APPLICATION OF EM38 FOR SOIL SALINITY APPRAISAL: AN INDIAN EXPERIENCE

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Case study 1: V.B. Kuligod, S.B. Salimath, K. Vijayashekhar, S.N. Upperi and P. Balakrishnan. 1999.

Case study 2: B. Rajendra Prasad, P.R.K.Prasad, G. Anitha, A. Sambaiah and M. Ratnam.1999.

Case study 3: S. Banerjee, D. K.Das, B.R.Yadav, Navindu Gupta, H. Chandrasekharan, A. K. Ganjoo and Ranjit Singh, 1998.

Case study 4: Sharma, P.N., Rana, J.S. Mathur, D.S., Sharma, C.P. and Gupta, V.K. 1997.

Abstract

Limited work has been done in the country on the application of EM-38 for survey and mapping of salt affected soils. Nonetheless during the last few years work has been reported at least from three places in Andhra Pradesh, Karnataka and Delhi. The work is of similar nature but these studies have been covered as a part of this paper. It has been reported that with proper calibration and equation development, EM-38 could be a useful tool for quick diagnostic surveys in the country. In our opinion, the application of EM-38 has not picked up in India because of the cost of the instrument, its limited application in the mapping of alkali lands and general limitation of after sales service of the imported equipment. It seems that with emphasis on the mapping of salt affected soils of the country, its use should gain momentum.

1 Introduction

Soil salinity is one of the major environmental problem that affects the crop yield and consequently the socio-economic condition and health especially of the farming community. Monitoring the degree and the progressive development of soil salinity in a command area is important to assess its adverse effect on production and productivity and on environmental degradation. So far, the assessment of the extent of soil salinity in irrigation commands is based on the extent of waterlogging. The water table data being observed by the soil conservation and soil survey departments serves to define the extent of waterlogging. Assessment of soil salinity problems based on such an approach would not represent a true picture in an irrigation command. On a smaller scale, soil salinity is also monitored. Presently, the monitoring of soil salinity is based on traditional methods that is visual or by analyzing the samples in the laboratory. The visual salinity assessment enables to detect trends within the growing season, whereas the laboratory methods are time, capital and labour intensive, which is a serious disadvantage in large scale or periodic monitoring. Therefore, there is a need to develop and standardize the methods, which are rapid, non-destructive and measure the soil salinity directly in the field. The advantage of such methods over the presently available methods should be their fastness, limited effect of spatial variability on measurement and possibility to use under dry wet, stony, cropped and uncropped soil conditions.

During the last two decades many new techniques like Wenner Array (Rhoades and Ingvalson, 1971), the insertion of Rhoades's electrical conductivity probe (Rhoades, 1976), Time Domain Reflectrometry (TDR) and Electromagnetic Induction (McNeill, 1980a and 1980b) have been developed to measure the soil salinity in-situ. Electromagnetic induction technique is more convenient and faster because its measurements do not require soil sampling and their preparations. This technique is now used world over for surveying the salt affected soils. In India, its use was limited till the UNDP and Indo-Dutch Network Project started functioning at CSSRI, Karnal. In these projects 3 EM38 probes have been made available to CSSRI and four EM38 probes have been supplied to the Network centers. Different centers used the EM38 for soil salinity appraisal in their project areas. A "Training Course on Application of EM38 for Diagnostic Survey and Salinity Mapping" was organized from 15-22 March, 1999 at Central Soil Salinity Research Institute, Karnal in the framework of Indo-Dutch Network ORP on Drainage and Water Management for Salinity Control in Canal Commands. Thirteen participants from different Network Centers attended the course. The objective of the course was increasing the participant's capability in using EM38 for salinity surveys and mapping soil salinity in irrigated agricultural lands. This course focused on the practical aspects of working with the EM38 instrument. This paper briefly describes the application of EM 38 by different organization in India to calibrate and use it for assessing the soil salinity in different textured soils. A brief account of an attempt made to develop a low cost EM38 probe by the department of Electronics and its test results are also presented. The instrument besides soil mapping could also be used for the following activities:

1. Reclamation of arid lands
2. Mapping terrain conductivity for electrical grounding
3. Mapping saline seeps
4. Locating buried pipes & metallic conductors
5. Mapping pollution plumes In groundwater
6. Measurement of magnetic susceptibility of resistive soils

2 Mapping Salt Affected Soils: Case Studies

2.1 Case Study (1) of IDNP-Bheemarayanagudi (Karnatka) in Black Soils (Kuligod *et al., 1999*)

The soils at the study site are deep black and are classified into Typic Pellusterts. Texture is clayey (clay content 45-60%) with low hydraulic conductivity. Inductive electromagnetic meter readings at 48 sites of ORP were recorded at Islampur village (Gulbarga District) in UKP command during June, 1998 when salts accumulated at the surface layer by capillary fringe of saline groundwater. Therefore, salinity profiles are inverted in nature and the corresponding horizontal EM meter readings are more than the vertical.

At each site of the observation two sets of readings were taken, EMh and EMv at 1.5m height and EMh and EMv at ground level. The correction factor, calculated from 1.5m height was either added or deducted depending on the sign to ground level reading because in-phase nulling of the instrument was not possible (as per operator manual of the instrument)[1].

[1] Editor: This correction factor is described in the normal instrument zero section of the manual. It is not mentioned as a procedure to correct an unsuccessful initial in-phase nulling. In-phase nulling is to cancel or null the large primary signal from the transmitter so that it does not overload the electronic circuitry and we can measure the secondary signal of interest. Under normal conditions nulling and instrument zeroing are both done. EM values reported from this instrument may have to be regarded with some trepidation as to their correctness.

Soil samples from the same sites in the depth range of 0-15, 15-30, 30-60 and 60-90 cm depth were collected, processed, and the EC of the saturation paste extract was determined with an EC meter. EM meter readings (horizontal and vertical) taken at forty sites were normalized by fourth root transformation and used for calculations of coefficients K_H, K_V and K in the equation given by Corwin and Rhoades (1982). Multiple regression analysis technique was used to solve the equation. Only eight random readings were used to test the validity of the equation for prediction.

Predicted bulk soil salinity (EC_a) using the equation given by Banerjee et al. (1998, Table 12) for 30-60 and 60-90 cm depth were too low compared to the estimated EC_e in laboratory (Table 9). The equations developed by Banerjee et al. (1998) were for alluvial salt-affected soils of Gangetic belt. Predicted EC_a values using Rhoades et al. (1989a) equation (Table 7 and Table 9) also deviated to a large extent from the estimated EC_e determined in the laboratory. These equations developed elsewhere using the data for experiments conducted under different field conditions and soils do not hold good for the black soils of UKP command.

Table 7 Reported equation for determination of EC_a at different depths

Depth (cm)	Rhoades *et al.*(1989)
EM(H) < EM(V)	
0-30	$(EC_a)^*$=3.023 EM(H) – 1.982 EM(V)
0-60	(EC_a)=2.757 EM(H) – 1.539 EM(V)-0.097
0-90	(EC_a)=2.028 EM(H) – 0.887 EM(V)
30-60	(EC_a)=2.585 EM(H) – 1.213 EM(V)-0.204
60-90	(EC_a)=0.958 EM(H) – 0.323 EM(V)-0.142
EM(H) > EM(V)	
0-30	(EC_a) = 1.690 EM(H) – 0.591 EM(V)
0-60	(EC_a) = 1.209 EM(H) – 0.089
0-90	(EC_a) = 1.107 EM(H)
30-60	(EC_a) = 0.554 EM(H) – 0.595 EM(V)
60-90	(EC_a) = -0.126 EM(H) + 1.283 EM(V) – 0.097

* The letters in parentheses indicate quadratic transformation

Significant positive relation that exists between EC_e (estimated in laboratory) and EM38 meter readings revealed that, the EM38 meter can be used for determination of bulk salinity of soils at discrete depths (Table 8). This relation was stronger at lower layers (at 30-60 and 60-90cm where r values were 0.84 and 0.88, respectively) compared to surface (at 0-15 and 15-30cm where r values were 0.70 and 0.72, respectively) layers.

Table 8 Relation between soil electrical conductivity (EC_e) of saturation extract at different depth and inductive electromagnetic meter measurement

Depth (cm)	Equation	n	SE (dSm^{-1})	r	r^2
0-15	(EC_a)=1.12(H)-0.61(V)-0.10	40	0.24	0.7	0.49
15-30	(EC_a)=0.74(H)-0.27(V)-0.07	40	0.21	0.72	0.51
30-60	(EC_a)=0.42(H)-0.09(V)-0.30	40	0.15	0.84	0.70
60-90	(EC_a)=0.33(H)-0.261(V)-0.59	40	0.15	0.88	0.77

The equations developed through multiple regression analysis with 40 readings were used to predict EC_e at eight random sites. The results revealed a close relation between the predicted and estimated EC_a values (Table 9). The relation between predicted and estimated EC_e of random sample sets was also positively significant. The co-efficient of determination ranged from 0.79 to 0.89 for different depths (Figure 6). Good correspondence between predicted and observed salinity was noticed on the whole range of readings. Therefore, the estimation based on EM38 hold good for both low and high salinity conditions.

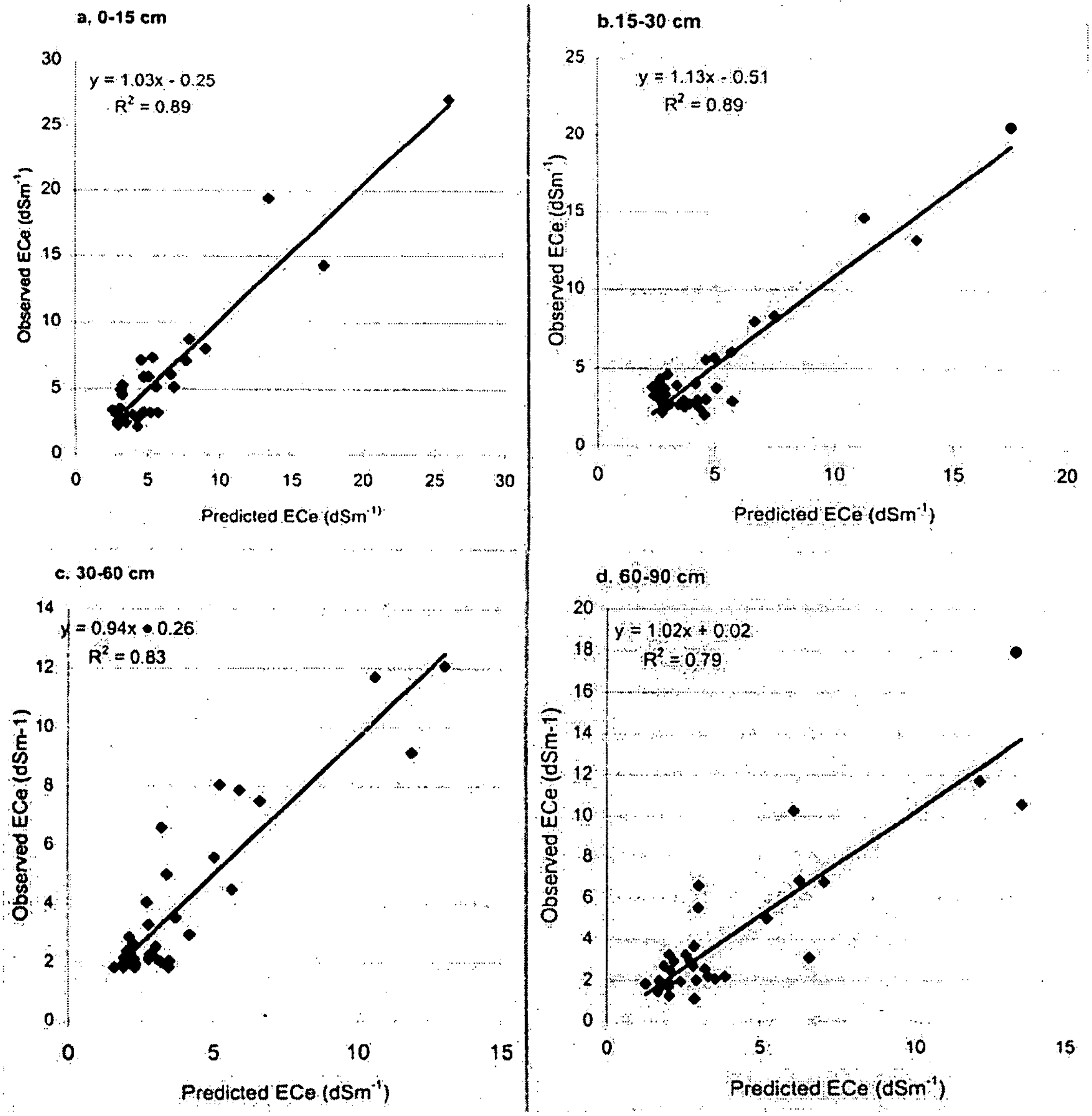

Figure 6 Relationship between measured and predicted ECe values of random sample sets of UKP command black soils.

Significant positive correlation observed between EC_e and EM38 meter in deep black soils inferred that the EM38 meter could be successfully used to estimate the salinity of soils at discrete depths to cover large areas periodically in very short time. Besides, it is more useful in studying the spatial and temporal variability of salinity in a command area. Predicted values of EC_e calculated through calibrated multiple regression from the above investigation could be used to assess the soil salinity precisely in the UKP command area.

Table 9 Inductive electromagnetic meter readings for horizontal (EM_H) and vertical (EM_V) predicted (EC_a) and estimated (EC_e) at different depths.

Site No.	Predicted EC_e(dSm^{-1}) by using equations under the present study				Observed EC_e (dSm^{-1}) of saturation extract			
	0-15	15-30	30-60	60-90	0-15	15-30	30-60	60-90
1	3.27	2.88	2.30	2.07	3.22	3.33	2.12	2.49
2	6.86	5.00	3.43	3.01	5.12	5.67	4.98	5.53
3	7.69	5.75	4.20	3.89	7.10	2.93	2.93	2.20
4	3.06	2.70	2.12	1.88	2.42	3.07	2.85	2.71
5	9.03	7.54	6.65	7.07	8.02	8.34	7.5	6.77
6	7.91	6.72	5.95	6.27	8.70	7.98	7.87	6.84
7	26.08	17.52	13.03	13.52	27.08	20.50	12.08	10.61
8	13.47	11.28	10.61	12.09	19.40	14.64	11.71	11.71

2.2 Case Study (2) of IDNP – Bapatla (A.P.) (Rajendra Prasad *et al. 1999)*

Fifty-eight sites were selected on a grid of size 60 x 60 m^2 covering the entire Konanki ORP site where EM38 readings were taken. From each site five[2] readings were taken in vertical and horizontal mode during the first week of June'99. Soil samples were collected from each site at different depth intervals namely 0.0 to 0.2, 0.2 to 0.5 and 0.5 to 1.0 m. These samples were subjected to EC_e measurements by conventional method in the laboratory.
By using predictive equations, EC values for each site were calculated for composite and discrete depths (0.0 to 0.2, 0.2 to 0.5 and 0.5 to 1.0 m) in the soil profile from ground level. A positive and significant correlation between EC_{pr} and EC_e revealed that the instrument can be used as an alternative for the conventional method (Table 10).

Development of predictive equations*:* Field data (H and V readings along with respective EC_e) valued were subjected to multiple regression analysis. New predictive equations were developed for discrete and composite depths using EM38 data and soil electrical conductivity (EC_e) (Table 10). Analysis indicated that EC_e values were well correlated when both horizontal (EM_h) and vertical (EM_v) readings of EM38 were considered together.

[2] Editor: One reading was taken in the centre where the soil sample located and four in a 2-meter radius around the centre. An average of the five values was taken to compare with laboratory measurement. It was not known anymore which of the five readings was the centre one. This may explain the relatively low r^2 values in Table 10.

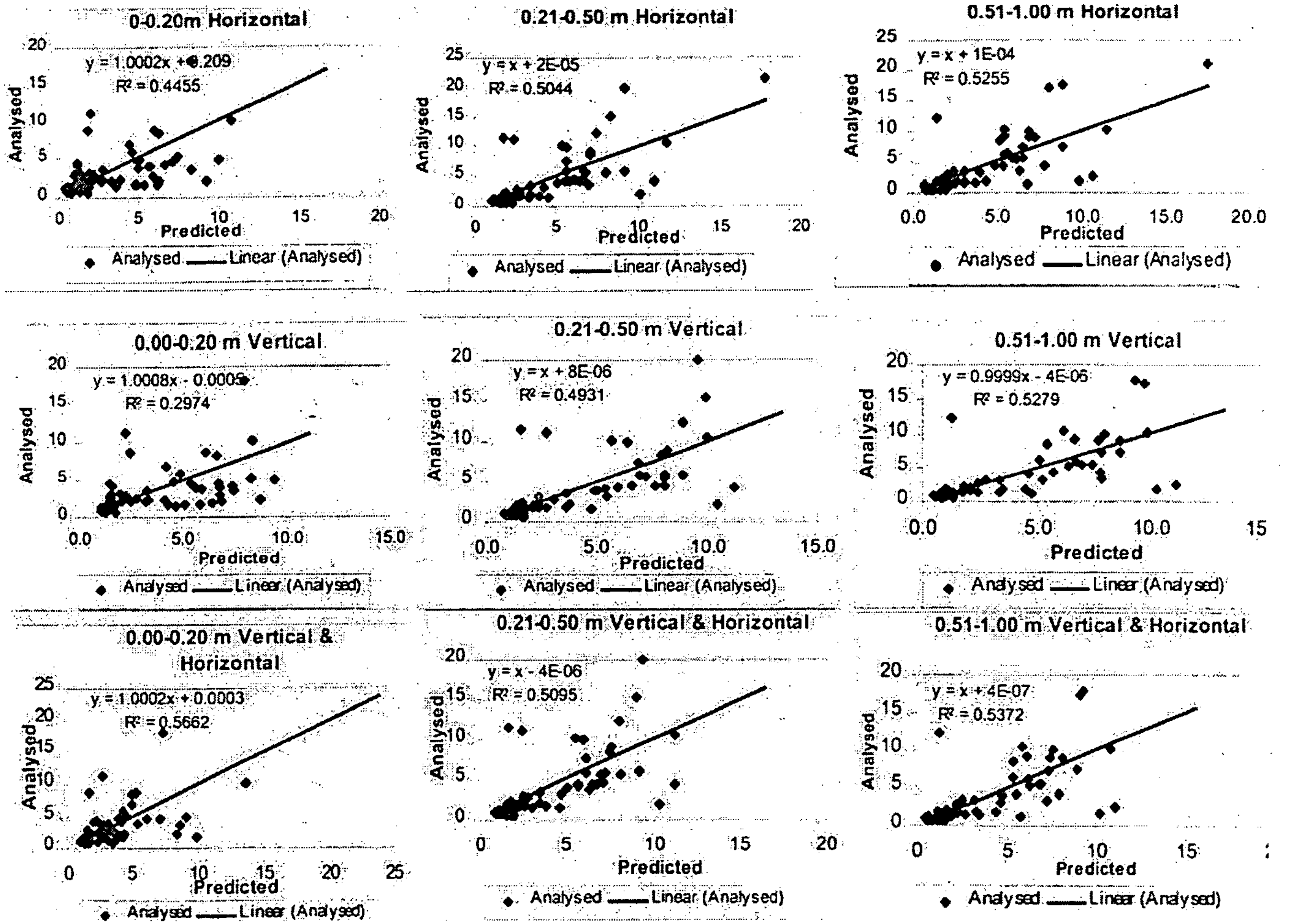

Figure 7 Comparison of EMv and EMh with ECe values for different depths at Konanki ORP site.

The distribution of EC_{pr} (electrical conductivity calculated by using predictive equations) with EC_e when plotted for all depth intervals showed that EC_{pr} values were relatively closer to the EC_e values[1] (Figure 7). Similar results were also reported by Banerjee et al., 1998. Effect of clay content on electrical conductivity was found to be insignificant indicating that EM38 can be an independent tool.

The spatial variation of electrical conductivity were studied in the light of EC_{pr} as it had been proved that EM38 meter can provide reliable understanding of soil salinity and the equations developed in the present study have given better and more significant results. To study the spatial variation iso-EC_{pr} - contours were drawn for different depth intervals. The electrical conductivity values decrease gradually towards top and showed higher values in mid of the ORP site. The iso - EC_{pr} - contours for discrete depths showed that the variation of EC in the upper layers was more than the lower layers, which may be due to the effect of evaporation.

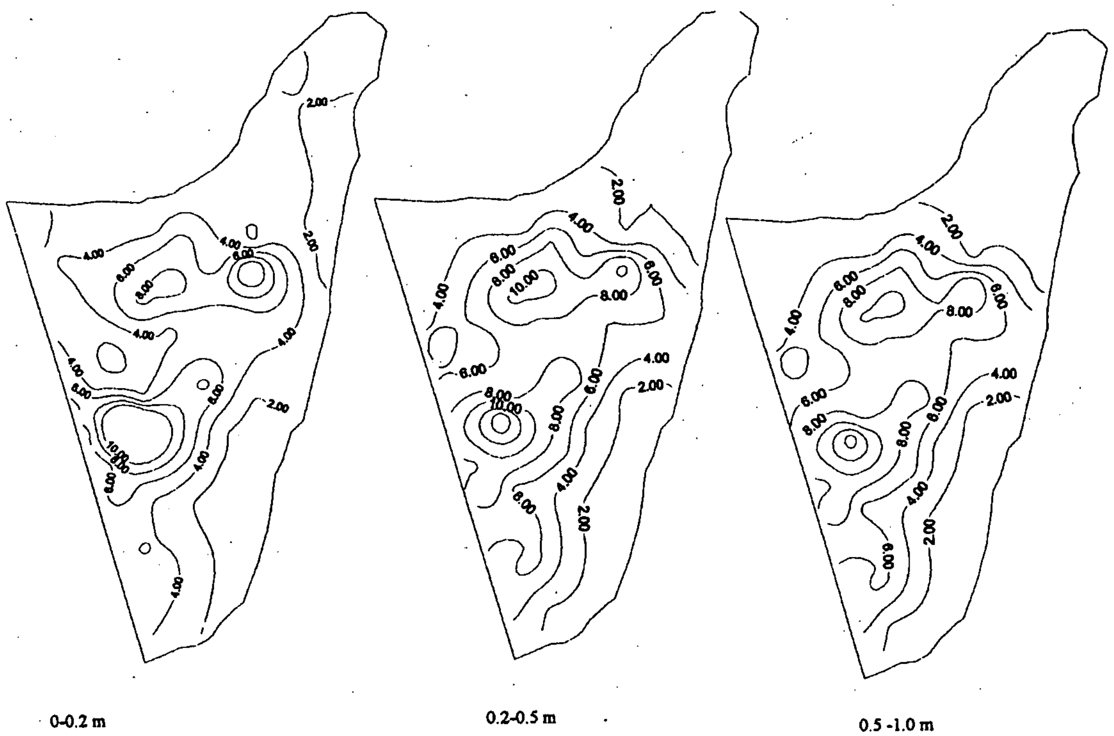

Figure 8 EC_{pr} contour lines Konanki ORP site.

A similar study was conducted at Uppugunduru ORP site. The sampling procedure has been the same as explained for the Konanki site. Based on the predictive equations developed the ECa was calculated for 0 - 50, 0 - 120 and 20 - 120 cm depths (Table 11). Among the predictive equations horizontal and vertical equations were found to be good for Uppugunduru soils.

1 Editor: EC_{pr} was calculated using the Table 10 equations. Then a new set of soil samples was taken and EC_{pr} compared with EC_e in Figure 7. This is a strange practice and the equations shown in Figure 7 serve no purpose while the r^2 is used to judge how well EC_{pr} compared to EC_e. The question arises why was the second set of soil samples not used to refine/expand the calibration set of Table 10.

Table 10 Predictive Equations for Estimation of EC based on EM38 Data for Konanki site.

S. No	Depth (m)	Predictive Equation	Std. Error	r	r^2
1.	0.0-0.20	$EC = -0.03988 \times EM_v + 0.06677 \times EM_h + 1.1514$	3.22	0.75	0.57
2.	0.21-0.50	$EC = 0.007913 \times EM_v + 0.015968 \times EM_h + 0.456733$	3.31	0.71	0.51
3.	0.51-1.00	$EC = 0.011925 \times EM_v + 0.011914 \times EM_h + 0.028219$	3.19	0.733	0.54
4.	0.0-0.50	$EC = -0.0112 \times EM_v + 0.0363 \times EM_h + 0.7346$	3.0	0.747	0.55
5.	0.0-1.00	$EC = 0.00036 \times EM_v + 0.024 \times EM_h + 0.381$	2.93	0.753	0.56
6.	0.21-1.00	$EC = 0.01 \times EM_v + 0.0134 \times EM_h + 0.189$	3.17	0.732	0.53

Table 11 Predictive Equations to Estimate EC based on EM-38 Data for Uppugunduru site.

S. No	Depth (m)	Predictive Equation EC_a in dS/m, EM_v and EM_h in mS/m	Std. Error (dS/m)	r	r^2
1.	0.0-0.20	ECa = -0.068 X EMv + 0.139 X EMh + 0.80	6.93	0.86	0.74
2.	0.20-0.50	ECa = 0.0053X EMv + 0.0489 X EMh –4.16	3.67	0.93	0.87
3.	0.50-1.20	ECa = 0.023 X EM v + 0.027 X EMh - 0.948	4.73	0.88	0.77
4.	0.0-0.50	ECa = -0.0241 X EM v + 0.085 X EMh –2.12	4.54	0.91	0.84
5.	0.0-1.20	ECa =-0.003 X EM v + 0.0513 X EMh – 1.46	4.15	0.91	0.83
6.	0.20-1.20	ECa = 0.0174 X EM v + 0.034 X EMh –1.91	4.18	0.90	0.82
7.	0.0-0.20	ECa = 0.059 X EM v –13.27	8.37	0.78	0.62
8.	0.20-0.50	ECa = 0.049X EM v –9.10	4.01	0.91	0.84
9.	0.50-1.20	ECa = 0.048 X EM v –3.70	4.78	0.87	0.76
10.	0.0-0.20	ECa = 0.067 X EMh –7.68	7.31	0.84	0.71
11.	0.20-0.50	ECa = 0.054X EMh –3.50	3.65	0.93	0.86
12.	0.50-1.20	ECa = 0.051 X EMh +1.86	4.77	0.88	0.77

2.3 Case Study (3) at IARI, New Delhi in Alluvial Soils (Banerjee et al. 1998)

Central Scientific Instruments Organization, Chandigarh developed an instrument for the measurement of soil salinity and has been tested at two locations in the country. The project was sponsored by the Department of Electronics, New Delhi. The specifications summarized below:

EM System Specifications

Conductivity Ranges	:	1000 mS/m 100 mS/m
Measurement Precision	:	± 0.1% of maximum scale reading
Measurement Accuracy	:	5% at 50 mS/m
Primary Field Source	:	Self contained dipole transmitter
Sensor	:	Self contained dipole receiver
Inter Coil Spacing	:	1 meter

Operating Frequency	:	14.5 KHz[2]
Power Supply	:	9v alkaline battery

This instrument has been used at IARI, New Delhi, for measurement in medium texture soils. Twenty sites were investigated on grid pattern covering the whole IARI farm wherein 28 EM readings were taken. In addition to these, 17 more points in the farm area were chosen at random to verify the predictive equations developed during the study. From each site, two readings were taken, one keeping the instrument on the ground at horizontal position with its coil parallel to the surface (Readings termed as EM_H) and other by keeping the instrument at vertical position with its coil perpendicular to the soil surface (Reading termed as EM_V). EM_H and EM_V were used to calculate EC_a by equations given by Rhoades et al. (1989b) for different depths. Soil samples were collected from each EM survey points at different depth intervals, namely 0 - 0.30, 0.3 - 0.6 and 0.6 - 0.9m. These samples were used for $EC_{1:2}$ measurements, determination of gravimetric moisture content and particles size analysis by conventional methods.

Using the regression equations developed by Rhoades et al. (1989b) EC_a values for each site were calculated for composite and discrete depths (0.3 m interval) up to 0.9m in the soil profile from ground level. A positive and significant correlation exists between EC_a and $EC_{1:2}$. It revealed that the instrument could be used as an alternative for the conventional method (Table 6). The EC_a values for composite depths (0 - 0.3, 0 - 0.6 and 0 - 0.9 m) are found to be better correlated than discrete depths (0.3 - 0.6 and 0.6 - 0.9m).

The plots of EC_a (for both horizontal reading (H) greater than vertical (V) and vice versa) with soil water contents do not indicate any definite relationship for all the discrete depth intervals. To study the EC_a variation due to clay content, different locations having the same EC_a values were considered. It was observed that for a particular $EC_{1:2}$, EC_a values marginally decreased with clay content though there are a few exceptions which may be due to the presence of large number of fine pores. Water and salt remain in "immobile" phase (Rhoades *et al.* 1989b) in soil and thus EM technique gives a little lower value. No variation in EM readings due to the soil temperature (measured at 0.15m depth at different times of a day) were observed. Thus, soil water, clay content and soil temperature either together or independently do not seem to affect the EC_a values computed from EM data.

The regression equations developed by Rhoades et al. (1989c) which were used for EC_a computation, were established on the basis of experiments conducted under different field locations with respect to the present study area. Further those equations were obtained on the basis of four electrode probe which itself needs proper location-specific calibration with standard EC values. Keeping this in view, an attempt has been made to develop new regression equations using EM data and soil electrical conductivity ($EC_{1:2}$) values determined by conventional method.

Initially, the analyses were carried out in two categories, namely; horizontal EM reading greater than vertical (H > V) and *vice versa.* As the surface layer was not highly saline compared to the lower layers which was the basis of categorization of H > V or V > H in case of Rhoades *et al.*(1989c), insignificant correlation coefficients were obtained not to mention that there were only five readings where H < V in the field data. Hence, results of the analyses are discussed without any categorization.

[2] Editor: the frequency of the EM38 of Geonics is 13.2 KHz (Box 1) hence the response and calibrations of the EM of the IARI study will be (slightly) different and the calibrations in Table 12 and Figure 9 cannot be compared directly with EM38 calibrations reported elsewhere.

Field data [H and V readings along with respective $EC_{1:2}$] values were subjected to multiple regression analysis for different configuration of parameters such as linear, square, square root and quadratic root. Analysis indicated five different linear equation with good correlation. The resulting equations are presented in (Table 12).

Table 12 Predictive equations for estimation of EC based on inductive electro-magnetic survey data (Banerjee et al. 1998).

Depth (m)	Predictive equation	Standard error	Multiple r^2
0-0.3	[EC] = 0.396 [H] – 0.090 [V] + 0.187	0.06	0.72
0-0.6	[EC] = 0.234 [H] – 0.006 [V] + 0.161	0.04	0.74
0-0.9	[EC] = 0.133 [H] – 0.058 [V] + 0.263	0.05	0.54
0.3-0.6	[EC] = 0.298 [H] – 0.055 [V] + 0.189	0.04	0.80
0.6-0.9	[EC] = 0.252 [H] – 0.022 [V] + 0.208	0.04	0.79

The distribution of both EC_a and EC_{pr} with $EC_{1:2}$ when plotted with 1:1 line for all depths intervals show that EC_{pr} values are relatively closer to the 1:1 line than ECa values (Figure 9).

2.4 Case Study (4) of Rajad, Kota (Sharma et al. 1997)

The area of Chambal command lies between 25^0, 02', 10" to 25^0, 45', 33" N latitude and 75^0, 37' to 75^0,37', 0" E longitude in Rajasthan. These investigations were carried in two blocks i.e. C2 (5087 ha) and C3 (4727 ha) by special grid system with grid lines extending from north to south and from east to west for site identification and orientation in the field. The grid lines were parallel to and divide the longitudes and latitudes of the national topographic system may sheets. Each of created tetragons/polygons was 77.7 ha in area, which was further divided into nine sites of sub polygons, each representing 8.6 ha area. The soils of the Chambal Command are mainly clay to clay-loam. There exists a layer with high calcium carbonate concentrations at varying depths. These soils are very fine textured with a sub-angular blocky structure and dense consistency.

Calibration of EM-38

For the calibration of EM-38, 39 field sites representing variable salinity conditions from normal to highly saline conditions were sampled in 0.30 m in increment intervals to a depth of 1.8 m. The soil samples were analysed in saturation extract (EC_e) for each site and depth-wise. These EC_e values were converted in single weighted (WEC_e) in horizontal and vertical modes by considering the weights as suggested by Wollenhaupt et al (1986) as given in the following equations:

$$EC_e\,WH=0.54\,EC_{e\,0\text{-}30}+0.26\,EC_{e\,30\text{-}60}+0.13\,EC_{e\,60\text{-}90}+0.08\,EC_{e\,90\text{-}120cm}$$

$$EC_eWV=0.19EC_{e0\text{-}30}+0.30EC_{e30\text{-}60}+0.21EC_{e60\text{-}90}+0.15EC_{e90\text{-}120}+0.11EC_{e120\text{-}150}+0.04EC_{e150\text{-}180cm}$$

The weighted EC_e (horizontal) and weighted EC_e (vertical) have been selected to compare with EM38 readings. The model assumed was

$$WEC_e = a\,e^{bR}$$

Where WEC_e is weighted EC_e and R is the meter reading. The a and b are parameters which are transferred to:

$$\text{Log}\,(WEC_e) = \text{Log}\,a+bR$$

By taking Ln transformation

Y=A+bR

A and b were estimated by least square technique. The functions are given below:

Horizontal $WEC_e = 0.1501\ e^{0.0227R}$
Vertical $WEC_e = 0.1122\ e^{0.0235R}$

The r^2 values are significantly high and explain about 87 and 85% of variations in WEC_e of horizontal and vertical positions respectively. Further, a look at the value indicates that WEC_e is slightly underestimated when readings are high.

Following the calibration of the EM-38, soil survey was carried out using both the traditional and EM-38 techniques. Soil samples were taken from each horizon for reference; as well as composite samples were taken from root zone (0-30 cm) and sub root zone (30-100 cm) and sub soil (100-150 cm) for laboratory analysis in saturation paste. The EM38 readings and its EC_a values were also taken at the same grid.

The total area surveyed by traditional method was 9815 ha at 300 meter grid in blocks C2 and C3, out of which saline and saline sodic area identified from laboratory value was 1064 ha (21%) in C2 and 875 ha (18%) in C3. The area surveyed by EM38 at the same grid revealed saline and saline sodic area as 1310 ha of C2 and 710 ha of C3 block with 25.7% and 16.7% respectively. Thus out of total area, in block C2 and C3 was 19.7% by laboratory values and 21.4% by EM38 as saline and saline sodic (Table 13), remaining area was non-saline, non-sodic (6426 ha) along with 1450 ha as sodic land (Table 14). Only 2% more saline area was observed by EM38 as compared to the area identified by laboratory analysis, thus justifying the preliminary information and its suitability in assessing the soil salinity. It is undoubtedly very useful for assessing the soil salinity, however, it does not measure the soil sodicity. The difficulty faced in planning and delineating the saline area urgently can be solved satisfactorily by this technique. Its limitation to measure the sodicity and ECe beyond 16 dS/m needs further investigation. Because of various other factors than the soil salinity, which can affect the bulk soil conductivity, conventional salinity measurements still need to be continued at some interval for verifications.

Table 13 Comparison of Saline Area identified by EM38 and Lab. Values

Block	Total area ha	Area delineate by Lab. Values	%	Area delineate by EM38	%
C2	5087.94	1063.92	20.91	1310.00	25.74
C3	4727.58	875.16	18.51	790.00	16.71
Total	9815.52	1939.08	19.75	2100.00	21.39

Table 14 Block-Wise Area in ha for Saline Sodic Soils

Block	Total Block area ha	Non Saline Non Sodic	Non Saline Sodic	Saline Non Sodic	Saline Sodic	Total of Saline Non Sodic and Saline Sodic
C2	5087.94	3509.22	514.80	248.82	815.10	1063.92
C3	4727.58	2917.20	935.72	137.28	737.88	875.16
Total	9815.52	6426.42	1450.02	386.10	1552.98	1939.08

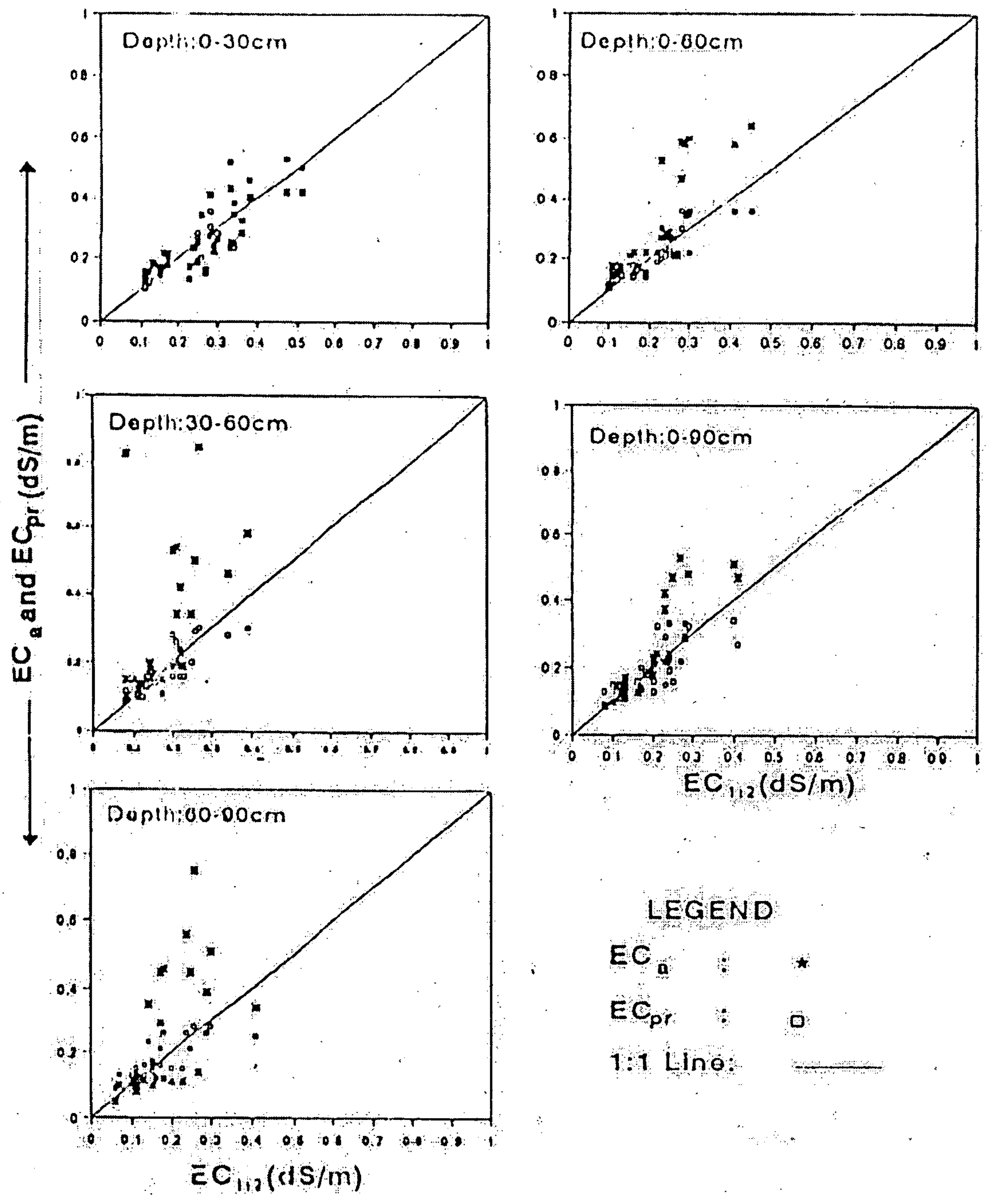

Figure 9 **Comparison of EC_a and EC_{pr} with $EC_{1:2}$ values for different depths.**

4 References

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ELECTROMAGNETIC INDUCTION DEVICE (EM38) CALIBRATION AND MONITORING SOIL SALINITY/ENVIRONMENT (PAKISTAN)

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Abstract

Like many other countries, located in the arid to semi-arid climatic region of the world, vast productive area in Pakistan has gone out of cultivation due to salinity/sodicity. Under such situations the soil salinity monitoring is frequently required to evaluate the impact of different land reclamation schemes, techniques and to keep track of the accumulation of salts in the agricultural lands. The most straightforward and reliable method is to take soil samples and to measure the electrical conductivity of the saturated soil paste extract (EC_e) in the laboratory. However, electromagnetic induction is a promising method for rapid quantitative assessment of soil salinity. The method yields data on bulk salinity of the soil profile in terms of apparent electrical conductivity (EC_a). As soil salinity for agricultural purposes is commonly expressed in electrical conductivity of the soil saturated paste extract EC_e, therefore, conversion of the EC_a to EC_e is always required in the use of EM38 for EC_e determination. The broad objective of this study was to calibrate the EM38 for conversion of EC_a to EC_e and to monitor soil salinity and environment.

The study was conducted for loam and sandy loam soil of Sub-surface Trial Site No.2 of Fordwah Eastern Sadiqia South (FESS) project area, Bahawalnagar, Pakistan. Extensive soil salinity survey of the area was conducted with EM38 and various fields, representing different salinity classes (low, medium and high), were selected for calibration. From selected fields EM38 readings were recorded to find apparent electrical conductivity (EC_a) and at the same time soil samples were collected from eleven depths ranging from surface to 150 cm depth to determine EC_e. Soil samples were analyzed in laboratory for determination of EC_e, saturation percentage (SP), soil water content and clay percentage. EC_e was weighted according to the instrument response curve. The relation between EC_e and temperature corrected EC_a, soil water content, SP and clay content, was determined with simple regression analysis.

Different regression equations were developed for different situations both for the vertical and horizontal modes of the instrument. In vertical mode the maximum response of the instrument was up to 150 cm depth whereas in horizontal mode the maximum response was up to 75 cm depth. The regression coefficients under various soil conditions have been drawn and discussed in the paper. For general purpose two regression equations i.e. $EC_e = -0.38 + 0.03 * EC_a(v)$ and $EC_e = 0.51 + 0.038 * EC_a(h)$[1] for vertical and horizontal modes respectively can be safely applied in almost all possible field situations without losing much accuracy. It is concluded that EM38 can be used successfully for EC_e determination up to 150 cm depth of soil, which is the range of active rootzone for almost all crops grown in the country.

1 Editor: the authors used EC_a for direct EM readings. So $EC_a(h) = EM_h$ and $EC_a(v) = EM_v$ in mS/m and EC_e is in dS/m.