reported to have protective effect against cerebrovascular diseases (Yang 1998) and hypertension (Yang et al. 1999b).

Effect of hardness on urinary system

Urolithiasis is a process of urinary stone formation involving multiple factors, i.e. not only intake of water, liquids, but also genetic predisposition, eating habits, climatic and social conditions, gender etc. Several studies reported that higher water hardness is associated with higher risk of urolithiasis. However in contrast, more studies found softer water to be associated with higher risk for urolithiasis.

Some study reported lower Mg to Ca ratio to be associated with a higher risk for urolithiasis regardless of type and incidence of urolithiase to correlate with the type of geological subsoil (Kohri et al. 1989) and another study found correlation between the higher Mg to Ca ratio and higher incidence of infectious phosphate urolithiasis (Kohri et al. 1993).

Effect of hardness on prevalence of dermatitis problem

Among several other environmental factors, water hardness has been suggested as a risk factor for childhood eczema (Flohrs et al. 2014). Eczema (oratopic dermatitis) is a chronic inflammatory skin disease currently affecting 15–30% of children characterized by a persistent itching (Bieber2008). Around 60% of eczema cases begin within the first year of life and 85% before 5 year of age (Bieber 2008). Exposure to hard water has been suggested as a risk factor for eczema in childhood. Earlier studies found a positive association between residential water hardness and prevalence of eczema disease among school aged children of specific aged groups (McNally et al. 1998, Miyake et al. 2004, Arnedo-Pena et al. 2007, Chaumont et al. 2012). However, a randomized control trial of installation of a water softener at home failed to show an improvement in eczema severity in children 0–16 year of age (Thomas et al. 2011). Font-Riberia et al. (2015) carried out a study on prevalence of eczema due to exposure to hard water in childhood. However, no association was detected between water hardness at home and current or ever eczema at 1 and 4 year of age. The Japanese study conducted among children aged 6–12 year aged group found a positive association among the oldest but not among the youngest children (Miyake et al. 2004).

Effect of hardness on Fisheries

Water hardness is reported to be very important for fish culture and is commonly reported as an important aspect of water quality. Calcium and magnesium are reported to be essential in the metabolic processes of fish (bone and scale formation, blood clotting and other metabolic reactions). Fish can absorb calcium and magnesium directly from the water or from food (Wurts and Durborow 1992). Different species of fish have varied water hardness requirements. For most pond fish species, i.e. koi and goldfish, moderate to hard water is best. Water hardness affects fish health as it influences the process of osmo-regulation. Being open systems, fish is reported to be affected by the makeup of the surrounding water. As a consequence of osmosis, freshwater fish are subject to encounter a continuous influx of water, while marine fish have to live with a continuous outflow of water (Frank 2017).Hardness is reported to reduce the toxicity of various metals to fish and other aquatic life through competitive inhibition of metal binding to gill surfaces by Ca^{2+}(Hollis et al. 1997).

Because water chemistry is a major driver of aquatic invertebrate, species presence, health, and community composition, drastic changes in the ionic composition of water are of concern. New (2002) recommended an ideal total hardness range of 50 to 150 mg/L $CaCO_3$ to be suitable for nursery and grow-out facilities for *M. rosenbergii*, while Vasquez et al. (1989) found 20 to 200 mg/L to be optimal. Very high water hardness often results in encrustation with *Bryozoa sp.* and *Epistylis sp.* which retard growth rate. However, earlier study of Bartlett & Enkerlin (1983) postulated that high calcium levels may not be detrimental unless combined with high carbonate levels. Adhikari et al. (2007) investigated the effect of calcium hardness levels from 92 to 384 mg/L $CaCO_3$ for 42 days on the performance of *M. rosenbergii* juveniles (0.045 ± 0.007 g, 25 days old), found that the maximum survival rate (100%) was observed at a level of 92 mg/L $CaCO_3$. The lowest survival (60%) was at the highest calcium hardness level (384 mg/L). An extreme, concomitant increase in water hardness and alkalinity resulting in $CaCO_3$ precipitation was >98% lethal to *D. magna*, yet also that <10% mortality occurred in the same alkalinity water if hardness was reduced (Bogart et al. 2016).

Effect of hardness on animals

The hardness of water has no effect on animal performance or water intake (Looper and Waldner 2002).Water intake of cattle and milk production were unaffected by water containing up to 290ppm of hardness (NRC 1974). There is very limited research on the impact of hardness, all of which indicate no effect on milk production, weight gain, or water consumption (Graf and Holdaway 1952, Blosser and Soni 1957, Allen et al. 1958).

Effect of hardness on poultry

The response to water hardness increase varies from species to species. Too soft water (10 mg/L $CaCO_3$) and too hard water (300 mg/L $CaCO_3$) are not suitable for *Pterophyllum* *scalare* incubation and larval rearing (Kasiri et al. 2011). Calcium is necessary for the development and survival of rainbow shark minnow eggs. Calcium, although necessary, was found to have a detrimental effect at higher concentrations due to its increasing osmotic concentration of the incubation water which directly affected the swelling of the eggs, reducing larval survival (Abernathy 2004).

Irrigational effect of water hardness on plant metabolism

The use of saline irrigation water poses adverse effect on soil–water–plant relations, occasionally severely affecting normal physiological activity and productive capacity of the crops (Pascale et al. 2013, Plaut et al. 2013). Irrigation water containing a high proportion of soluble calcium may form scale inside the irrigation component (Haman 1990) and form scale like deposits on plant parts when overhead sprinkler irrigation system is used (Haman and Yeager 2000). Magnesium is an important element in the groundwater which may reduce crop yield by inducing Ca deficiency at high concentration of Mg (Ayers and Westcot 1985). If the soil water salt concentration is too high, the plant will not be able to absorb water. It will wilt and begin to die. The point at which this happens depends on the type of species; some crops are more tolerant to salts than others. Saeed et al. (2015) reported utilization of grey (soap) water is beneficial for the cultivation of medicinal plant (*Sesbania grandiflora* L.) under scarcity of freshwater irrigation. Soap water is a source of compounds like, surfactants, soaps, oils, boron and other salts (sodium) which can alter the soil and plant characters (Travis et al. 2008,Wiel-Shafran et al. 2006).

Effect of water hardness on soil microbiology

The microbial communities of the soil perform an ecological role in biogeochemical cycling of nutrients, in the volume of organic matter in the soil and in maintaining plant productivity. Thus it is important to understand the microbial response to environmental stress, such as water content of soil, high concentrations of heavy metals of salts. Stress can be detrimental for sensitive microorganisms and decrease the activity of surviving cells, due to the metabolic load imposed by the need for stress tolerance mechanisms (Schimel et al. 2007, Yuan et al. 2007, Ibekwe et al. 2010, Chowdhury 2011). The excessive amounts of salts provided by irrigation waters can have adverse effects on the chemical and physical properties of the soils and on their biological processes (Garcia & Hernandez 1996, Rietz & Haynes 2003, Tejada & Gonzalez 2005). These effects include mineralization of the carbon and nitrogen and enzymatic activity, which are crucial for the decomposition of organic matter and liberation of the nutrients necessary for sustainability of the production (Azamand Ifzal 2006, Wong et al. 2008). The agricultural practices influence the microbial population, thus altering the activity, source and persistence of the enzymes in the soil (Parham et al. 2003). Vincent (1962) studied effect of calcium and magnesium on the growth of *Rhizobium trijiolii* and reported that deficiency of calcium (Ca), in the presence of sufficient magnesium (Mg), caused reduction in growth rate, the level of maximum growth and the proportion of viable cells. On the other hand, although shortage of Mg (Ca sufficient) was without effect on growth rate down to the lowest concentration at which growth occurred, maximum growth and the proportion of viable organisms were markedly decreased.

Cytotoxicity of aluminum (Al) has been earlier reported in plants (Delhaize and Ryan 1995, Horst et al. 1999, Kollmeier et al. 2000, Marienfeld et al. 2000, Teresa 2001). It is generally known that plants grown in acid soils due to Al solubility at low pH have reduced root systems and exhibit a variety of nutrient-deficiency symptoms, with a consequent decrease in yield. With respect to growth determinants (auxin, gibberelic acid and ethylene), aluminum (Al) apparently interacts directly and/or indirectly with the factors that influence organization of the cytoskeleton, such as cytosolic levels of Ca^{2+} (Jones et al. 1998), Mg^{2+} and calmodulin (Grabski et al. 1998), cell-surface electrical potential (Takabatake & Shimmen 1997), callose formation (Horst et al. 1997), and lipid composition of the plasma membrane (Zhang et al. 1997).

Hardness and metal toxicity

Heavy metals are ubiquitous pollutants and occur in water from natural sources as well. Several important factors are known to make heavy metals biologically less active and therefore less toxic. Heavy metals are more toxic in the soft water than in hard water because they are more soluble in soft water and it is known that the dissolved forms of heavy metals are the active toxic agents. Spear and Pierce (1979) discussed the lethal levels of copper for fish, as determined by several investigators, and find that Cu toxicity decreased with an increase in water hardness. Brown (1968) found a correlation between total hardness of water and 48 hr LC_{50} of rainbow trout for nickel, lead, zinc, cadmium and copper. Hardness is also reported to lowers the toxicity of some heavy metals (Pb, Cd, Cr, Zn) (Taylor et al. 2000).

Correlation between hardness and occurrence of diseases

The correlation helps in the study of existence and magnitude of the direction of the relation between two or more variables. The role of water hardness as a risk factor for cardiovascular disease has been widely investigated and evaluated in cardiovascular disease. Nerbrand et al.(2003) reported that individuals living in soft and hard water areas showed significant correlations between the content of calcium in water and major cardiovascular risk factors. Various researchers have reported positive correlations between water and dietary magnesium and calcium and blood pressure (Kesteloot 1985, Kesteloot and Joossens 1988). In Finland and South Africa it was reported that the incidence of death ascribed to ischaemic heart disease is inversely correlated with the concentration of magnesium in drinking water (Luoma et al. 1983, Leary et al. 1983). Landin (1989) reported that magnesium levels in the skeletal muscle were significantly higher in persons living in an area with higher water magnesium. Maheswaran et al. (1999) reported an association between magnesium and cardiovascular mortality in a study of magnesium in drinking water supplies and mortality from acute myocardial infarction in north-west England. Nerbrand et al. (2003) found negative correlations between calcium in water and s-cholesterol and s-LDL indicated that a high content of calcium could lower the levels of s-cholesterol and s-LDL but on the other hand may increase systolic blood pressure (SBP).A recent study on cancer mortality found a significant negative relationship between drinking water hardness and gastric, pancreatic, and colorectal cancer mortality (Yang et al. 1997, 1999a, b, Yang and Hung 1998).

Hard water can cause some chemicals to precipitate. Chemicals that tend to do this often have agents added to overcome this problem. Hard water can also affect the balance of the surfactant system and affect properties such as wetting, emulsification and dispersion. Chemicals with amine formulations, which include the herbicides: glyphosate, 2, 4-D amine, MCPA amine and dicamba are adversely affected by hard water. The solubility of the herbicide is reduced which leads to it being less absorbed by the weeds (McDougall 2012). Increasing carrier water hardness from 0 to 1,000 mg L^{-1} reduced mesotrione efficacy 28, 18, and 18% (or greater) on giant ragweed, horseweed, and *Palmer amaranth*, respectively (Devkota et al. 2016).

Impact of hardness on other water quality parameters

Hardness is often confused with salinity or TDS, but the two are not necessarily related meaningfully. For example, high saline water may contain an abundance of Na salts of chloride and sulfate and yet be quite soft if relatively low concentrations of Mg and Ca are present. Hardness is a chemical parameter of water that represents the total concentration of calcium and magnesium ions. Calcium typically represents 2/3 of total hardness, Mg typically about 1/3. It is commonly confused with alkalinity. The confusion relates to the term used to report both measures, mg/L $CaCO_3$. If limestone is primary source of both hardness and alkalinity, the concentrations will be similar if not identical. However, where sodium bicarbonate ($NaHCO_3$) is responsible for high alkalinity it is possible to have low hardness and low calcium. The carbonate fraction of hardness (expressed as $CaCO_3$ equivalents) is chemically equivalent to the bicarbonates of alkalinity present in water (Burton and Pitt 2002) in areas where the water interacts with limestone (Timmons et al. 2002). Any hardness greater than alkalinity represents non-carbonate hardness. Hard water is naturally likely to also have a high pH because it is also high in carbonates that buffer the pH toward the alkaline side (due to carbonate hardness).

Remedial technologies

Hardness in water is an aesthetic and health concern because of the unpleasant taste. It is reported to cause scale formations in pipes and applied distribution system (BCC 2007). The most common method for hardness removal at household level in the drinking water is boiling. However, there are various methods for removal of calcium and magnesium hardness from groundwater such as reverse osmosis, ion exchange, combination of ultrasound and ion exchange and chemical treatment with lime-soda ash method.

Water softening: Water softening uses an ion exchange process. The ion exchange process is one of the most effective methods to remove hardness in the groundwater (Entezari and Tahmasbi 2009, Entezari and Tahmasbi 2011). An ion exchange water softener replaces calcium and magnesium ions with sodium or, less commonly, potassium ions. Pentawma et al. (2011) studied removal of hardness from groundwater by synthetic resin from waste polystyrene plastics. The results revealed that the hardness removal efficiency of added made resins in the system was higher than no added resin (43% vs. 12%).

Membrane separation: Because hardness ions are larger, a coarser, less expensive, membrane can be used. This membrane is known as a nanofiltration membrane. The nanofiltration can also be used for hardness removal from groundwater. It is an effective process in term of higher recovery for hardness removal (Schaep et al. 1998). Presently, nanotechnology such as zero valent iron and carbon nano tube is a new and promising technology for groundwater remediation for drinking and reuse. Nano-remediation has emerged to have the potential to clean up large contaminate site and reducing the contaminant concentration to near zero (Rajan 2011). Reverse osmosis (RO) is one of the most popular membrane processes.

Bioremediation: Algae based remediation technology can provide an excellent solution for water hardness quality problems. Many micro and macro algae are being used in various bioremediation techniques especially in polluted hard waters. Sivasubramanian et al. (2012) studied application of algal technology (Phycoremediation) to reduce total hardness in waste waters and industrial effluents. Worku and Sahu (2014) reported that by using micro algae (*Synechocystis salina*) almost 60% Cr, 66% Fe, 70% Ni, 77% Hg, 65% Ca^{2+}, 63% Mg^{2+} and 78% of total hardness was reduced in 15 days of treatment.

CONCLUSION

Hard water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of water resources. The effects of water pollution are not only devastating to people, but also affect animals, fish, and birds; also destroy aquatic life and reduce their reproductive ability. It affects the ecosystem services thereby affecting the overall set up of an ecosystem. Hard water in the municipal water supply also raises economic issues as a considerable amount of money is spent yearly to ensure that water is softened to avoid its negative impacts such as degrading soaps and precipitate deposition on faucets. Eventually, it is a hazard to human health. Higher Mg and Ca levels in water are mostly associated with higher levels of the other dissolved solids that may not be beneficial to health. Individuals living in soft and hard water areas showed significant correlations between the content of calcium in water and major cardiovascular risk factors. However, the use of softened drinking water in the households has several positive effects such as reduced consumption of energy and laundry detergents and prolonged service lives of household appliance. Hard water lowers the toxicity of heavy metals also. Heavy metals are more toxic in soft water than in hard water as dissolved forms of heavy metals are the active toxic agents. Although hardness affects taste of water, magnesium and calcium are having some protective effect on cardiovascular mortality and other diseases as reported by many researchers. When hardness of drinking water went up, the rate of death from cardiovascular disease went down. Although a certain minimum quantity of these elements is desirable, it definitely does not mean the more the better. Thus, regular monitoring of the status of water resources and development of low cost technology for rural population of India is needed. The quality of our water is directly linked to the quality of our lives. Access to safe, clean water is to access the life.

REFERENCES

Adhikari, S., V.S. Chaurasia, A.H. Naqviand and B.R. Pillai.2007.Survival and growth of *Macrobrachium rosenbergii* (de Man) juvenile in relation to calcium hardness and bicarbonate alkalinity. Turkish Journal of Fisheries and Aquatic Sciences 7: 23-26.

Ahn, M.K., R. Chilakala, C. Han and T. Thenepalli. 2018. Removal of hardness from water samples by a carbonation process with a closed pressure reactor. Water 10: 54, doi:10.3390/w10010054.

Arnedo-Pena, A., J. Bellido-Blasco, J. Puig-Barbera, A. Artero-Civera, J.B. Campos- Cruanes, M.R. Pac-Sa et al. 2007. Domestic water hardness and prevalence of atopic eczema in Castellon (Spain) school children. Salud Publica Mex 49: 295–301.

Abernathy, M.A. 2004. Effect of water hardness on the survival of rainbow shark minnow (*Epalzeorhynchos frenatum*) eggs and larvae. M.Sc. Thesis, University of Florida, Florida, 63pp.

Alemu, Z.A., K.T. Teklu, T.A. Alemayehu, K. H. Balcha and H. D. Mengesha. 2015. Physicochemical quality of drinking water sources in Ethiopia and its health impact: a retrospective study. Environmental Systems Research 4:22.

Allen, N.N., D. Ausman, W. N. Patterson and O.E. Hays. 1958. Effect of zeolite treatment of hard drinking water on milk production. Journal of Dairy Science 41:668-691.

Alfy, M.A., A. Lashin, F. Abdalla and A. Al-Bassam. 2017. Assessing the hydrogeochemical processes affecting groundwater pollution in arid areas using an integration of geochemical equilibrium and multivariate statistical techniques. Environmental Pollution xxx 1:11.

Altura, B.M. and B.T. Altura.1991. Cardiovascular Risk Factors and Magnesium: Relationships to Atherosclerosis, Ischemic Heart Disease and Hypertension. Magnesium and Trace Elements10 (2-4):182-92.

Amor, M.B., D. Zagolli, M. M. Tlili and A.S. Manzola. 2004. Influence of water hardness, substrate nature and temperature on heterogeneous calcium carbonate nucleation. Desalination 166: 79-84.

Anne, K. 2011. Magnesium and calcium in drinking water and heart diseases. Geological Survey of Finland, Kuopio, Finland. Elsevier B.V.

APHA (American Public Health Association). 2012. Standard Methods for Examination of Water and Wastewater.22th, Ed. Washington DC, USA.

Appelo, C.A.J.and D. Postma. 2005. Geochemistry, Groundwater and Pollution, 2ndEdn. London, C.R.C. Press.

Arabi, A.S., I.I. Funtua, B.B.M.Dewu, M.L. Garba, S. Okoh, M.Y. Kwaya and M.T. Bolori. 2013. Assessment of calcium and magnesium concentrations in groundwater as supplements for sleep related ailments. Journal of Applied Environmental and Biological Sciences 3(7):29-35.

Arnedo-Pena, A., J. Bellido-Blasco, J. Puig-Barbera, A. Artero-Civera, J.B. Campos-Cruañes, M.R. Pac-Sa, J.L. Villamarín-Vázquez and C. Felis-Dauder. 2007. Domestic water hardness and prevalence of atopic eczema in Castellon (Spain) school children. Salud Pública De México 492 (4): 295–301.

Ayers, R.S. and D.W. Westcot. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29, (Rev.), FAO, Rome, pp: 174.

Azam, F. and M. Ifzal. 2006. Microbial populations immobilizing NH_4^+-N and NO_3—N differ in their sensitivity to sodium chloride salinity in soil. Soil Biology & Biochemistry 38(8):2491-2494.

Bartlett, P. and E. Enkerlin. 1983. Some results of rearing giant prawn, *Macrobrachium rosenbergii*in asbestos asphalt ponds in hard water and on a low protein diet. Aquaculture 30: 353-356.

Bhatnagar, A., S.N. Jana, S.K. Garg, B.C. Patra, G. Singh and U.K. Barman. 2004. Water quality management in aquaculture. In: Course Manual of summerschool on development of sustainable aquaculture technology in fresh and saline waters, CCS Haryana Agricultural, Hisar (India), pp 203- 210.

Bieber, T. 2008. Atopicdermatitis.The New England Journal of Medicine 358(14):1483–1494.

Biglin, A. and M.U. Konanc. 2016. Evaluation of surface water quality and heavy metal pollution of Coruh river basin (Turkey) by multivariate statistical methods. Environmental Earth Sciences 75:1029.

BIS. 2012. Specification for Drinking water ISI: 10500, Bureau of Indian Standards, New Delhi.

Blosser, T.H. and B.K. Soni. 1957. Comparative influence of hard and soft water on milk production of dairy cows. Journal of Dairy Science 40:1519.

Bogart, S.J., S. Woodman, D. Steinkey, C. Meays and G.G. Pyale. 2016. Rapid changes in water hardness and alkalinity: Calcite formation is lethal to *Daphnia magna*. Science of the Total Environment 559: 182–191.

Boswinkel, J.A. 2000. Information Note, International Groundwater Resources Assessment Centre (IGRAC), Netherlands Institute of Applied Geoscience, Netherlands. In: UNEP (2002), Vital Water Graphics - An Overview of the State of the World's Fresh and Marine Waters, UNEP, Nairobi, Kenya.

Bouzourra, H., R. Bouhlila, L. Elango, F. Slama and N. Ouslati. 2015. Characterization of mechanisms and processes of groundwater salinization in irrigated coastal area using statistics, GIS, and hydrogeochemical investigations. Environmental Science and Pollution Research 22: 2643-2660.

British Columbia of Canada.2007.Hardness in groundwater fact sheet. TheBritish Columbia groundwater association.

Brown, V.M. 1968. The calculation of the acute toxicity of mixtures of poisons to rainbow trout. Water Research 2:723-733.

Brown, T. E. H. E. Lemay and B. E.Buster. 1997. Chemistry: the Central Science, 7th ed. Upper Saddle River, NJ: Prentice Hall, p. 681-3.

Burton, G. A., Jr., and R.E. Pitt. 2002. Storm Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers. Lewis Publishers, Boca Raton, FL.

Cairncross, S. and V. Valdmanis. 2006. Water Supply, Sanitation, and Hygiene Promotion.

Calderon, R.L. and P. Hunber. 2009. Epidemiological Studies and the Association of Cardiovascular Disease Risks with Water Hardness, Calcium and Magnesium in Drinking Water Public health Significance. Geneva: WHO. pp. 108–142.

Cassardo, C. and J.A.A. Jones. 2011. Managing water in a changing world. Water 3:618–628.

Chandra, A.K., P. Sengupta, H. Goswami and M. Sarkar. 2013. Effects of dietary magnesium on testicular histology, steroidogenesis, spermatogenesis and oxidative stress markers in adult rats. Indian Journal of Experimental Biology 51:37-47.

Chari, K.V.R and M.G. Lavanya. 1994. Groundwater contamination of Cuddapah urban area, Andhra Pradesh. In: Proceedings on Regional Workshop of Environmental aspects of groundwater development. K.U.Kurukshetra, Oct. 17-19, Kurukshetra, India, 130-134.

Chaumont, A., C. Voisin, A. Sardella and A. Bernard. 2012. Interactions between domestic water hardness infant swimming and atopy in the development of childhood eczema. Environmental Research 116: 52–57.

Chen, F., P. Cole, Z. Mi and L. Xing. 1992. Dietary trace elements and esophageal cancer mortality in Shanxi, China. Epidemiology 3: 402-406.

Chowdhury, N., P. Marschner and R.G. Burns. 2011. Soil microbial activity and community composition: impact of changes in matric and osmotic potential. Soil Biology and Biochemistry 43(6):1229-1236.

Copatti, C.E., L.D.O.G. Garcia, D. Kochhann, M.A.D. Cunha, A.G. Becker and B. Baldisserotto. 2011. Low water hardness and pH affect growth and survival of silver catfish juveniles. Ciência Rural, Santa Maria 41(8): 1482-1487.

Crawford, T. and M.D. Crawford. 1967. Prevalence and pathological changes of ischemic heart-disease in a hard-water and in a soft-water area. The Lancet 2 : 229-232.

Crawford, M.D., M.S. Garner and J.N. Morris. 1971.Changes in water hardness and local death rates. Lancet 2: 327-329.

Delhaize, E. and P.R. Ryan. 1995. Aluminum toxicity and tolerance in plants. Plant Physiology 107: 315-321.

Devkota, P., D.J. Spaunhorst and C.W.G. Johnson. 2016. Influence of carrier water pH, hardness, foliar fertilizer, and ammonium sulfate on mesotrione efficacy. Weed Technology 30(3):617-628.

Durlach, J. 1989. Recommended dietary amounts of magnesium: Mg RDA. Magnesium Research 2: 195-203.

Durlach, J., M. Bara, M. Guiet-Bara and P. Colley.1986. Relationship between magnesium, cancer and carcinogenic or anticancer metals. Anticancer Research 6: 1353-1362.

Ebel, H. and T. Günther.1980. Magnesium metabolism: a review. Journal of Clinical Chemistry and Clinical Biochemistry 18: 257-270.

El Alfy, M and T. Faraj. 2016. Spatial distribution and health risk assessment for groundwater contamination from intensive pesticide use in arid areas. Environmental Geochemistry and Health39 (1): 231e253.

Entezari, M.H. and M. Tahmasbi. 2009.Water softening by combination of ultrasound and ion exchange. Ultrasonics Sonochemistry 16:356-360.

Entezari, M. and M. Tahmasbi. 2011. Water softening by combination of ultrasound and ion exchange. Ultrasonics Sonochemistry 16: 356–360.

Flohr, C. and J. Mann. 2014. New insights into the epidemiology of childhood atopic dermatitis. Allergy 69: 3–16.

Floyd, F. J. 2004. Studies of Minerals and Cardiac health in Selected Population. Internet search http://www.who.int/water_sanitation_health/dwq/nutrientschap8.pdf

Font-Riberia, L., E. Gracia-Lavendan,A. Esplugues,F. Ballester,A.J. Zabla,L.S. Marina, A. Fernandez-Somoano, J. Sunyer and C.M.

Villanueva. 2015. Water hardness and eczema at 1 and 4 y of age in the INMA birth Cohort. Environmental Research 142: 579–585.

Frank, P.I. 2017. Water hardness and fish health. Internet search http://www.cichlid-forum.com/articles/hardness.php

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall Inc., New Jersey, pp. 604.

Furihata, C., K. Sudo and T. Matsushima. 1989. Calcium chloride inhibits stimulation of replicative DNA synthesis by sodium chloride in the pyloric mucosa of rat stomach. Carcinogenesis 10: 2135–2137.

Garcýa, C. and T. Hernandez. 1996. Influence of salinity on the biological and biochemical activity of a calciorthird soil. Plant and Soil 178(2): 255–263.

Ghalib, H.B. 2017.Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq. Applied Water Science 7: 3447-3467.

Gopinath, S., K. Srinivasamoorthy, K. Saravanan, R. Prakash, C.S. Suma, F. Khan, D. Senthilnathan, V.S. Sarmaand and P. Devi. 2015. Hydrogeochemical characteristics of coastal groundwater in Nagapattinam and Karaikal aquifers: implications for saline intrusion and agricultural suitability. Journal of Coastal Sciences 2(2):1-11.

Grabski, S., E. Arnoys, B. Bush and M. Schindler. 1998. Regulation of actin tension in plant cells by kinases and phosphatases. Plant Physiology 116: 279-290.

Graf, G.C. and C.W. Holdaway. 1952. A comparison of “hard” and commercially softened water in the ration of lactating dairy cows. Journal of Dairy Science 35: 998.

Graham, S., J. Marshall, B. Haughey, J. Brasure, J. Feudenheim, M. Zielezny, G. Wilkinson, and J. Nolan. 1990. Nutritional epidemiology of cancer of the esophagus. American Journal of Epidemiology131: 454-467.

Gumashta, J., R. Gumashtab and S.K. Sadawarte. 2012. Hard water and heart: the story revisited. IOSR Journal of Pharmacy and Biological Sciences 1(1): 07-20.

Gunten,V. U. 2003. Ozonation of drinking water: part I. Disinfection and byproduct formation in presence of bromide, iodide or chlorine. Water Research 37:1469–1487.

Gupta, P., M. Vishwakarma and P.M. Rawtani. 2009. Assesment of water quality parameters of Kerwa Dam for drinking Suitability. International Journal of Theoretical and Applied Sciences 1 (2): 53-55.

Haddock, R.L., D.R. Olson, L. Backer and J. Maliley. 2016. Urolithiasis, urinary cancer, and home drinking water source in the United States territory of Guam, 2006–2010. International Journal of Environmental Research and Public Health13: 523.

Hall, P. and I. Jungner. 1993. Hard drinking water and ischemic heart disease: calcium, bloodlipids, and acute myocardial infarcts. Journal of Medical System 17(3/4): 277-281.

Haman, D.Z. 1990. Causes and prevention of emitter plugging in microirrigation systems. BUL258. University of Florida, USA.

Haman, D.Z. and T.H. Yeager. 2000. Foliar deposits and stains from irrigation water. Fla Coop Ext Ser. Fact Sheet ENH 150. University of Fla. Florida, USA.

Hashemian, M., H. Poustchi, C.C. Abnet, P. Boffetta, S.M. Dawsey, P. J. Brennan, P. Pharoah, A. Etemadi, F. Kamangar, M. Sharafkhah, A. Hekmatdoost and R. Malekzadeh. 2015. Dietary intake of minerals and risk of esophageal squamous cell carcinoma: results from the Golestan Cohort Study. The American Journal of Clinical Nutrition 102:102–8.

Heyden, S. 1976.The hard facts behind the hard-water theory and ischemic heart disease. Journal of Chronic Diseases 29(3): 149-157.

Hollis, L., L. Muench and R.C. Playle.1997.Influence of dissolved organic matter on copper binding, and calcium on cadmium binding, by gills of rainbow trout. Journal of Fish Biology 50: 703-720.

Horst, W.J., A.K. Pûschel and N. Schmohl. 1997. Induction of callose formation is a sensitive

marker for genotypic aluminium sensitivity in maize. Plant Soil 192: 23-30.

Horst, W.J., N. Schmohl, M. Kollmeier,F. Baluska and M. Sivaguru. 1999. Does aluminium inhibit root growth of maize through interaction with the cell wall-plasma membrane-cytoske-leton continuum? Plant Soil 215: 163-174.

Ibekwe, A.M., J.A. Poss, S.R.Grattan, C.M. Grieve and D. Suarez. 2010. Bacterial diversity in cucumber (*Cucumis sativus*) rhizosphere in response to salinity, soil pH, and boron. Soil Biology & Biochemistry 42(4):567-575.

Itokawa, Y. 1991. Cardiovascular disease and magnesium: epidemiological and experimental data. Proceedings of the Finnish Dental Society 87: 651-657.

Itsadanont, S., S. J. F. Camehorn, S. Soontravanich, D.A.Sabatini and S. Chavadej. 2014. Dissolution of soap scum by surfactant part I: effects of chelant and type of soap scum. Journal of Surfactants & Detergents 17(5):849-857.

Iwami, O., T. Watanabe, C.S. Moon, H. Nakatsuka and M. Ikeda. 1994. Motor neuron disease on the Kii Peninsula of Japan: excess manganese intake from food coupled with low magnesium in drinking water as a risk factor. Science of the Total Environment 149: 121-135.

Jain, K. P. 1998. Hydrogeology and quality of ground water around Hirapur district Sagar (M.P.) (A case study of Proterozoic rocks). Pollution Research 17(1): 91-94.

Jain, P.K. 1996. Hydrogeochemistry and ground water quality of Singhari river basin, district Chatarpur (M.P). Pollution Research 15: 407-409.

Jain, C.K., A. Bandyopadhyay and A. Bhadra. 2009. Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India. Environmental Monitoring and Assessment 166:663–676.

Jones, D.L., L.V. Kochian and S. Gilroy. 1998. Aluminum induces a decrease in cytosolic calcium concentration in BY-2 tobacco cell cultures. Plant Physiology 116: 81-89.

Kasiri, M., M. Sudagar and S.A. Hosseini. 2011. Effect of water hardness on egg hatchability and larval viability of angelfish (*Pterophyllum scalare* (Schultze, 1823). International Journal of Research in Fisheries and Aquaculture1(1): 6-10.

Kesteloot, H. 1985. Blood pressure, calcium and water-hardness. In: Handbook of Hypertension.

Kesteloot, H. and J.V. Joossens. 1988. Relationship of dietary sodium, potassium, calcium, and magnesium with blood pressure. Belgian Interuniversity Research on Nutrition and Health. Hypertension 12:594-9.

Khan, I.A. and A.A. Khan. 1985. Physical and chemical condition in Seika Jheel at Aligarh. Ecology 3: 269-274.

Khound, N.J., P. Phukon and K.G. Bhattacharyya. 2012. A comparative study of groundwater and surface water quality in the Jia – Bharali river basin, India with reference to Physico-chemical characteristics. International Journal of Applied Sciences and Engineering Research 1(3): 512-521.

Kibona, D., G. Kidulile and F. Rwabukambara.2009.Environment, climate warming and water management. Transition Studies Review 16:484-500.

Kirda, C. 1997. Assessment of irrigation water quality. Options Mediterraneennes 31:367–377.

Kobayashi, J. 1957. On geographical relations between the chemical nature of river water and death rate from apoplexy. Berichte d OharaInst f landwirtschBiologie11:12-21.

Kohri, K., M. Kodama,Y. Ishikawa,Y. Katayama, M. Takada,Y. Katoh, K. Kataoka, M. Iguchi and T. Kurita. 1989. Magnesium-to-calcium ratio in tap water, and its relationship to geological features and the incidence of calcium-containing urinary stones. The Journal of Urology 142: 1272-1275.

Kohri, K., Y. Ishikawa, M. Iguchi, T. Kurita, Y. Okada and O. Yoshida. 1993. Relationship between the incidence infection stones and the magnesium calcium ratio of tap water. Urological Research 21: 269- 272.

Kollmeier, M., H.H. Felle and W.J. Horst. 2000. Genotypical differences in aluminum resistance of maize are expressed in the distal part of the transition zone. Is reduce basipetalauxin flow involved in inhibition of root elongation by aluminum? Plant Physiology 122: 945-956.

Kumar, M., A.L. Ramanathan, M.S. Rao and B. Kumar. 2006. Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. Environmental Geology50: 1025–1039.

Landin, K., H. Bonevik, R. Rylander and B.M. Sandstorm. 1989.Skeletal muscle magnesium and drinking water magnesium level.Magnesium-Bulletin11:177-179.

Leary, W.P., A.J. Reyes, C.J. Lockett, D. D. Arbuckle and K. Van der Byl. 1983. Magnesium and deaths ascribed to ischaemic heart disease in South Africa. A preliminary report. South African Medical Journal 64:775- 6.

Leelavathi, C., U.K.KrishnaSainath and A.K. Rabbani. 2016. Physicochemical characterization of ground water of Autonagar, Vijayawada, Krishna district. International Journal of Engineering Development and Research 4(2): 1324-1328.

Leoni, V., L. Fabiani and L. Ticchiarelli. 1985. Water hardness and cardiovascular mortality rate in Abruzzo, Italy. Archives of Environmental Health 40:274 8.

Lipkin, M. and H. Newmark. 1985. Effect of added dietary calcium on colon epithelial-cell proliferation in subjects at high risk for familial colonic cancer. The New England Journal of Medicine 313: 1381–1384.

Liu, C.W., C.S. Jang, C.P. Chen, C.N. Lin and K.L. Lou. 2008. Characterization of groundwater quality in Kinmen Island using multivariate analysis and geochemical modeling. Hydrological Process 22:376– 383.

Looper, M.L. and D.N. Waldner. 2002. Water for Dairy Cattle. Guide D-107. New Mexico State University Cooperative Extension Service.

Lui, J., A. Dorjderem,J. Fu,X. Lei,H. Lui,D. Macer, Q. Qiao,A. Sun,K. Tachiyama,L. Yu and Y. Zheng. 2011. Water ethics and water resource management. Ethics and Climate Change in Asia and the Pacific (ECCAP) Project, Working Group 14 Report, UNESCO Bangkok.

Luo, S., B.B. Wu, X. Xiaoq and J. Wang. 2016. Effects of total hardness and calcium:magnesium Ratio of water during early stages of rare minnows (*Gobio cyprisrarus*). Comparative Medicine 66(3): 181–187.

Luoma, H., A. Aromaa, S. Helminen, H. Murtomaa, L. Kiviluoto, S. Punsar and P. Knekt. 1983. Risk of myocardial infarction in Finnish men in relation to fluoride, magnesium and calcium concentration in drinking water. Journal of Internal Medicine 213(3):171-176.

Mackinnon, A.U. and S.H. Taylor. 1980. Relationship between 'sudden' coronary deaths and drinking water hardness in five Yorkshire cities and towns. International Journal of Epidemiology 9:247 9.

Maheswaran, R., S. Morris, S. Falconer, A. Grossinho, I. Perry, J. Wakefield and P. Elliott. 1999. Magnesium in drinking water supplies and mortality from acute myocardial infarction in northwest England. Heart 82:455-60.

Malpas, P., S. Lloyd and C.R. Lowe. 1973. Cardiovascular disease in hard and soft water areas. Lancet 301(7798): 321.

Malnasi, G., S. Jakab, A. Incze, A. Apostol, J.M. Csapo, E. Szabo, J.J. Csapo and K. Jakab. 1976. An assay for selecting high risk population for gastric cancer by studying environmental factors. Neoplasma23: 333–341.

Margat, J. 2008. Exploitations et utilisations des eauxsouterrainesdans le monde. Coédition: UNESCO et BRGM, 52p.

Margat, J., and J. Van der Gun. 2013. Groundwater around the world: a geographic synopsis. CRC Press.

Marienfeld, S., N. Schmohl, M. Klein, W.H. Schröder, A. J. Kuhn and W.J. Horst. 2000. Localisation of aluminium in root tips of *Zea mays* and *Vicia faba*. Journal of Plant Physiology 156: 666-671.

Masironi, R., Z. Pisa and D. Clayton. 1979. Myocardial infarction and water hardness in the WHO myocardial infarction registry network. Bulletin of the World Health Organization 57:291 9.

Matthess, G. 1982. The properties of groundwater. Wiley, New York, p 498.

McDougall, S. 2012. Water quality for chemical spraying. Internet search www.dpi.nsw.gov.au/publications.

McNally, N. J., H.C. Williams, D.R. Phillips, M. Smallman-Raynor, S. Lewis and A. Venn. 1998. Atopic eczema and domestic water hardness. Lancet 352: 527–531.

Mildred, S.S. 1989. Cardiovascular consequences of magnesium deficiency and loss: pathogenesis, prevalence and manifestations- magnesium and chloride loss in refractory potassium repletion. The American Journal of Cardiology 63(14):G4-G21.

Milhome, M.A.L., P.L.R. Sousa,F.A.F. Lima and R.F. Nascimento. 2015. Influence the use of pesticides in the quality of surface and groundwater located in irrigated areas of Jaguaribe, Ceara Brazil. International Journal of Environmental Research 9 (1): 255-262.

Mishra, R.K. and S.C. Dubey. 2015. Freshwater availability and its global challenge. International Journal of Engineering Science Invention Research & Development 2(6):351-407.

Miyake, Y., T. Yokoyama, A. Yura, M. Iki and T. Shimizu.2004. Ecological association of water hardness with prevalence of childhood atopic dermatitis in a Japanese urban area. Environmental Research 94: 33–37.

Morris, R.W., M. Walker and L.T. Lennon. 2008. Hard drinking water does not protect against cardiovascular disease: new evidence from the British Regional Heart Study. European Journal of Cardiovascular Prevention and Rehabilitation 15(2): 185-189.

Moyo, P., L. Chapungu and B. Mudzengi 2013. Effectiveness of water hyacinth (*Eichhornia crassipes*) in remediating polluted water: The case of Shagashe river in Masvingo, Zimbabwe. Advances in Applied Science Research 4(4):55-62.

Nadler, J.L. and R.K. Rude. 1995.Disorders of magnesium metabolism. Endocrinology and Metabolism Clinics of North America 24:623–641.

Nag, S.K. and A. Lahiri. 2012. Hydrochemical characteristics of groundwater for domestic and irrigation purposes in Dwarakeswar watershed area, India. American Journal of Climate Change 01(04):217–230.

National Research Council. 1974. Nutrients and toxic substances in water for livestock and poultry.National Academy Science, Washington, D.C.

Nerbrand, C., L. Agreus, R.A. Lenner, P. Nyberg and K. Svardsudd. 2003. The influence of calcium and magnesium in drinking water and diet on cardiovascular risk factors in individuals living in hard and soft water areas with differences in cardiovascular mortality.BMC Public Health3:21.

New, M.B. 2002.Farming Freshwater Prawns: A Manual for the Culture of the Giant River Prawn, *Macrobrachium rosenbergii*. FAO Fisheries Technical Paper No. 428. Rome, 212pp.

Nishikawa, A., F. Furukawa, M. Mitsui,T. Enami, T. Kawanishi, T. Hasegawa and M. Takahashi. 1992. Inhibitory effect of calcium chloride on gastric carcinogenesis in rats after treatment with N-methyl-N¢-nitro-N-nitrosoguanidine and sodium chloride. Carcinogenesis 13: 1155–1158.

Park, J. E and K. Park. 1980. Environment and Health. 11th edn., B. B. Publisher, Jabalpur, India: 437.

Pascale, D.S., F. Orsini and A. Pardossi. 2013. Irrigation water quality for greenhouse horticulture. In: Good Agricultural Practices for Greenhouse Vegetable Crops, FAO Plant Production and Protection Paper 217, Food and Agriculture Organization of the United Nations: Rome, Italy.169–204.

Patil, P.N., D.V. Sawant and R.N. Deshmukh. 2012. Physico-chemical Parameters for Testing of Water–a review. International Journal of Environmental Sciences 3(3): 1202-1203.

Pentamwa, P.,W. Thipthara and S. Nuangon. 2011. Removal of hardness from groundwater by synthetic resin from waste plastics. International Journal of Science and Development 2(6):479-483.

Plaut, Z., M. Edelstein and M. Ben-Hur. 2013. Overcoming salinity barriers to crop production using traditional methods. Critical Reviews in Plant Sciences 32:250–291.

Pourkhabbaz, A., M.E. Kasmani, V. Kiyaniand and M.H. Osynzadeh. 2011. Effects of water hardness and Cu and Zn on LC50 in *Gambusia holbrooki*. Chemical Speciation & Bioavailability 23(4): 224-228.

Prepas, E.E, B. Pinel Alloul,P.A. Chambers,T.P.Murphy,S. Reedykand andG. Sandland. 2001. Lime treatment and its effects on the chemistry and biota of hardwater eutrophic lakes. Freshwater Biology 46:1049 60.

Raja, R.E., S. Lydia, M. Princy and G. Chritopher. 2002. Physico chemical analysis of some ground water samples of Kotputli town, Jaipur, Rajasthan. Indian Journal of Environment Protection 22(2): 137.

Rajan, C.S. 2011. Nanotechnology in groundwater Remediation. International Journal of Environmental Science and Development 22 (30): 182-186.

Rajankar, P.N., S.R. Gulhane, D.H. Tambekar, D.S. Ramteke and S.R. Wate. 2009. Water quality assessment of groundwater resources in Nagpur region (India) based on WQI. E-Journal of Chemistry 6(3): 905-908.

Rajesh, R., K. Brindha, R. Murugan and L. Elango. 2012. Influence of hydrogeochemical processes on temporal changes in groundwater quality in a part of Nalgonda district, Andhra Pradesh, India. Environmental Earth Sciences 65:1203–1213.

Ramya, P., A.J. Babu, E.T. Reddy and L.V. Rao. 2015. A study on the estimation of hardness in ground water samples by EDTA tritrimetric methods. International Journal of Recent Scientific Research 6(6): 4505-4507.

Ranjeeta, C., P. Ratwani and M. Vishwakarma. 2011. Comparative study of drinking water quality parameters of three manmade reservoirs i.e. Kolar, Kaliasote and Kerwa dam. Current World Environment 6(1):145-149.

Rasool, A., T. Xiao, Z. Baig, S. Masood, K. Mostofa and M. Iqbal. 2015. Co-occurrence of arsenic and fluoride in the groundwater of Punjab, Pakistan: source discrimination and health risk assessment. Environmental Science and Pollution Research 22: 19729-19746.

Razmkhah, H., A. Abrishamchi and A. Torkian 2010. Evaluation of spatial and temporal variation in water quality by pattern recognition techniques: a case study on Jajrood River (Tehran, Iran). Journal of Environmental Management 91:852–860.

Rietz, D.N. and R.J. Haynes.2003. Effects of irrigation induced salinity and sodicity on soil microbial activity. Soil Biology & Biochemistry 35(6):845–854.

Rogers, M. A., D.B. Thomas, S. Davis, T.L. Vaughan and A.E. Nevissi. 1993. A case-control study of element levels and cancer of the upper aerodigestive tract. Cancer Epidemiology, Biomarkers & Prevention 2:305-312.

Rommens, W, J. Maes, N. Dekeza, P. Inghelbrecht, T. Nhiwatiwa, E. Holsters, F. Ollevier, B. Marshall and L. Brendonck. 2003. The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). I. Water Quality. Archiv für Hydrobiologie 158:373 – 388.

Rubenowitz, E., G. Axelssonand and R. Rylander. 1996. Magnesium in drinking water and death from acute myocardial infarction. American Journal of Epidemiology 143: 456-462.

Saeed, R., A.A. Mirbahar, B. Jahan and A. Zehra. 2015. Effect of grey water (soap water) irrigation on growth and root nodules of medicinal plant (*Sesbania grandiflora*) L. Fuuast Journal of Biolology 5(1): 115-121.

Sakamoto, N., M. Shimizu, I. Wakabayashi and K. Sakamoto. 1997. Relationship between mortality rate of stomach cancer and cerebrovascular disease and concentrations of magnesium and calcium in well water in Hyogo prefecture. Magnesium Research 10: 215-223.

Sarath, P., S.V., Magesh, N.S., Jitheshlal, K.V., N. Chandrasekarand and K. Gangadhar. 2012. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. Applied Water Science 2(3):165–175.

Sawyer, G.N. and D.L. McCarty. 1967. Chemistry of sanitary engineers, 2nd edn. McGraw Hill, New York, p 518.

Schaep, J., B. Bruggen, S. Uytterhoeven and R. Croux. 1998. Removal of hardness from groundwater by nanofiltration. Desalination 119: 295-302.

Schimel, J.P., T.C. Balserand and M. Wallenstein. 2007. Microbial stress response physiology and its implications for ecosystem function. Ecology 88(6):1386-1394.

Schroeder, H. A. 1960. Relations between mortality from cardiovascular disease and treated water supplies. J.A.M.A. 172:1902. Internet search https://sci-hub. tw/ 10.1001/ jama. 1960. 03020170028007

Sengupta, P. 2013. Potential health impacts of hard water. International Journal of Preventive Medicine 4(8): 866-875.

Sheikhy, N. T., M.F.Ramli, A.Z. Aris, W.N.A. Sulaiman, H. Juahir and K. Fakharian.2014. Identification of the hydrogeochemical processes in groundwater using classic integrated geochemical methods and geostatistical techniques, in amol-babol plain, Iran. Scientific World Journal 1–15.

Singh, C.K. and S. Mukherjee. 2015. Aqueous geochemistry of fluoride enriched groundwater in arid part of Western India. Environmental Science and Pollution Research Journal 22: 2668-2678.

Singh, R.B., M.A. Niaz, S. Ghosh, V. Rastogi, R. S. Raghuvanshi and M. Moshiri. 1996. Epidemiological study of magnesium status and risk of coronary artery disease in elderly rural and urban populations of north India. Magnesium Research 9(3):165-72.

Sivasubramanian, V., V.V. Subramanian, M. Muthukumaran and R. Murali. 2012. Algal technology for effective reduction of total hardness in wastewater and industrial effluents. Phykos 42 (1): 51– 58.

Skipton, S.O. and B.I. Dvorak. 2014. Drinking water treatment: water softening (ion exchange). NebguideG1491.

Sobsey, M.D. 2006. Drinking water and health research: a look to the future in the United States and globally. Journal of Water and Health 04(suppl):17–21.

Spear, P. A. and R.C. Pierce.1979.Copper in the aquatic environment: chemistry, distribution and toxicology. National Research Council of Canada, Environmental Secretariat, NRCC, No. 16454.p. 192-227.

Swaminathan, R. 1998. Disorders of Metabolism 2. In: Textbook of Adverse Drug Reactions.5th ed. Chapman & Hall Medical, London. pp. 442–540.

Takabatake, R. and T. Shimmen. 1997. Inhibition of electrogenesis by aluminum in characean cells. Plant Cell Physiology 38: 1264-1271.

Taylor, L. N., J.C. McGeer, C.M. Wood and D.G. McDonald. 2000. The physiological effects of chronic copper exposure to rainbow trout (*Oncorhynchus mykiss*) in hard and soft water: an evaluation of chronic indicators. Environmental Toxicology and Chemistry 19: 2298-2308.

Tejada, M. and J. L. Gonzalez. 2005. Beet vinasse applied to wheat under dry land conditions affects soil properties and yield. European Journal of Agronomy 23(4):336-347.

Teresa, M.P. 2001. Effect of aluminium on plant growth and metabolism. Acta Biochimica Polonica 48(3): 673-686.

Thomas, K. S., T. Dean, C. O'Leary, T.H. Sach, K. Koller and A. Frost. 2011. A randomized controlled trial of ion-exchange water softeners for the treatment of eczema in children. PLoS Medicine 8(2): e1000395.

Timmons, M. B., J.M. Ebeling, F.W. Wheaton, S.T. Summerfelt and B.J. Vinci. 2002. Recirculating Aquaculture Systems, 2nd ed. CAYUGA AQUA VENTURES, Ithaca, N.Y.

Tiwari, A.K., A.K. Singh, A.K. Singh and M.P. Singh. 2017.Hydrogeochemical analysis and evaluation of surface water quality of Pratapgarh district, Uttar Pradesh, India. Applied Water Science 7(4):1609–1623.

Travis, M.J., N. Weisbrod and A. Gross. 2008. Accumulation of oil and grease in soils irrigated with grey water and their potential role in soil water repellency. Science of the Total Environment 394(1): 68–74.

Turner, R. C. 1962. Radioactivity and hardness of drinking waters in relation to cancer mortality rates. British Journal of Cancer 16(1): 27–45.

Twort, A. and C.A. Dickson.1994. Elementary Water Supply Engineering. Vol. 1.

Vasquez, O.E., D.B. Rouse and W.A. Rogers. 1989. Growth response of *Mucrobrachium rosenbergii*to different levels of hardness. Journal of the World Aquaculture Society 20: 90-92.

Van Rensburg, S. J., J.M. Hall and P.S. Gathercole. 1986. Inhibition of esophageal carcinogenesis in corn-fed rats by riboflaven, nicotinic acids, selenium, molybdenum, zinc, and magnesium. Nutrition and Cancer 8(3): 163-170.

Vincent, J.M. 1962. Influence of calcium and magnesium on the growth of *Rhizobium*. Journal of General Microbiology 28: 653-663.

WHO Guidelines for Drinking Water Quality. 1996. 2nd .ed. Vol. 21, Geneva, Switzerland.

WHO 2010. Hardness in drinking water. Background document for development of WHO Guidelines for Drinking-water Quality.

Wiel-Shafran, A., Z. Ronen, N. Weisbrod, E. Adar and A. Gross. 2006. Potential changes in soil properties following irrigation with surfactant-rich grey water. Ecological Engineering 26(4): 348-354.

Wimalawansa, S.J. 2016. Effect of water hardness on non-communicable diseases, including chronic kidney disease of multifactorial origin (CKDmfo/CKDuo). Journal of Environment & Health Science 2(1): 1-11.

Wong, V.N.L., R.C. Dalal and R.S.B. Greene. 2008. Salinity and sodicity effects on respiration and microbial biomass of soil. Biology and Fertility of Soils 44(7):943-953.

World Health Organization. 2003. Hardness in drinking water. Background document for preparation of WHO guidelines for drinking water quality. Geneva. (WHO/SDE/WSH/03.04/6).

Worku, A. and O. Sahu. 2014. Reduction of heavy metal and hardness from ground water by algae. Journal of Applied & Environmental Microbiology 2 (3):86-89.

Wurts, W.A. and R.M. Durborow.1992.Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds. Southern Regional Aquaculture Center 464.

Yang, C.Y. 1998.Calcium and magnesium in drinking water and risk of death from cerebrovascular disease. Stroke29: 411-414.

Yang, C.Y., J.F. Chiu, H.F. Chiu, T.N. Wang, C.H. Lee and Y.C. Ko. 1996. Relationship between water hardness and coronary mortality in Taiwan. Journal of Toxicology and Environmental Health 49(1): 1-9.

Yang, C.Y., H.F. Chiu, J.F. Chiu, S.S. Tsai and M.F. Cheng. 1997. Calcium and magnesium in drinking water and risk of death from colon cancer. Japanese Journal of Cancer Research 88(10): 928-933.

Yang, C. Y., H.F. Chiu, J. F. Chiu, M.F. Cheng and W.Y. Kao.1997.Gastric cancer mortality and drinking water qualities in Taiwan. Archives of Environmental Contamination and Toxicology 33(3): 336-340.

Yang, C.Y., M.F. Cheng, S. S. Tsai and Y.L. Hsieh. 1998. Calcium, magnesium, and nitrate in drinking water and gastric cancer mortality. Japanese Journal of Cancer Research 89(2): 124-130.

Yang, C. Y., and C.F. Hung. 1998. Colon cancer mortality and total hardness levels in Taiwan's drinking water. Archives of Environmental Contamination and Toxicology 35(1): 148-151.

Yang, C.Y., H.F. Chiu, M.F. Cheng, S. S. Tsai, F. Hung and M.C. Lin. 1998. Esophageal cancer mortality and total hardness levels in Taiwan's drinking water. Environmental Research 81(4): 302-308.

Yang, C. Y., H.F. Chiu, M. F. Cheng, S. S. Tsai, C. F. Hung and Y.T. Tseng. 1999a. Pancreatic cancer mortality and total hardness levels in Taiwan's drinking water. Journal of Toxicology and Environmental Health 56(5): 361-369.

Yang, C. Y., S.S. Tsai, T. C. Lai, C. F. Hung and H.F. Chiu. 1999b. Rectal cancer mortality and total hardness levels in Taiwan's drinking water. Environmental Research 80(4): 311-316.

Yang, C.Y. and H.F. Chiu.1999b.Calcium and magnesium in drinking water and risk of death from rectal hypertension. American Journal of Hypertension 12(9): 894-899.

Yang, C.Y., H.F. Chiu, M.F. Cheng, S.S. Tsai, C.F. Hung and M.C. Lin. 1999c. Esophageal cancer mortality and total hardness levels in Taiwan's drinking water. Environmental Research 81(4): 302-308.

Yang, C.Y., H.F. Chiu, M.F. Cheng, S.S. Tsai, C.F. Hung and Y.T. Tseng 1999d. Pancreatic cancer mortality and total hardness levels in Taiwan's drinking water. Journal of Toxicology and Environmental Health 56(5): 361-369.

Yang, C.Y., S.S. Tsai, T.C. Lai, C.F. Hung and H.F. Chiu 1999e. Rectal cancer mortality and total hardness levels in Taiwan's drinking water. Environmental Research 80(4): 311-316.

Yang, C.Y., H.F. Chiu, M.F. Cheng, T.Y. Hsu, M.F.Cheng and T.N. Wu. 2000. Calcium and
magnesium in drinking water and the risk of death from breast cancer. Journal of Toxicology and Environmental Health 60(4): 231-241.

Yang, C.Y., H.F. Chiu, C.C. Chang, T.N. Wu and F.C. Sung. 2002. Association of very low birth weight with calcium levels in drinking water. Environmental Research, Section A. 89(3): 189-194.

Yuan, B.C., Z.Z. Li, H. Liu, M. Gao and Y.Y. Zhang. 2007. Microbial biomass and activity in salt affected soils under arid conditions. Applied Soil Ecology 35(2):319-328.

Zemla, B. 1980.Geography of the incidence of stomach cancer in relation to hardness of drinking water and water supply. Wiadomosci Lekarskie 33(13): 1027–1031.

Zhang, G., J.J. Slaski, D.J. Archambault and G.J. Taylor. 1997. Alteration of plasma membrane lipids in aluminum-resistant and aluminum-sensitive wheat genotypes in response to aluminum stress. Physiologia Plantarum 99: 302-308.

Zhu, C. and W. Schwartz. 2011. Hydrogeochemical processes and controls on water quality and water management. Elements 7(3):169–174.