Calibration of Inductive Electromagnetic Meter for Determining Electrical Conductivity of UAS, Raichur soil

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Abstract

EM-38 electromagnetic induction sensor is most useful instrument to determine the soil salinity. Significant positive correlation found between inductive electromagnetic meter (IEM) readings and saturated paste extract electrical conductivity (EC) revealed that this technique can be used for determination of soil salinity. However, calibration of instrument is necessary for interpretation of instrument readings in terms of meaningful parameters of soil salinity. The calibration equations developed elsewhere may not predict electrical conductivity of UAS, Raichur soil accurately. So, in this study, calibration of EM-38 was carried out to find the soil salinity of experimental site soil. Multiple linear regression equation was developed which valid up to 20 cm depth after calibration of the instrument for experimental site soil and this equation considered reliable as it shows significant positive correlation between predicted and measured soil salinity values. Co-efficient of determination (R^2) between predicted and measured EC values was found to be 0.817. While salinity measurements made with the EM-38 are not highly accurate, but measurements within reasonable accuracy can be made very rapidly. Hence, this equation enables the user of the EM-38 to derive a realistic index of salinity of soil under consideration in terms of EC.

Keywords: Soil salinity, Soil electrical conductivity, EM-38, Electromagnetic Induction.

1. Introduction

Irrigation is essential in arid and semi-arid regions for agricultural production. However, it should be noted that soil salinity may be a risk for sustainable agricultural production owing to mismanagement of irrigation schemes and other inherent problems of irrigation methods. Salt accumulation which may occur in plant root zone may closely be associated with the irrigation methods used. Irrigation with inferior quality of water may also increase soil salinity and it is one of the major pollutants which affect the crop yield and consequently the economic condition of farmers.

Soil salinity assessment with respect to area, severity and spatial variability is inevitable for the management and reclamation especially in canal commands, where salinity is one of the major constraints for crop production. Hence, the assessment of extent of soil salinity in irrigation command areas is necessary.

Traditional method of electrical conductivity measurement in saturation paste is laborious and time consuming as it requires extensive soil sampling and laboratory analysis. Therefore, there is a need to standardize the methods which should be rapid, non-destructive and measure the soil salinity directly in the field, without the involvement of any laboratory procedure. During the last two decades many new techniques like Wenner Array (Rhoades and Ingvalson, 1971), Rhoades's electrical conductivity probe (Rhoades, 1976), Time Domain Reflectrometry (TDR) and Electromagnetic Induction (McNeill, 1980a and 1980b) have been developed to measure the in-situ soil salinity. In India, EM-38 meter was calibrated for black soils of Upper Krishna Project command in which coefficient of determination (R^2) between predicted and measured EC values were ranged between 0.79 to 0.89 (Kuligod, V.B. et. al, 2001).

Electromagnetic induction (EMI) meters have been shown to be effective for accurately and rapidly diagnosing and mapping the spatial distribution of subsurface soil salinity (Corwin and Lesch, 2003). Serrano et al. (2010) tested a non-contact EMI probe with an aim to evaluate the soil and posture variability and find out that apparent electrical conductivity was positively and significantly correlated to pH and yield. Martini et al. (2017) conducted repeated EMI surveys for mapping of soil moisture and observed that soil moisture has little influence on the measured apparent electrical conductivity for the soils with low clay content. The meters detect the apparent electrical conductivity of soil by measuring the response of the soil to an induced electromagnetic (EM) field. EMI technique is more convenient and faster because its measurements do not require soil sampling and their preparations. In recent years, EMI sensors have experienced a rapid succession of design improvements and have been successfully integrated with new technologies like GPS receivers, Bluetooth etc. to become even more versatile and useful tool in soils research (Doolittle and Brevik, 2014). An instrument named EM-38, which worked on the principle of EMI (Electromagnetic Induction), is commercially available which can be used to measure soil salinity. EMI surveys using EM-38 were performed across salt affected farmland for digital mapping of soil salinity and crop yield and concluded that EMI surveys could be successfully used to characterize the spatial variability of soil salinity (Yao R. et al., 2016). Utilization of an EM-38 meter seems to be cost effective method for assessing field salinity and for experiments on salt tolerance of crops.

In saline soils, salt dominates the response of the EM meter and generally good correlations have been found between apparent soil electrical conductivity (ECa) and salinity (de Jong et al., 1979; Cameron et al., 1981; Williams and Baker, 1982). So, EM-38 records readings proportionate to the amount of salts in soil. Also, EM-38 does not require direct soil penetration; therefore a large number of readings can be taken at much lower cost than conventional soil sampling. It can be used to measure soil salinity to approximately 0.6 to 1.2 m depth depending on the orientation of meter.

Keeping all above points in mind, present study was carried out to calibrate the EM-38 meter and develop a multiple linear regression equation to determine the soil salinity of experimental area accurately and at faster rate.

2. Materials and Methods:

2.1 Working Principle and Setting Procedure of EM-38:

Robinson et al. (2004) showed the schematic diagram for working principle of EM-38. EM-38 consists of two electrical coils named transmitter coil and receiver coil, placed one meter apart. Transmitting coil creates a primary magnetic field and this magnetic field generates eddy current in ground. Generated eddy current loop induces its own magnetic field in soil. Ratio of primary magnetic field and magnetic field induce by eddy current are measured by receiver coil and this ratio is proportional to electrical conductivity of soil.

Before using EM-38 for taking readings, initial phase nulling of EM-38 is required to facilitate the receiver coils to measure the very small signal from eddy currents in presence of the much larger signal arising from the primary magnetic field. Setting procedure of EM-38 is readily available in the user manual of EM-38.

2.2 Experimental Site:

The experimental site is located in the UAS, Raichur campus comprises block No. 87 to 107 of agricultural land in Raichur district of Karnataka, India. This area is situated in the north eastern dry zone of Karnataka located at 16°21’N latitude, 76°24’E longitude and 389.5 mm above mean sea level. The daily climatological data during the period of study were recorded from the metrological station at the regional research station, Raichur. It is seen that the maximum temperature of 43.3°C was recorded in the month of May and the minimum temperature of 20°C was recorded in the month of January. The maximum average relative humidity of 78.5% was recorded in the month of January and minimum of 23.5% was recorded in the month of March. The maximum wind velocity of 21.2 km per hour was in the month of February. The maximum evaporation of 16.5 mm/day was in the month of May and the minimum evaporation of 2.0 mm/day was in the month of January.

2.3 Soil salinity data collection:

The data was collected from block No. 87 to 107 of experimental site. The soil type of experimental site is mainly black cotton soil in which clay, silt and sand is 24.3%, 8.8% and 66.9% respectively and soil bulk density is around 1.94 g/cm^3. Figure 1 show the map of study area and red dots in map denotes the plots from which samples were taken.

Fig. 1. Map showing sampling locations with red dots.

For taking readings using EM-38, place the EM-38 horizontally and record the reading, H. Then, place it vertically and record the reading, V. Collect the soil sample from same place to determine the electrical conductivity of soil of that point in laboratory.

2.4 Data Analysis:

After collection of data i.e. H and V values and finding out electrical conductivity (EC) of collected soil samples in laboratory, it was necessary to analyses data whether dependent variable i.e. electrical conductivity depend on independent variables i.e. H and V values. Figure 2 shows the graph between electrical conductivity and horizontal values. The coefficient of determination (r^2) is 0.7182 which is on higher side. So, we can say that electrical conductivity depends on horizontal values which we obtained using EM-38. Similarly, Figure 3 shows the graph between electrical conductivity and vertical values. The coefficient of determination (r^2) is 0.726 which suggest that electrical conductivity does depend on vertical values too.

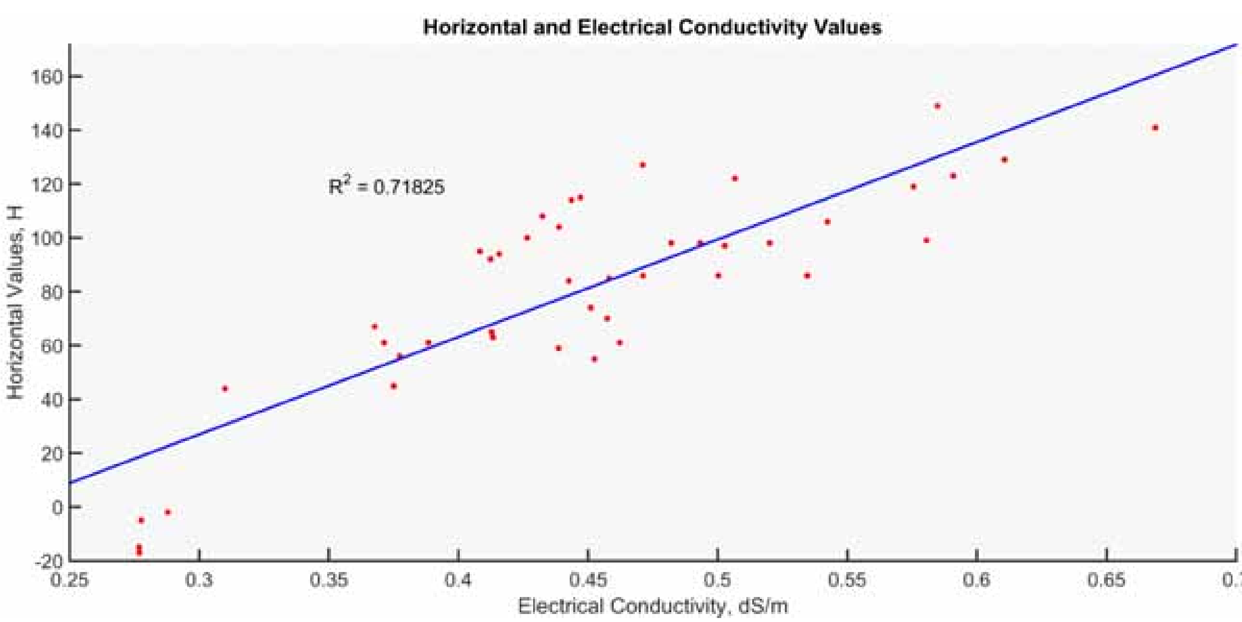

Fig. 2. Correlation coefficient between electrical conductivity and Horizontal values.

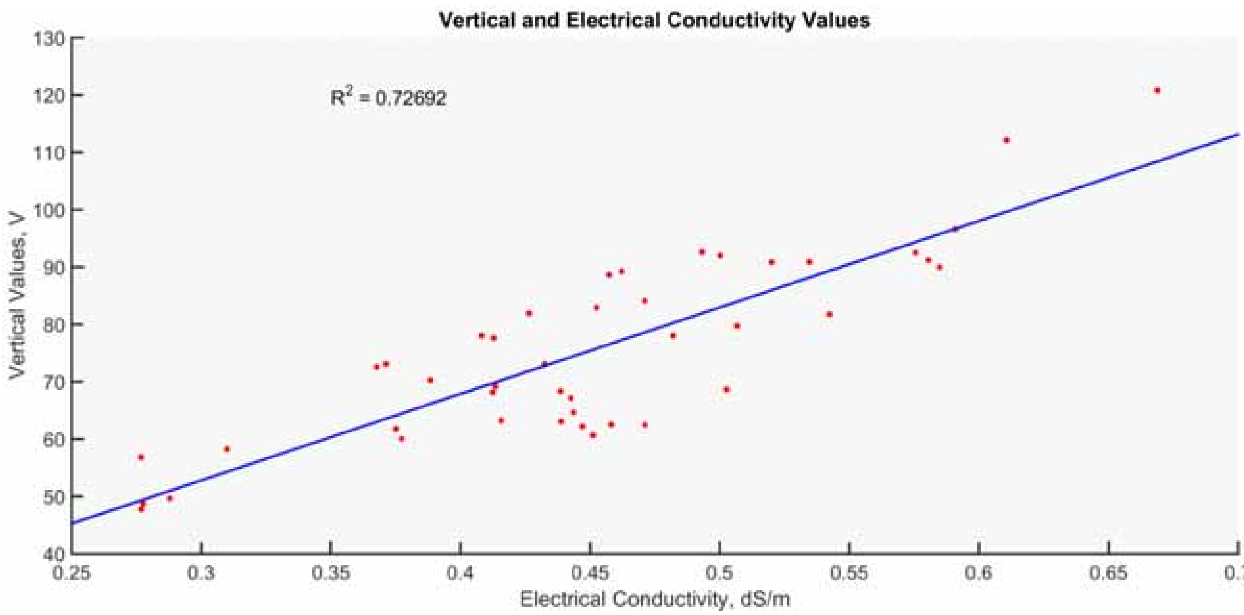

Fig. 3. Correlation coefficient between electrical conductivity and vertical values.

Multicollinearity is a condition in which independent variables in a regression model are correlated. Multicollinearity condition between independent variables also checked in this study because presence of multicollinearity reduces the precision of estimate coefficients, which weakens the statistical power of regression model. Figure 4 shows the graph between horizontal and vertical values and their coefficient of determination (r^2) is 0.425. From this, we can say that vertical and horizontal values are not highly correlated and hence multicollinearity is not present in this case.

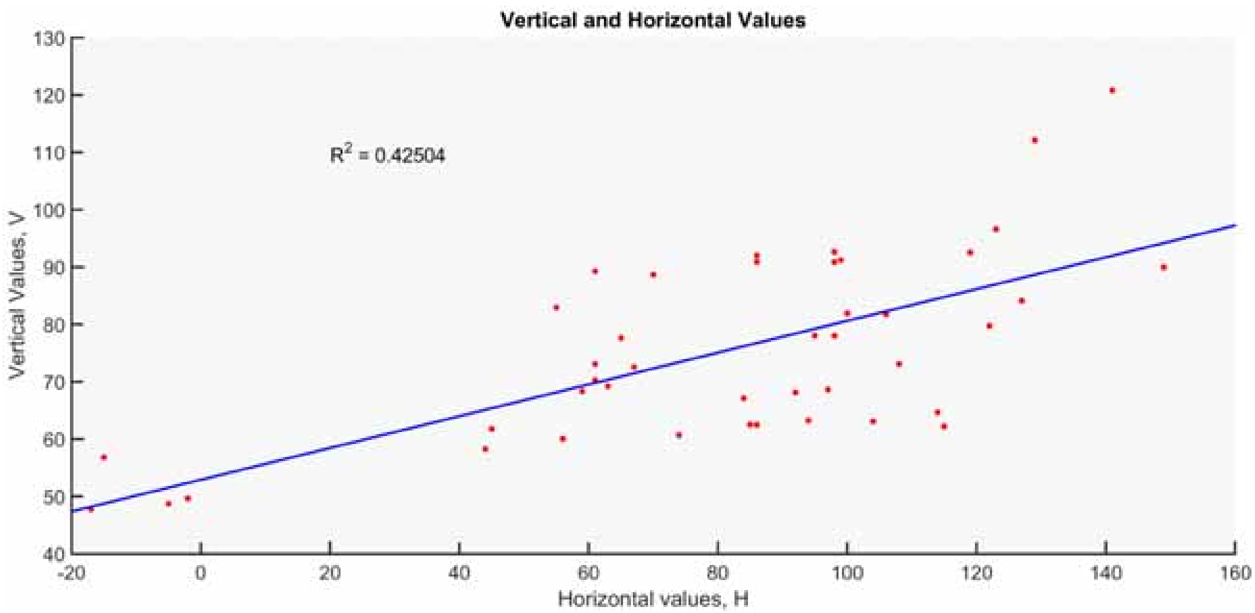

Fig. 4. Multicollinearity between horizontal and vertical values.

3. Results and Discussion:

3.1 Development of predictive equation:

Field data (H and V readings along with respective EC) valued were subjected to multiple linear regression analysis. New predictive equation was developed for depth of 0-20 cm using EM-38 data. Up to 20 cm depth is considered for this study because tillage operations usually performed up to 20 cm only. Table 1 show the output estimated coefficients obtained from multiple regression analysis. In Table 1, it observed that after conducting t-test, p-value of each predictor is less than 0.0001 at significance level of 5%.

Table 1. Estimated coefficients obtained from multiple linear regression analysis.

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.134103	0.026239	5.110819	8.31E-06	0.081072	0.187134
H	0.001176	0.000182	6.473375	1.02E-07	0.000809	0.001543
V	0.002919	0.000438	6.657588	5.64E-08	0.002033	0.003805

The multiple linear regression equation to predict EC with coefficient of determination (R^2) is shown in Table 2. As the coefficient of determination is more than 0.80 so we can say that this equation is able to predict EC accurately at faster rate as compare to conventional laboratory method.

Table 2. Developed equation and coefficient of determination.

Depth, cm	**Equation used**	**No. of samples**	**R^2**
0-20	0.00117(H) + 0.00292(V) + 0.134	43	0.824

To examine the quality of the fitted model, ANOVA is conducted on collected data as shown in Table 3. From Table 3, it observed that the effects of H and V in model are significant as p-value is less than 0.05 for both variables.

Table 3. Summary of ANOVA

	SS	DF	MS	F	p Value
H	0.048484	1	0.048484	41.36	1.17E-07
V	0.051511	1	0.051511	43.942	6.19E-08
Error	0.04689	40	0.001172		

3.2 Regression Model Evaluation:

Adequacy of a regression model was determined using residual analysis (residuals uncorrelated and normally distributed with zero mean and a constant variance (Montgomery and Peck, 1982). All statistical analyses required for model evaluation were performed using MATLAB 2014b. Significance was reported at a probability level of 0.05. The histogram of residual can be used to check whether the variance is normally distributed or not. Figure 5 shows the histogram of residuals. A symmetric bell-shaped histogram which is evenly distributed around zero indicates that the normality assumption is likely to be true.

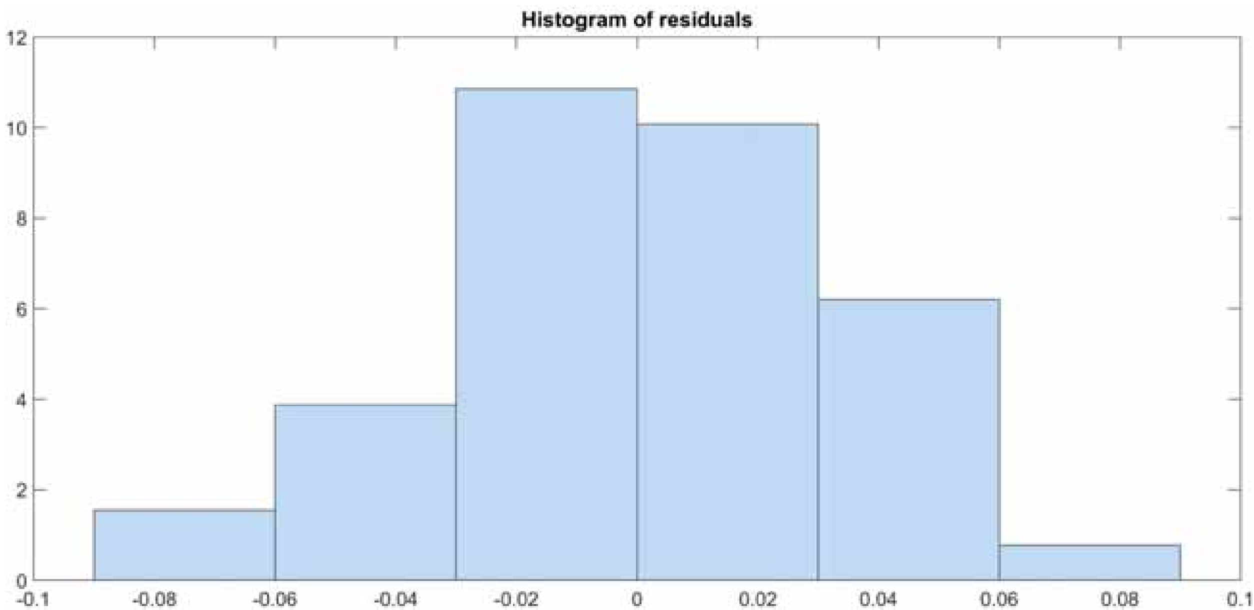

Fig. 5. Histogram of residuals.

A normal probability plot of residuals also be used in this study to check whether the variance is normally distributed or not. If the resulting plot is approximately linear, we can proceed assuming that the error terms are normally distributed. As shown in Figure 6 residuals are lying on line so we can say that variance is normally distributed.

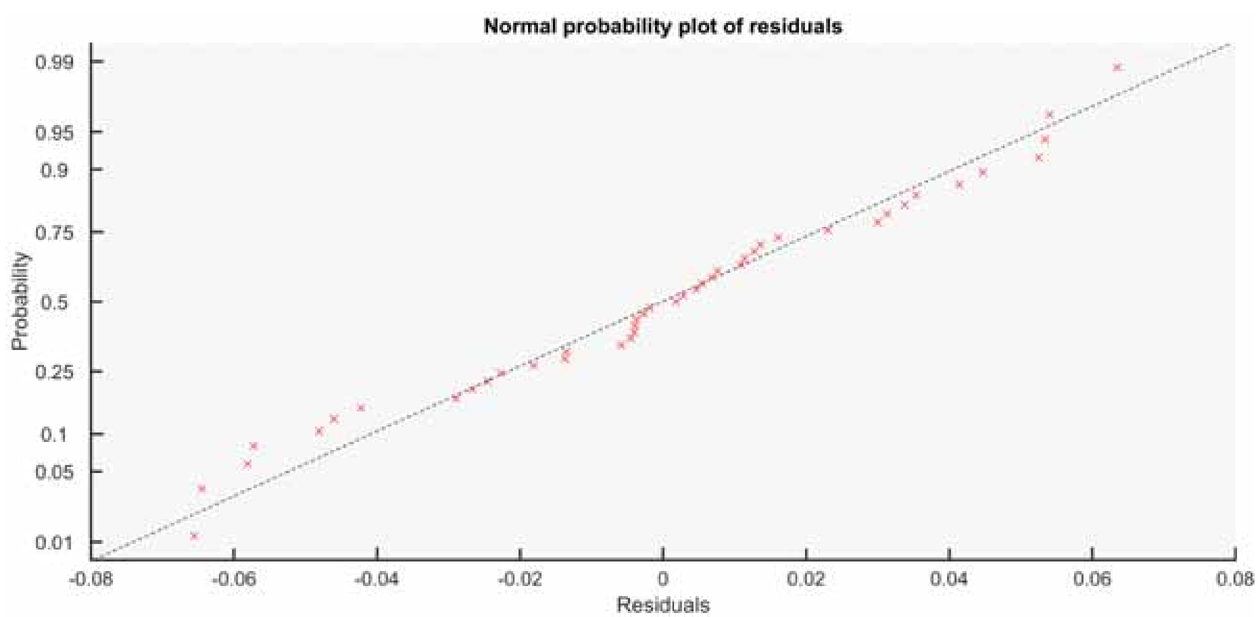

Fig. 6. Normal probability plot of residuals.

The residual error log plot, constructed by plotting residual (i) against residual (i-1) is useful for examining the dependency of error terms on each other. Any non-random pattern in a plot suggests that variance is non-random. As shown in Figure 7, the pattern is random which suggest that the variance is random and error terms are not related with each other.

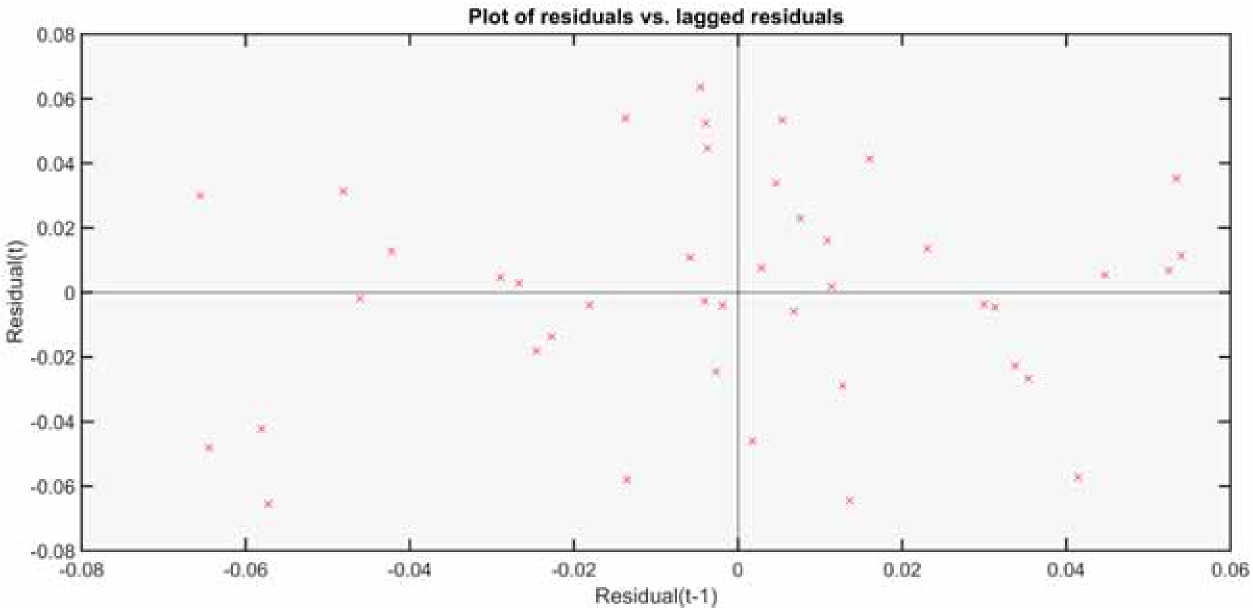

Fig. 7. Residual vs lagged residual graph.

Residual case order plot was used to find out outlier points. As shown in Figure 8 the interval around all the residual does contain zero. This indicates that the residual is smaller than expected in 95% of observations and it suggests that there were no outlier data points.

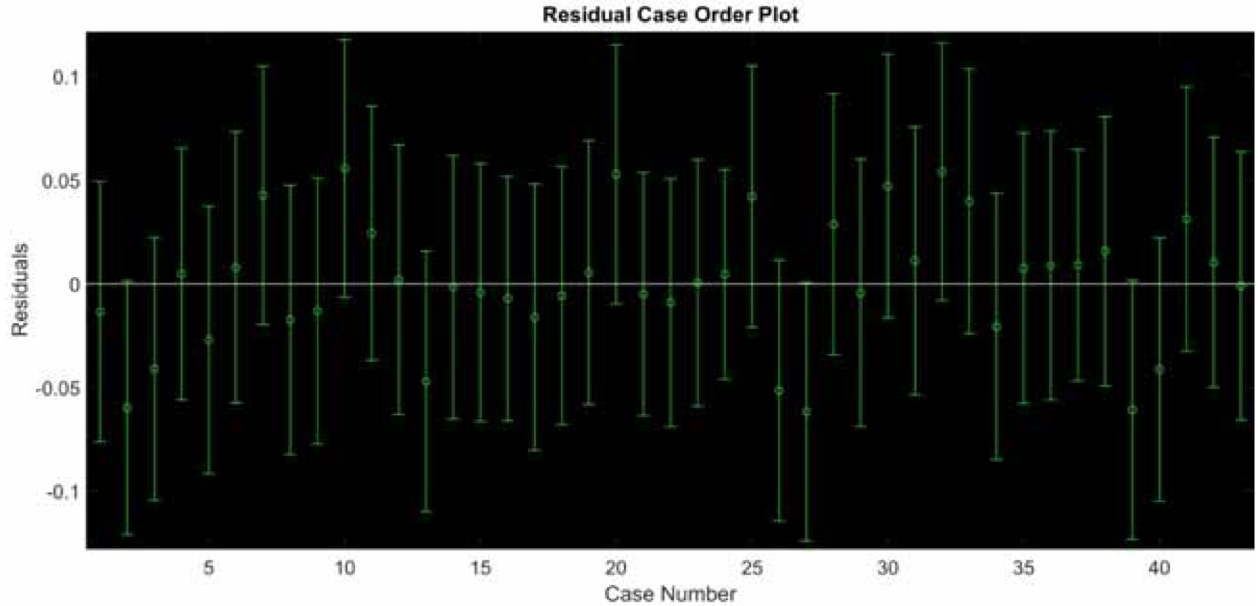

Fig. 8. Residual case order plot to find outlier data points.

Figure 9 shows the 3D plot between collected data and EC. Variation in EC is shown using 3D surface with color map bar.

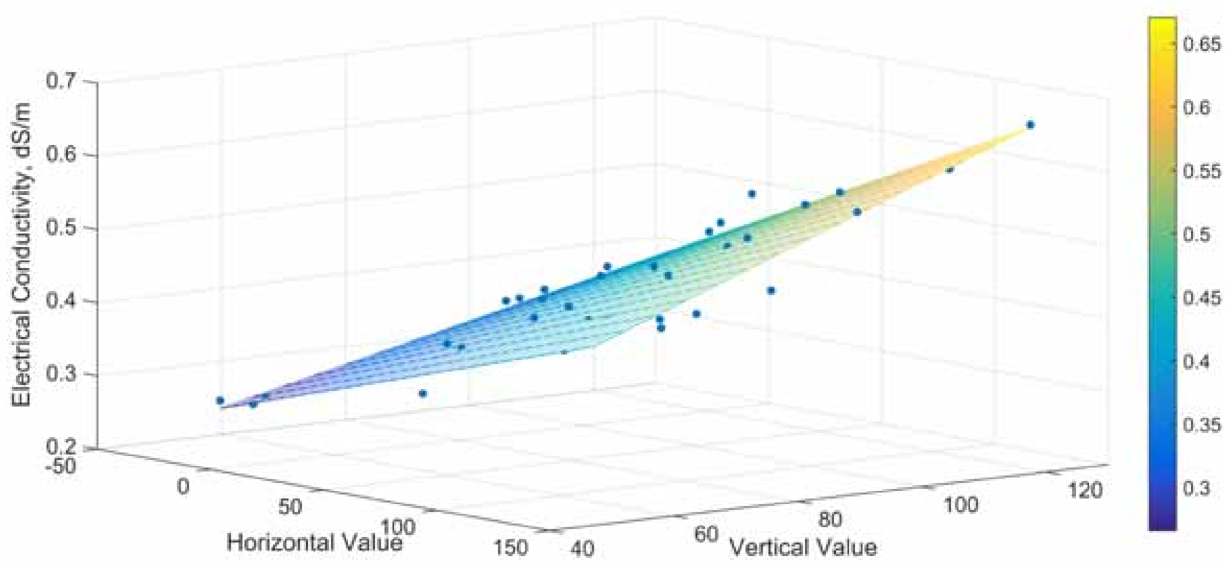

Fig. 9. Plot between collected data and EC.

To evaluate the accuracy and precision of suggested multiple linear regression model, 20 readings were taken using EM-38 and electrical conductivity of soil was found out in laboratory for the same places. Using model, electrical conductivity of soil at these points were predicted and graph was plotted between predicted and actual electrical conductivity as shown in Figure 10. From Figure 10, it observed that the coefficient of determination (r^2) is 0.817. Therefore, model proposed in this study can be used to predict electrical conductivity of experimental site soil.

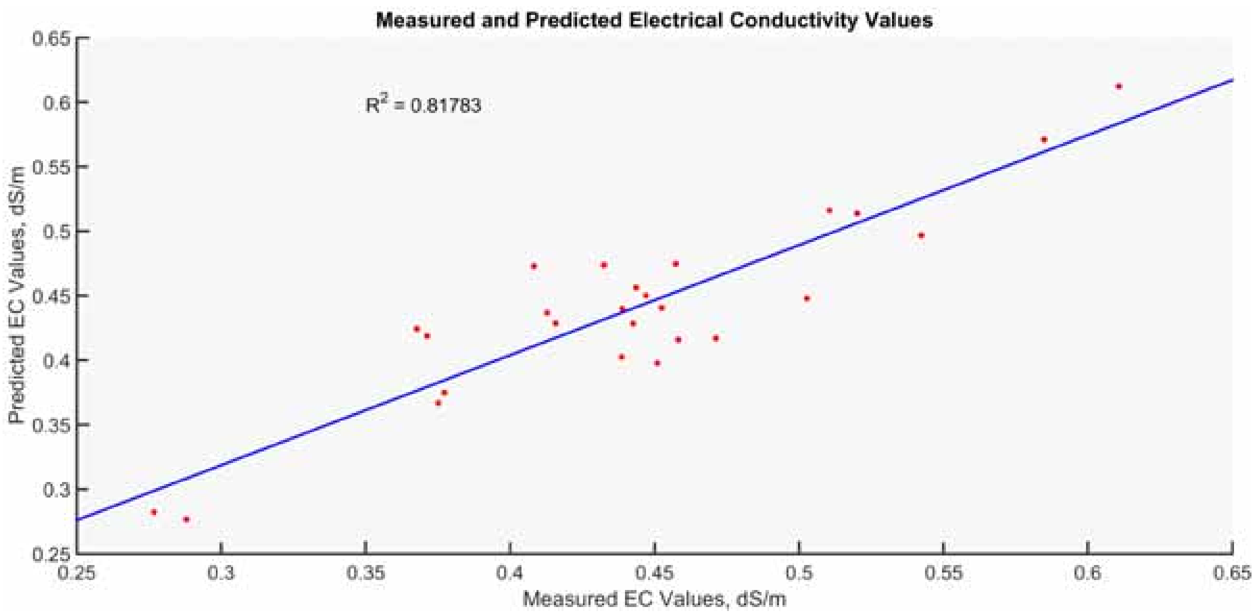

Fig. 10. Plot of measured and predicted EC values.

4. Conclusions:

The objective of this paper was to infer the soil salinity value of UAS, Raichur soil using EM-38 meter as this meter able to infer salinity rapidly without any post processing of soil sample in laboratory. Before using EM-38, its calibration is required to decrease errors in predicted soil salinity. Multicollinearity was not found between independent variables as r^2 value was 0.425. Also, high correlation was obtained when electrical conductivity values were plotted against horizontal values (r^2 = 0.718) and vertical values (r^2 = 0.727). Therefore, both values contributed significantly in prediction of electrical conductivity of soil. Normal probability plot of residuals shows that variance is normally distributed and error terms are independent with each other as find out from plot of residuals vs lagged residuals. Co-efficient of determination (R^2) between predicted and measured values of electrical conductivity was 0.817. Hence, proposed equation enables the user of EM-38 to derive a realistic index of soil salinity in terms of electrical conductivity.

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