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Correlation between conductivity and total dissolved solid in various type of water: A review

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Abstract. Conductivity (EC) and total dissolved solids (TDS) are water quality parameters, which are used to describe salinity level. These two parameters are correlated and usually expressed by a simple equation: TDS = k EC (in 25 ^{0}C). The process of obtaining TDS from water sample is more complex than that of EC. Meanwhile, TDS analysis is very important because it can illustrate groundwater quality, particularly in understanding the effect of seawater intrusion better than EC analysis. These conditions make research in revealing TDS/EC ratios interesting to do. By finding the ratio value, TDS concentration can be measured easily from EC value. However, the ratio cannot be defined easily. Previous research results have found that the correlation between TDS and EC are not always linear. The ratio is not only strongly influenced by salinity contents, but also by materials contents. Furthermore, the analysis of TDS concentration from EC value can be used to give an overview of water quality. For more precision, TDS concentrations need to be analyzed using the gravimetric method in the laboratory.

1. Introduction

Conductivity or electrical conductivity (EC) and total dissolved solids (TDS) are frequently used as water quality parameters, especially in the coastal area. These two parameters are indicators of salinity level which make them very useful as one way in studying seawater intrusion [1–4]. The value of EC and TDS are correlated [5–7]. EC is the measure of liquid capacity to conduct an electric charge [6,8]. Its ability depends on dissolved ion concentrations, ionic strength, and temperature of measurements [9]. The dissolved ions concentration is usually measured as TDS.

EC can be measured easily and inexpensively in situ by a portable water quality checker. On the other hand, the analysis of TDS is more difficult and expensive as it needs more equipment and time [10]. However, TDS analysis is very important and principal because it can illustrate groundwater quality, particularly in understanding the effect of seawater intrusion better than EC analysis [11]. Hence, researchers have done various investigations to find out the precise mathematical correlation between these two parameters, so TDS concentration can be simply calculated from the EC value. The correlation of these parameters can be estimated by the following equation:

$$\mathrm{TDS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) = \mathrm{k\ x\ EC}\left(\frac{\mu\mathrm{S}}{\mathrm{cm}}\right) \qquad (1)$$

The value of k will increase along with the increase of ions in water. However, the relationship between conductivity and TDS is not directly linear; it depends on the activity of specific dissolved ions average activity of all ions in the liquid, and ionic strength [9,12,13].

Previous studies to determine mathematical relationship between EC and TDS have been done decades ago [9,14,15]. In 1970, the ratio of TDS/EC (k value) for natural water was formulated [14]

(Table 1). Furthermore, later investigation [9] showed similar result with the former [14]. Even though those results become references for further research, but the results were not detailed enough because of the span of EC that was too large. The values spanned from fresh to brackish water, and have not yet explained k value for higher salinity.

Additionally, in 1989 a more detailed relationship between these two parameters was published [15]. As shown in Table 1, the author classified the correlation between EC and TDS by its salinity which has not been classified before [9]. Walton provided specific k value for a special range of EC.

Table 1. Correlation EC and TDS in various type of water.

EC in 25 ^{0}C	Ratio TDS/EC (k)	Source
Natural water for irrigation	0.55 - 0.75	[14]
Natural water, EC $= 500 - 3{,}000\ ^{\mu S}/_{cm}$	0.55 – 0.75	[9]
Distillate water, EC $= 1 - 10\ ^{\mu S}/_{cm}$	0.5	[15]
Freshwater, EC $= 300 - 800\ ^{\mu S}/_{cm}$	0.55	
Seawater, EC $= 45{,}000 - 60{,}000\ ^{\mu S}/_{cm}$	0.7	
Brine water, EC $= 65{,}000 - 85{,}000\ ^{\mu S}/_{cm}$	0.75	

TDS and EC ratio cannot be defined easily. Thus, the research on this subject continues until now with various modifications of research methods. This paper presents a review of the relationship between TDS and EC for various types of water.

2. TDS and EC

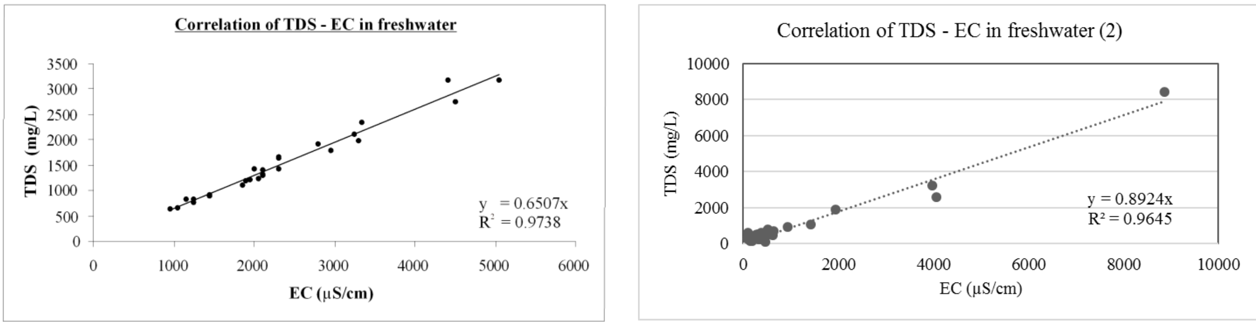
TDS concentration describes the present of inorganic salts and small amounts of organic matter in water and EC is the measure of water capacity to conduct electrical current [16]. The sources of material in TDS and EC can come from nature, i.e. geological condition and seawater, and from human activities, i.e. domestic and industrial waste and also agriculture [6,17–19].

There are many standards that govern TDS and EC in water. For health reason, desirable limit for TDS is between 500 mg/L and 1,000 mg/L and for EC is no more than 1,500 μS/cm [20]. Other quality standards classify these parameters based on salt content or salinity level [21,22]. TDS has also been classified into four types: type I is freshwater with TDS < 1,000 mg/L; type II is brackish water with TDS between 1,000 and 10,000 mg/L; type III is saline water with TDS from 10,000 till 100,000 mg/L; and type IV is brine water with TDS > 100,000 mg/L [21]. Hence, water classification based on EC, according to Rhoades (1992) [22], is divided into 6 types: type I is non-saline, if EC < 700 μS/cm; type II is slightly saline, if EC rely between 700 and 2,000 μS/cm; type III is moderately saline, if EC higher than 2,000 and less than 10,000 μS/cm; type IV is highly saline with EC value from 10,000 till 25,000 μS/cm; type V is very highly saline, if EC value between 25,000 and 45,000 μS/cm; and type IV is brine water with EC more than 45,000 μS/cm.

3. TDS/EC ratio

3.1 TDS/EC ratio in fresh water

Freshwater in this paper is defined as water that is uncontaminated, especially by human activities. The water samples of freshwater were taken from shallow groundwater from two locations. The main difference between the two locations is the EC value; in the first location the EC value is less than 6,000 μS/cm, while in the second location the EC value is higher up to 10,000 μS/cm. The samples from the first location were analyzed in 2009 [23]. The parameter analyzed is not only for EC and TDS, but also for major ions that are related to EC and TDS. Then, the samples from the second location were taken by the author. The correlation between these parameters is shown in figure 1a and 1b.



a. b.

Figure 1. TDS – EC correlation in freshwater.

Figure 1a shows that TDS/EC ratio in freshwater is 0.65 (R^2 = 0.97) or can be written as equation 2:

$$\mathrm{TDS} = 0.65 \text{ x } \mathrm{EC} \tag{2}$$

This value is among the range which has been published [9]. Whereas Figure 1b shows a higher ratio between TDS and EC with almost the same correlation (R^2 = 0.96). The equation for Figure 1b can be expressed as equation 3:

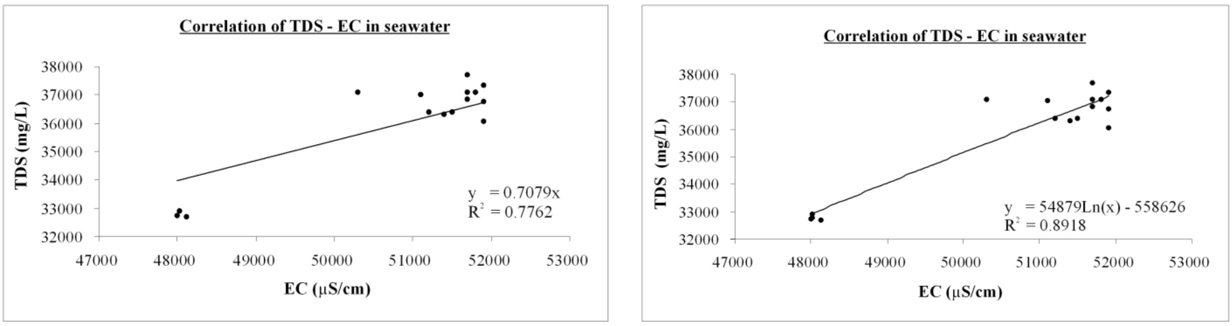
$$\mathrm{TDS} = 0.89 \text{ x } \mathrm{EC} \tag{3}$$

This difference indicates that the correlation of both parameters is strongly influenced by the EC values. Even so, all the findings are in agreement with the conclusion drawn by McNeil and Cox (2000) [24] in which the obtained variation of TDS/EC ratio for freshwater can be vary 0.5 till ≥ 1.00 [24]. The type of freshwater is generally sodium, calcium, magnesium, bicarbonate type or calcium, sodium, bicarbonate, chloride type [24]. In line with this, it has been found that the most correlated major ions, especially to TDS, are chloride, sodium, and magnesium [23].

3.2 TDS/EC ratio in saline water

The samples for saline water were taken from seawater. Figures 2a and 2b represent TDS and EC correlation in linear regression and logarithmic equation respectively. TDS/EC ratio in the form of linear only gives the determination coefficient (R^2) 0.77, whereas in logarithmic equation R^2 value is bigger, that is 0.89. Thus, the ratio in saline water is best described by logarithmic equation [23]. By conducting logarithmic equation, the mathematical formula between TDS and EC in seawater will fit equation 3.

$$\mathrm{TDS} = 54879 \ \mathrm{Ln(EC)} - 558626 \tag{4}$$



a. Linear b. Logarithmic

Figure 2. TDS- EC correlation in saline water [23].

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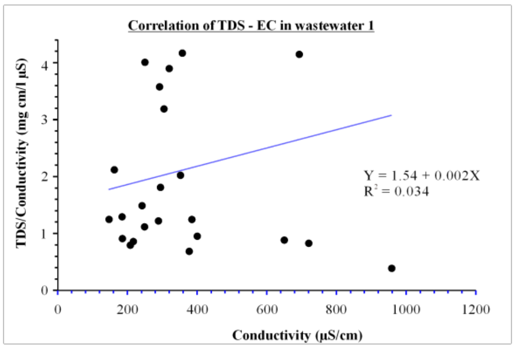
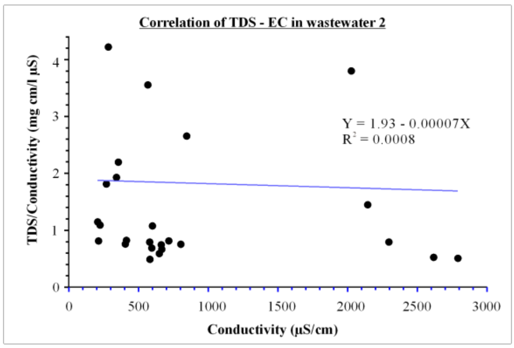
The type of saline water is usually dominated by sodium and chloride [18,25–28]. Other than cations and anions, organics are also associated with TDS but only in small quantities.

3.3 TDS/EC ratio in wastewater

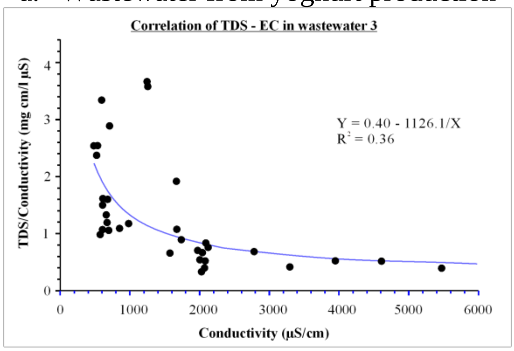
Wastewater samples were taken from food industry that have high organic load [29]. Wastewater samples were collected from different manholes. Wastewater 1, 2, and 3 came from milk and yoghurt productions, cheese production, and mix of both wastewater respectively. Lastly, the last sample was from treated wastewater.



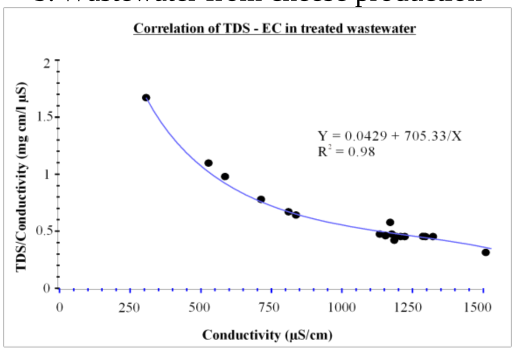
a. Wastewater from yoghurt production



b. Wastewater from cheese production



c. Wastewater from yoghurt and cheese production



d. Treated wastewater

Figure 3. TDS- EC correlation in wastewater [29].

Figures 3a, 3b, and 3c show very low value of R^2, which means there is no clear correlation between TDS and EC. However, figure 7 indicates a strong correlation between TDS and EC (R^2 = 0.98) and non-linear relationship. Unlike natural water or freshwater, the correlation between TDS and EC in wastewater cannot be described well (fig. 3a-3c) because the water is heavily influenced by many contaminants. Nevertheless, after the wastewater has been treated, the correlation between these two parameters becomes stronger with the TDS/EC ratio around 0.64 [29]. In addition, this ratio does not seem so different with the research result from Hem [9], Thirumilini [23], and McNeil and Cox [24].

4. Conclusions

EC and TDS are water quality parameters which indicate level of salinity. The measurement of EC value is far easier than the one of TDS. Meanwhile obtaining TDS concentration is principal because it can explain the water quality in a more complex manner than only from the EC value. Therefore, the calculation of TDS value based on EC value is very useful in doing water quality research. Numerous research have been conducted to find out the ratio between these two variables. The results of existing studies generally indicate the value of the TDS / EC ratio is in a particular range. Moreover, the

relationship between TDS and EC is not always linear. This situation highly depends on water salinity and material contents. The higher the salinity level or material contents, the more complex mathematical equations needed in describing those parameters. The strongest correlation between TDS and EC is found in natural water. Lastly, the acquisition of TDS from EC conversion can be conducted in explaining general condition of water quality. However, for deeper analysis, the TDS concentration is better conducted in a laboratory by applying gravimetric analysis.

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