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# ETM+ data applicability for remote sensing of soil salinity in Lighvan watershed, Northwest of Iran

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## Abstract

This study aims to examine the applicability of the ETM+ data for soil salinity prediction in Lighvan watershed, Northwest of Iran. The estimated soil salinity indices including SI1, SI2, SI3, NDSI, SI_1, SI2, and Si_3 were evaluated using ground measurements of EC ($EC_m$) from different land-uses and from bare soils only. The results do not have a correlation (average $R^2$ near to zero) $EC_m$ regarding to different land-uses in study area. There is also a similar outcome in the case of bare soils samples. Although employing a linear multivariate regression between $EC_m$ (as dependent variable) and salinity indices (as independent variables) led to a higher accuracy showing evaluating error (ER) of 34.9% vs. 35.9%, but the correlation between predicted and measured EC was still very low ($R^2$ of 0.07 vs. 0.002). As a result of this research the processing of the ETM+ data was not able to predict the necessary indices in this case. It is perhaps due to lower salinity amount and will probably give better estimations in wet regions with higher rate of evaporation.

**Keywords:** Electrical conductivity, Landsat data, Regression method, Salinity index, Satellite image

## Introduction

Arid and semiarid regions are very sensitive to environmental problems. Soil surface salinity is one of the major problems in this regions. Soil salinity, as a form of on-site soil degradation, usually occurs naturally or human-induced due to accumulation of soluble salts in the surface or near surface soil (Schofield et al. 2001). Kassas (1987) considered this factor as one of the oldest problems in agricultural lands and one of the seven major factors causing desertification. The United Nations Food and Agriculture Organization (FAO) estimated that 397 million hectares of the total land area of the world are affected by soil salinity (Koohafkan, 2012).
Quantifying of the soil salinity is the first step in monitoring and mapping of area suffering from this issue. Having enough knowledge about when, where, and how soil salinity may happen is a key parameter to the sustainable agriculture (Al-Khaier, 2003). Remedial actions require reliable information to choose the appropriate measure in each situation (Metternicht and Zinck, 2003). Ground-based electromagnetic measurements of soil Electrical conductivity (EC) are generally accepted as the most effective method to quantify soil salinity. Unfortunately, this method is expensive and time-consuming and needs more labour work and is not therefore inapplicable especially for large scale surveys (Bannari et al. 2008).
Several researchers have evaluated soil salinity using remote sensing as an alternative technique (Long and Nielsen, 1987; Everitt et al. 1988; Csillag et al. 1993; Verma et al. 1994; Bannari et al. 2008). However level detection of the soil salinity and sodicity is the most important challenge for this technique (Fraser and Joseph, 1998). On the other hand, the capability to evaluate quantity and spatial distribution of soil salinity at large scale is the potential advantage of the remote sensing technique. Several researchers have suggested that combination of extracted information from satellite images and ground trust data is the best solution to monitor soil salinity (Bishop and McBratney, 2001; Carré and Girard, 2002; Bouaziz et al. 2011). In this regard, several salinity indices such as SI1, SI2, and SI3 which are defined as following (Douaoui et al. 2006) have been introduced for estimation of soil salinity by remote sensing approaches.

$$SI1 = \sqrt{G \times R} \quad (1)$$

$$SI2 = \sqrt{G^2 + R^2 + NIR^2} \quad (2)$$

$$SI3 = \sqrt{G^2 + R^2} \quad (3)$$

where, R, G, and NIR imply for land reflectance in red, green, and near infrared spectrums of ETM+ data. Douaoui et al. (2006) showed that there are relatively moderate correlation (0.50, 0.44, and 0.49, respectively) among those indices and field measurements of EC ($EC_m$). The NDSI, SI_1, SI_2, and SI_3 are also other indices which have been introduced as salinity indices (Bannari et al. 2008). Bannari et al. (2008) defined these indices as below:

$$NDSI = \frac{(Band_3 - Band_4)}{(Band_3 + Band_4)} \quad (4)$$

$$SI\_1 = \frac{Band_5}{Band_7} \quad (5)$$

$$SI\_2 = \frac{(Band_4 - Band_5)}{(Band_4 + Band_5)} \quad (6)$$

$$SI\_3 = \frac{(Band_5 - Band_7)}{(Band_5 + Band_7)} \quad (7)$$

Where, $Band_i$ implies for the reflectance of ith band of ETM+ data. Bannari et al. (2008) by using EQ-1 satellite images reported that the $R^2$ between those indices and $EC_m$ were 0.427, 0.467, 0.361, and 0.469, respectively. Bouaziz et al. (2011) also evaluated several salinity indices using MODIS data.

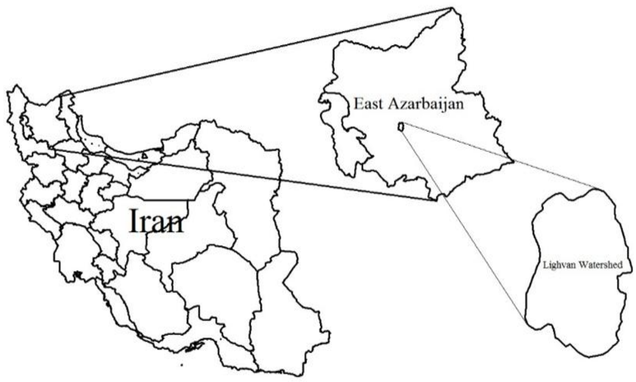


**Fig. 1. Location of the study area in east Azarbayjan and Iran.**

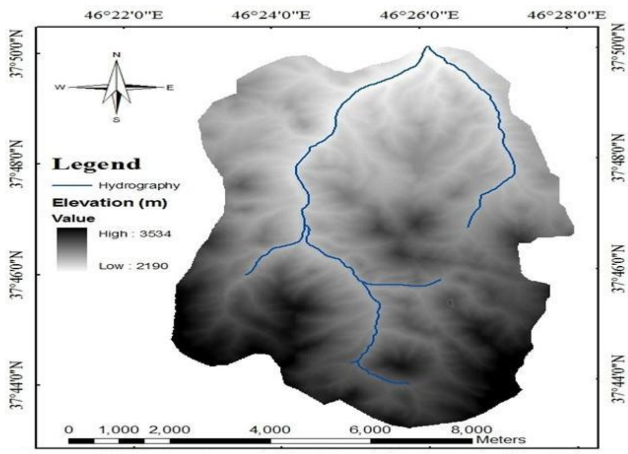


**Fig. 2. Digital elevation model (DEM) and river network of the study area.**

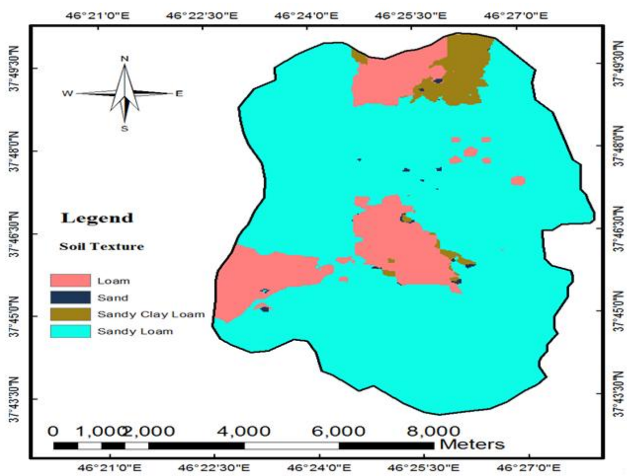


**Fig. 3. Soil map of the study area.**

Their results also showed no strong correlation between those salinity indices and $EC_m$.

The objective of this study was to evaluate ETM+ data capability in order to monitoring soil salinity in the Lighvan watershed, northwest of Iran.

## Materials and methods

### *Study area*

This research was carried out in the Lighvan watershed, East Azerbayjan, North West of Iran in last spring, 2012. The watershed is located at the rangelands of Sahand Mountain on the zone 38N (path=168 and row=34, 37° 43' 07" to 37° 50' 08" N, and 46° 22' 23" to 46° 28' 05" E). Fig. 1 depicts the location of the study area in East Azarbayjan, Iran.The Lighvan watershed has an area of 7,854 hectares and an elevation varying from 3534m in the uplands to 2190m at the watershed outlet (Fig. 2), with an annual average precipitation of 320 mm per year. Nearly all parts of the study area have coarse textured soils consisting of loam, sand, sandy clay loam, and sandy loam texture classes (Fig. 3).

### *Field and laboratory experiments*

Prior to soil sampling, study area was divided into 1 hectare square pixels using ArcGIS software and then soil samples were taken from each pixel. In general, 225 soil samples were taken from 45 cells (five samples from each cell). Fig. 4 indicates the location of the sampled pixels and the sampling strategy for each pixel. Soil textures were determined by hydrometer method (Gee and Or, 2002) and soil electrical conductivity by EC meter.

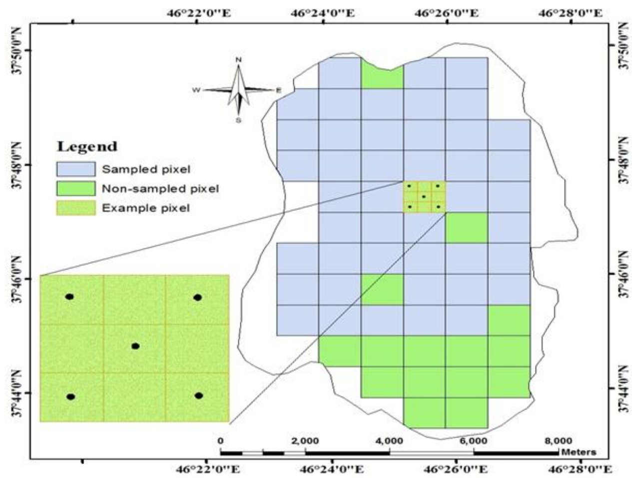


**Fig. 4. Location of the sampled cells and distribution of sampling points in the study area.**

### *Landsat data*

The spatial, spectrum, and temporal resolutions of the ETM+ data are 15 and 30 meters, 8 bands, and 16 days, respectively. The data were downloaded from USGS website at http://earthexplorer.usgs.gov/ dated 13-Jun-2012, 15-July-2012, and 17-Sep-2012 (only available images for study area during studying period). Finally, the data acquired on 17-Sep-2012 were selected for the analysis due to less clouds coverage comparing to others. The necessary pre-processing and corrections were applied to the selected data in order to accurate calculations.

*Remote sensing of soil salinity*

The salinity indices SI1, SI2, and SI3 introduced by Douaoui et al. (2006) and NDSI, SI_1, SI_2, and SI_3 reported by Bannari et al. (2008) were applied in this study. In order to estimate soil salinity, indices were extracted from ETM images of the area and the correlations between $EC_m$ and the indices were then evaluated using linear regressions.
Beside the seven mentioned linear regressions, we also tried to create a multivariate regression (linear and exponential) between $EC_m$ (as dependent variable) and salinity indices (as independent variables) to predict soil salinity via remotely sensed data. The linear and exponential multivariate regressions were defined as below:

$$EC=a_1+a_2SI1+a_3SI2+a_4SI3+a_5NDSI+a_6SI\_1+a_7SI\_2+a_8SI\_3 \quad (1)$$

$$EC=a_1\exp\left(\frac{SI1}{a_2}\right)+a_3\exp\left(\frac{SI2}{a_4}\right)+...+a_{13}\left(\frac{SI\_3}{a_{14}}\right) \quad (9)$$

Finally, a linear multivariate regression was also applied between $EC_m$ and reflectance’s from seven bands of ETM+ data (Band1 to Band7) to predict soil salinity.

$$EC=a_1+a_2Band1+a_3Band2+...+a_8Band7 \quad (10)$$

*Model performance*

The following criteria beside determination coefficient ($R^2$) were used to evaluate the models performances:
Root mean square error (RMSE)

$$\text{RMSE}=\sqrt{\frac{\sum_{t=1}^{N}\left[\text{EC}_{t,\text{Obs}}-\text{EC}_{t,\text{Sim}}\right]^2}{N}} \quad (11)$$

Evaluating error

$$\text{ER}=\frac{\text{RMSE}}{\overline{\text{EC}_{\text{Obs}}}}\times 100 \quad (12)$$

Where, EC implies electrical conductivity, Obs and Sim indicate the measured and predicted data at location “t”, respectively, with the number of measurements N and the average value of $\overline{EC_{Obs}}$ for the measured one. The RMSE, scale-dependent, varies between 0 (perfect fit) and + ∞ (no correlation), and ER, showing error percent, lies between 0 (perfect fit) and + ∞ (no correlation).

**Results and discussion**

Regarding EC prediction, EC of soil samples were measured initially using all soil samples (225 soil samples) taken from the whole sections of the study area and salinity indices were extracted from ETM data. So, several regressions (as stated in previous sections) were examined between $EC_m$ and each salinity index individually and finally, models accuracy were evaluated. Table 1 illustrates the evaluating results for applied regressions. Evidentially correlations between $EC_m$ and salinity indices were very weak. Regressions with average evaluating error (ER) of 36 and 40 % and $R^2$ of around zero for the calibration and validation stages, respectively, makes a strong hesitation about possibility of the ETM data application for the soil salinity estimation.

**Table 1. Results of the applied regression between $EC_m$ (225 soil samples) and salinity indices extracted from ETM+ data.**

| Calibration | | | Validation | | |
|---|---|---|---|---|---|
| RMSE (mS/cm) | ER (%) | $R^2$ | RMSE (mS/cm) | ER (%) | $R^2$ |
| 0.251 | 35.97 | 0.0002 | 0.275 | 39.83 | 0.0002 |
| 0.251 | 35.98 | 0.0000 | 0.275 | 39.82 | 0.0040 |
| 0.251 | 35.98 | 0.0002 | 0.275 | 39.83 | 0.0002 |
| 0.251 | 35.97 | 0.0006 | 0.275 | 39.93 | 0.0070 |
| 0.250 | 35.89 | 0.0053 | 0.276 | 39.91 | 0.0002 |
| 0.251 | 35.94 | 0.0022 | 0.275 | 39.75 | 0.0037 |
| 0.250 | 35.88 | 0.0057 | 0.276 | 39.92 | 0.0000 |
| 0.251 | 35.94 | 0.0020 | 0.275 | 39.86 | 0.0022 |

**Rows as polynomials are: EC=a+b×SI1, EC= a+b ×SI2, EC= a+b ×SI3, EC= a+b ×NDSI, EC= a+b ×SI_1, EC= a+b ×SI_2, EC= a+b ×SI_3 and Mean, respectively.**

Although Douaoui et al. (2006) and Bannari et al. (2008) evaluated salinity indices using $EC_m$ in bare soils, our ground measurements were carried out within four different land cover types including bare land, poor pasture, and Irrigated and dry-land farming (Fig 5).

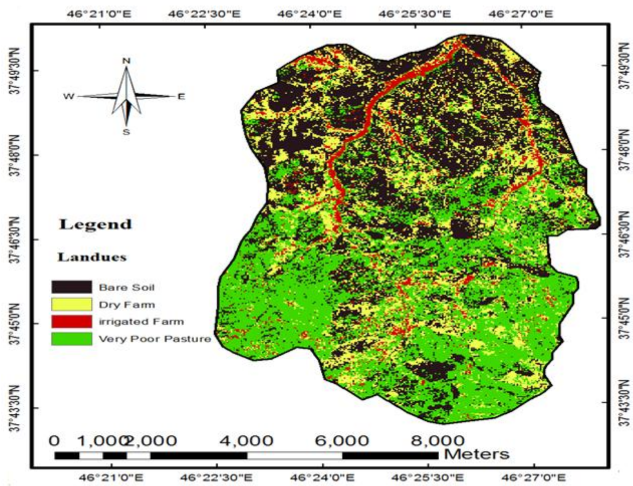


**Fig. 5. Land-uses map of the study area.**

The poor correlations between $EC_m$ and salinity indices probably originates from the effects of the different land covers. In order to overcome this problem on regressions analysis results, the mentioned regression models were calibrated and re-evaluate using $EC_m$ from bare soils only (102 soil samples). Beside the seven linear regressions reported by Table 1, we also created two linear (Eq. 8) and exponential (Eq. 9) multivariate regressions between $EC_m$ and salinity indices for remote sensing of soil salinity. As stated before, a linear multivariate regression (Eq. 10) was also applied between $EC_m$ and image bands reflectance (Band1 to Band7) to predict soil salinity.
The evaluating results of seven linear regressions beside three multivariate regressions (Eq. 8 to 10) are listed in table 2. Although employing multivariate regressions and using both salinity indices and image reflectance revealed slightly better correlations (Table 2).

**Table 2. Evaluation results of the applied regression between $EC_m$ in bare soils (102 soil samples) and salinity indices extracted from ETM+ data.**

| Calibration | | | Validation | | |
|---|---|---|---|---|---|
| RMSE (mS/cm) | ER (%) | $R^2$ | RMSE (mS/cm) | ER (%) | $R^2$ |
| 0.263 | 36.22 | 0.0002 | 0.282 | 39.43 | 0.0007 |
| 0.263 | 36.22 | 0.0001 | 0.282 | 39.42 | 0.0001 |
| 0.263 | 36.22 | 0.0002 | 0.282 | 39.43 | 0.0007 |
| 0.264 | 36.22 | 0.0000 | 0.282 | 39.43 | 0.0142 |
| 0.263 | 36.11 | 0.0060 | 0.280 | 39.18 | 0.0146 |
| 0.264 | 36.22 | 0.0000 | 0.282 | 39.37 | 0.0287 |
| 0.263 | 36.10 | 0.0064 | 0.280 | 39.18 | 0.0143 |
| 0.254 | 34.91 | 0.0707 | 0.284 | 39.68 | 0.0178 |
| 0.259 | 35.55 | 0.0364 | 0.281 | 39.21 | 0.0110 |
| 0.257 | 35.28 | 0.0511 | 0.306 | 42.77 | 0.0157 |
| 0.259 | 35.91 | 0.0171 | 0.290 | 39.71 | 0.0118 |

**Rows as polynomials are: EC=a+b×SI1, EC=a+b ×SI2, EC=a+b ×SI3, EC=a+b ×NDSI, EC=a+b ×SI_1, EC=a+b ×SI_2, EC=a+b ×SI_3, Equation 8, Equation 9, Equation 10 and Mean, respectively.**

Our results were in line with results from the previous investigations (Douaoui et al. 2006; Bannari et al. 2008; Bouaziz et al. 2011) reporting poor correlations between $EC_m$ and salinity indices. Douaoui et al. (2006) evaluated correlations between $EC_m$ and salinity indices including SI1, SI2, and SI3 by reporting $R^2$ of 0.50, 0.44, and 0.49, respectively. Bannari et al. (2008) also evaluated correlations between $EC_m$ and salinity indices (BI, NDSI, SI, ASTER_SI, SI_1, SI_2, and SI_3) using Eq-1 satellite data. They also reported poor correlations for their applied regression with $R^2$ from 0.022 to 0.469. Bouaziz et al. (2011) reported also a poor correlations between $EC_m$ and salinity indices extracted from MODIS data. In overall, the literature review indicates that soil salinity is not correlated strongly with remotely sensed data. Regarding salinity indices, researchers have focused on remote sensing of soil salinity based on its effects on the land reflectance from visual and infrared spectrums and it therefore may show a better functionality for soil salinity in the wet regions and with a high amount of soil evaporation which may result in high amount of soil salinity.

## Conclusion

The results revealed that salinity indices extracted from ETM data in Lighvan watershed were not reliable to estimate the soil salinity both in the whole area and even in the bare soils. The correlation between $EC_m$ and salinity indices were really poor. Considering the lower amounts of the soil salinity in the study area according to the ground measurements, the salinity indices may indicate a better correlation with $EC_m$ in other regions with a higher levels of salinity or at least on summer months with high level of soil evaporation rate that will cause more salinity on the soil surface.

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