Scope
Volume 14 Number 03 September 2024

Functional Dependance of Adiabatic Compressibility of Water on Total Dissolved Salts – A Pilot Study

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Abstract: Investigation on functional dependance of adiabatic compressibility of water with varying salt contents and temperature, have been analyzed in the present study. Three water samples distilled (TDS = 06) , Reverse Osmosis (TDS = 74) and Tap water (TDS = 1060) were taken. Factors analyzed were Ultrasonic velocity, refractive index, density and acoustic impedance along with adiabatic compressibility. All three water samples showed variations from usual trend in specific temperature ranges. Ultrasonic velocity showed a minor increase in tap water between (285 – 288K), instead of decreasing, similarly for RO water ultrasonic velocity varied as per comparison with literature review in the range (291K – 294K), and for distilled water ultrasonic velocity showed small variations between (286 – 287K). Density of the three water samples under study, showed a uniform decline with increase in temperature, highest value was observed for tap water 1000.716 kg/m3 and lowest for distilled water 995.706kg/m3. Regression Statistics yielded positive results for correlation between TDS and adiabatic compressibility for Tap water (highest TDS)only, while it showed negative correlation for water sample with low salt content. Further studies on compressibility of water with varying salt content, could pave way for growth of new technology based on the concept of application of compressibility of fluids (specially water).

1 Introduction

When a change of pressure is applied to a liquid , then the relative change in volume that occurs measures the compressibility of the liquid. The degree of compressibility of a fluid has strong implication for its dynamics. Sound propagation is dependent on compressibility of the medium [1, 2]. Literature review [3- 9] states that water is approximately incompressible, and the compressibility factor of water can be avoided when doing calculations. Low compressibility of water happens because of high density of water. [10– 11]. Till date, very few studies have been carried out to find the correlation between compressibility factor of water with varying salt content. Compressibility of liquids has been neglected to a great extent, however in cases where sudden pressure variations appear, pressure waves originate compressibility of water is taken into account. artistic water fountains make use of compressibility factor of water. In industrial applications water can be tremendously compressed and used to do things like cut through metals etc. The compressibility factor finds numerous applications in our daily life specially hydraulics [12].

Measurement of physiochemical properties like ultrasonic velocity, adiabatic compressibility, acoustic impedance, density, Total Dissolved Salts(TDS), of different forms of water used by humans for various purposes are of great importance. As water is basic source of survival for life on earth. [13,14]. Acoustic impedance was also computed, acoustic impedance is relevant in a number of areas, like medical ultrasound, where acoustic impedance is observed between different tissue types at interface., for example for study of bone analysis ultrasonic wave encounters muscle tissues. Acoustic impedance is used in packaging materials used to encapsulate hydrophones, for such materials acoustic impedance should be close to water. Study of acoustic impedance will help in growth of new technology for ultrasonic equipment's. TDS typically found in water are the mineral content [15,16]. Water being a good solvent is prone to impurities easily. TDS (Total Dissolved Salts) present in our water sample comprise of minerals, inorganic salts, calcium, chemicals etc. With increasing forms of water consumption available and different types of water plants being set up all over the country either for human consumption, or hydraulic purposes, quality of water and which is best suitable for survival of life will always remain a topic of research.

These days every home, office, public place etc are installed with RO filters of different types [17,18]. Distilled water is used for many medical and experimental purposes [19-20]. Also, tap water being supplied by water authorities is also used by humans for various purposes.

The purpose of the present work is to analyse the physiochemical properties of three water samples differentiated on the basis of TDS present in them in the temperature range of (280 – 303K). Pure water samples with varying TDS, were purposely chosen for the study as they will help in providing appearance of new forms of water samples which can be beneficial for humans and new hydraulic based technology.

2 Materials and Methods

2.1 Experimental Technique

Ultrasonic interferometer was used to measure ultrasonic velocity of water samples. It is a simple and direct device which yields accurate and consistent data, for velocity of ultrasonic sound in a liquid medium with high degree of accuracy. A crystal-controlled interferometer (model M-83S) which was supplied by Mittal Enterprises, New Delhi, operating at a frequency of 2MHz, , and measuring accuracy of about , ±1.0 m/s, the inlet outlet pipes fitted with the system help in taking readings with temperature variation. Total Dissolved Salts (TDS) were measured with the help of digital TDS meter, model number (TDS 3),simple mercury thermometers were used to measure temperature variations they were inserted in the water bath. Densities of the water samples were measured using a 25 ml specific gravity bottle weight of liquid was measured with the help of an electronic balance (Model Shimadzu AX200). Abbe's Refractometer was used to measure the refractive index with great accuracy.

2.2Theory

Ultrasonic velocity was calculated with the help of ultrasonic interferometer**.** The ultrasonic waves are produced by the piezoelectric method. In a fixed frequency variable path interferometer, the wavelength of sound in an experimental liquid medium is measured and from this the ultrasonic velocity is calculated [21].
The acoustic parameters were calculated as follows.

Ultrasonic Velocity

The ultrasonic velocity is calculated as

$$v = f\lambda \quad (1)$$

where f is the frequency of the ultrasonic waves (2 MHz) and λ is the measured wavelength value of ultrasonic wave.

Adiabatic Compressibility is measure's the relative volume change water samples for response to pressure change.
Adiabatic compressibility (β) is calculated, from the ultrasonic velocity "v" and the density "ρ" of water samples from Newton-Laplace equation

$$\beta = \frac{1}{\rho v^2} \quad (2)$$

Acoustic impedance (Z) measure of resistance offered to the propagation of ultrasound waves through water samples following formula is used for the same [21]

$$Z=\rho v \quad (3)$$

where ρ and v are the density and velocity of the solution, respectively. It basically describes how much resistance an ultrasound beam encounters as it passes through a tissue.

3 Results and Discussion

The experimentally obtained values of density, TDS, refractive index, ultrasonic velocity , density , adiabatic compressibility and acoustic impedance with varying temperature are reported in Tables 1, 2and 3 for Tap Water, RO water and Distilled water respectively.

Table 1 Observations for Tap Water

Temperature (in K)	TDS	Refractive Index	UV Ultrasonic Velocity (v) (m/s)	Density (ρ) (kg/m^3)	Adiabatic Compressibility (β) (m^2/N)(x 10^{10})	Acoustic Impedance (MPa)
281	1060	1.414	1480	1000.71	4.56	1.48
282	1060	1.414	1400	1000.64	5.09	1.40
283	1060	1.414	1480	1000.56	4.56	1.48
284	1060	1.414	1440	1000.46	4.82	1.44
285	1060	1.414	1480	1000.35	4.56	1.48
286	1060	1.414	1520	1000.23	4.32	1.52

Table 2 Observations for RO Water

Temperature (in K)	TDS	Refractive Index	UV Ultrasonic Velocity (v) (m/s)	Density (ρ) (kg/m^3)	Adiabatic Compressibility (β) (m^2/N)(x10^{10})	Acoustic Impedance (MPa)
277	74	1.349	1520	1000.06	4.33	1.52
281	74	1.349	1480	999.93	4.57	1.47
282	74	1.349	1546	999.88	4.18	1.54
283	100	1.414	1466.66	999.80	4.65	1.46
287	100	1.414	1480	999.35	4.57	1.47
288	100	1.414	1440	999.20	4.83	1.43
291	83	1.414	1440	999.68	4.84	1.43
293	113	1.36	1490	998.32	4.51	1.48
294	116	1.355	1600	998.11	3.91	1.59
295	116	1.355	1500	997.88	4.45	1.49
296	116	1.355	1584	997.65	3.99	1.58
297	116	1.356	1480	997.41	4.58	1.47

298	116	1.356	1496	997.16	4.48	1.49
299	116	1.356	1480	996.90	4.58	1.47
300	116	1.355	1573.33	996.63	4.05	1.56
303	116	1.358	1460	995.76	4.71	1.45

Table 3 Observations for Distilled Water

Temperature (in K)	TDS	Refractive Index	UV Ultrasonic Velocity (v) (m/s)	Density (ρ) (kg/m^3)	Adiabatic Compressibility (β) (m^2/N)($x10^{10}$)	Acoustic Impedance (MPa)
283	06	1.360	1500	999.75	4.44	1.49
284	06	1.360	1416	999.66	4.98	1.41
285	06	1.360	1480	999.55	4.56	1.47
286	06	1.360	1500	999.43	4.44	1.49
287	06	1.360	1840	999.30	2.95	1.83
293	06	1.360	1488	998.26	4.52	1.48
296	06	1.360	1480	997.59	4.57	1.47
298	06	1.413	1500	997.10	4.45	1.49
299	06	1.413	1666.66	996.84	3.61	1.66
303	06	1.423	1613.33	995.70	3.85	1.60

With change in temperature Total Dissolved Salts (TDS) 1060 of Tap water does not vary, which might be because of salts not getting dissolved at higher temperature (table 1).While in RO water with increase in temperature minor variations are coming in TDS (74 ~ 116), as shown in Table 2, and since pure distilled water is almost free of salts , no variation in TDS was observed even at higher temperatures (table-3).

Refractive index did not show variation for Tap water, but minor changes (1.349 ~ 1.414) were observed in RO water Table 2, and in distilled water it varied between (1.36 ~ 1.423), Table 3. Since, Abbe's refractometer is a very sensitive apparatus, variation in refractive index could be due to the presence of dust particles in almost pure water (RO and Distilled), while Tap water already carries highest amount of TDS, hence variations were not observable [22].

As shown in figure 1a, **ultrasonic velocity** varies between 1400m/s to 1520m/s for Tap water , major increase in ultrasonic velocity takes place in the temperature range 285 to 286 K, where velocity changes from 1480m/s to 1520m/s. For RO water Figure 1b, the ultrasonic velocity varies between 1440 to 1600 m/s. Highest value was observed at 294K, where TDS was 116 and lowest value was observed at 288K and 291K.For distilled water Figure 1c, ultrasonic velocity varied between 1416m/s to 1840m/s. Highest value was observed at 287K and lowest at 284K.

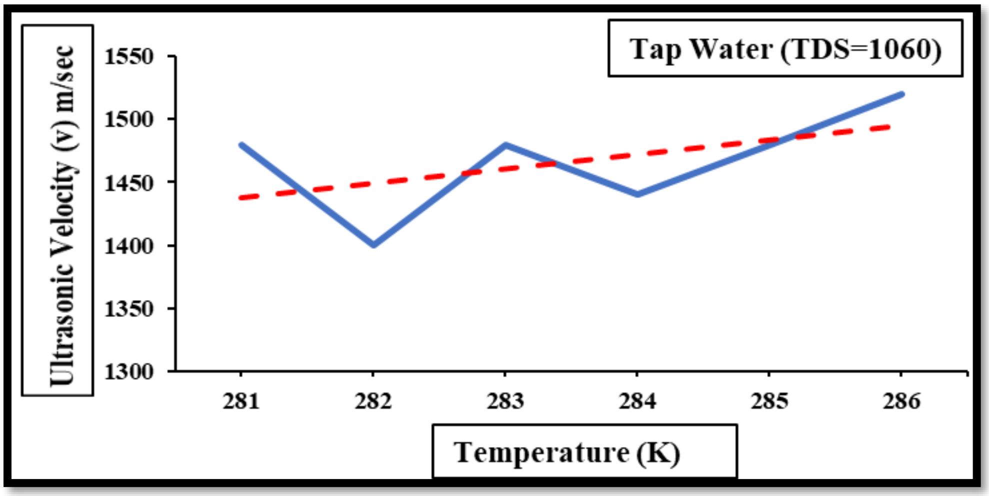

Figure 1a: Variation in ultrasonic velocity with temperature for Tap water.

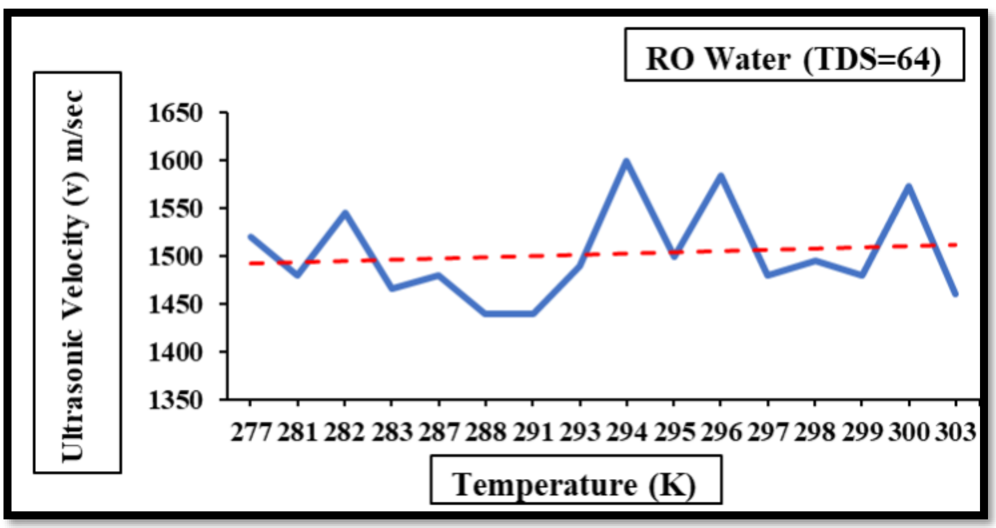

Figure 1b : Variation of ultrasonic velocity with temperature for RO water.

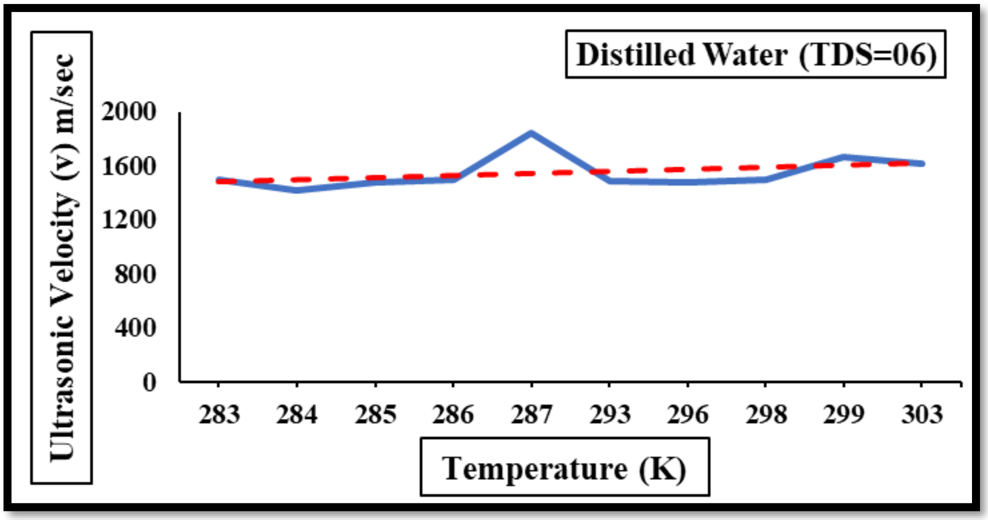

Figure 1c: Variation of ultrasonic velocity with temperature for Distilled Water .

Density depends on mass and volume, [23,24] temperature variations lead to changes in molecular associations, resulting in changes in mass and volume and hence density variations are reported in Tables 1, 2 and 3, for the three water samples. Under a set of experimental conditions the values of the three water samples , are affected by Total Dissolved Salts and Temperature.

Adiabatic Compressibility variation for Tap water as shown in figure 2a varies between 4.37×10^{10} to $5 \times 10^{10} m^2/N$. Lowest value was observed at 286K and highest at 282K. Figure 2b shows variation for RO water , carrying a TDS of 74. In temperature range (291 K – 294K) the graph shows a dip , while in the rest of the temperature range , the compressibility is constant. Trendline also shows a constancy throughout.

In this case adiabatic compressibility varied between 3.9×10^{10} to 4.84×10^{10} m^2/N. Lowest value was observed at 294K with TDS of 116 and highest was observed at 291K with TDS of 83.

Similarly for distilled water the adiabatic compressibility range varied from 2.9×10^{10} to 4.9×10^{10}. Lowest value as observed at 287K and highest was observed at 284K, TDS remaining same as shown in 2c.A sharp dip was observed in the graph at 287K, while the trendline followed a pattern of minor decline.

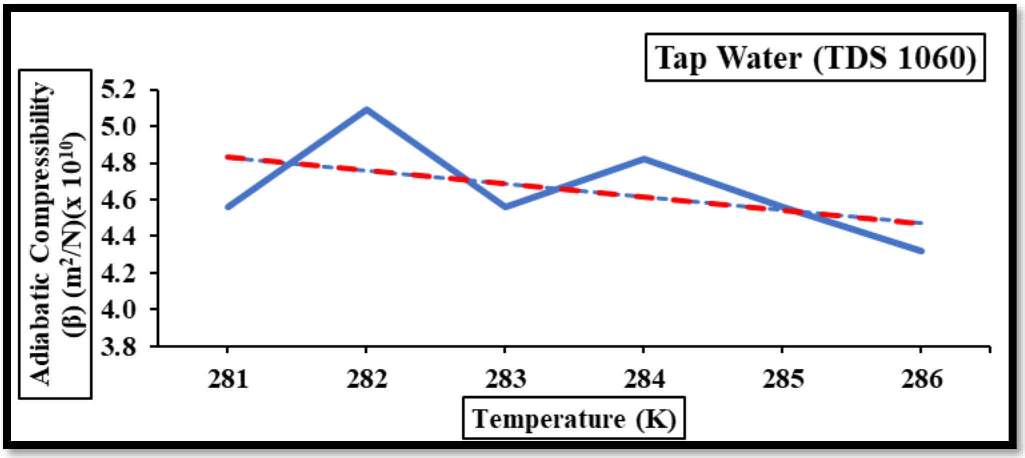

Figure 2a: Adiabatic compressibility with the function of temperature for tap water

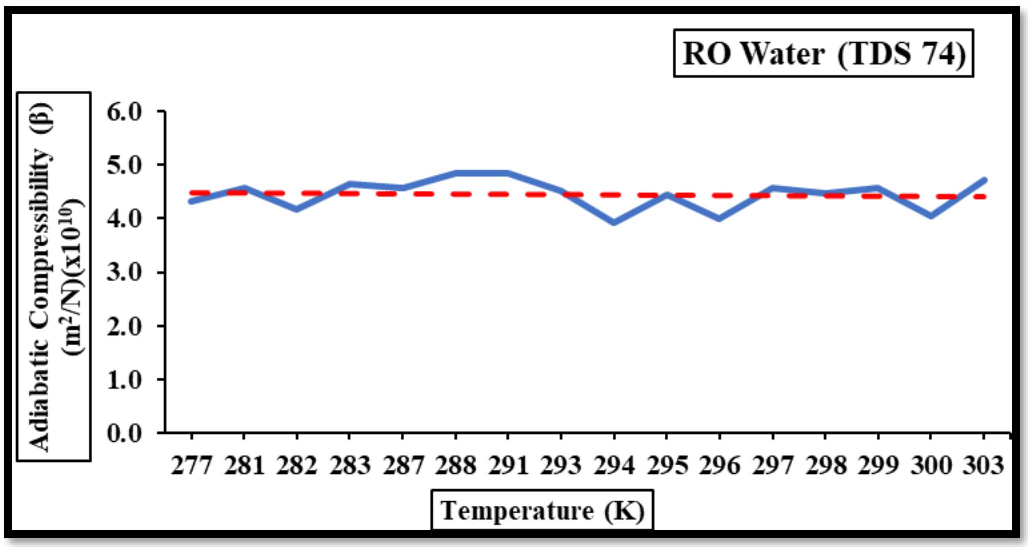

Figure 2b: Adiabatic compressibility with the function of temperature for RO water.

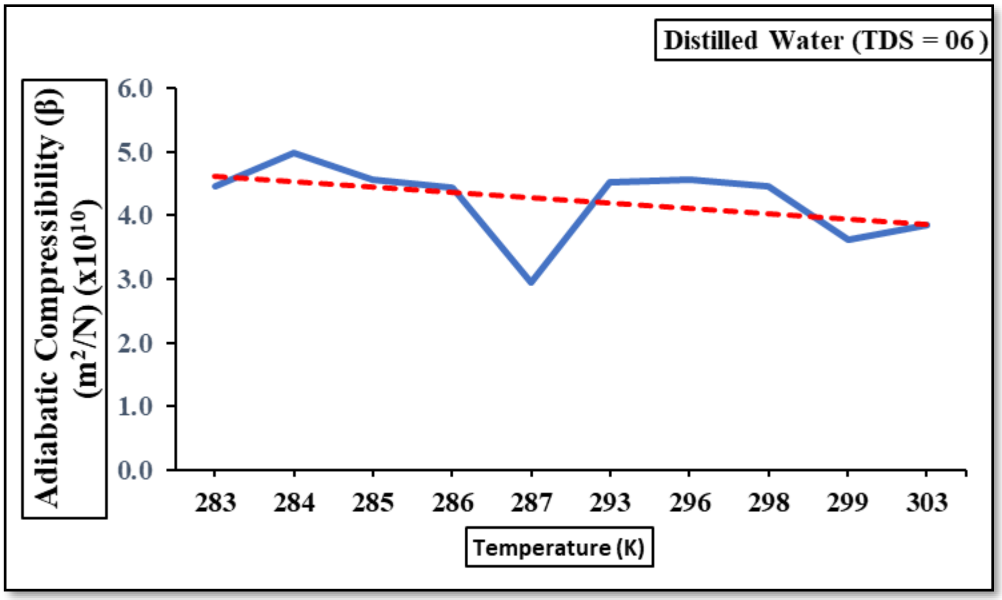

Figure 2c: Adiabatic compressibility with the function of temperature for Distilled water

Acoustic Impedance: variation's are shown in Figures 3a, 3b and 3c for the three water samples. For Tap water it varied between 1.4 MPa to 1.5MPa. Highest value was observed at 286K and lowest at 282K , no major variations were observed for Tap water. For RO water adiabatic compressibility varied between 1.43 to 1.59 MPa. Lowest value was observed at 291K with TDS of 83 and highest value was observed at 294K with TDS 116. Figure 3c shows variation of adiabatic compressibility for distilled water , variation is between 1.41 MPa to 1.83MPa, lowest reported value was at 284 K and highest at 287K with TDS remaining same throughout.

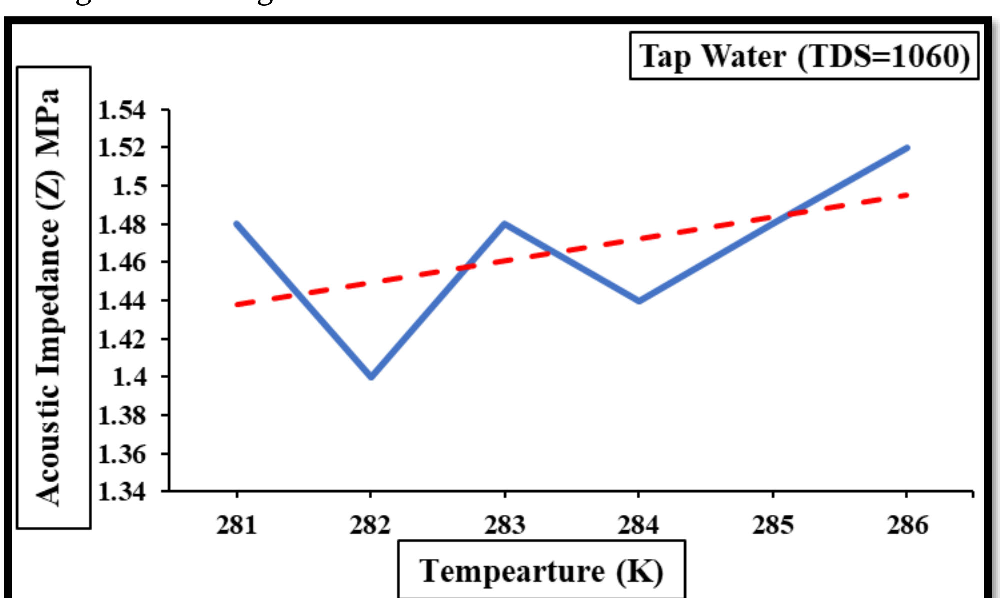

Figure 3a: Variation of acoustic impedance with temperature for Tap Water.

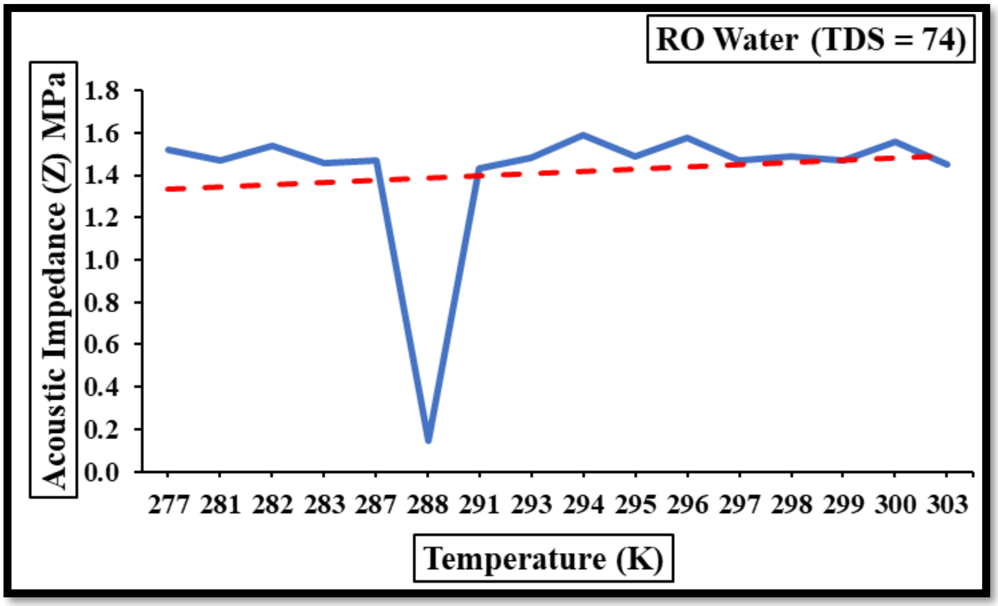

Figure 3b: Variation of acoustic impedance with temperature for RO Water.

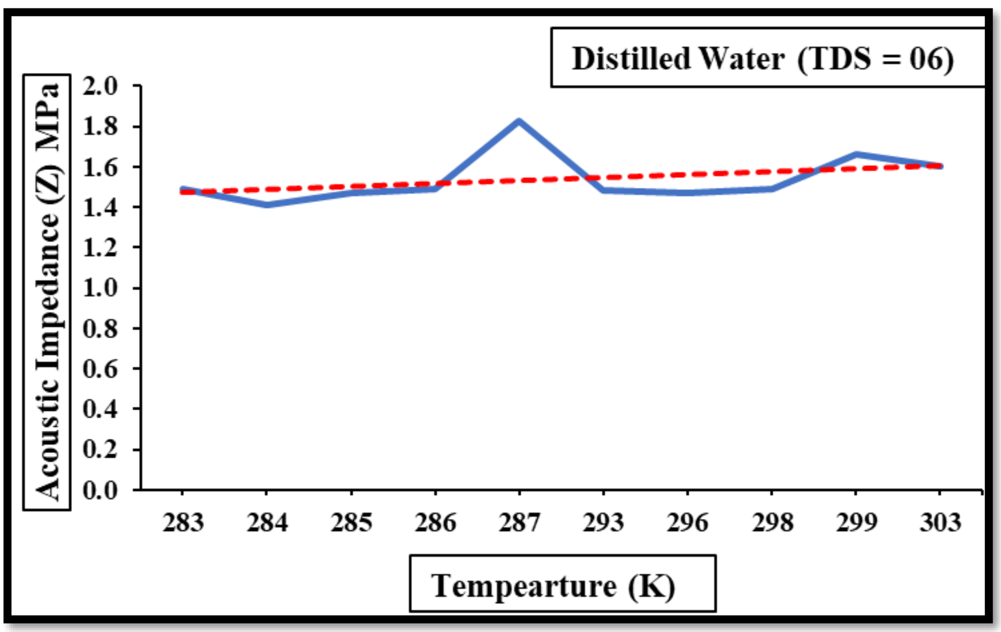

Figure 3c: Variation of acoustic impedance with temperature for Tap Water.

3.1 Multiple Regression Analysis in Excel

While doing analysis with regression analysis [25] TDS was taken as independent variable and adiabatic compressibility as the dependent variable, regression analysis was performed for all the three samples, out of which positive correlation was found for tap water only while the other samples RO and distilled showed negative correlation.

Regression Statistics

Regression Statistics was applied to find the relation between adiabatic compressibility and TDS (Total Dissolved Salts) of the three water samples. The regression statistics for all three water samples(Tap water, RO water and Distilled Water) where temperature was taken as independent variable and adiabatic compressibility was taken as dependent variable showed very poor correlation. The correlation coefficient R, which measures the strength between the two variables (temperature and adiabatic compressibility) was found to be very poor 23% for Tap Water, approximately 0% for RO water, and 8 % for distilled water.

Also, the F value (significance F), which states that if F value is less than 0.05 (5%) then model is acceptable. For all the three water samples F value was greater than 0.05 (0.26 for tap Water, 0.77 for RO water, 0.44 for distilled water, hence rejecting the possibility of correlation between temperature and adiabatic compressibility.

Regression Statistics yielded positive result for correlation between TDS and adiabatic compressibility for tap water. The correlation coefficient R was found to be 0.61(61%) and the F value (significance F) was found to be 0.034 (less than 0.05), this model finally passes the statistical test and comes under category of being acceptableas summarized in Table 4.

Table 4 Regression Statistics between Tap Water and Adiabatic Compressibility

Regression Statistics	
Multiple R	0.790
R Square	0.625
Adjusted R Square	0.550
Standard Error	0.165
Observations	7

The R-squared value of 62, indicates that our model accounts for 62% of the dependent variable's variance. Usually, higher R-squared values are better. F value which shows that whether the model is acceptable or not (value should be less than 0.05), also passes the test of acceptability.

The standard error which shows how certain one can be of result, smaller the number, more certain one can be of result is 0.16, showing that the result comes in the range of being acceptable (smaller the number the more certain one can be of result).

Table 5 ANOVA Statistics for Tap Water and Adiabatic Compressibility

	Df	SS	MS	F	Significance F	df
Regression	1	0.227650155	0.227650155	8.339279392	0.034275401	Regression
Residual	5	0.136492702	0.02729854		5.09	Residual
Total	6	0.364142857			4.56	Total

In the ANOVA Table 5, for Tap water the F- test for overall significance, significance F is 0.03 (< 0.05) which shows that the model is acceptable.
Our p-value for the overall F-test is 8.33783E-09. (8.33×10^{-9}). Since the value is too small, use of scientific notation has been done , where in E-09, means that, we need to move the decimal point 09 places to the left. Hence, we can conclude that our regression model as a whole is statistically significant.
We included variables in our model: TDS and Adiabatic Compressibility. The coefficient is approximately 4.64. The positive sign indicates that as TDS increases, adiabatic compressibility also tends to increase. There is a positive association between these two variables. For every one-unit increase in TDS, compressibility increases by an average of 4.64.

4 Conclusions

Till date literature survey shows that liquids (specially water) has very minute or almost nil compressibility, because of this reason compressibility of water is neglected in mathematical calculations. In our study we took water samples with varying TDS and after finding the ultrasonic velocity, computed the adiabatic compressibility and acoustic impedance, with varying temperature. When statistical analysis was performed and regression model applied, negative correlation was observed between TDS and adiabatic compressibility, for RO and distilled water but for tap water positive correlation was observed.Also, no correlation was observed between temperature and adiabatic compressibility.The work paves way for further studies on relation between varying salt content and adiabatic compressibility, leading to growth of new technology based on application of compressibility of liquids like hydraulics etc. Also, mathematically new equations can be framed showing mathematical relation between salt and adiabatic compressibility in liquids, as this field remains yet to be explored.

Authors' contributions: Divya Ghildyal wrote the main text after doing the experimental work on the laboratory set up at institute, while Manisha Chaudhary prepared the tables, statistical analysis and formatting part. All authors reviewed the manuscript.

Funding: No funding was received for conducting this study.

Declarations:

Conflicts of interest/Competing interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Data availability

The dataset on ultrasonic velocity, temperature, refractive index is available with the author. As these experiments have been duly performed in the laboratory by the author.

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