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Determining the importance of soil properties for clay dispersibility using artificial neural network and adaptive neuro-fuzzy inference system

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Abstract

The main purpose of the current research is comparing the results of Artificial Neural Network (ANN) with Adaptive Neuro-Fuzzy Inference System (ANFIS) with regard to determination of the importance of soil properties affecting clay dispersibility. After taking samples from two depths of 0-40 and 40-80 cm, the spontaneous and mechanical dispersions of clay were recorded using both weighing and turbidimetric methods. To determine the degree of importance of soil properties affecting clay dispersibility, first ANNs and ANFIS in MATLAB Software were determined, using all research variables. After determining less effective properties and omitting them, the mentioned networks with the remaining variables including percentage of clay and sand, soil reaction, Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) were measured and the degree of importance of each variable in clay dispersibility was determined. Finally, the results of ANNs and ANFIS were compared by calculation of validation parameters. Existence of high correlation between calculated values for weighing and turbidimetric methods showed a linear relationship between the two methods. In general, in both depths and for both weighing and turbidimetric methods, the sensitivity of clay dispersibility to the percentage of the clay, sand and SAR, was higher than any other variable. Although the results obtained from the validation statistics indicate high accuracy of both ANN and ANFIS models, the last model showed relatively better results as compared to ANN model.

Keywords**:** Arid regions; Dispersible clay; Land degradation; Neuro-fuzzy models; Sodic soils

1. Introduction

Land degradation is a process that reduces the quality and quantity of soil fertility potential and ability of land for production, and the results in regressing soil productivity and land potential (Wimp and Elhadji, 2002). Since land degradation is often caused by incorrect usage of the land, it leads to a drop in quality and ultimately, to lack of usability of land (Eswaran *et al*., 2001). After the twentieth century, this problem became global, therefore, more than 50% of the world's dry lands are now faced with destruction (Gregne and Chou, 1994).

Degradation of soil by sodic salts is one of the key threats to sustainability of crop and cattle production in most of the world's arid and semiarid regions (Gharaibeh *et al.*, 2010; Korkanç and Korkanç, 2016). In other words, excess of sodium in soil is one of the most important processes that have reduced vegetable production in arid and semiarid regions (Ayars *et al*., 1993). The most important effect of excess of sodium in the soil is creating unfavorable physical properties (Neath *et al*., 1996). One of the main reasons that renders these properties undesirable is clay dispersibility.

When the process of clay dispersibility happens, soil structure can dramatically face a reduction in the rate of water infiltration and soil aeration (Boardman, 2010). From an agricultural perspective, this process causes dryness stress in the plants. Also, clay dispersibility is the main factor affecting the reduction of soil hydraulic conductivity. On the other hand, clay dispersibility blocks the pores

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below the soil surface and increases surface crust formation (Agassi *et al.*, 1981; McIntyre, 1985) and as a result of surface crust formation, inter-rill erosion caused by rain water rises (Ithaca *et al*., 1983). Similarly, clay dispersibility can cause cavities and channels in the soil that eventually lead to the formation of deep water-tracks. In addition, the transfer of different contaminants (such as pesticides) to the surface water and groundwater by clay particles creates serious environmental problems (Barin, 1984).

Igwe and Udegbuhnam (2008) determined some soil properties that are effective on clay dispersion in the Ultisols of Nigeria. These properties included the amount of organic carbon, soil pH, exchangeable calcium, exchangeable acidity, cation exchange capacity, SAR, and the amount of clay and silt. They also stated that the use of organic matter could be effective in reducing the dispersion of clay.

Etana *et al*. (2009) investigated clay dispersibility and particle transport as affected by shallow tillage and mouldboard ploughing in five Swedish long-term reduced tillage experiments and concluded that readily dispersible clay and particle transport were significantly lower for shallow tillage than for mouldboard ploughing. They also argued that shallow tillage generally produced positive environmental effects without negative effects on crop yield because of reducing clay dispersibility, especially on soils with high clay content.

Using fuzzy logic, Zorluer *et al*. (2010) studied clay dispersibility in the soils of west Antalya in Turkey and stated that the results of this method in identifying features of dispersing clay soils are more realistic and more acceptable than the results obtained from previous researches.

Paradelo *et al*. (2013) stated that application of sodium or potassium salts deteriorated the degree of soil aggregation, with increased bulk density and clay dispersibility values, whereas amendment with manure or calcium salts ameliorated soil aggregation, with decreasing bulk density and clay dispersibility. Liu *et al.* (2016) shown that alkaline saline conditions (high pH and Na^+ saturation) facilitate the formation of water dispersible clays in soils. Besides, Kumari *et al*. (2017) declared that water dispersible clays strongly and positively correlated with exchangeable monovalent cations and clay content in soils of Denmark.

According to the results of the above mentioned studies, it can be understood that the general focus of these studies is on the identification and the importance of clay dispersion and how clay particles disperse. In other words, a study that examines the importance of properties influencing the dispersion of clay particles can be hardly found. Consequently, the main objective of the present study is to determine the importance of soil properties affecting clay dispersibility in the soils of pistachio orchards of Bayaz area in Anar using ANN and ANFIS models.

2. Materials and Methods

Bayaz area, a part of Anar in Kerman province, Iran, with an area of 625 ha was selected for this study. This region is located between latitudes of 30° 40' 9" and 30° 41' 50" N and longitudes of 55° 30' 47" and 55° 32' 24" E (Fig.1), and it has an average elevation of 1152 m a.s.l. The region has a dry climate and its average annual rainfall over a period of 20 years (from 1994-2013) is 80.3 mm. The minimum and maximum average annual temperatures of the region in the same period are -10 and 40 °C, respectively. Current land use of the area is pistachio orchards with an average age of about 35 years.

First, geographical coordinates of 100 observation points in a regular grid pattern with dimensions of 250 by 250 m were obtained using Global Positioning System (GPS). Then, sampling was performed at each observation point, from depths of 0-40 and 40-80 cm using an auger.

After transferring the samples to the laboratory, they were air-dried and passed through a 2 mm sieve. Soil samples were analyzed to determine particle-size distribution (hydrometer method), calcium-carbonate equivalent (HCl treatment or titrimetric method), soil reaction (saturated paste), EC (saturated extract at 25 °C), percentage of coarse fragments (by volume), and soluble sodium, calcium and magnesium in saturation extract (by an atomic absorption spectrophotometer) (Soil Survey Staff, 1996). Then, using the amounts of soluble cations, the numerical value of the SAR was calculated. To measure clay dispersibility, both spontaneous and mechanical methods (Rengasamy, 1984) were used and the amount of dispersed clay was measured by two methods of weighting and using a turbidimetric device.

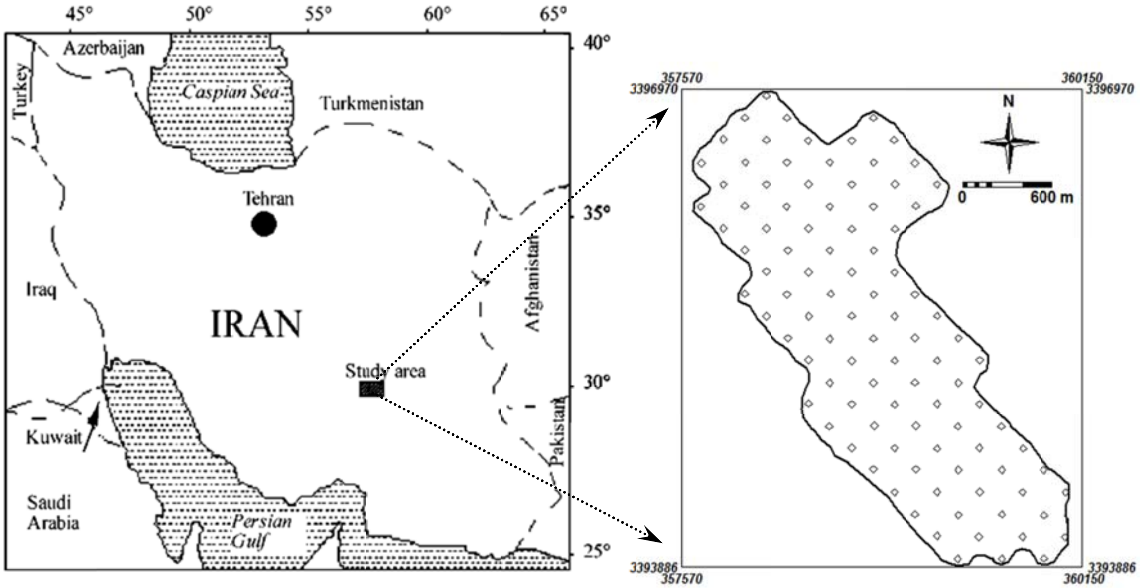

Fig. 1. Location of the study area in the Bayaz region, southeast Iran

2.1. Analyses of ANN

First, the ANN model with all measured variables (including the percentage of clay, sand, coarse fragments, and saturation moisture, EC, SAR and pH) was created and trained. Then, insignificant variables were excluded by the sensitivity analysis test. The importance of input variables was evaluated according to the following steps (Shirani *et al*., 2015):

1- The coefficient of determination (R^2) was calculated by exercising all entries (for all data or training data).

2- One desired variable was selected and removed from input variables and re-modeling with the remaining variables was done and the coefficient of determination ($R^{2}*$) was calculated again.

3- The difference between the coefficients calculated in (1) and (2) was obtained by the following equation:

$$\Delta R^2 = R^2 - R^{2*} \quad (1)$$

4- The importance of removed variable, i.e., variable importance (VI), was calculated from the following equation:

$$VI = \frac{\Delta R^2}{R^2} \quad (2)$$

These four steps were performed for each of the variables. After comparing the importance of required variables, the percentage of coarse fragments and saturation moisture were excluded because they had a negative impact. This means that by removing these variables, modeling precision was increased. Then, the ANN model with five variables, including percentage of clay, percentage of sand, SAR, EC and soil reaction, which had a higher level of importance as model inputs, in both study depths, was used. Finally, the order of importance of the remaining variables (input variables of the ANN model) was determined according to the steps mentioned above.

Because to measure clay dispersibility, both spontaneous and mechanical methods were used and in each method, dispersed clay was once measured by weighing and measured once more by turbidimetric device, so the number of variables used for the purpose of ANN method consists of four variables for each depth (a total of eight targets) whose details are given in Table 1. After writing the required commands in MATLAB software and carrying out trial and error test, suitable networks were designed and chosen. The coefficient of determination (R^2) was used to evaluate the network. In order to assess the importance of variables, the training data was used whose coefficient of determination in all models was over 90 percent.

Table 1. Topology for ANNs used for different methods in each of the study depths

Depth (cm)	Method[A]	No. of training data	No. of testing data	Normalization method	Kind of ANN	No. of neurons in hidden layer	Training algorithm
0-40	S-W	85	15	LT[B]	SLFF[D]	10	LM[F]
	S-T	85	15	WN[C]	SLFF	10	LM
	M-W	85	15	WN	DLFF[E]	4 in first and 5 in second layer	LM
	M-T	85	15	LT	SLFF	14	LM
40-80	S-W	85	15	WN	SLFF	15	LM
	S-T	85	15	WN	SLFF	14	LM
	M-W	85	15	WN	DLFF	7 in first and 5 in second layer	LM
	M-T	85	15	WN	SLFF	14	LM

[A] S-W: Spontaneous-Weighing; S-T: Spontaneous-Turbidimetric; M-W: Mechanical-Weighing; M-T: Mechanical-Turbidimetric
[B] Linear transformation (data were converted in [-1,+1])
[C] Without normalization
[D] Single layer Feed Forward
[E] Double layer Feed Forward
[F] Levenberg-Marquardt.

2.2. Analyses of ANFIS

ANFIS model automatically determines the parameters of membership functions. In fact, this model is trained by a set of training data consisting of input and output (target) - such as ANNs- and optimizes the parameters of membership functions. In general, the parameters of membership functions are computed in a way that the fuzzy inference system is adapted on a set of input–output (target) data. In this section, the subtractive clustering techniques were used to create the initial fuzzy inference system. Table 2 shows different parameter types and their values used for training ANFIS.

Table 2. Different parameter types and their values used for training ANFIS

ANFIS parameter type	ANFIS (Subtractive clustering)
Membership function type	Gaussian
Number of membership functions	4
Output membership function	Linear
Number of training data	85
Number of testing data	15
Number of fuzzy rules or clusters	10

2.3. Validation of the results

To evaluate and compare the results of two models of ANN and ANFIS with each other, the regression plot of the estimated values for each objective test specimens (data not used in the model) and corresponding actual (observed) values were plotted and statistical validation of each model, including the coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}) (Ezekiel, 1930), Root Mean Squares Error (RMSE) (Farifteh *et al*., 2007) and relative RMSE (RMSE') (Park and Vlek, 2002) were calculated.

3. Results and Discussion

Statistical description of the studied samples is given in Table 3 which indicates high levels of sand, and lower levels of clay in the region in both study depths. However, salinity and SAR in the second depth has increased compared to the first depth. This is while the soil reaction rate is low and the changes in both depths are constant. The overall variability of the variables can be assessed by examining their coefficient of variation (CV). The CVs less than 10% indicate a low variability of the properties and the CVs of more than 90% indicate a high variability (Wei *et al*., 2008). According to Table III, soil reaction has the lowest CV among the studied soil properties. Perhaps the calcareous nature of the soils of the region (Vahdati Daneshmand, 1990) as well as the buffering properties of soil can be regarded as a reason for this. However, with the exception of soil reaction, other studied properties (except spontaneously dispersible clay by weighing method in the second depth) have showed moderate CV. A possible reason for the high variability of spontaneously dispersible clay in the weighing method can be different behavior of dispersible clay of the soil in wet and dispersion conditions. Amezketa *et al*. (2003) have presented the similar argument in this regard.

Table 3. Summary statistics of the studied soil properties for both sampling depths

Variable[A]	Depth (cm)	Mean	Median	Variance	Min.	Max.	Skewness	(%) CV[B]	P-value
Clay (%)	0-40	12.80	12.00	24.00	2.00	24.50	0.40	38.30	0.140
	40-80	14.30	14.00	50.10	2.00	44.00	0.90	49.40	0.120
Sand (%)	0-40	66.10	67.00	100.30	41.00	88.00	-0.30	15.10	0.630
	40-80	57.00	59.00	247.20	21.00	87.50	-0.40	27.50	0.520
Silt (%)	0-40	21.00	19.70	69.10	3.00	48.50	0.60	39.50	0.370
	40-80	28.60	26.50	162.20	7.50	62.50	0.60	44.60	0.380
pH	0-40	7.84	7.83	0.02	7.45	8.11	-0.17	1.97	0.810
	40-80	7.84	7.85	0.02	7.45	8.19	-0.39	1.89	0.690
SDC_W	0-40	1.14	0.97	0.95	0.01	5.37	1.72	63.85	0.025*
	40-80	2.38	1.42	6.00	0.01	28.36	2.36	102.94	0.010*
SDC_T	0-40	1.68	1.32	1.70	0.26	5.39	0.97	77.70	0.045*
	40-80	3.66	3.54	7.61	0.29	50.34	3.03	75.37	0.001*
MDC_W	0-40	2.42	1.91	3.97	0.01	9.38	1.27	82.33	0.053
	40-80	2.51	2.02	4.88	0.05	10.63	1.26	88.01	0.055
MDC_T	0-40	3.60	2.73	8.54	0.52	16.35	2.15	81.40	0.001*
	40-80	4.00	2.90	11.34	0.52	18.70	1.73	84.18	0.012*
EC	0-40	9.30	8.50	16.90	2.20	28.40	1.30	44.10	0.200
(dS m^{-1})	40-80	10.30	9.80	15.00	2.30	27.60	1.10	37.40	0.450
SAR	0-40	47.50	42.90	583.20	6.20	139.50	1.70	50.70	0.150
(mmol $L^{-1})^{0.5}$	40-80	60.20	55.30	1017.40	8.10	202.00	1.40	52.90	0.230

*Significant at $P< 0.05$ by Kolmogrov-Smirnov test.

[A] SDC_W= spontaneous dispersion of clay using weighing method, SDC_T = spontaneous dispersion of clay using turbidimetric method, MDC_W = mechanical dispersion of clay using weighing method, MDC_T = mechanical dispersion of clay using turbidimetric method, EC = electrical conductivity, SAR = sodium adsorption ratio.

[B] Coefficient of variation.

Generally, a high correlation between numerical values calculated by the two methods of weighing and turbidity measurement (spontaneous or mechanical), indicates a linear relationship and many similarities between the two methods (Fig. 2). In this connection, Kay *et al*. (1994), Pavanelli and Pagliarani (2002), Czyz *et al*. (2002) and Etana *et al*. (2009) have obtained similar results.

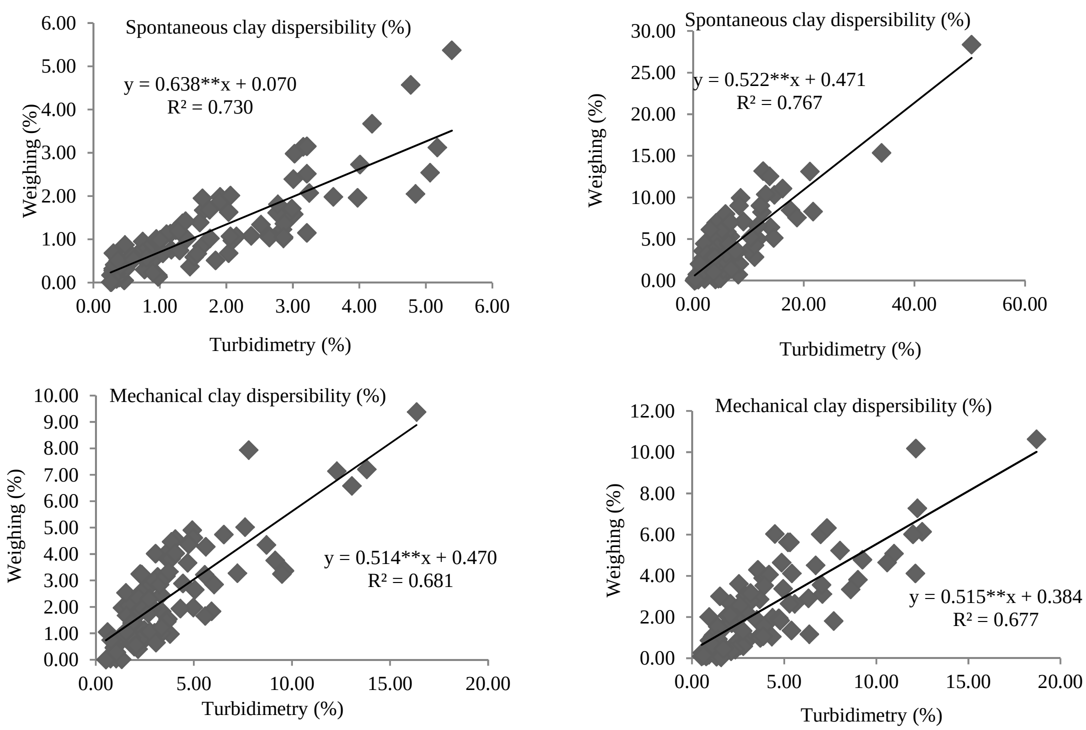

Fig. 2. Regression relationship between weighing and turbidimetric methods at depths of 0-40 (left) and 40-80 (right) cm

By identifying the effect of input variables on the prediction of the target variable, we can assess the importance of each input variable. For this reason, the importance of the input variables on spontaneous and mechanical dispersible clay was investigated by the weighing and turbidimetric methods in the depths of 0-40 and 40-80 cm (as output parameters) and the results are given in Table 4.

As Table 4 shows, spontaneously dispersible clay, by weighing and turbidimetric methods in the first depth, has the highest sensitivity to EC, SAR and the percentage of sand. It has the lowest sensitivity to the percentage of clay and soil reaction. Irrigation management (irrigation with saline waters) and the use of mineral fertilizers (such as ammonium sulfate, potassium sulfate, urea and ammonium nitrate) and organic fertilizers (such as chicken and cow manures) with relatively high salinity coefficients may be the reason for more sensitivity to the EC in this depth. In other words, water evaporation from the surface of the soil results in the salts remaining on the surface and local saltiness of the soil and this increases the range of the EC change in the first study depth (Table 3). As a result, more salts on the soil surface have increased the effects of salinity. In addition, Jones (1964) has stated that the increase in osmotic pressure due to increased salinity, can affect the movement of clay particles, resulting in their dispersion.

Table 4. The importance of ANN's and ANFIS's input variables on the percentage of spontaneous and mechanical dispersible clays using weighing and turbidimetric methods at depths of 0-40 and 40-80 cm

Model	Depth (cm)	Method[A]	EC[B]	SAR[C]	Sand	pH	Clay
ANN	0-40	S-W	0.313	0.288	0.272	0.081	0.046
		S-T	0.327	0.125	0.459	0.052	0.037
		M-W	0.136	0.274	0.265	0.153	0.172
		M-T	0.145	0.180	0.178	0.152	0.345
	40-80	S-W	0.111	0.132	0.334	0.073	0.350
		S-T	0.139	0.197	0.326	0.012	0.326
		M-W	0.109	0.314	0.239	0.022	0.316
		M-T	0.139	0.301	0.182	0.051	0.327
ANFIS	0-40	S-W	0.400	0.160	0.090	0.040	0.310
		S-T	0.350	0.110	0.100	0.070	0.370
		M-W	0.150	0.210	0.100	0.110	0.430
		M-T	0.170	0.250	0.160	0.060	0.360
	40-80	S-W	0.220	0.200	0.140	0.030	0.410
		S-T	0.270	0.210	0.140	0.080	0.300
		M-W	0.120	0.220	0.160	0.110	0.390
		M-T	0.090	0.210	0.190	0.070	0.440

[A] S-W: Spontaneous-Weighing; S-T: Spontaneous-Turbidimetric; M-W: Mechanical-Weighing; M-T: Mechanical-Turbidimetric
[B] Electrical conductivity
[C] Sodium adsorption ratio

The use of organic fertilizers (in the form of 40-50 cm fertilizer pits) in pistachio orchards in the region under study (Alipour and Hosseinifard, 2006) has caused the clay particles to have a less effective role than other variables in the first depth and in the spontaneous method; because organic materials play an important role in the stability of soil structure and soil aggregates (Tisadle and Oades, 1982; Emerson, 1983; During and Chaney, 1984; Goldberg *et al*., 1990; Kretzscmar *et al.*, 1993) and formation of exchangeable surfaces with negative charge (Evelyn *et al*., 2004). Although organic materials gain some positive charge due to protonation of the amine groups, it is very small and negligible (Duxbury *et al.*, 1989). In other words, the proprietary charge of organic materials is negative. Although clay particles also have a net negative charge, in the race to establish links with sodium cations, organic materials are winners (Evelyn *et al*., 2004). Fuller *et al.* (1995) and Paradelo *et al*. (2013) have also highly stressed the role of fertilizer management (especially organic fertilizer) in the amount of dispersion of clay particles. High sensitivity of spontaneously dispersible clay to SAR (Table 4) can be linked to the high level of this property in the soils of study region (Table 3). In other words, when in the sodic soils, SAR is very high, the dispersion of clay particles occurs spontaneously (Amezketa *et al.,* 2003).

In the second study depth (40-80 cm), the importance of clay percentage of soil in clay dispersion has significantly increased over the importance of EC, which was considered as an important soil property in the first depth (Table 4). Increase in the clay percentage from the surface to the depth (Table 3) can be regarded as the probable cause of this issue. In their studies, Rashad and Dultz (2007) have also identified the percentage of clay particles as the major factor in the degree of clay dispersion.

In general and in mechanical method (weighing and turbidity measurement) for both depths, clay percentage and SAR of the soil have the greatest importance in the dispersibility of clay particles (Table 4). As noted above, on one hand, corrosion in the mechanical method (Rengasamy *et al*., 1984) and on the other, more water flow between clay particles (Sumner, 1993), cause the water to cover greater a number of sodium ions and disperse more clay particles. Similarly, a large amount of water-dispensed sodium ions hinders the effectiveness of organic matter in the flocculation of clay particles. However, reduction of the amount of organic materials from the surface to the soil depth also should not be neglected in this regard. Amezketa *et al.* (2004) stated that in the mechanical method, newer surfaces of the soil aggregates or peds are subject to dispersion due to the breakdown. In addition to all the above, the increase in the amounts of clay percentage and SAR from the surface to the soil depth (Table 3) could be effective in explaining the reason of the mentioned sensitivity process. However, the results of sensitivity analysis in ANN model (Table 4) suggest that the amount of dispersible clay enjoys low sensitivity as compared to soil reaction. Limited range of pH changes (Table 3) is the affecting factor on insignificance of this variable in the studied area. A glance at Table 3 reveals the fact that the soils in the area are mainly calcareous (Vahdati Daneshmand, 1990) and the rate of their pH change is limited (i.e., 7.5-8.3).

An overview of Table 4 shows that the percentage of sand particles has a significant role in clay dispersion. High amounts of sand in the studied area (Table 3) could be a possible reason for this, because the lack of electric charges in the sand particles destroys soil structure. In fact, weakening of soil structure causes low resistance of particles against dispersion, which results in an increase in the dispersion.

The results of ANFIS, which are presented in Table 4, show their high concordance with the results of ANN model. Nevertheless, the results of ANFIS have a higher coefficient of determination (R^2) and validity degree (Tables 5 and 6). It should be noted that in this model, compared to ANN, the role of the clay particles is more important than that of the sand particles. Similarly, in the spontaneous method in the first depth (0-40 cm) salinity sensitivity to SAR has increased. According to SAR formula, when salts concentration is multiplied *n* times, SAR is equal to $\sqrt{n}$. This means that the SAR does not increase equally to the electrolyte concentration increase, so it does not have damaging effect. As a result, in this case, the impact of SAR is reduced, so less dispersion occurs.

Table 5. Results of regression analysis and validation statistics comparing the estimated and observed dispersible clay in the soil of both study depths in ANN

Depth (cm)	Method[A]	Linear regression equation	R^{2B}	R^2adj^C	$RMSE^D$	$RMSE'^E$ (%)
0-40	S-W	$y = 0.874^{**}x + 0.156$	0.769	0.754	0.549	34.314
	S-T	$y = 0.877^{**}x + 0.091$	0.818	0.805	0.515	29.524
	M-W	$y = 1.224^{**}x - 0.931$	0.881	0.872	1.165	36.923
	M-T	$y = 1.202^{**}x - 0.186$	0.806	0.791	0.768	36.956
40-80	S-W	$y = 0.888^{**}x - 0.224$	0.855	0.844	1.249	38.901
	S-T	$y = 0.875^{**}x + 0.390$	0.721	0.700	1.435	35.685
	M-W	$y = 1.051^{**}x - 0.277$	0.887	0.878	0.738	32.586
	M-T	$y = 1.239^{**}x - 0.692$	0.884	0.875	1.423	39.256

** Significant at *P*< 0.01.
[A] S-W: Spontaneous-Weighing; S-T: Spontaneous-Turbidimetric; M-W: Mechanical-Weighing; M-T: Mechanical-Turbidimetric
[B] Coefficient of determination.
[C] Adjusted coefficient of determination.
[D] Root mean square error.
[E] Relative root mean square error.

Table 6. Results of regression analysis and validation statistics comparing the estimated and observed dispersible clay in the soil of both study depths in ANFIS

Depth (cm)	Method[A]	Linear regression equation	R^{2B}	R^2adj^C	$RMSE^D$	$RMSE'^E$ (%)
0-40	S-W	$y = 0.897^{**}x - 0.774$	0.939	0.936	0.411	35.107
	S-T	$y = 0.898^{**}x + 0.151$	0.856	0.842	0.309	20.996
	M-W	$y = 1.029^{**}x - 0.427$	0.900	0.893	0.975	30.950
	M-T	$y = 1.035^{**}x - 0.234$	0.823	0.811	0.700	34.412
40-80	S-W	$y = 0.959^{**}x + 0.435$	0.830	0.818	1.165	27.276
	S-T	$y = 0.845^{**}x + 0.345$	0.823	0.810	1.238	30.772
	M-W	$y = 1.089^{**}x - 0.013$	0.890	0.882	0.618	26.318
	M-T	$y = 0.928^{**}x + 0.113$	0.898	0.891	0.972	22.466

**Significant at *P*< 0.01.
[A] S-W: Spontaneous-Weighing; S-T: Spontaneous-Turbidimetric; M-W: Mechanical-Weighing; M-T: Mechanical-Turbidimetric
[B] Coefficient of determination.
[C] Adjusted coefficient of determination.
[D] Root mean square error.
[E] Relative root mean square error.

Although the use of both ANN and ANFIS models estimated the amount of dispersion of clay with relatively good accuracy (Tables 5 and 6), it can be said that since the ANFIS uses fuzzy logic (Zadeh, 1965) in its calculations, rather than a binary attitude (zero and one) to the soil, it considers the continuous nature of soil. Therefore, it appears that the ANFIS model is more adaptable to the nature of the changes in environmental variables. Consequently, it offers more appropriate responses according to the calculated validation statistics (Table 6) as compared to the ANN (Table 5).

4. Conclusion

The results of studying the importance of input variables in ANN model show clay sensitivity to the level of salinity, SAR and the percentage of sand in the first depth. However, in turbidimetric method, the sensitivity to SAR was lower than the weighing method. Meanwhile, in the second depth, level of sensitivity to the percentage of clay had increased as compared to the salinity level. Mechanical methods in both methods (weighing and turbidity measurement) and for both depths had almost similar results. Overall, in both depths and for both weighing and turbidimetric methods, the sensitivity to the percentage of clay and sand, and SAR were higher than other variables. On the other hand, sensitivity of dispersible clay to soil reaction was low.

The results of studying the importance of input variables in ANFIS model showed spontaneous dispersible clay by weighing and turbidimetric methods in the first depth had more sensitivity to clay percentage than ANN model. However, with increase in depth, the degree of sensitivity to SAR increased. In addition, in spontaneous method, the lowest sensitivity to the percentage of sand and soil reaction was observed. Mechanical dispersible clay in weighing in the depth of 0-40 cm showed great sensitivity to clay percentage and SAR, as the turbidimetric method sensitivity to sand percentage has increased. In the depth of 40-80 cm, the sensitivity was almost similar to the first depth but the difference was that the sensitivity of sand percentage to salinity in the second depth increased as compared to the first depth. In this model, like ANN model, the least sensitivity of dispersible clay, spontaneous or mechanical, was observed with respect to the soil reaction in both depths. However, the ANFIS model results as compared with ANN model had relatively higher accuracy, and higher performance of ANFIS model for the study of environmental variables was proved.

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