

# A Study on the Utility of Electrical Conductivity as an Index of Quality of Irrigation Water\*

by

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**Synopsis:** In this paper, the author reports that the determination of EC alone in water samples does not enable soil chemists declare categorically a water sample, "Good" "Permissible", "Doubtful", or "Harmful" from the point of view of irrigable suitability and that the determination of individual anions and cations as inevitable for the valuation of irrigation water.

**Introduction:** In a predominantly agricultural country like India, the role of Irrigation projects, and underground sources of water like wells, in pushing up food production needs no emphasis. It has been reported that in the Thanjavoor district in Madras State, the underground sources of water are going to be tapped for the purpose of providing irrigation facilities during Summer also. Hence it can be expected that a good number of water samples of ryots will flow to the Soil Testing Laboratories for the determination of their suitability for irrigation. At present in the Soil Testing Laboratories of this State, the quality of water is judged, only by the EC and pH. The following three categories of water based on the Electrical conductivity are employed as yardsticks for determining the quality of water in the Soil Testing Laboratories. (1) EC upto 1.00 Harmless. (2) EC from 1.00 to 3.00 Critical. (3) EC from 3.00 and above Injurious. In the present study an attempt has been made to show that the determination of EC alone in water samples does not enable a Soil Chemist to declare categorically a water sample, "Good", "Permissible", "Doubtful", or "Harmful" from the point of view of irrigable suitability.

**Review of Literature:** Asghar and Dhawan (1947) obtained significant correlations between the Electrical conductivity values and total solids content of ground waters. The United States Department of Agriculture (1954) also reported a similar relationship between total solids and electrical conductivity values. Sree Ramulu (1962) reported that the Electrical conductivity value was highly correlated with the three anions, Chlorides, Sulphates and Bi-carbonates or with the first two anions, Chlorides and Sulphates taken together. Kelley (1963) observed that neither conductivity nor total concentration is, as expressed by parts per million, especially meaningful, for neither reflects the actual composition of water, and there simply is no substitute for chemical analysis.

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**Materials and Methods:** The Electrical conductivity, and pH, were determined for 32 water samples, besides the detailed analysis of the same for various cations and anions. The Electrical conductivity values obtained for the 32 water samples analysed, were critically examined as to their suitability for evaluating the quality of the water samples for irrigation.

For this, both inductive and deductive methods of reasoning were employed. In the inductive method, theoretical equations were derived from the already established facts, and tested with the data available, by the statistical methods. In the deductive process, the classifications were made, based on EC alone and the nature and amount of ions present.

**Results and Discussion:** The thirty two water samples in which the EC and pH were determined, were also analysed for the various cations ( $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ) and anions ( $\text{CO}_3$ ,  $\text{HCO}_3$ ,  $\text{SO}_4$ ,  $\text{Cl}$ ,) by employing the methods of analysis proposed by the United States Department of Agriculture (1954). The data thus obtained for the various cations and anions are furnished in Table I. The difference between the total of anions and that of cations has been taken as the value for Sodium.

**Inductive Method:** The Electrical conductivity of water samples is mainly contributed by solids and the salts are mainly  $\text{CO}_3$ ,  $\text{HCO}_3$ ,  $\text{Cl}$ ,  $\text{SO}_4$  of Na, K, Ca, and Mg and these salts are highly dissociated and exist as ions. The total Electrical conductivity of a sample is therefore made up of contributions from different ions. According to the Kohlrausch's law of Independent migration of ions, each ion contributes a definite amount of conductance to the total amount of conductance, irrespective of the nature of other ions. This law is strictly true in ideal solutions but at moderate concentrations, the law may be expected to hold good at the accuracies needed for routine work.

The conductance contributed by each ion may be arrived at from the following equation.

$$\Lambda = \Lambda_0 - (A + B \Lambda_0) c \quad \dots \dots \dots (1)$$

$$\Lambda = \Lambda_0 - A \sqrt{c} \quad \dots \dots \dots (2)$$

where  $\Lambda_0$  is the equivalent conductance at infinite dilution and  $\Lambda$  is the equivalent conductance at concentration C in Gms equivalent / lit; A and B are constants depending on the nature of solvents and ions; and  $K$  conductance =  $[\Lambda - A \sqrt{c}] C / 1000$  where C is the concentration in Gram equivalents/litre. Therefore, approximately the conductance of a solution containing different ions is equal to

$$K = \frac{[\Lambda_1 + A_1 \sqrt{c_1}] c_1}{1000} + \frac{[\Lambda_2 - A_2 \sqrt{c_2}] c_2}{1000} \dots \dots \dots \frac{[\Lambda_n - A_n \sqrt{c_n}] c_n}{1000} \quad (3)$$

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TABLE I  
Results of Analysis of Water samples.

No.	Details of Samples	EC	pH	Total Solids in ppm.	Meq / Litre						Na	SAR	Class
					CO <sub>3</sub>	HCO <sub>3</sub>	Cl	SO <sub>4</sub>	Ca	Mg			
1.	Sample No. 1	1.1	7.0	962	Nil	8.3	6.0	1.5	5.4	5.8	4.6	1.95	C <sub>3</sub> -S <sub>1</sub>
2.	"	0.9	7.5	670	0.8	6.6	3.0	1.2	1.9	2.1	7.7	5.46	"
3.	"	0.8	7.2	630	0.8	4.9	3.0	1.0	1.8	3.4	4.5	2.81	"
4.	"	0.8	7.8	820	1.4	6.8	4.0	1.7	2.2	4.1	7.6	4.30	"
5.	"	0.8	7.7	758	0.4	5.6	4.0	2.1	4.4	2.5	5.2	2.81	"
6.	"	0.5	7.5	440	1.0	6.4	1.0	0.7	3.8	4.1	1.9	1.02	"
7.	"	0.9	7.4	1064	1.2	7.9	1.6	1.4	1.1	6.8	4.2	2.11	C <sub>2</sub> -S <sub>1</sub>
8.	"	0.5	7.8	800	0.5	3.4	1.4	0.8	1.6	0.3	4.2	4.24	C <sub>3</sub> -S <sub>1</sub>
9.	"	0.3	7.9	850	...	5.7	1.4	0.4	3.5	1.4	2.6	1.62	C <sub>3</sub> -S <sub>1</sub>
10.	"	0.5	7.9	644	0.5	3.4	1.0	1.1	2.0	2.0	2.0	1.45	"
11.	"	0.6	7.7	520	0.6	3.7	0.6	0.2	1.2	2.1	1.8	1.43	"
12.	"	0.9	8.1	932	...	10.8	1.0	0.3	1.7	1.8	8.5	6.44	C <sub>3</sub> -S <sub>2</sub>
13.	"	0.7	8.0	964	1.0	6.9	1.6	3.8	0.3	2.2	10.8	9.72	C <sub>2</sub> -S <sub>2</sub>
14.	"	0.6	8.2	704	2.4	6.3	1.9	0.2	1.0	1.8	8.1	6.82	C <sub>2</sub> -S <sub>1</sub>
15.	"	0.3	8.0	754	1.8	4.2	1.6	1.3	0.8	3.1	5.0	3.58	"
16.	"	0.7	7.5	388	1.0	2.2	2.3	0.9	1.1	4.1	1.2	0.71	"
17.	"	0.6	7.4	790	1.8	2.7	2.7	0.5	1.1	4.1	2.5	1.53	"
18.	"	0.7	7.0	760	2.4	3.8	1.4	0.5	1.0	0.6	6.5	7.27	C <sub>2</sub> -S <sub>2</sub>
19.	"	0.5	7.2	364	1.2	2.5	2.1	1.1	0.9	0.7	5.3	5.90	C <sub>2</sub> -S <sub>1</sub>
20.	"	0.4	7.2	274	0.6	4.4	2.7	0.6	1.1	0.5	0.7	7.42	"
21.	"	0.9	7.8	462	3.0	4.9	10.9	0.9	0.7	1.3	17.6	17.47	C <sub>3</sub> -S <sub>2</sub>
22.	"	0.5	7.8	304	1.6	3.0	2.7	0.3	0.8	0.7	6.1	6.95	C <sub>2</sub> -S <sub>1</sub>
23.	"	1.3	7.5	1000	1.2	8.2	5.0	1.4	2.9	3.6	9.3	5.15	C <sub>3</sub> -S <sub>1</sub>
24.	"	0.6	7.9	370	1.2	4.3	4.7	0.4	0.8	0.6	9.2	10.92	C <sub>3</sub> -S <sub>2</sub>
25.	"	1.6	7.7	1088	3.5	7.5	10.1	0.6	0.8	2.0	18.9	16.04	C <sub>3</sub> -S <sub>2</sub>
26.	"	0.9	7.5	714	1.4	6.7	7.0	0.7	0.6	2.3	12.9	10.63	C <sub>3</sub> -S <sub>2</sub>
27.	"	1.3	7.6	1000	1.2	9.7	5.0	1.7	4.1	2.4	11.2	6.20	"
28.	"	0.9	7.5	584	1.6	5.4	3.9	0.3	0.9	1.4	8.9	8.22	"
29.	"	1.0	8.2	1110	1.0	10.2	4.0	1.1	3.1	3.4	9.8	5.44	C <sub>3</sub> -S <sub>1</sub>
30.	"	0.6	7.8	202	0.6	3.4	4.3	0.8	1.7	0.7	0.7	6.06	C <sub>2</sub> -S <sub>1</sub>
31.	"	1.5	7.8	1114	1.4	9.6	2.8	2.1	3.5	5.2	7.2	3.45	C <sub>3</sub> -S <sub>1</sub>
32.	"	1.4	7.6	1310	1.6	10.2	2.8	1.8	3.9	4.4	8.1	3.95	"

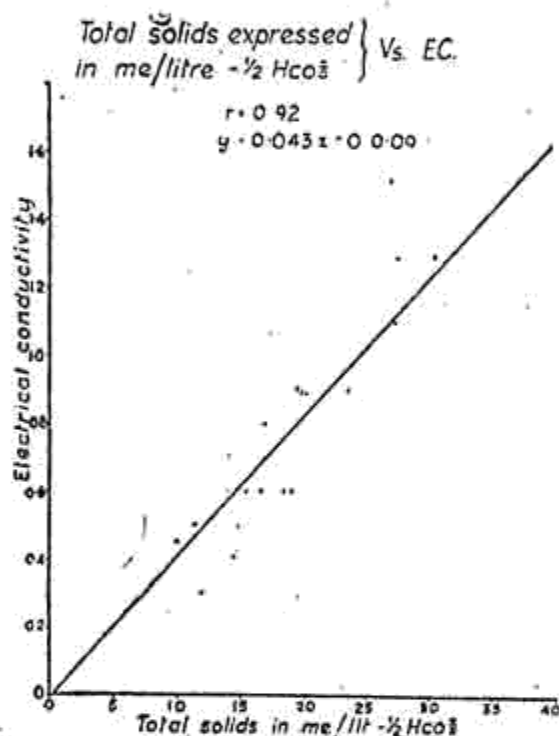
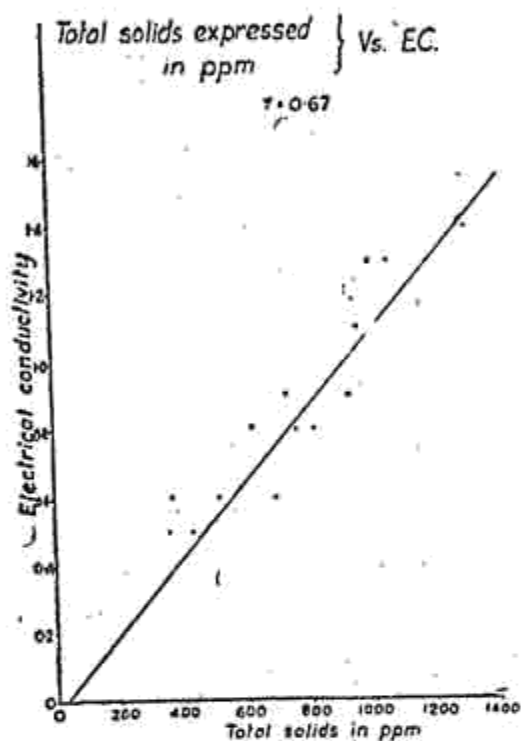
and for practical purposes it can be written as  $K = x_1 c_1 + x_2 c_2 \dots x_n c_n$  (4) where  $x_1, x_2, etc$  are proportional to the ionic conductivities at infinite dilution, and their rate of change of conductance with concentration or to the term  $\frac{[\Lambda - \frac{\Lambda}{\sqrt{c}}]}{1000}$  and  $c_1, c_2$  are concentrations of different ions expressed on equivalent basis. But at accuracies needed for routine work, the contributions by the cations Na, Ca, and Mg may be taken as equal since their magnitude of ionic conductivities are of the same order. Similarly the magnitude of ionic conductivities of Cl,  $SO_4$  and  $CO_3$  are of same order while that of  $HCO_3$  is approximately half of the former ions. (vide Table II). Hence if  $\frac{1}{2} HCO_3$  ion concentration is taken, so that its ionic conductivity may be set up at the same order of other ions, the  $HCO_3$  ionic concentration may be added to other ions for calculating the contributions by anions. Therefore for all practical purposes, the true conductance is contributed by total cations and by total anions  $-\frac{1}{2} HCO_3$  and it is possible to set up the theoretical equation of the type:  $x_1 c_1 + x_2 (c_1 - \frac{1}{2} HCO_3) = EC$  where  $x_1$  is the contribution by cations,  $x_2$  is the contribution by anions, and  $c_1$  is the concentration of cations in meq/litre.  $c_1$  is also the total number of anions as the system is electrically neutral, and  $\frac{1}{2} HCO_3$  ions in meq/litre is subtracted as the bicarbonate conductance is set at twice its normal level for inclusion with other anions. This type of equation thus derived for practical purposes is tested and multiple correlation calculated is high ( $R = 0.98$ ). Theoretically though it is possible to have  $R \rightarrow 1$ , as at moderate concentrations, the interionic attraction and other factors like incomplete dissociation occur, the correlation coefficient of 0.98 itself is high and justifies the assumptions made.

TABLE II.

*Ionic conductance at 'infinite dilution at 25 C ohm<sup>-1</sup> cm<sup>2</sup>'*

Ions	Equivalent conductance
Na <sup>+</sup>	50.11
Ca <sup>++</sup>	59.5
Mg <sup>++</sup>	53.1
$\frac{1}{2} CO_3$	83.0
$HCO_3$	44.5
Cl <sup>-</sup>	76.3
$\frac{1}{2} SO_4$	79.8

The total solids expressed in parts per million, for all the thirty two samples, the total solids expressed in me/lit and the total solids expressed in me/lit- $\frac{1}{2}$  HCO<sub>3</sub> were correlated with the Electrical conductivity values of these samples and the correlation coefficients thus obtained are furnished in Table III. It will be seen from the Table III, that the correlation coefficient obtained for the relationship, total solids- $\frac{1}{2}$  HCO<sub>3</sub> vs EC is 0.92, and is more than those obtained for the relationships total solids in ppm vs EC and total solids in me/lit vs EC (Vide Plates). This therefore



indicates that EC represents total milliequivalents of salts present rather than the total quantity of the salts. Therefore EC is a good measure of total milliequivalents of all ions, and half of them are cations and the other half being anions. As the contributions of all cations and anions are equal for all practical purposes, the use of EC to predict the nature of cations and anions is restricted, and is always to be discouraged. The relationship between EC and other individual ions may sometimes become significant when that particular individual ion shows large variation while others are maintained at about the same level. But they lack the theoretical basis and may fail when put to practical use. Therefore, it is seen that EC is not a good indicator of the nature of ions present and for a critical examination of water for the purpose of irrigation the analysis of individual ions is essential. If EC values of water samples are alone banked upon for the evaluation of quality of water, it will lead to dubious conclusions. Kelley (1963) has also observed that the evaluation of water based on its EC and total solids in parts per million is not sound like that of a detailed chemical analysis.

TABLE III.  
Statistical Analysis.

Correlation between x	y	r n-2=30	Significance at p =	Regression equation
1. Total solids in ppm	E. C.	0.67	.001	
2. Total solids in meq/lit		0.86	.001	
3. Total solids in meq/lit $\frac{1}{2}$ HCO <sub>3</sub>		0.92	.001	$y = 0.043 x - 0.09$
4. Total cations in meq/lit		0.86	.001	
5. Total anions in meq/lit		0.86	.001	
6. Total anions- $\frac{1}{2}$ HCO <sub>3</sub> in meq/lit		0.96	.001	$y = 0.062 x + 0.25$
<i>Multiple correlation :</i>				
7. Total cation x1 and Total anion- $\frac{1}{2}$ HCO <sub>3</sub> x2		0.98	.001	$y = 0.014 x_1 + 0.100 x_2 - 0.10$

*Deductive method:* Sodium adsorption ratios were worked out for all the thirty two water samples and they have been classified into different groups according to the monogram of Thorne and Peterson (1954) *vide* Table I. This classification has been compared with that of the Soil Testing Laboratories, which is based on EC alone. The distribution of samples in the different classifications are given in Table IV. According to the classification based on EC, twenty five samples are harmless and can be used for irrigation. But in the classification based on salinity and alkalinity, seven out of these 25 samples are harmful for irrigation as they would tend to develop alkalinity in the soil if proper, corrective measures are not adopted. Another five samples can be safely used for irrigation provided due allowance is made for leaching requirements in the consumptive use of water. Only 13 samples can be safely used without any precautionary measure. Hence the EC classification adopted in the Soil Testing Laboratories holds good only for the 50 per cent of the samples studied.

TABLE IV.  
Distribution of samples in the Different Classifications.

S. No.	C. E.	(Soil testing laboratories)	No. of samples	Classification based on Salinity & Alkalinity				
				c2s1	c3s1	c2s2	c3s2	c3s3
1.	0-1	Harmless	25	13	5	3	3	1
2.	1-3	Critical	7	—	5	—	1	1
3.	above 3	Injurious	—	—	—	—	—	—

**Summary and conclusions:** Thirty two water samples were analysed for their chemical composition of dissolved salts, including EC and pH. The utility of EC in the interpretation of quality of water is critically examined both by inductive and deductive processes. In the inductive process, it has been shown that the EC represents only the total milliequivalents of cations and anions present in the water samples, and it is not influenced by the nature of cations and anions. In the deductive process, the classifications based on EC and salinity and alkalinity are compared. Here also it is seen that EC does not throw full light on the quality of irrigation water.

Therefore it is seen that the EC is not a good criterion for judging the suitability of irrigation water and the determination of individual anions and cations is inevitable for the evaluation of irrigation water.

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