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Prediction of Irrigation Water Salinity by Means of Hydrometry

F. Khorsandi[1*] and F. Alaei Yazdi[2]

ABSTRACT

Salinity is the primary water quality concern in irrigated agriculture. An Electrical Conductivity (EC) meter and a hydrometer are two possible methods for measurement of irrigation water salinity. The conductivity meter method is based on measuring the amount of electrical current that a fluid will support. Although it is the most widely used method, the instrumentation is rather expensive and in some instances may require sample dilution. The hydrometer method is based on measuring the density of the fluid. The main objectives of this study were to compare these two methods and, based on hydrometer method, develop empirical models for prediction of EC, sodium adsorption ratio (SAR), and the principle ion concentrations in the irrigation waters of Yazd Province, Iran. The electrical conductivity, temperature, and density of 206 water samples from wells across Yazd Province were measured. Temperature correction factors for adjusting the hydrometer reading to 25 ^oC were determined. The correlation between EC and hydrometer readings was high (R^2 = 0.97). Although the empirical model developed for prediction of EC slightly underpredicted the measured values, it is still accurate enough for practical purposes. Hydrometer readings were also highly correlated with the principle ions and SAR. The salt type also affected the hydrometer readings. Magnesium sulfate solution had the highest density among the major salt types present in irrigation waters. Finally, a chart was developed for rough estimations of EC, sodium and chlorine concentrations in irrigation waters of Yazd Province, Iran.

Keywords: Conductivity meter, Electrical conductivity, Hydrometer, Salinity.

INTRODUCTION

An adequate water supply of appropriate quality is an essential part of irrigated agriculture. Irrigation water quality depends on the amount and kind of salts present in the water. It can affect the physical, chemical, and biological properties of the soil, as well as the growth and development of crops. All irrigation waters contain varying amounts of different salts. The soluble salts originate mainly from dissolution or geochemical weathering of the rocks and soil minerals, such as lime, gypsum, and other slowly dissolved minerals (Ayers and Westcot, 1985). In most irrigation projects the primary water quality concern is the salinity level. Other characteristics of importance are pH and the sodium adsorption ratio (SAR). The major components of salinity are calcium, magnesium and sodium cations, and chlorine, sulfate and bicarbonate anions (Pratt and Suarez, 1990).

Several practical and useful guidelines for water quality evaluation are available. Some are proposed globally (Ayers and Westcot, 1985), while others are for regional use (Fipps, 1996., Glover, 1996). To use these guidelines as a management tool, laboratory determination and calculations are needed. Based on the available equipment, budget,

[1] Soil and water Research Institue, N. Kargar Avenue, Tehran, Islamic Republic of Iran.
[*] Corresponding author
[2] Yazd Agricultural Research Center, P. O. Box: 89195-315, Yazd, Islamic Republic of Iran.

and number of samples the most appropriate method should be selected and used. Analytical accuracy within 5 percent is considered adequate for these purposes (Ayers and Westcot, 1985).

The primary water quality concern for irrigation is the salinity level. Salinity is the total amount of dissolved salts in the water. Thus, to know the salinity of a water, its salt content should be determined. A conductivity meter is the method of choice for most professional water quality monitoring. The amount of electrical current that a fluid will support (conductivity) is proportional to the concentration of charged particles in that fluid. The more salt present in the water, and the higher the temperature, the better the water sample conducts electricity. This principle is the basis for the operation of a conductivity meter. The conductivity meter measures effectively the concentration of charged particles in a water sample, and reports it in units of salinity (dS m^{-1}). The electrical conductivity (EC) of water is temperature dependent. In the range of 15^o C to 35^o C, EC increases about 2% for each degree increase in temperature (Jurinak and Suarez, 1990). Therefore, for a valid comparison, all EC values are normalized to a temperature of 25 ^oC. The new models of conductivity meter are fast and directly give the EC in salinity units, as well as automatically compensating for temperature. Although conductivity meters have become more affordable, they are still too expensive. Depending on the model and its range, conductivity meters cost between $60 (for a simple pocket size) up to $3,000 depending on their capabilities (Bergstrom, 2002). If the EC of the water solution is out of the range of the conductivity meter, dilution is necessary, which is a potentiol source of error. In addition, EC meters require energy (i.e. a battery) and, in case of breakdown, the cost of repaire could be high.

Another less expensive method of measuring salinity is hydrometer method. Mainly marine scientists use this method routinely for measuring and monitoring sea and ocean water salinity. The density of a water sample can be measured by using a hydrometer. Water density, which is the amount of material per unit volume (g cm^{-3}), is proportional to its temperature and salinity. Since salt waters are more dense than fresh waters, objects float higher in them. This is the main principle behind using a hydrometer for salinity determination. Since the density of water changes with temperature, the values measured by a hydrometer should be corrected for temperature as well. The corrected readings can be converted to salinity by means of conversion tables. The cost of a hydrometer is about $25 (Bergstrom, 2002). Although using a hydrometer is not as fast as using a conductivity meter, it is still relatively rapid and simple to perform. The required equipment is inexpensive, and does not require sample dilution at very high salinity levels. This method can be used in the field, but, it requires clean water and a larger water sample volume than the EC meter.

Underground waters of different salinity levels are used for the irrigation of crop fields and orchards in Yazd Province, Iran. The salinity of some of the irrigation waters is as high as 23 dS/m, which is comparable to Caspian Sea salinity. Since some laboratories or individuals may not be able to afford to purchase expensive conductivity meters, a hydrometer can offer an alternative inexpensive, simple method of measuring the salinity of water.

The main objective of this study was to evaluate the usefulness of the soil texture hydrometer (found and used routinely in any soil and water analysis laboratory) for measuring the salinity of irrigation waters in Yazd Province, Iran. Other objectives of this study were: (i) to investigate the effects of temperature and salt type on hydrometer readings; (ii) to establish the relationship between hydrometer readings (HR) and water salinity measured by a conductivity meter; (iii) to compare hydrometer and conductivity meter methods; (iv) to develop and validate an empirical model for the estimation of irrigation water salinity by means of hydrometry for Yazd Province, Iran; and (v) to investigate the possibility of estimating other water quality parameters (anions, cations, and sodium adsorption ratio) by means of hydrometry.

MATERIALS AND METHODS

A total of 206 water samples from wells throughout the Yazd Province with different salinity levels were collected. Out of the total number of water samples, 171 samples were used for development of the empirical model and prediction of irrigation water electrical conductivity (EC_{iw}) from the hydrometer method. The rest of the water samples (35 samples) were set aside for validation of the empirical model.

The EC and temperature measurements of the samples, and the hydrometer readings were performed concurrently. A 250 ml graduated cylinder was filled with enough water so that a standard soil texture hydrometer could freely float. Then, the EC and temperature of the water were measured using a conductivity meter (WTW LF318 model), and a hydrometer (standard ASTM no. 152H with bouyoucos scale in g/l) was inserted immediately into the cylinder to read the density of the water sample. This type of hydrometer is readily available in any soil, water and plant analysis laboratory, since it is used as a standard method of soil texture determination (Gee and Bauder, 1986). The results were compared after temperature correction of the hydrometer reading for 25ºC. The salinity of water is reported as standard at 25ºC in dS/m. Thus, the hydrometer reading was also corrected for 25ºC.

Temperature Effect

Standard salinity hydrometers usually come with a set of tables for temperature correction and conversion of the readings to salinity. Since in this study one of the objectives was to use basic equipment available in any laboratory, a soil texture hydrometer was used. Thus, it was necessary to establish the temperature correction factor (CF) for this type of hydrometer. Four water samples of different salinities (5, 10, 15 and 20 dS m^{-1}) were heated to about 60ºC, and then EC, temperature and hydrometer readings were recorded at different temperatures as the samples were cooling down to room temperature. Then the same samples were placed in a cold room, where they reached to a temperature of about 1ºC. Again, the EC, temperature and hydrometer reading were recorded as the samples were warming up to room temperature. A well water sample with the EC of 23 dS m^{-1} was diluted with enough deionized water to reach the desired salinity level. Thus the proportion of ions within each sample was the same for all four water samples. The data was used to develop correction factors for hydrometer readings. The hydrometer readings of the original 206 water samples were corrected for 25ºC (HR25) using the developed charts and equations.

Salt Type Effect

To examine the effect of salt type on the hydrometer reading, eight salt solutions with the salinity of 5.8 dS/m were prepared. The salts were $CaCl_2$, KCl, K_2CO_3, $KHCO_3$, $MgSO_4$, NaCl, $NaHCO_3$, and Na_2SO_4. Four samples of each salt solution were prepared as replicates. The temperature and hydrometer readings of all the solutions were recorded. The hydrometer readings were corrected for temperature. Mean comparisons were based on Duncan's Multiple Range Test (DMRT) (Steel and Torrie, 1980) which was performed using the SAS statistical program (SAS Institute, 1989).

Anions, Cations and SAR

Concentrations of the cations and anions of 132 water samples were determined.

Chlorine, sulfate, carbonate, and bicarbonate were the anions measured, and calcium, magnesium, and sodium were the cations. Levels of carbonate and bicarbonate were determined by the sulfuric acid titration method, chlorine by the silver nitrate titration method, sulfate by the acetone method, calcium and magnesium by the EDTA titration method and sodium by flame photometry. The sodium adsorption ratio (SAR), an important water quality parameter, was calculated by using the concentrations of Na, Ca, and Mg ions (Jurinak and Suarez, 1990).

The anion and cation concentrations and SAR were correlated with EC and HR25 by using the PROC CORR procedure of the SAS statistical program (SAS Institute, 1989). The purpose was to develop empirical models for predicting SAR and other ions from hydrometer readings for use in Yazd Province.

Data Set for Validation of the Models

To examine the accuracy of the empirical models developed for Yazd Province, 35 samples were randomly selected from the total number of water samples received. Temperature, EC and hydrometer readings (HR) of the samples were measured. Anion and cation concentrations of 16 samples were measured and SAR was calculated. The HR values were corrected for temperature. The HR25 values were used in the model to predict EC, SAR, and principle ions concentrations. The predicted values were graphically compared with actual measured values.

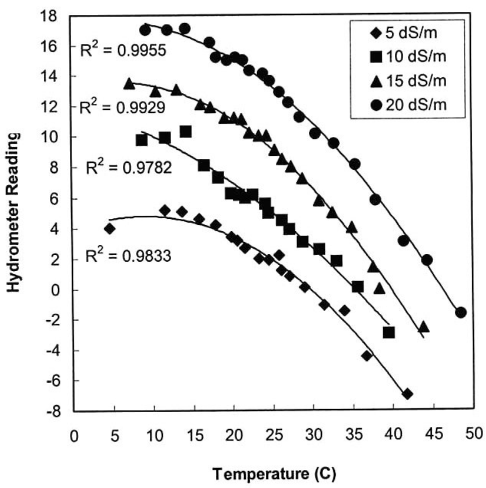

Figure1. Temperature effect on hydrometer readings at four salinity levels.

Table 1. Temperature correction factor for the bouyoucos hydrometer.

Temperature (°C)	CF[a]
15.0	-3.2
16.0	-3.0
17.0	-2.7
18.0	-2.4
19.0	-2.2
20.0	-1.8
21.0	-1.5
22.0	-1.2
23.0	-0.8
24.0	-0.4
25.0	0.0
26.0	0.4
27.0	0.9
28.0	1.3
29.0	1.8
30.0	2.3

[a] Temperature Correction Factor

RESULTS AND DISCUSSIONS

Temperature Effect

A hydrometer measures the density of the water sample, which is proportional to its total amount of dissolved salts or salinity. Since water density is temperature dependent, and the hydrometer reading (HR) should then be corrected for its effect. The electrical conductivity of irrigation water (EC_{iw}) and soil solution extracts are reported in dS/m at 25 ºC. Thus, it was attempted to correct the HR to 25 ºC (HR25), and then establish a relationship between HR25 and EC_{iw}.

The effect of temperature on density of the water solution (HR) at different levels of salinity is shown in Figure 1. The results indicate that temperature strongly influences the HR at all salinity levels. Generally, as the temperature increases, the density decreases and thus the hydrometer reading is lower. The trend and shape of graphs were similar at all salinity levels. Table 1 summarizes the correction factors for adjusting the hydrometer reading at a particular temperature to a reading of 25 ºC. The temperature of the water sample should be measured by a thermometer. Then, the CF for that temperature can be found in Table 1. The CF should be added to the HR to get the HR25 value. Also, CF can be calculated mathematically using Equation. [3]. This equation is the best fit equation for the graph of CF versus temperature.

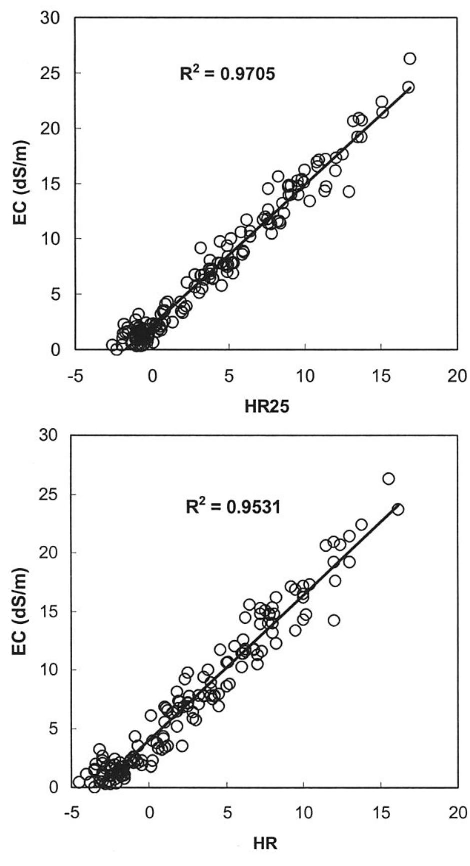

Figure 2. The relationship between the measured Electrical Conductivity (EC) and the Hydrometer readings corrected for 25°C (HR25) and uncorrected (HR) of the irrigation waters in Yazd Province, Iran.

Empirical Model for Prediction of EC_{iw}

There was a linear relationship between measured EC_{iw} and the hydrometer readings (Figure 2). The R^2 value, which is a measure of precision, was improved from 0.9531 for uncorrected HR to 0.9705 for temperature corrected HR. The empirical model for predicting the EC_{iw} in Yazd Province is:

$$EC_{iw} = 1.2622HR25 + 2.2485 \quad (1$$

$$HR25 = HR + CF \quad (2$$

$$CF = 0.0097T^2 – 0.0703T – 4.3227 \quad (3$$

$$EC_{iw} = 1.2622HR+0.01224T^2-0.0887T - 3.2076 \quad (4$$

In which HR is the hydrometer reading, HR25 is the HR corrected for 25 ºC temperature, T is the temperature of the solution (ºC) and CF is the temperature correction factor. It is reminded that the model is empirical and at the moment it is only intended for use in Yazd Province.

Validation of the Model

The electrical conductivity of 35 water samples with a wide range of salinity levels from wells across Yazd Province was measured directly (EC_{iw}), and estimated using Equation 4 (EC_p). Comparison of measured and predicted electrical conductivities is presented in Figure 3. The

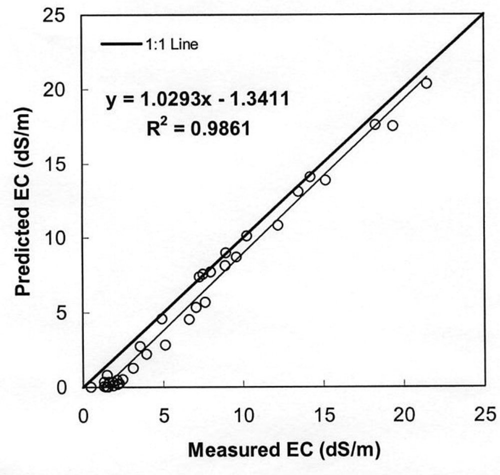

Figure 3. Comparison of the measured and predicted EC of the irrigation waters in Yazd Province, Iran.

Table 2. An example of the hydrometer reading and dominant salt type in irrigation waters of Yazd Province.

Sample #	EC_{iw} (dS/m)	HR25	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+
93	14.22	12.9	0	1.95	125.0	59.05	25.0	46.0	115
118	14.30	11.3	0	2.35	106.0	72.25	25.8	20.5	135
119	14.70	11.4	0	2.60	105.5	75.90	28.3	20.7	135

Ion concentrations are in meq/l

R^2 value between measured EC_{iw} and EC_p was high (0.9863). Bergstrom (2002) compared conductivity and hydrometer methods. He compared 159 pairs of values collected at 0.1 m depth from Magothy River, USA, during 1997-2001. The water salinity ranged from 0.5-14 ppt (0.7-20.6 dS/m). According to his results, the hydrometer performed well in terms of both accuracy and precision. The salinity measurements averaged about 1 ppt (1.47 dS/m) higher than salinity measured using a conductivity meter (Bergstrom, 2002). In this study, on average, the empirical model underestimated the measured EC_{iw} by 1.16 dS/m (Figure 3). Although the empirical model slightly underpredicts the actual EC_{iw}, it still is accurate enough for practical purposes.

The Effect of Salt Type

The major constituents of seawater across the world are in nearly constant proportions. Although the salinity of seawater may vary from place to place, the major constituents are present in the same relative proportions. However, that is not the case with underground waters, because their salt compositions may vary from one location to another due to different rocks and soil minerals present. During this study, some waters with the same salinity level showed different HR. To explain the reason, the effect of different salt types on HR was examined. The salt type had a strong influence on HR25 (Figure 4). Hydrometer readings of sulfate and bicarbonate salts were significantly higher for chloride salts.

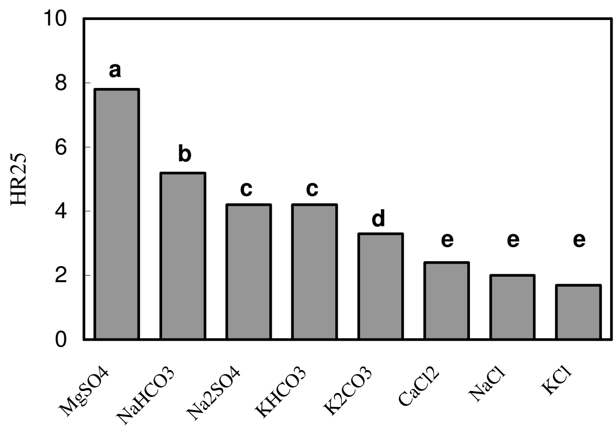

Figure 4. Comparison of the mean hydrometer readings of pure solution of different salt types corrected for 25 °C. The small letters on the bars are the rankings based on Duncan's Multiple Range Test (p=0.01).

Table 3. Correlation coefficients between HR25 and water quality variables of irrigation waters in Yazd Province, Iran.

Variable	R value	Significance
EC_{iw}	0.9849	**
CO_3	-0.0602	NS
HCO_3	-0.0571	NS
Cl	0.9370	**
SO_4	0.8419	**
Ca	0.7274	**
Mg	0.8783	**
Na	0.9135	**
SAR	0.8569	**

NS: Not Significant
**: significant at 0.01 probability level

Magnesium sulfate salt solution was by far the densist among the salt solutions. Due to the differences in molecular weight, different amounts of a particular salt are needed to bring the salinity of the solution to a particular level. That, in turn, affects the density of the solution and thus the hydrometer reading. For instance, about 12 g of $MgSO_4$ was needed to make a 5.8 dS/m salt solution, while only about 3.5 g NaCl was needed to make the same level of salt solution. Waters with a high magnesium concentration have a high density and are considered "hard water".

The relative proportion of the salt types and ions are not constant in irrigation waters. Therefore, at a particular salinity level, the dominant salt type of the water affects the HR. An example is given in Table 2. In this instance, the three water samples have similar EC, anions, Ca and Na. The main difference is in the Mg concentrations. The

Table 4. Rough estimations of EC_{iw}, sodium and chlorine concentrations of the irrigation waters in Yazd Province, from temperature corrected hydrometer reading (HR25).

HR25	EC_{iw} (dS/m)	Cl^-	Na^+
-1	1.0	3.7	4.4
0	2.2	13.2	13.9
1	3.5	22.7	23.4
2	4.8	32.1	32.8
3	6.0	41.6	42.3
4	7.3	51.1	51.7
5	8.6	60.5	61.2
6	9.8	70.0	70.7
7	11.1	79.5	80.1
8	12.3	88.9	89.6
9	13.6	98.4	99.1
10	14.9	107.9	108.5
11	16.1	117.3	118.0
12	17.4	126.8	127.5
13	18.7	136.3	136.9
14	19.9	145.7	146.4
15	21.2	155.2	155.9
16	22.4	164.7	165.3
17	23.7	174.1	174.8
18	25.0	183.6	184.3
19	26.2	193.1	193.7
20	27.5	202.5	203.2

Ion concentrations are in meq/l

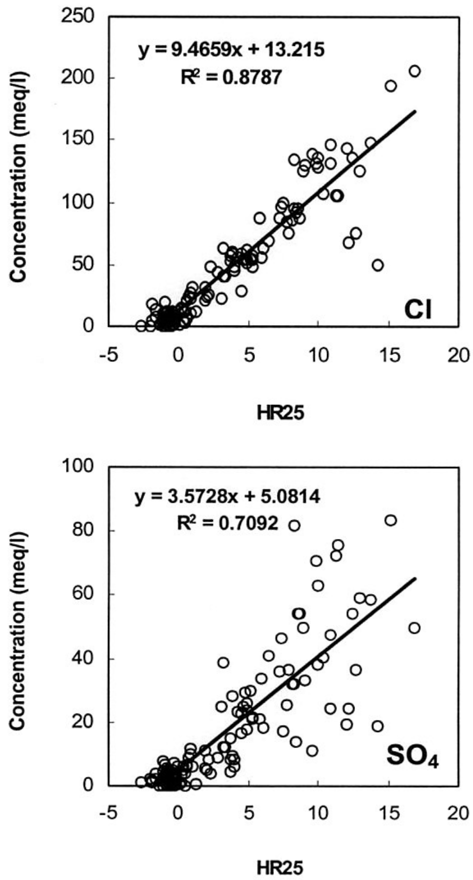

Figure 5. Relationship between the concentration of principal anions and HR25 in irrigation waters of Yazd Province, Iran.

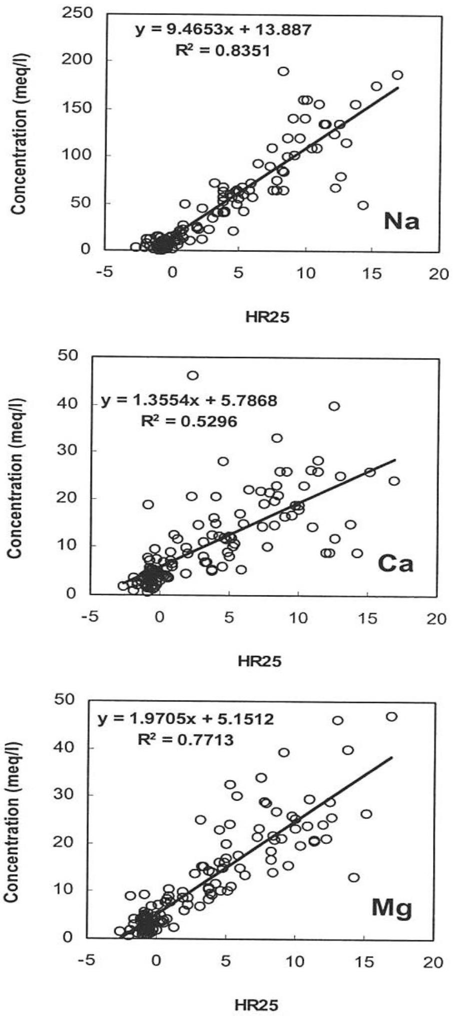

Figure 6. Relationship between the concentration of principal cations and HR25 in irrigation waters of Yazd Province, Iran.

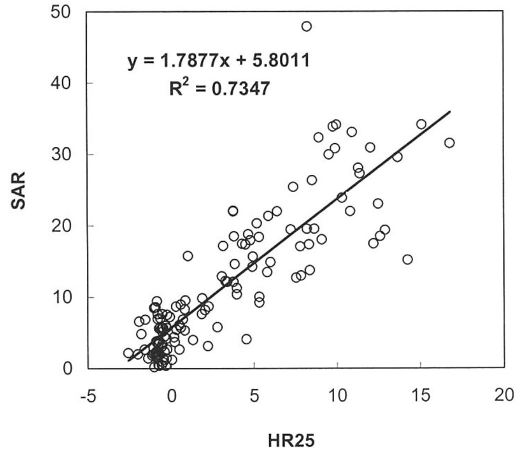

Figure 7. Relationship between sodium adsorption ratio (SAR) and HR25 in irrigation waters of Yazd Province, Iran.

magnesium content of water sample number 93 is twice that of water sample numbers 118 and 119. Magnesium salt solution is denser than other types of salt solutions (Figure 4). This is the reason why the HR25 of sample 93 is higher than the other two samples, although its EC_{iw} is less than their EC_{iw}.

Anions, Cations and SAR

The relationship between HR25, SAR, and the principle anions and cations in water samples were also investigated. This is useful and in certain situations can give a rough estimate of the SAR, anion and cation concentrations in the water sample. Table 3 summarizes the correlation coefficients between HR25 and EC, SAR and the principle ions in irrigation waters of Yazd Province. HR25 was not significantly correlated with carbonate and bicarbonate ions, but it was significantly correlated with other anions and cations. It had the highest correlations with chlorine and sodium ions.

The relationship between anions, cations, and SAR with HR25 are graphically presented in Figures 5 to 7. The linear empirical models are included in the graphs. To test the linear models, 16 random water samples were analyzed to measure their anion and cation contents and calculate their SAR. The same parameters were predicted using the empirical models, with HR25 as the input. The comparisons of the measured and predicted values are presented in Figures 8 to 9. Sodium and chlorine had the highest R^2 values (Figures 8 and 9). The models appear to predict the chlorine and sodium contents reasonably well, but not the other anions, cations, and SAR.

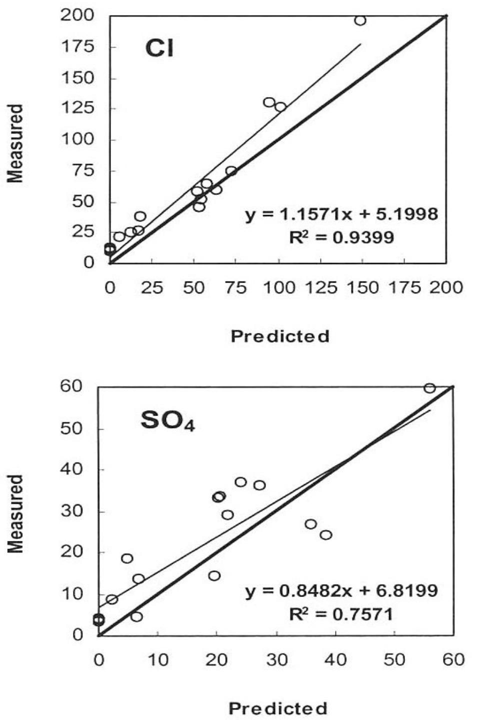

Figure 8. Comparison of the measured and predicted (meq/l) principal anions of the irrigation waters in Yazd Province, Iran.

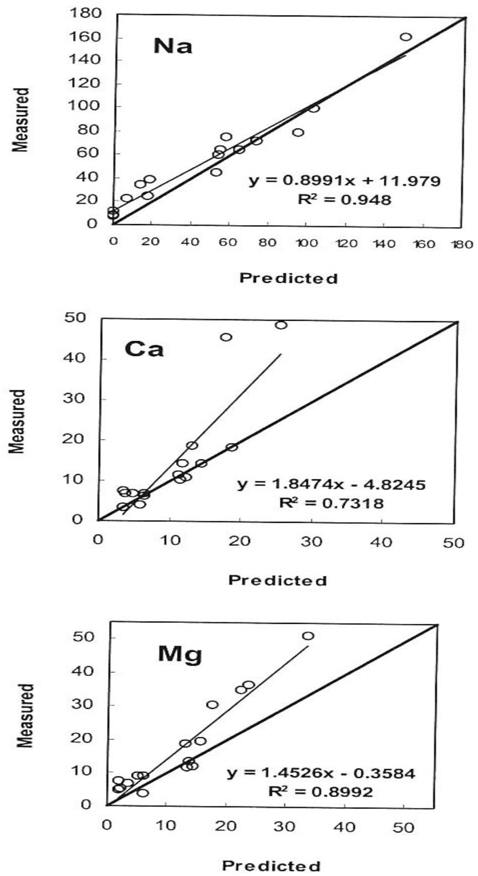

Figure 9. Comparison of the measured and predicted major cations (meq/l) of the irrigation waters in Yazd Province, Iran.

CONCLUSIONS

From the results of this study, it is concluded that hydrometer method can offer a simple, relatively rapid, and inexpensive way of estimating salinity and Na and Cl concentrations in irrigation waters of Yazd Province, Iran. Using the information gathered and analyzed in this experiment, Table 4 was prepared as a management tool using hydrometer. By measuring the HR25 of irrigation water, EC_{iw}, sodium and chlorine concentrations can be roughly estimated in a short time, and in the field if desired. A hydrometer can be used as an alternative method to the EC meter in case an EC meter is not available for any reason (i.e. breakdown, no battery). At the moment this chart is intended for use only for the irrigation waters in Yazd Province. For other regions a similar procedure can be used to develop the proper empirical model for that location or region.

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تعیین شوری آبهای آبیاری با روش هیدرومتری

ف. خورسندی و ف. علائی یزدی

چکیده

شوری مهم‌ترین عامل تعیین‌کنندهٔ کیفیت آب در کشاورزی آبی می‌باشد. جهت تعیین شوری آب از روش‌های اندازه‌گیری هدایت الکتریکی آب و هیدرومتری می‌توان استفاده کرد. روش اندازه‌گیری هدایت الکتریکی بر اساس قابلیت عبور جریان الکتریسیته از یک محلول بوده و متداول‌ترین روش در آزمایشگاه‌ها می‌باشد. ولیکن هزینهٔ دستگاه آن نسبتاً بالا می‌باشد. روش هیدرومتری بر اساس چگالی می‌باشد. هدف اصلی این آزمایش مقایسهٔ بین دو روش و ارائه مدل‌های تجربی جهت تخمین شوری آب‌های استان یزد می‌باشد. هدایت الکتریکی، دما و چگالی ۲۰۶ نمونه آب از چاه‌های استان یزد اندازه‌گیری شدند. در مرحلهٔ اول ضرایب تصحیح دما به ۲۵ درجه سانتی‌گراد تعیین گردید. همبستگی بین هدایت الکتریکی و هیدرومتر قوی بود (R^2=۰/۹۷). مدل تجربی ساخته شده جهت تخمین هدایت الکتریکی آب‌های آبیاری، مقادیر اندازه‌گیری شده را کمی کمتر تعیین کرده، ولیکن از نظر عملی دارای دقت کافی می‌باشد. همچنین هیدرومتر همبستگی بالایی با SAR و غلظت یون‌های غالب داشت. نوع نمک نیز بر عملکرد هیدرومتر تأثیرگذار بود. چگالی محلول سولفات منگنز از دیگر محلول‌های نمک موجود در آب‌های آبیاری سنگین‌تر بود. بر اساس نتایج حاصله جدولی جهت برآورد اولیهٔ هدایت الکتریکی و یون‌های سدیم و کلر آب‌های آبیاری، با استفاده از روش هیدرومتر ارائه گردید.

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