Applied Sciences Research Periodicals – ISSN 3033-330X
April 2024, Vol. 2, No. 4, pp. 21-29

Estimation of Hardness Level and Total Dissolved Solids in Ground Water at Shendi Town, River Nile State, Sudan

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Abstract:
Water is life but hardness in water is harmful to human health. This descriptive and analytical study was conducted to determine the levels of hardness and concentration of Total Dissolved Solids (TDS) in drinking water in Shendi town of Sudan. The drinking water samples of 150 (50 samples for each season) were collected from wells, distribution channels and storage facilities and tested per season. The analysis of these samples was done using photometer device to determine the water hardness and result is displayed as mg/l CaCO3, while for estimation of TDS Conductivity / TDS meter and results were noted in parts per million (PPM). The results of this study found that water hardness is found in 48%, 56% and 50% of tested samples during Summer, Autumn and Winter seasons respectively. While Water Quality Index (WQI) base on TDS showed that water quality is excellent and good in autumn and winter seasons, but unacceptable for drinking during the summer season. Based on the findings, the study recommends that Civil Water Corporation should improve the quality of drinking water by treating the water before supplying to the community.

Keywords: Water quality, index, cardiovascular diseases, hardness, Shendi Town, concentration.

INTRODUCTION

Life on earth cannot survive without water as it is one of the basic requirements of human daily consumption, yet most of the world's population struggles to find consistent access to safe drinking water as recommended by the WHO drinking-water quality guidelines. Currently, about two billion people in the world live without access to safe drinking water (WHO 2017a, 2017b).

Hardness

The hardness in water is caused mainly by four dissolved compounds such as Calcium bicarbonate, magnesium bicarbonate, calcium sulphate, and magnesium sulphate. The other compounds like chloride, nitrate, calcium, magnesium, iron, manganese, aluminum etc. will also cause water hardness but generally they are present in such small quantities (Park, 2005). Water hardness is mainly because of the major amount of calcium and magnesium cations in water. Hardness is mostly expressed as milligram of calcium carbonate ($CaCO_3$) equivalent per liter and also can be mentioned in terms of carbonate (temporary) and noncarbonated (permanent) hardness. The hardness in water naturally occur in groundwater is because of limestone weathering, sedimentary rock and calcium bearing minerals and man-made water hardness is by industrial effluents such as chemicals, mining industry or excessive use of lime in pesticides during farming. Water hardness is measured in cations (cations = ions which bear positive electron charges) dissolved in the water and is therefore, related to total dissolved solids in water. More the cations dissolved in water, "harder" the water will be. The most common cations of this type are calcium and magnesium. Iron, strontium, and manganese may also contribute, but they are seldom present in appreciable amounts. Hardness is usually reported as an equivalent amount of calcium carbonate (CaCO3) and is determined by the concentration of multivalent cations in the water. Multivalent cations are cations (positively charged metal complexes) with a charge greater than 1+. Usually, the cations have the charge of 2+. Common cations found in hard water include Ca2+ and Mg2+. These ions enter a water supply by leaching from minerals within an aquifer. Common calcium-containing minerals are calcite and gypsum. A common magnesium mineral is dolomite (which also contains calcium). Rainwater and distilled water are soft, because they also contain few ions.

The following equilibrium reaction describes the dissolving/formation of scales calcium carbonate – $CaCO_3 + CO_2 + H_2O \leftrightarrows Ca^{+2}$ $2HCO^{-3}$. Water hardness is differentiated as if calcium carbonate concentration is below 60 mg/l it is generally considered as soft; 60–120 mg/l is considered as moderately hard; 120–180 mg/l is considered as hard; and more than 180 mg/l is as considered as very hard (McGowan, 2000). Although hardness is caused by cations, it may also be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness (WHO, 2011). Hardness is an important water quality parameter because excess hardness is not suitable for drinking and other purpose. According to previous studies, an inverse relationship between the hardness of drinking water and cardiovascular disease has been reported by Smith and Crombie and other some diseases like encephalopathy and cancer also caused by hardness of water (Meena KL *et al*., 2011). Some studies have shown a weak inverse relationship between water hardness and cardiovascular disease in men with concentration level of 170 mg/l of calcium carbonate in water. The World Health Organization has reviewed the evidence and concluded that the data is inadequate to allow recommendation for water hardness level. Recommendations have been made for the maximum and minimum levels for calcium as 40–80 ppm and for magnesium 20–30 ppm in drinking water, and a total hardness expressed as the sum of the calcium and magnesium concentrations of 2–4 mmol/l. Groundwater is often harder than surface water and may have levels up to several thousand mg/l because of its highly soluble potentials, particularly for rocks containing gypsum, calcite and dolomite. Source of hardness include sewage and run-off from soils particularly limestone formations, building materials containing calcium oxide and textile and paper materials containing magnesium (DHEC, 2009).

Total Dissolved Solids (TDS)

TDS level has an important effect on taste of drinking water, the palatability of water with a TDS level of less than 600mg/L is generally considered to be good. Drinking water becomes increasingly unpalatable at TDS levels greater than 1200mg/L. Water with extremely low concentration of TDS may be unacceptable because of it filet (Park, 2005). Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions (WHO, 2003). TDS in drinking water comes from natural sources, sewage, urban runoff and industrial wastewater. Brackish or saline aquifers can exist naturally or develop overtime in coastal regions with sea water infiltration due to lowering of a quiver depth.

Drinking water with high concentrations of total dissolved solids will not make people sick. Although there are no direct health concerns, TDS concentrations greater than 1,200 mg/L (e.g., brackish or saline water) cause a bitter or salty taste. Some people can taste salt in drinking water at levels around 500 mg/L, and it may cause them not to use it and choose another, possibly contaminated, water source instead (CAWST, 2009). The total dissolved solids test is a measure of the amount of dissolved and suspended material in the water. "Mineral water" typically has a high total dissolved solids level. The maximum recommended level for total dissolved solids is 500 milligrams per liter (mg/1) (DHEC, 2009). The quality of groundwater for drinking purpose can be expressed in terms of total dissolved solids. Groundwater with a TDS values less than 500 mg/L can be considered as excellent for drinking purpose (Navneet Kumar, 2010). The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as excellent if TDS is less than 300 mg/liter; good if the TDS level is between 300 and 600 mg/liter; fair if the TDS level is between 600 and 900 mg/liter and poor if the TDS level is between 900 and 1200 mg/liter; and unacceptable, greater than 1200 mg/liter. Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste (WHO, 2003). TDS is related to other water quality parameters like hardness, which may occur if the high TDS content is due to the presence of carbonates. Total dissolved solids can also be responsible for scaling in water heaters, spotting on dishes, particles forming in ice, rings on cooking utensils, and particles forming in food during cooking. The most noticeable effect of excessive TDS is the taste it gives to water. If a large part of the TDS are chlorides, the water will have a salty taste, if it is Sulfates, they give bitter taste; while bicarbonates give the water a medicinal taste (DHEC, 2009).

Water Quality Index

Water quality Index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water. WQI reduces the large amount of water quality data to a single numerical value which is calculated from the human consumption point of view. Water quality and its suitability for drinking purpose have been considered for calculation of WQI. In this method, the weightage for various water quality parameters is assigned to be inversely proportional to the recommended standards for the corresponding parameters (Vasanth avigar *et al*., 2010).

For healthy living, potable safe water is absolutely essential. It is a basic need of all human being to get the adequate supply of safe and fresh drinking water. One of the most effective ways to communicate water quality is Water Quality Index (WQI), where the water quality is assessed on the basis of calculated water quality indexes. Quality of water is defined in terms of its physical, chemical, and biological Parameters. However, the quality is difficult to evaluate from a large number of samples, each containing concentrations for many parameters (Almeida, 2007). A water quality index provides a single number that expresses overall water quality at a certain location on several water quality parameters and turns complex water quality data into information that is understandable and useable by the general people. WQI is a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts (Islam, s. et al. 2011).

Calculation of Water Quality Index

$$\text{Water quality index [WQI]} = Q_iW_i$$

Where, Q_i is water quality rating

$$Qi = 100*[Va-Vi]/[Vs-Vi]$$

- Va = Actual value of the parameters present in water sample
- Vs = Standard value
- Vi = ideal value
- Wi = K/Sn, Where Wi = Unit weightage

K[constant] = 1/[(1/S1) + (1/S2) + (1/S3) + ….. + (1/Sn) **(**Maruthi Devi *et al*., 2011)

WQI has been classified into five classes according to arithmetic method in the following:

0-25 is excellent, 26-50 is good, 51-75 is poor, 76-100 is very poor and above 100 is unfit for drinking purposes **(**Maruthi Devi *et al*., 2011).

MATERIALS AND METHODS

The study design is based on descriptive and analytical model done in the Shendi town of Sudan which is a historical and third largest town in River Nile State primarily depending on ground water for drinking. It is in the arid zone of Sudan with annual rain fall ranging between 0 and 119 mm per year (WHO, 1993). Shendi town has no sewage system, as the population mainly depend on septic tanks, aqua privies, pour flush latrines and traditional pit latrines for disposal of fecal waste and other liquid waste making the fecal matter mixing with ground water. The water samples are collected from ground water (Wells), distribution system and storage facilities that are used directly for drinking purpose in the community per season with sample size of 150 as determined by WHO guidelines based on total population (WHO, 1993).

Samples were stored in 500ml plastic bottles (high-density polyethylene bottles recycled from similar, bottled distilled water products), cleaned with liquid detergent, and rinsed with distilled water and air dried. A "control wash" was employed by pre-rinsing the collection bottle 3 times with 20 ml of sample water before final collection. Bottles were then filled completely up to the brim to avoid inclusion of air. Air bubbles were also eliminated, and bottles were capped tightly and appropriately labeled. Samples were stored overnight in the refrigerator, not cooler than 4°C, and were tested within 24 hours. No additional filtration or purification techniques were employed before total hardness and TDS measurements. The water hardness analysis is done using reagents and equipment like Palin test, hardicol NO 1 tablet, Palin test hardicol NO 2 tablets, Palin test automatic wavelength selection photometer and round test tubes 10 ml glass. The sample test was done as per the standards using following steps respectively; the test tube was filled with sample to the 10 ml mark as a blank, other test tube was filled with sample up to 10 ml mark and hardicol NO 1 tablet was added then crushed & mixed to dissolve, added one hardicol NO 2 tablet then crushed & mixed to dissolve and ensured all particles are completely dissolved, waited for two minutes to allow full color development, hardness choice was selected on photometer and took photometer reading in usual manner after using the blank sample, and the total hardness result is displayed as mg/l $CaCO_3$. The TDS analysis is done using conductivity/TDS meter, conductivity cell, standard solution, distilled water, phosphoric acid, volumetric flasks and graduated cylinder. Test of samples was completed according to standard methods for examination of water. After calibration, the instrument for water sample was put in the glass beaker and TDS/conductivity meter was immersed into this water sample. TDS were selected from conductivity/TDS meter, then it was allowed to stand until it achieved stable reading and the reading was noted in PPM. The data was carefully analyzed using Microsoft word and Excel software and the results are presented using percentage tables and statistical graphs.

Analysis

The hardness level of the water is analyzed carefully and the results are displayed in the below table and graph. Out of the 50 samples collected the results show that in summer season, 48% of the samples had $CaCO_3$ concentration of 120mg/L to < 180mg/L and 24% of the samples had $CaCO_3$ concentration of 180mg/L and greater. In autumn season, 56% samples are had $CaCO_3$ concentration of 120mg/L to < 180mg/L and 16% of the samples had $CaCO_3$ concentration of 180mg/L and greater. In winter season, 50% samples are had $CaCO_3$ concentration of 120mg/L to < 180mg/L and 24% of the samples had $CaCO_3$ concentration of 180mg/L and greater.

RESULTS

Table 1: Water hardness level measurement over the seasons

Hardness category	CaCO3 concentration	Summer		Autumn		Winter	
		Samples	%	Samples	%	Samples	%
Soft	< 60 mg/L	0	0	0	0	2	4
Moderate hard	60mg/L to < 120mg/L	14	28	14	28	11	22
Hard	120mg/L to < 180mg/L	24	48	28	56	25	50
Very hard	180mg/L and greater	12	24	9	16	12	24
Total		**50**	**100**	**50**	**100**	**50**	**100**

The below graph shows the water hardness level comparison over the seasons

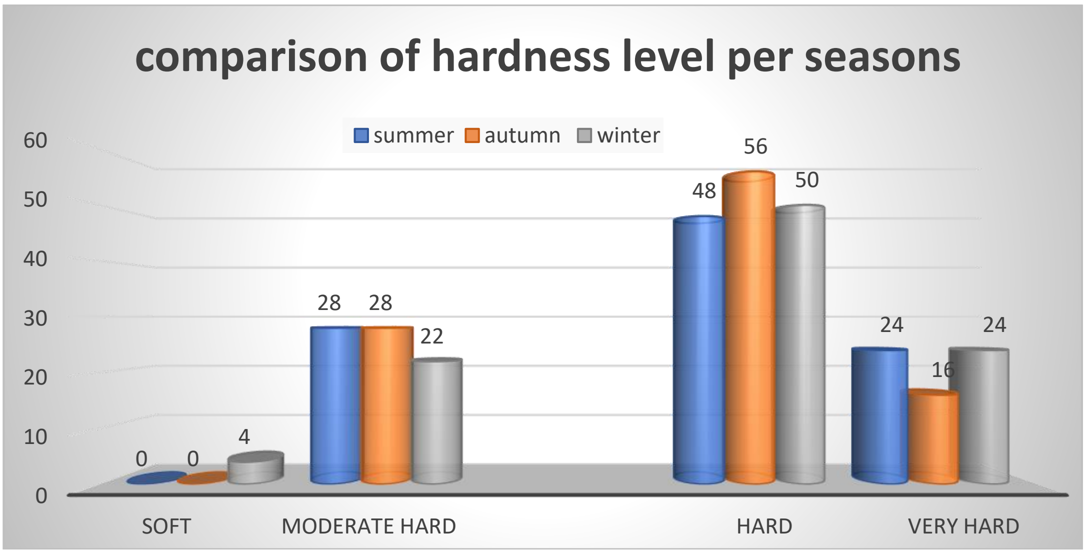

Figure 1: Water hardness level comparison over the seasons

The TDS level of water samples during the various seasons show that during the summer season, the water TDS range of all the 50 samples is 1200mg/L and greater which is making it completely unacceptable for drinking.

During the autumn and winter seasons, the TDS level is very less making it excellent to drink. Out of 50 samples, the TDS levels in autumn and winter seasons are less than 300mg/L in 92% and 98% of samples respectively.

Table 2: TDS range measurement over the seasons

Quality category	TDS range	Summer		Autumn		Winter	
		Samples	%	Samples	%	Samples	%
Excellent	< 300mg/L	0	0	46	92	49	98
Good	300mg/L to < 600mg/L	0	0	4	8	1	2
Fair	600mg/L to < 900mg/L	0	0	0	0	0	0
Poor	900mg/L to 1200mg/L	0	0	0	0	0	0
Unacceptable	1200mg/L and greater	50	100	0	0	0	0
Total		**50**	**100**	**50**	**100**	**50**	**100**

The below graph shows that WQI base on TDS showed that water quality is excellent and good in autumn and winter seasons respectively but however it is unacceptable for drinking in summer season.

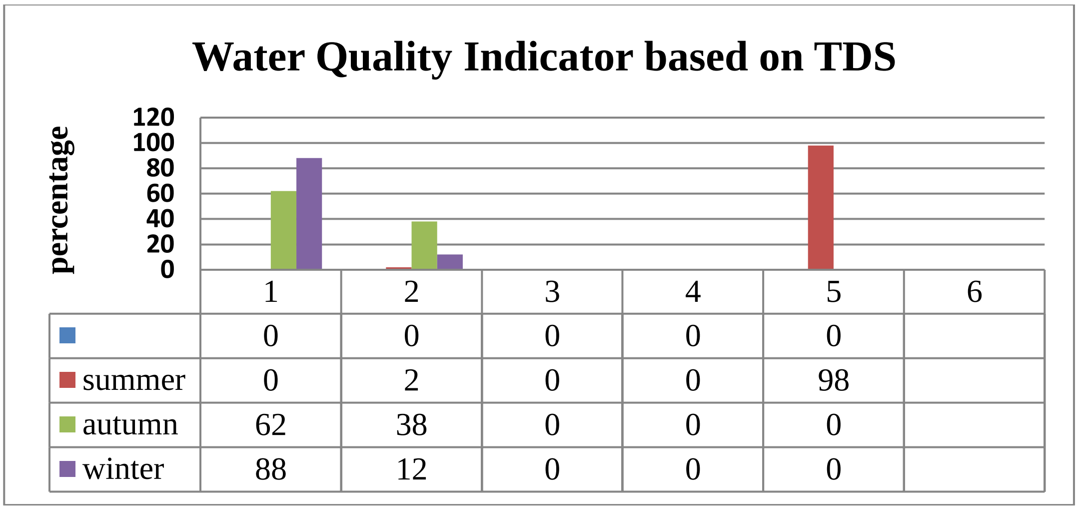

Fig 2: Comparison of water quality indicator base on TDS over the seasons

DISCUSSION

Water hardness is determined based on amount of calcium and magnesium present in it. Water hardness is measured by adding up the concentrations of calcium, magnesium and converting this value to an equivalent concentration of calcium carbonate ($CaCO_3$) in milligrams per liter (mg/L) of water. Unsafe drinking water is one of the basic health problems in Sudan. The present study showed that 48% and 24% of water tested samples are indicated that drinking water is hard and very hard respectively in summer season. Also, this study pointed that 56% and 16% of water samples are hard and very hard respectively in autumn season. While in winter season, 50% and 24% of water samples showed that drinking water is hard and very hard. Consumption of hard water causes serious health problems like urolithiasis, cardiovascular disorders, according to past studies and there is inverse relationship between the hardness of drinking water and cardiovascular diseases (Smith and Crombie 1987), other diseases like anencephaly and cancer also caused by hardness of water (Subramanian., 2011). According to the present study findings, we can expect some of the health problems facing by the population living in this study area. The previous studies resulted that there was an inverse relationship between the hardness of drinking water and cardiovascular disease (Anderson TW *et al*., (1975); Masironi R, Piza Z, Clayton D. (1979); Leoni V, Fabiani L Licchiarelli L. (1985); Zeighami EA *et al*., (1985); Smith WC and Crombie IK (1987); Kubis M. (1985); Dzik AJ. (1989). However, no such association has been found in some studies (Mackinnon AU and Taylor SH (1980); Sonneborin M. *et al*., (1983). Nevertheless, in a number of studies, a weak inverse relationship was reported after allowance was made for climatic and socioeconomic factors (Pocock SJ *et al*., (1980), and after major risk factors such as hypertension, smoking habits, and elevated serum lipids were considered (Nerbrand C. 1998). A variety of hypotheses have been proposed to explain the possible inverse association between hardness of drinking water and cardiovascular diseases (Lacey RF, and Shaper AG. 1984; Alexa L *et al*., 1988; Hopps HC and Feder GL. 1986; Mareir JR and Neri LC. 1985; Singh RB. 1990; Derry CW, Bourne DE and Sayed AR. 1972). However, none has been fully substantiated, nor has a particular element been found to be conclusively associated with cardiovascular disease. The results of several studies have suggested that a variety of other diseases are also inversely correlated with the hardness of water, including anencephaly (Crawford MD, Gardner MJ and Sedgwich PA 1972; Bound *et al*., 1981), and various types of cancer (Zemla B. 1980; Wigle DT *et al*., 1986). However, the significance of these results is unclear, and it has been suggested that the associations may reflect disease patterns that can be explained by social, climatological, and environmental factors, rather than by the hardness of the water.

CONCLUSION

The current study showed that TDS in drinking water in winter and autumn is acceptable because content of it below 500ml/l, less than WHO and SSMO guidelines. While contents of TDS are above permissible limits in summer, this may be due to the temperature levels. The temperature has effect in solubility of substances, high values of TDS in ground water generally are not harmful to human beings, but high content of TDS affect persons who suffer from kidney and heart diseases (USGS,2017). WQI of TDS pointed out that drinking water quality is excellent and good in winter and autumn. However, it indicated that water quality is unfit for drinking in summer. This concludes that drinking water hardness varied among seasons, where 48%, 56% and 50% of examined samples are indicative of water quality being hard during summer, autumn and winter seasons respectively. While WQI base on TDS showed that water quality is excellent and good in autumn and winter seasons, and unacceptable for drinking in summer season.

RECOMMENDATIONS

For healthy living, potable safe water is absolutely essential. It is the basic need for all human beings to get an adequate supply and pure drinking water. So, based on the findings of this study we recommend that Civil Water Corporation should be improving the quality of currently drinking water by subjecting it to treatment processes to remove or decrease level of hardness of drinking water as soon as possible.

ACKNOWLEDGMENTS

The authors acknowledge the family of the Federal Ministry of Health (Environmental health and food control directorate) for their administrative help. Also, we would like to thank the family of the Ministry of Health, River Nile state (Environmental health and food control department) for providing laboratory facilities. We send many thanks to all those who are supported, contributed, and helped us in this study.

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