Journal of Metallurgy and Materials Science, Vol. 63, No. 3-4, July-December 2021
Printed in India, © NML, ISSN 0972-4257

Total Dissolved Solids (TDS) in Packaged Drinking water in India: A Review

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1. ABSTRACT :

Many parameters are used to determine the quality of water. One vital parameter is Total dissolved solids (TDS) which measure the deterioration of water quality. Regular consumption of low TDS in packaged drinking water leads to adverse health effects like chronic gastritis, cardiovascular diseases, homeostasis, and metabolic acidosis in humans. In this review, an overview of low TDS and its ill effects on human health due to the consumption of packaged drinking water containing low minerals is discussed.

Keywords : *Total dissolved solids (TDS), Packaged drinking water (PDW), Impacts of low TDS, Human health and TDS, Low minerals.*

2. INTRODUCTION

Total Dissolved Solids (TDS) is one of the water quality parameters which can be defined as the presence of inorganic salts like Ca, Mg, Na, CO_3^-, Cl^-, SO_4^-, NO_3^- and other cations and anions as their major constituents in the water [1]. It is determined by weighing the residue left after the evaporation of the filtered water sample at 180^0 C [2].

$$\text{TDS } (\frac{mg}{l}) = \frac{Mass\ of\ solids\ (W_2 - W_1)\ (g)}{Volume\ of\ sample\ (ml)} \times 1000$$

Where, the value of W_2 is the final weight of the dish and filtrate after evaporation, and W_1 is the initial weight of the dish before evaporation. TDS is one of the oldest parameters for determining the quality of water and has always been taken to represent materials present in the water [3]. Low level of TDS in packaged drinking water like bottled water, sachet water, and distilled water is believed to cure arthritis by "washing out" calcium from deposits in joints. Many believed that consuming water containing low TDS, those which are treated by distillation, reverse osmosis, or deionization tends to leach out minerals from the body and causes its deficiencies and other ill-effects [4]. Recent years have witnessed high emergence and rapid growth of the bottled water industry; perhaps due to its ease of availability in carrying, inexpensive cost, and absence of harmful contaminants have made packaged water a good alternate source for drinking in maximum developing and developed countries [5]. Bottled water represents water sealed in plastic containers without any added ingredients, containing safe and harmless antimicrobial agents which are suitable for drinking [6]. In India, the bottled water industry showed remarkable growth when Parley launched Bisleri. India is now counted in the top ten countries in terms of bottled water utilization. According to the survey data analysis in several restaurants and hotels in Kolkata West Bengal, India, it was observed that the packaged drinking water like Kinley had a maximum market share off around 52%, followed by Bisleri and Aquafina 14% each, bailey shared 4% of the market share, and other companies shared the rest 16%[7]. Due to the over-treatment of packaged drinking water, they lack in essential minerals hence resulting in low TDS of water. The classification of water, based on mineral content and concentration of TDS along with its palatability with respect to the European Union mineral water directive (EU) [8] and Bureau of Indian Standards (BIS) [9], is mentioned in Table-1

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Table-1 ***Classification of different water type based on concentration of TDS***

EU		BIS	
Water Type	***Criteria TDS (mg/l)***	***Concentration of TDS (mg/l)***	***Palatability remark***
Very low mineral concentration	Mineral content (TDS) <50 mg/l	< 300 mg/l	Excellent
Low mineral concentration	TDS 50-500 mg/l	300-600 mg/l	Good
Average mineral concentration	TDS 500-1500 mg/l	600-900 mg/l	Fair
High mineral concentration	TDS > 1500 mg/l	900- 1200 mg/l	Poor
-	-	>1200 mg/l	Unacceptable

Even though the consumption of bottled drinking water has increased worldwide, strict standardization and periodic inspection are essential factors for both economy and human health. The World Health Organization (WHO) provides general guidelines that are essential for better water quality [10, 11]. Similarly, in India Bureau of Indian Standards (BIS) formulates Indian standards drinking water specifications required in drinking water [9]. Studies elsewhere have shown non-compliance of physicochemical properties of packaged drinking water with the results mentioned in their labeling. Bottled water is also regulated by various international guidelines provided by International Bottled Water Association (IBWA), Food and Drug Administration (FDA), and United State Environmental Protection Agency (USEPA) as mentioned in table-3 [9-12].

2.1. Correlation of TDS with pH and EC of water

TDS, pH, and Electrical Conductivity (EC) are the essential parameters that determine the quality of water. pH is the measure of acidity and alkalinity of the solution. The scale of pH ranges from 0-14. The scale is logarithmic, not linear. For example, if the solution has pH 6 then it is ten times more acidic than pH 7. Pure water is said to have a pH of 7. Water below pH value 7 is considered acidic while pH above 7 is considered as basic or alkaline. Electrical conductivity can be defined as the capacity of the solution to carry an electric current. The ability to pass electrical flow mainly depends on the concentration of ions present in it along with the optimum temperature. Solutions with more inorganic salts, acid, and bases have good EC [13]. TDS and EC are indicators of salinity in the water and are correlated [14, 15]. Researchers have done various investigations to find out the precise mathematical correlation between EC and TDS. TDS concentration can be easily calculated from the EC value as per the given equation [14].

$$\text{TDS}\left(\frac{mg}{l}\right) = \text{k} \times \text{EC}\left(\frac{\mu s}{cm}\right)$$

Where k measures the ionic concentrations and the value of k depends on the ion concentration and it increases with the increasing ions in water. If EC increases the amount of TDS also increases. Thus TDS when correlated with conductivity directly, affects the pH of the drinking water. If the EC is high, TDS becomes more and the pH of the water decreases resulting in acidity [1].

2.2. Desirable TDS Content of Drinking Water

If the TDS level changes then the texture and taste of water also change. Maintaining the TDS level of bottled water is essential for maintaining good health. According to Bisleri, TDS level 50-150 mg/l is excellent and is considered as the most suitable and acceptable limit for drinking [16]. According to World Health Organization, 1980 report, a minimum of 100 mg/l of TDS is required to be present in water. The recent guidelines of WHO, 2017 recommended TDS level <1000 mg/l as suitable for drinking.

Thus, the research on TDS and packaged drinking water continues with various modifications in research methods. This paper presents the overview of drinking low TDS water such as packaged drinking water and its

impact on consumer's health due to low mineral consumption and the various methods adopted in determining TDS of water.

3. REVIEW OF LITERATURE

Various methods for testing TDS in packaged water at research levels are adopted and presented in the technical papers, which have been referred to, for the present review. The critical findings from these papers are discussed below.

Mahajan et al. [17] took seventeen bottled samples of various brands, collected from various retailed shops in Amritsar, India. The physical and chemical parameters, like TDS, Ca, Mg, pH, Cl, K, hardness, Zn, Cd, Cu, and Chlorine demand of the sample were analyzed in the laboratory to match it with the recommended limits of WHO and USEPA. The pH of the samples was determined using a pH meter, TDS was determined using the evaporation method and Conductivity using a conductometer. The authors analyzed the pH of the samples, out of 17 samples 3 samples were found slightly acidic with pH values around 6.79, 6.83, and 6.73 respectively. Thus, all the commercially packaged drinking water had pH value within the prescribed limits by WHO and USEPA. It was observed through the experiment that all the samples had TDS values lower than the recommended limit of 500 ppm, three of the packaged water had TDS < 50, and another four <100 ppm. The authors discussed the results and pointed out that the water lacks essential minerals and is lower than the desirable limits and the majority of the brands of packaged water are over-treated. This paper gives an overview about over treatment of packaged drinking water resulting in low mineral content, when consumed it can lead to mineral deficiency in the body. Studies all across the world revealed that various methods are adopted for determining the TDS present in water as shown in Table-2.

Table-2. Various methods to determine TDS of water

Parameter	Various Methods	Sources
TDS (mg/l)	Evaporation method	[17], [18]
	Gravimetric method	[19], [20]
	Digital TDS meter	[1], [21], [22], [23], [24], [25]
	*AAS	[26]
	YSI-Multiparameter	[27], [28]
	Conductivity meter	[11], [29],[30]
	TDS and EC relationship	[31]

*AAS- Atomic Absorption Spectrophotometer.

Ray et al. [32] conducted a study to access the physicochemical quality of Packaged Drinking Water (PDW) in the city of Kolkata, West Bengal, India. The authors took 27 types of PDW and 10 different types of bubble top can PDW. The analysis of the sample was done at the School of Water Resource Engineering, Jadavpur University, West Bengal, as per the prescribed guidelines of the American Public Health Association (APHA). Another, eighteen samples were collected randomly from Kolkata Municipal Corporation (KMC) in different localities. The samples were analyzed and the result of PDW and KMC were compared with each other. The samples were tested for both bacteriological and physicochemical parameters. The pH and turbidity of the samples were determined using digital pH meter and Nephelo-turbidity meter, and TDS was measured with a digital TDS meter, whereas Fluoride, Chloride TH was determined using Ion-selective Electrode (ISE), argentometric method, and EDTA titration method, respectively. The study also showed that 41% of PDW had a pH value of 6.5 and was acidic. The minerals content, TDS, Ca, Mg, the types of PDW were found low and F^- were found negligible. All PDW showed the minimum TDS level between 38.26 mg/l for bottled water, 24.68 mg/l for bubble top cans, and

the maximum of 117 mg/l, which signifies a low level of TDS in water. On the other hand, the samples of KMC water supply showed higher values of the above-mentioned physicochemical parameters. The study concludes that the regular consumption of low-mineralized water is not safe and may lead to potential health risks like an irritation to mucous membranes and cardiovascular diseases. The KMC water supply can be a good alternative for drinking purposes. This paper compared two different types of water that are packaged and tap water, where the data reveals that the packaged drinking water showed low mineral content as compared to water of Kolkata municipal corporation. The authors concluded that tap water is safer as compared to PDW due to its high mineral content.

Rao et al. [19] conducted a study to assess the physical, chemical, and bacteriological parameters of various packaged and public drinking water. The samples were collected from villages of Vikarabad, located in Telangana, India. One sample from each bore well from 35 villages in Vikarabad Mandal, one municipality tap water sample from Vikarabad municipality, and five samples of each brand of bottled, four sachets, and four canned water sample was collected from the same location. For analyzing the physical and chemical evaluation the bore well water samples, canned and municipality water samples were collected in sterilized white jerry cans of 1L capacity. For analyzing the bacteriological parameter same samples were collected in sterilized jars of 100 ml capacity along with bottled water and sachets of 1L capacity. All water samples were collected under sterilized conditions, numbered in the sequence and refrigerated to preserve the parameters, and transported to Telangana State Pollution Control Board, Hyderabad for analysis. The guidelines of the American Public Health Association (APHA) were followed for the analysis of the samples. The pH of the sample was examined using a pH meter, the EC of the sample was examined using a conductivity meter and the TDS of the samples were determined using the gravimetric method. The values obtained from the studied parameters were compared with the guidelines provided by the Bureau of Indian Standards (BIS) given in table-3.

Table-3. ***Guidelines for the maximum allowable levels of contaminants in drinking water***

Parameters	*IBWA*	*FDA*	*USEPA*	*WHO*	*BIS*
pH	6.5-8.5	-	6.5-8.5	6.5-8.5	6.5-8.5
TDS (mg/l)	500	500	500	<1000	500
EC (µS/cm)	-	-	-	400	-

***IBWA**- International Bottled Water Association; **FDA-** Food and Drug Administration; **USEPA-** U.S Environmental Protection Agency; **WHO-** World Health Organization; **BIS-**Bureau of Indian Standard.

The statistical analysis and Pearson's correlation of the result were obtained using the SPSS package (Version 21.0) given in Table-4.

Parameter	Min/Max/Mean	Bottle	Sachet	Can	Bore well	Tap water
pH	Minimum	5.52	5.98	7	5.9	
	Maximum	6.89	7.58	7.5	9.4	
	Mean	6.34	7.13	7.2	6.8	7.8
Electrical Conductivity	Minimum	47	53	48	49	
	Maximum	181	174	690	1299	
	Mean	104.4	111.5	214.5	658.7	456
TDS	Minimum	31	34	31	32	
	Maximum	118	113	445	1012	
	Mean	67.8	73	139.5	498.2	296

Table-4:*Mean values of physicochemical parameters assessed in drinking water.*

The physicochemical quality of drinking water from different sources like bottled, sachet can, bore well and tap water was not within the permissible limits in Vikarabad, India.

Khatri et al. [33] conducted a study to assess the quality of drinking water in nine villages of Harij Taluka, located in Patan district in Northern Gujarat, India. Water from nine villages was sampled for the analysis of parameters that are crucial for drinking, such as TDS, F, Mg, Cl, dissolved oxygen, and many others at GEMI'S Laboratory, Gandhinagar, Gujarat. Weekly analysis of the samples for pH was done for six consecutive weeks.The result was observed and noted. The pH of the water was found in the range between 6.5-8.5which was within the range provided by BIS [9] in all the samples for the six consecutive weeks. The conductivity of water samples was analyzed for six consecutive weeks. It was found that the conductivity of water samples was below 400 µS/cm except for the two villages, where it was present beyond the acceptable limits. The samples were analyzed for TDS in water. It was found that the TDS of water was above 500 mg/L in Jaswantpura and Jasomav for all the weeks, which was beyond the acceptable limits of BIS [9]. Only the second week at Bhalana showed TDS level beyond the acceptable limits as per BIS as shown in Fig 1. The authors concluded that the quality of water in all the nine villages is of good quality and safe for human consumption.

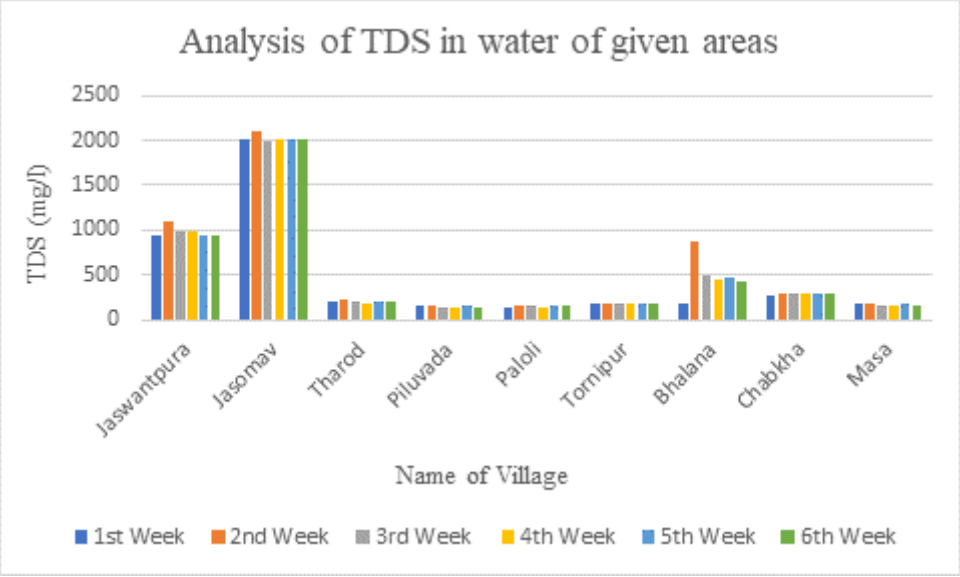

Fig 1. Graphical representation of scientific analysis of TDS in water samples [33].

4. IMPACT OF LOW TDS ON HUMAN HEALTH

Levallois et al. [34] state that the taste of water has an intense impact on a person's willingness to drink it. When consumers experience an unacceptable taste in drinking water, they typically look for different water sources. The sudden growth of bottled water is one of the reasons for this notion. In addition, the water treatment devices installed in buildings and homes of the consumers are the sign that they are searching for ways to improve drinking water taste [35]. The artificially produced desalinated/deionized water was previously used by laboratories and industries and not for drinking. However,in the last three decades, treated water has become a widely practiced technique in providing safe and clean drinking water. However, deionized water may vary in composition due to the existing treatment facilities which may result in minimum TDS and other minerals content. The high risk of health effects due to long-term consumption of desalinated water is of interest in countries and places where freshwater is not available and bottled water is consumed. Verma KC and Kushwaha AS [36] state that Ca and Mg are important elements for health. Although, drinking water is not the only source of our Ca and Mg but along with supplements they can outweigh its nutritional contribution to the body. Bubble top cans now a days are found in many homes and the demineralized water is utilized for cooking. Desalinated water when used

for cooking causes substantial losses of all essential elements from foods like cereals and vegetables etc. The substantial losses may reach up to 60% for Ca and Mg or may also eliminate other microelements.

Demineralized or deionized water are those which is completely free from dissolved minerals resulting in low TDS (1 mg/l) of water. Such water also shows a low EC value. Research has been carried out to find the possible adverse health effect of water that lack dissolved mineral content. The ill effects of demineralized water on health are discussed below.

4.1. *Effect of low mineral content of water directly on the mucous membrane of intestine, metabolism of body and homeostasis*

Some research in the laboratories has been conducted on animals and humans and the observation was noted accordingly. TDS less than 50 mg/l can impart a negative taste to the consumers. This type of water is also reported to be less thirst-quenching [37]. Although they have no high health risks, they should be taken into account when considering the suitability of low mineral content for consumption. Williams [38] reported that deionized water when introduced into the intestine of rats changed the epithelial cells. Schumann et al. [39] in their experiment for 14 days on rats concluded that there is no sign of erosion, ulceration, and inflammation in the stomach, oesophagus of rats. It has been adequately demonstrated [40] that water with low mineral content impart negative effect on the body's mechanism of homeostasis. The mechanism of homeostasis ensures equilibrium in the Urinary system. If the mineral content is low in the water, then the urine increases the elimination of major intra and extracellular ions from the body. Experiments on rats upto one year have shown that intake of distilled or deionized water that has a TDS value <75 mg/l leads to diuresis, increasing tendency of thirst, elimination of Na and Cl ions from the body. It also slows down the volume of red cells and leads to hematocrit changes [37]. The WHO 1980 report [40] came in agreement with the results of experiments evaluated by the researchers and agreed that low TDS water (TDS < 100 mg/l) results in diuresis, homeostasis, and increases the leaching of potassium, chloride, calcium, and magnesium ions from the body. The low mineral content in water acts on osmoreceptors of the gastrointestinal tract resulting in decreased aldosterone secretion and increasing sodium elimination. The German Society for Nutrition gave resembling conclusion about the effect of deionized or distilled water and warned the public against drinking it. Studies have shown that consuming low mineral water regularly may lead to acute damage such as hyponatremic shock or delirium. Hyponatremic shock, so-called "Water intoxication" increases with decreasing levels of TDS in water. More severe risk like acidosis and oedema was observed in infants whose drink was prepared using distilled, deionized or low-mineral bottled water [41].

4.2. *Low or no intake of Ca and Mg from demineralized water*

Calcium (Ca) and Magnesium (Mg) are essential elements for the body. Ca is a substantial component of bones and teeth while Mg acts as cofactor and activator of more than 300 enzymatic reactions including glycolysis. It also helps in transporting elements such as Na, K, Ca through membrane synthesis of protein and nucleic acids. Although drinking water is not the only source of Ca and Mg in our body, they add its nutritional contribution along with the supplemental intake. The epidemiological studies in many countries reported that drinking water low in Mg is directly associated with the mortality and morbidity rate due to cardiovascular diseases. Studies concluded that intake of soft water, water low in Ca may create higher risks of bone fractures in children [42] and certain diseases related to neurons [43]. Several studies suggested low intake of these elements leads to cardiovascular disorder, tiredness, weakness or muscular cramps [37]. Lutai [37] conducted an epidemiological study in the Ust-Itim region of Russia. The study focused on physical development and morbidity rate in 7658 adults, 562 children, and 1582 pregnant women and their newborn babies. The area was divided into two different localities and one locality was supplied with water containing high minerals and another with water containing low minerals. The population of both areas did not differ in terms of food, air, and social habits. It was observed that the locality supplied with low minerals water showed a higher rate of goiter, hypertension, duodenal ulcers, chronic gastritis,

heart disease, and nephritis. Children exposed to low mineral water exhibited slower physical development and more growth abnormalities. Pregnant women showed edema and anemia. Whereas, the locality supplied with high mineral content showed no such symptoms. The author concluded Such water is physiologically optimum.

4. CONCLUSION

TDS normally indicates the presence of salinity in water. Water containing no dissolved solids is intolerable and releases a flat taste to consumers. Earlier data shows water containing TDS <100 mg/l has negative impacts on human health like hyponatremia shock, metabolic acidosis, brain oedema, cardiovascular disease, chronic gastritis, goitar, etc. Also, TDS <50 mg/l is considered to be less thirst-quenching. According to reputed packaged drinking water manufacturers, minimum range between 50-100 mg/l TDS is required in drinking water. However recent data shows very less information on ill effects due to consumption of low TDS water. According to WHO 1980 Report, the minimum permissible limit required for TDS was 100 mg/l. However, recent guidelines of WHO 2017 remain silent on the minimum TDS level required in drinking water and only show the maximum permissible limits of TDS in drinking water i.e., <1000 mg/l. It can be highlighted that a minimum TDS level between 50-100 mg/l is recommended to be present in drinking water to avoid a negative impact on human health.

5. ACKNOWLEDGMENT

The authors are thankful to the DST-Women Technology Park for capacity building and entrepreneurship development (GAP 0288) and CSIR Integrated Skill Initiative (NWP 100) for the research grant.

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