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Investigation of the relationship between landform classes and electrical conductivity (EC) of water and soil using a fuzzy model in a GIS environment

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Abstract. Soil genesis is highly dependent on landforms as they control the erosional processes and the soil physical and chemical properties. The relationship between landform classification and electrical conductivity (EC) of soil and water in the northern part of Meharloo watershed, Fars province, Iran, was investigated using a combination of a geographical information system (GIS) and a fuzzy model. The results of the fuzzy method for water EC showed 36.6 % of the land to be moderately land suitable for agriculture; high, 31.69 %; and very high, 31.65 %. In comparison, the results of the fuzzy method for soil EC showed 24.31 % of the land to be as not suitable for agriculture (low class); moderate, 11.78 %; high, 25.74 %; and very high, 38.16 %. In total, the land suitable for agriculture with low EC is located in the north and northeast of the study area. The relationship between landform and EC shows that EC of water is high for the valley classes, while the EC of soil is high in the upland drainage class. In addition, the lowest EC levels for soil and water are in the plains class.

1 Introduction

The pedogenesis of the soils is determined by the climate (Cerdà, 1998a), the parent material (Prosdocimi et al., 2016) and human management (Debolini et al., 2015; Yan et al., 2015; Zhao et al., 2015; Cerdà et al., 2016), however also as a consequence of the landforms and processes that act on them. Soil features are largely controlled by the landforms on which they are developed. The physiographic penetration on soil properties is recognised based on the progress of the soil–landform relationship (Ali and Moghanm, 2013). The landforms formed by the same geomorphic processes are the main key feature because they can easily be identified, and were responsible for producing the undercoat material of the soils (Park and Burt, 2002; Henderson et al., 2005; Mini et al., 2007; Poelking et al., 2015). Previous studies have shown that there is a clear relationship between landform and soils, in that landforms and soil both control hydrological erosional, biological and geochemical cycles. Based on the type of landform, other parameters of watersheds can be predicted, such as soil, erosion, biological parameters and so on (Berendse et al., 2015; Brevik et al., 2015; Decock et al., 2015; Keesstra et al., 2012; Adugna et al., 2015; Ochoa-Cueva et al., 2015; Smith et al., 2015).

A geographical information system (GIS), with features such as the ability to acquire and exchange many different sources, organisation, retrieval and display of data, analysis of numerous data and possibility to provide multiple services, has been introduced as an efficient tool in planning. Combining a GIS with fuzzy logic provides a comparatively new land evaluation method (Badenko and Kurtener, 2004; Oinam et al., 2014; Wang et al., 2015). Incorporating both of these methods is more flexible, and reflects human creativeness and understanding in making decisions. Fuzzy inference is considered as a deduction for mathematical modelling in imprecise and vague processes, i.e. uncertainty about data, and thus creates a context for modelling uncertainty (Kurtener, 2005).

Ali and Moghanm (2013) studied the variation of soil properties over the landforms around Idku Lake, Egypt, with the spatial distribution of $CaCO_3$, electrical conductivity (EC), organic matter (OM), pH, nitrogen (N), phosphorus (P), potassium (K), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) over the various landforms discussed in detail. The results showed that the changes of $CaCO_3$, EC and OM are minimal in the landforms of sand sheets, hammocks, sabkhas, clay flats and former lake bed.

Aliabadi and Soltanifard (2014) apply a GIS and fuzzy inference for determination of the impact of water and soil EC and calcium carbonate on wheat crops. Regarding the results of the fuzzy inference system, 76 % accuracy was achieved using the Mamdani's method and 52 % of accuracy was achieved for the Sugeno technique.

In addition, El-Keblawy et al. (2015) investigated relationships between landforms, soil characteristics and dominant xerophytes in the northern United Arab Emirates. Soil texture, electrical conductivity (EC) and pH were determined in each sample point. The results showed that soil and landforms also control the geomorphological and hydrological processes (Cerdà and García-Fayos, 1997; Cerdà, 1998b; Dai et al., 2015; Nadal-Romero et al., 2015).

One of the largest wheat-producing regions in Iran is located in the Shiraz Plain, Fars province (Bijanzadeh et al., 2014). The aim of this study is to investigate the relationship between landform classes and EC of water and soil in this area using a combination of a GIS and a fuzzy model. The methodology employed in this study is summarised in Fig. 1.

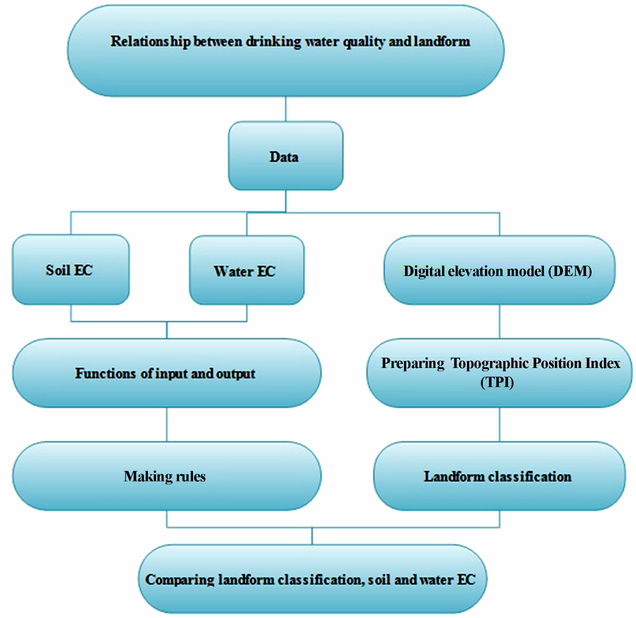


Figure 1. Flowchart of the methodology employed to investigate the relationship between landform classification, and soil and water EC.

2 Material and methods

The study area has an area of 3909 km^2 and is located at a longitude of 29°06–29°43 N and a latitude of 52°18 to 53°28 E (Fig. 2). The altitude of the study area ranges from the lowest at 1433 m to the highest at 3083 m. The region is located in the north of the Fars province, which has cold winters and hot summers. The average temperature for the area is 16.8 °C, ranging between 4.7 and 29.2 °C (Soufi, 2004). The research area demonstrates a biodiversity of mountains, relief and lithology, and geological characteristics such as, for instance, sedimentary basin and elevated reliefs (Soufi, 2004). The main agricultural produce consists of grain, fruit and vegetables, while the partly wooded mountains are used for pasture. The main land use types of the region are agriculture, range land, farming and forests.

In terms of geology, the Precambrian Hormoz series and the Quaternary units are the oldest and youngest rocks in the basin, respectively. Spans of outcropped rocks, covering from the Cretaceous to Quaternary, are carbonate sediments of deep to shallow marine facies. These sedimentary sequences include large and small stratigraphic gaps in the form of disconformity and sometimes nonconformity (Khaksar et al., 2006).

The area is situated in an arid and semi-arid region. Rainfall varies from 150 mm on the plains to 650 mm on the high mountains, with an average of 350 mm. The rainfall is concentrated in cold seasons, while the precipitation is very low from June to October (Sigaroodi et al., 2014).

During winter, several migratory bird species from north of Caspian Sea, flamingos (*Phoenicopterus roseus*), common shelducks (*Tadorna tadorna*) and mallards (*Anas platyrhynchos*) spend 4 months in the area feeding on brine shrimp (*Artemia franciscana*). Thus, the lake has important ecological value (Sigaroodi et al., 2014).

2.1 Inverse distance weighted (IDW) model

An IDW model was used for interpolating the EC properties. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will be used to measure neighbourhood values in the predicted location. Assumed value of an attribute f at any unsampled point is an average of distance-weighted sampled points lying within a defined neighbourhood around that unsampled point. Basically, it is a weighted moving average

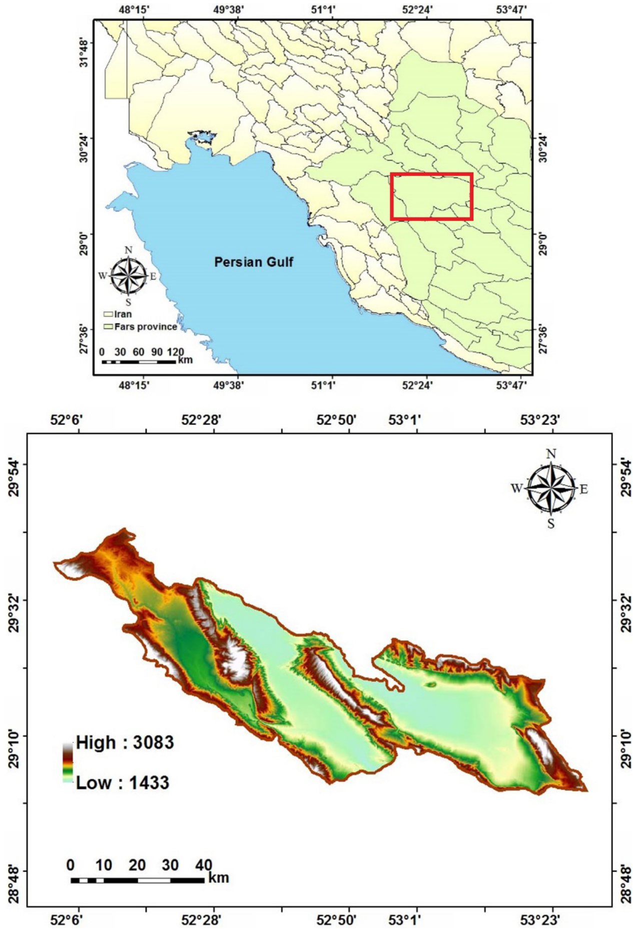


Figure 2. Location of the study area (DEM with spatial resolution of 30 m) (source: http://earthexplorer.usgs.gov).

Table 1. Classification of water EC values (Kumar et al., 2003).

Class	EC (ds/m)
Low	< 0.25
Moderate	0.25–0.75
High	0.75–2.25
Very high	> 2.25

(Burrough et al., 1998):

$$\hat{f}(x_0) = \frac{\sum_{i=1}^{n} f(x_i) d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}}, \tag{1}$$

where x_0 is the estimation point and x_i are the data points within a chosen surrounding. The weights (r) are related to distance by d_{ij}.

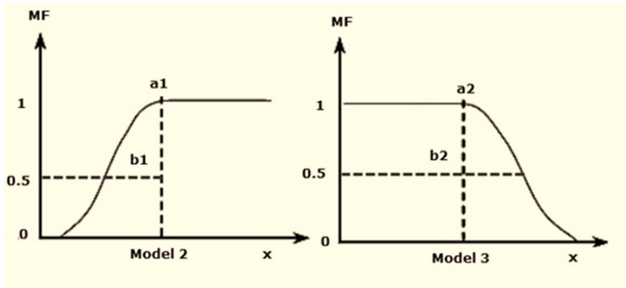


Figure 3. Membership functions.

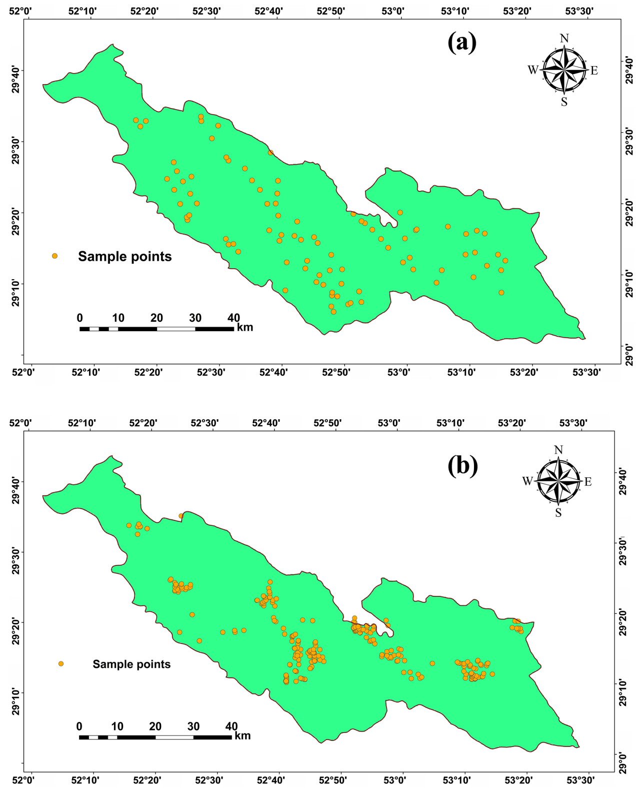


Figure 4. Position of sample points for **(a)** water and **(b)** soil EC.

2.2 Fuzzy method

In research, model functions are accustomed to computing membership function (MF), as described in Fig. 3 (Burrough and McDonnell, 1998). According to Fig. 3, an asymmetric function needs to be applied (Models 1 and 2) (Fig. 3). If $\mathrm{MF}(x_i)$ shows individual membership value for ith land property x, then in the computation process these model functions (Models 1 to 2) show the following form.

For asymmetric left (Model 1),

$$\mathrm{MF}(x_i) = [1/(1+\{(x_i - a_i - b_1)/b_1\}^2)] \text{ if } x_i < (a_1 + b_1). \tag{2}$$

For asymmetric right (Model 2),

$$\mathrm{MF}(x_i) = [1/(1+\{(x_i - a_2 + b_2)/b_2\}^2)] \text{ if } x_i > (a_2 - b_2). \tag{3}$$

Table 2. Classification of soil EC values (Mokarram et al., 2010).

Class	EC (ds/m)
Low	< 8
Moderate	8–12
High	12–16
Very high	> 16

In this study, in order to define fuzzy-rule-based membership functions, the categories shown in Tables 1 and 2 are used.

2.3 Landform classification

The Topographic Position Index (TPI) (Weiss, 2001) compares the elevation of each cell in a digital elevation model (DEM) to the mean elevation of a specified neighbourhood around that cell. Positive TPI (Eq. 4) compares the elevation of each cell in a DEM to the mean elevation of a defined neighbourhood around that cell. Mean elevation is subtracted from the elevation value at the centre (Weiss, 2001):

$$\mathrm{TPI}_i = Z_0 - \sum_{n-1} Z_n / n, \tag{4}$$

where Z_0 is the elevation of the model point under evaluation, Z_n is the elevation of grid and n is the total number of surrounding points employed in the evaluation.

Incorporating TPI at small and large scales permits a number of nested landforms to be distinguished (Table 3). The actual breakpoints among classes can be selected to optimise the classification for a specific landscape. As in slope position classifications, additional topographic metrics, such as, for example, differences of elevation, slope or aspect within the neighbourhoods, can help delineate landforms more accurately (Weiss, 2001).

Additionally, the classes of canyons, deeply incised streams, mid-slope and upland drainages and shallow valleys tend to have strongly negative plane form curvature values. On the other hand, local ridges/hills in valleys, mid-slope ridges, small hills in plains and mountain tops and high ridges have strongly positive plane form curvature values.

3 Results and discussion

3.1 Inverse distance weighted (IDW) interpolation

IDW interpolation was used to produce the prediction of soil and water EC, as shown in Fig. 4. According to Fig. 4, sample points were selected randomly in the study area. These data were prepared by the Organization of Agriculture Jahad Fars province in 2012. The lowest and highest output for IDW were 0.016 and 14.48 respectively for water EC, while the lowest and highest soil EC was 0 and 34.5 respectively. The

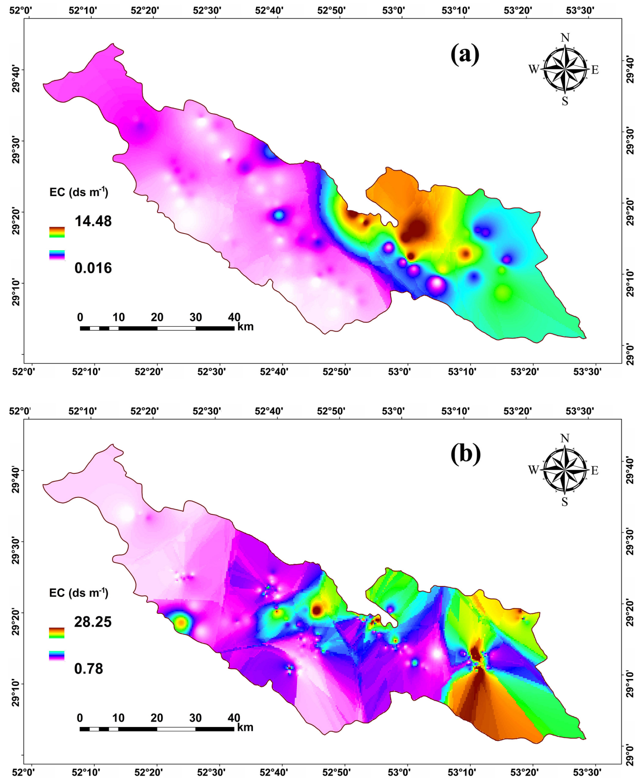


Figure 5. Interpolated maps of study area for **(a)** water and **(b)** soil EC.

interpolation maps for soil and water EC are shown in Fig. 5. The statistical properties of the interpolated soil and water EC are shown in Table 4.

3.2 Fuzzy method

Fuzzy maps were prepared for soil and water EC, as shown in Fig. 6. The fuzzy values were classified into four classes. EC < 0.25, EC between 0.25 and 0.5, EC between 0.5 and 0.75 and EC > 0.75 are in the classes of low, moderate, high and very high respectively (Shobha et al., 2014). The areas of the classes for soil and water EC are shown in Table 5.

For water EC, the fuzzy model showed that 36.6 % of the land was in the moderate class; high, 31.69 %; and very high, 31.65 %. In comparison, the results of the fuzzy model for soil EC showed that 24.31 % of the land was in the low class; moderate, 11.78 %; high, 25.74 %; and very high, 38.16 %. Based on the results obtained, the land suitable for wheat agriculture is located in the north and northeast in the study area.

3.3 Landform classification

In order to determine of relationship between landform classification, and soil and water EC, the landform map of the study area was prepared. Using the TPI, the landform classi-

Table 3. Topographic Position Index (TPI) thresholds for small and large neighbourhoods used to define landscape feature classes.

Landform	TPI Small neighbourhood	Large neighbourhood
Plains	$-1 < \text{TPI} < 1$	$-1 < \text{TPI} < 1$*
Open slopes	$-1 < \text{TPI} < 1$	$-1 < \text{TPI} < 1$**
U-shaped valleys	$-1 < \text{TPI} < 1$	$\text{TPI} < -1$
Mountain tops/high ridges	$\text{TPI} > 1$	$\text{TPI} > 1$
Upper slopes/mesas	$-1 < \text{TPI} < 1$	$\text{TPI} > 1$
Mid-slope drainages/shallow valleys	$\text{TPI} < -1$	$-1 < \text{TPI} < 1$
Canyons/deeply incised streams	$\text{TPI} < -1$	$\text{TPI} < -1$
Mid-slope ridges/small hills in plains	$\text{TPI} > 1$	$-1 < \text{TPI} < 1$
Upland drainages/headwaters	$\text{TPI} < -1$	$\text{TPI} > 1$
Local ridges/hills in valleys	$\text{TPI} > 1$	$\text{TPI} < -1$

* Plain landform class required a slope of < 0.5. ** Open slopes landform class required a slope of > 0.5

Table 4. Descriptive statistics of the water and soil EC.

Statistic parameter	Water EC (ds/m)	Soil EC (ds/m)
Maximum	14.48	28.25
Minimum	0.016	0.78
Average	3.80	3.91
Standard deviation	6.13	3.82
Skewness	6.54	3.09
Kurtosis	62.97	15.46

Table 5. Areas of the classes for water and soil EC.

Class	Area (%)		Area (km^2)	
	Water EC	Soil EC	Water EC	Soil EC
Low	0.00	24.31	0.11	950.23
Moderate	36.60	11.78	1430.87	460.63
High	31.69	25.74	1238.91	1006.27
Very high	31.65	38.16	1237.10	1491.86

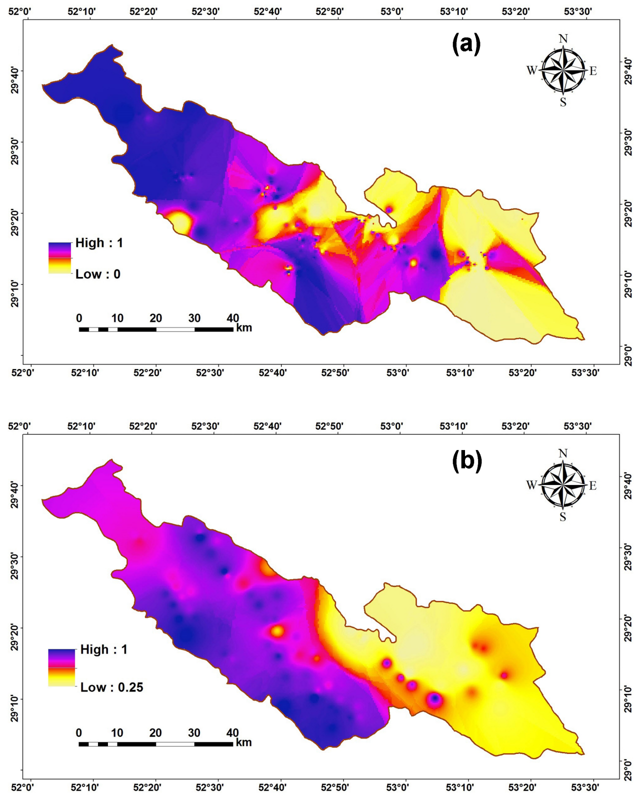
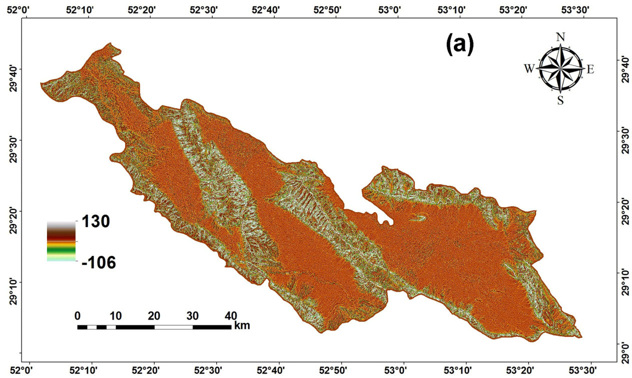


Figure 6. Fuzzy maps of the study area for **(a)** soil and **(b)** water EC.

fication map of the study area was generated. The TPI maps generated using small and large neighbourhoods are shown in Fig. 7. The TPI is between -106 to 130 and -334 to 533 for 3 and 45 cells for small and large neighbourhoods respectively (Fig. 8). The landform maps generated based on the TPI values are shown in Fig. 8. The classification has 10 classes: high ridges, mid-slope ridges, upland drainage, upper slopes, open slopes, plains, valleys, local ridges, mid-slope drainage and streams. The areas of the landform classes are shown in Fig. 9. It is observed that the largest landform is streams, while the smallest is plains.

The average EC for each landform class was determined, and the relationship between EC and landform was prepared. According to Fig. 9, the EC of water is high for the valley class while the high EC of soil is in the upland drainage class. The lowest EC levels for soil and water are in the plains class.

Dazzi and Monteleone (2001) investigated the relationship between soil properties and landform in Italy. The results show that in plains, the EC value is greater than the other landform types that are similar to results of the study area. Ali and Moghanm (2013), who investigated relationship between soil properties and landform classes in Idku Lake, Egypt, also



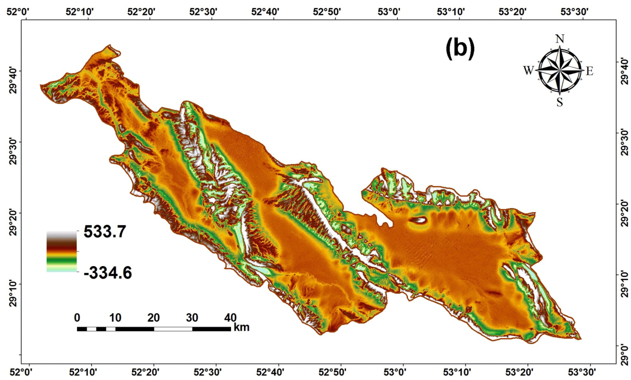


Figure 7. TPI maps generated using **(a)** small (3 cells) and **(b)** large (45 cells) neighbourhood.

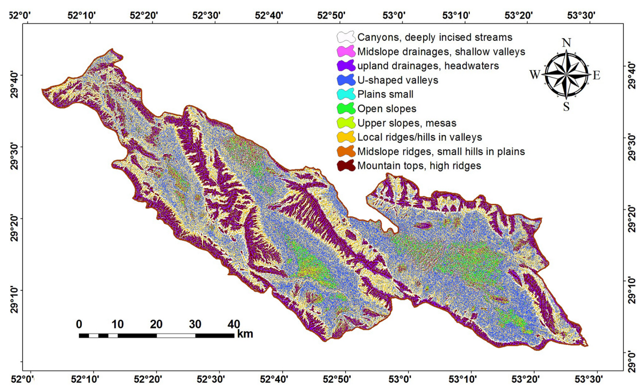


Figure 8. Landform classification using the TPI method.

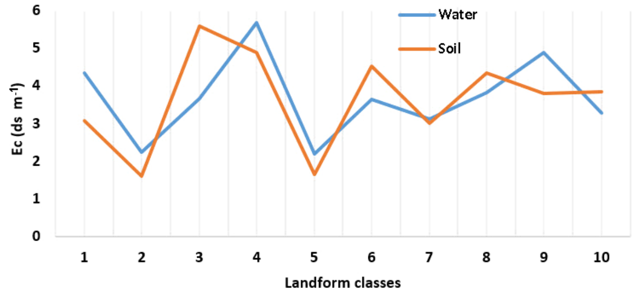


Figure 9. Relationship between landform classes.

found that the lowest EC was in plain class. In fact, there is a relationship between soil parameters and land use (Wasak and Drewnik, 2015; Kukal and Bawa Debasish-Saha, 2014). Yu et al. (2014) showed that there is relationship between soil parameters (such as soil organic carbon (SOC), soil total nitrogen (STN)) and types of land cover (grassland, farmland, swampland). Niu et al. (2015) and Yu et al. (2015) investigated the relationship between land use and soil moisture. The results provided an insight into the significance for land use and farming water management in this area. Saha and Kukal (2015) found that there is a relationship between soil structural stability and land use. The results indicated the degradation of soil physical attributes due to the conversion of natural ecosystems to farming system and increased erosion hazards. In fact the landforms are located at high elevation such as in mountains; the leaching process is high, while in landforms which are located at low elevation such as plains, the accumulation process is evident. Therefore, in the study area and similar research, the EC value was recorded high in lower topographical positions (Walia and Chamuah, 1994; Singh and Rathore, 2015). In fact EC and other soil properties can be estimated easily and without measuring salinity in the laboratory using satellite data such as from a digital elevation model (DEM) that save time and money.

4 Conclusion

In this study, the relationship between classes of landform and electrical conductivity (EC) of soil and water in the Shiraz Plain was investigated using a combination of a geographical information system (GIS) and a fuzzy model. The results of the fuzzy method for water EC showed 36.6 % of the land to be moderately land suitable for agriculture; high, 31.69 %; and very high, 31.65 %. In comparison, the results of the fuzzy method for soil EC showed 24.31 % of the land to be as not suitable for agriculture (low class); moderate, 11.78 %; high, 25.74 %; and very high, 38.16 %. In total, the land suitable for agriculture with low EC is located in the north and northeast of the study area. The relationship between landform and EC shows that EC of water is high for the valley classes, while EC of soil is high in the upland drainage class. In addition, the lowest EC levels for soil and water are in the plains class.

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