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***Research Article***

# EVALUATING THE CAPABILITIES OF FUZZY LOGIC AND ANALYTIC HIERARCHY PROCESS (AHP) IN IDENTIFYING AND MAPPING THE SOILS OF COMPLEX TERRAINS (IRAN - LORESTAN)

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## ABSTRACT
Identifying and mapping soils provides the most important basic data for many studies. To name but a few studies that rely on such data, one can mention land evaluation, measuring the percentage and territory of the usable soils, identifying sites for construction, industrial, and urban projects, and measuring the biological products potential. Maps produced through traditional methods are very expensive and time consuming and updating them requires a review of the basic data. On the other hand, the accuracy and quality of these maps is largely dependent upon the level of the knowledge of the experts and the methods used for drawing those maps. Thus, modern mapping methods and drawing various digital maps have been developed by the experts as a way to resolve the shortcomings of the traditional methods. Some of these methods are based upon inference of soil forming factors and their influence on the type of the soil formed. Soil inference engine (SIE) is a knowledge-based model based on the fuzzy logic which utilizes 2 type of knowledge: the rules which are defined as values of the environmental factor, and the cases which are defined in geographical space. In SIE model, the soil mapping is conducted based on soil-environment model. In this research, we have attempted to draw the digital soil map of Polharoo watershed located in Lorestan province with area of 933.5 hectares using soil inference engine model and analytic hierarchy process in the Geographical Information System. To draw digital maps, rule-based and case-based knowledge bases were established and digital elevation model extracted from ASTER sensor with spatial resolution of 10 meters and the digital layers extracted from it (such as slope, direction of slope, wetness index, etc.) and the geological digital layer (1:250000) were utilized as the environmental inputs of the model. To validate the digital map of the soil produced, the map of the soil of that area was drawn with traditional methods and the error matrixes resulting from the comparison of both maps were compared with one another. The validation results show a 95% overall accuracy which indicates the acceptable quality and accuracy of the digital map produced through soil inference engine (SIE) model.

***Keywords**: Soil Digital Map, Remote Sensing, GIS, Fuzzy Logic, Analytic Hierarchy Process*

## INTRODUCTION
Digital soil mapping has undergone a rapid development in the past decade (McBratney *et al.*, 2003; Grunwald, 2006; Lagacherie and McBratney, 2007). Generally there are two approaches being taken in DSM research and practice. One aims at truly automatic, objective, and quantitative mapping, taking advantage of the techniques in statistics, geostatistics, machine learning, and data mining, and generally relying heavily on densely sampling from either fi eld or existing soil maps. McBratney *et al.*, (2003) provides a comprehensive review of this approach. Some researchers taking this approach have also challenged the traditional class mapping paradigm and proposed to directly map soil layers and properties (e.g., McSweeney *et al.*, 1994; Gessler *et al.*, 1995). The other approach tries to fi t within the conventional soil survey and mapping framework, including the conventional process and standard. It aims to effectively utilize the soil scientist's knowledge, while reduce the inconsistency and cost associated with the traditional manual process (Zhu *et al.*, 2001; Shi *et al.*, 2004). Its major digital components include the knowledge engineering techniques for knowledge acquisition, knowledge representation, and knowledge-based inference. While the two approaches are in no sense mutually exclusive (Grunwald, 2006; Walter *et al.*, 2007), the differences in philosophy and technical emphasis

between them may lead to different plans and strategies for implementing DSM. One of the knowledge-based models is the soil inference engine model first proposed by Shi in 2004. In this model, the soil mapping is conducted through soil-environment model. In other words, soil is a function of other environmental factors:

Equation (1): $S = f(E)$

SIE model is a knowledge based model which utilizes 2 types of knowledge. One is the rule which is defined as the values of environmental factor, and the other one is the case which is defined in the geographical environment. This model is based on the fuzzy logic where the initial output of the inference model is a series of the maps of fuzzy membership function with the Raster format (Shi, 2010). The inference algorithm in SIE model is composed of three P, E, and T functions:

Equation (2):

$$S_{ij,k} = T_k\left\{P_c\left[E_{c,a}\left(z_{ij,a}, z_{c,a}\right)\right]\right\}$$

In this equation, $S_{ij,k}$ is the value of fuzzy membership function in location *ij* for soil k, $T_k$ is the function that determines the value of the final fuzzy membership function for soil k in location *ij* based on all evidences from soil k, $P_c$ is the evaluation method of fuzzy membership function on the control level, $E_{c,a}$ is the evaluation function of optimality value on the environmental factor level, $Z_{ij,a}$ is the value of environmental factor in location *ij*, and $Z_{c,a}$ is the highest optimized domain given by the control. In this study, the digital map of the soil of Polharoo watershed located in Lorestan province was produced using inference of the environmental layers extracted from telemetry data and the elevation data based on the fuzzy logic in analytic hierarchy process in the environment of GIS.

## MATERIALS AND METHOD

### *Geographical Location of the Area Studied*

The study area is subbasine of Polharoo watersheds with area of 933.5 hectares located in Lorestan province between the eastern longitude of 48° 44′19″ to 48° 46′ 55″ and the northern latitude of 33° 28 ′22″ to 33° 30′ 41 ″(figure 1).

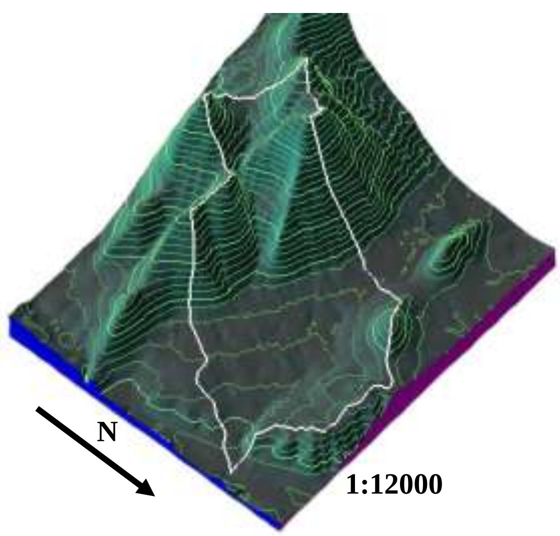


**Figure 1: The Polharoo watershed**

### *The Geology and Terrain of the Area Studied*

In terms of geology, the area studied is located in Sanandaj-Sirjan zone. It has 2 units of current sediments (Qc) belonging to Cenozoic period, Quaternary period (the 4th geological period) and orbitolina lime (k1) belonging to Mesozoic and Cretaceous period (the 3rd geological period) (figure 2). In terms of climate, this area has the moisture regime of Xeric and the thermal regime of Mesic.

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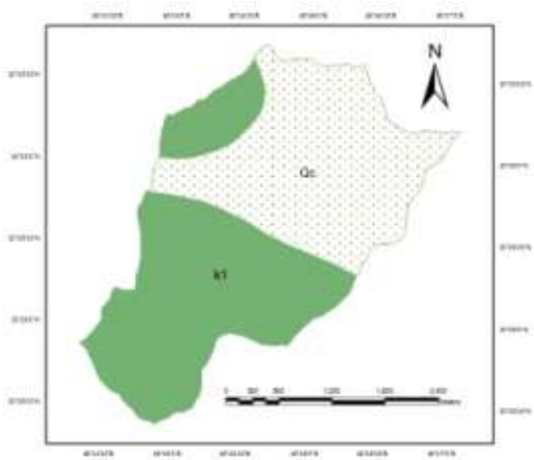


**Figure 2: The geological map of the area studied (the geological map 1:250000, Iranian Geology institute)**

***Producing the Digital Map of the Soil Based on Soil Inference Engine Model (SIE)***

*Data and Software*

To produce the digital layers for the input of the model, the Raster layer of digital elevation model of the reference land produced by the Esther sensor with a resolution of 10 meters was used. The geological digital layer as one of the input layers of the model was produced in the Geographical information system (GIS) environment based on the geological map 1:250000 of the Iranian Geology Bureau (figure 2).

To form and process various information layers, various softwares such as Arc GIS version 9.3, Arc SIE version 2.3, and 3DMapper version 2.11 were used in this study.

*Processes*

The input layers to SIE model include: geological digital layers and the environmental layers resulting from Digital Elevation Model (DEM) consisting of elevation, slope gradient, planform Curvature, and wetness index. These environmental layers are produced through ArcSIE tool.

After producing the input layers required by the model, an environmental database was formed using these layers and, afterwards, the knowledge base was produced based on 2 reason-based and case-based reasoning frameworks for all types of soil. Using the environmental data base containing environmental factor, the given weight through hierarchy method, geological data base and digital layer, inference operation and fuzzy membership functions for each type of soil as the output of inference were produced (table 1). Finally after applying Hardening operation on fuzzymembership functions produced through inference, the digital map of the soil was drawn.

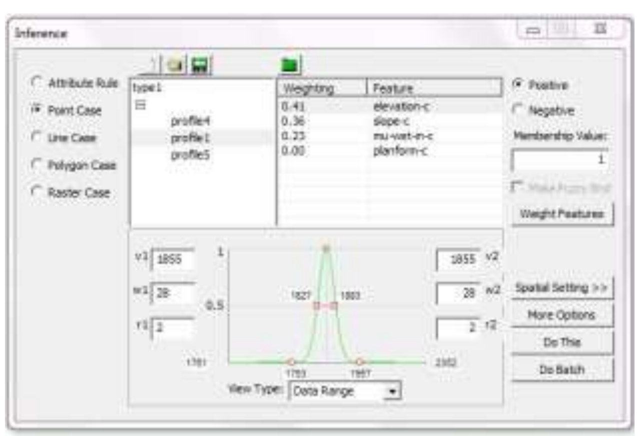


**Figure 3: Producing knowledge base in ArcSIE tool**

The case-based knowledge base was produced separately for the 2 soil types through 6 profiles dug in the area studied. The rule-based knowledge base was produced through the information gathered from the area for the bedrock unit through selection of the curve type and determining the optimized threshold for each environmental factor. ArcSIE was used in both cases (figure3).
Weighting each one of the environmental factors for each type of soil was conducted through analytic hierarchy process in ArcSIE tool (figure 4). Table 2 represents the weights assigned to each one of the environmental factors for each unit of the map.

**Table 1: Parent material type, function type, and the threshold values of environmental factors of knowledge bases**

| Soil type | Inference type | Case or sample | Geology | Environmental factors | Curvature type | V1, W1 | V2, W2 |
|---|---|---|---|---|---|---|---|
| Fine Mesic Typichaploxerept (type1) | Case-based | Profile 1 | Qc | Elevation | Bell | 1855, 28 | 1855, 28 |
| | | | | Slope | Bell | 2.8, 3.4 | 2.8, 3.4 |
| | | | | Wetness index | S | 2.5, 0.77 | |
| | | Profile 4 | Qc | Elevation | Z | | 1804, 28 |
| | | | | Slope | Bell | 4.5, 3.4 | 4.5,3.4 |
| | | | | Wetness index | S | 2.3, 0.77 | |
| | | Profile 5 | Qc | Elevation | S | | 8.5, 1.5 |
| | | | | Slope | Z | 1828, 28 | |
| | | | | Wetness index | S | 1.4, 2.5 | |
| Fine Mesic Typicxerorent (type 2) | Case-based | Profile 2 | K1 | Elevation | Bell | 1874, 28 | 1874, 28 |
| | | | | Slope | Z | | 9.1, 3.4 |
| | | Profile 3 | K1 | Elevation | Bell | 1875, 28 | 1875, 28 |
| | | | | Slope | Bell | 9.5, 3.4 | 9.5, 10 |
| | | Profile 6 | K1 | Elevation | Bell | 1933, 50 | 1933, 27 |
| | | | | Slope | Z | | 18.11, 6 |
| Bedrock | Rule-based | Example1 | K1 | Elevation | S | 1900, 20 | |
| | | | | Slope | S | 25, 22 | |

*V1 and V2: the lower and upper limits of the highest optimality of environmental factor a for soil k*
*W1 and W2: the lower and upper limits of 0.5 optimality of environmental factor a for soil k*


**Figure 4: Weighting environmental factors through AHP method**

**Table 2: Weights assigned to environmental factors for each one of the map units**

| Map unit | Environmental factor | weight |
|---|---|---|
| Soil type 1 | Elevation | 0.41 |
| | Slope | 0.36 |
| | Wetness index | 0.23 |
| Soil type 2 | Elevation | 0.50 |
| | Slope | 0.50 |
| Bedrock | Elevation | 0.26 |
| | Slope | 0.74 |

*Validation*

To validate the map produced through soil inference engine model, the error matrixes of the digital map produced by the model and the map produced through traditional methods were calculated through ILWIS software.

***Results***

The input layers of SIE model including digital layers of elevation, slope gradient, and wetness index are represented in figure 5.

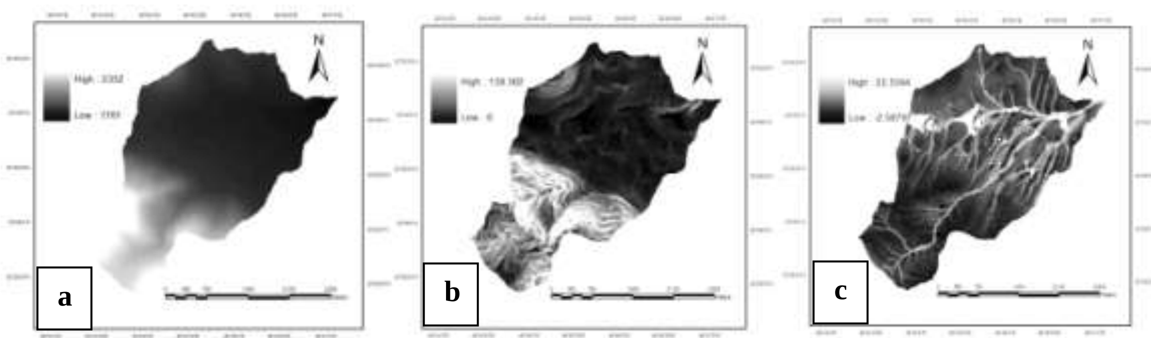


**Figure 5: a) map of the elevation digital model, b) slope gradient and c) wetness index of the watershed studied**

The results of the inference operation on Raster functions are fuzzy membership functions for each type of soil. In these functions, each pixel is assigned a value from 0-100. The closer this value be to 100, the more probably does that pixel belong to the desired soil unit. Figure 6 shows the fuzzy membership functions resulting from inference operation for three map units (soil type 1, soil type 2, and bedrock).
The final output of SIE model is the soil digital map which is created by Hardening fuzzy membership functions (figure 7-a). Figure 7-b also shows the soil map of the area studied drawn through traditional method. The error matrix of comparing 2 traditional and digital maps is shown in table 3.

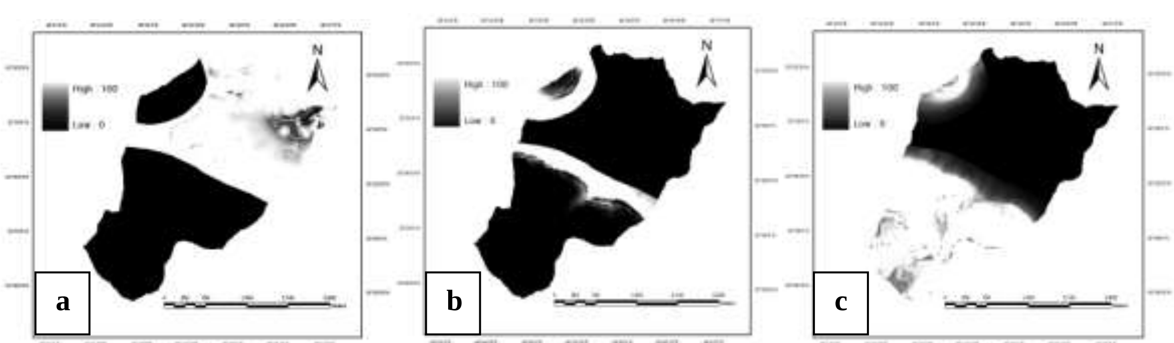


**Figure 6: a) Soil membership function type 1, b) soil membership function type 2, and c) bedrock of the watershed studied**

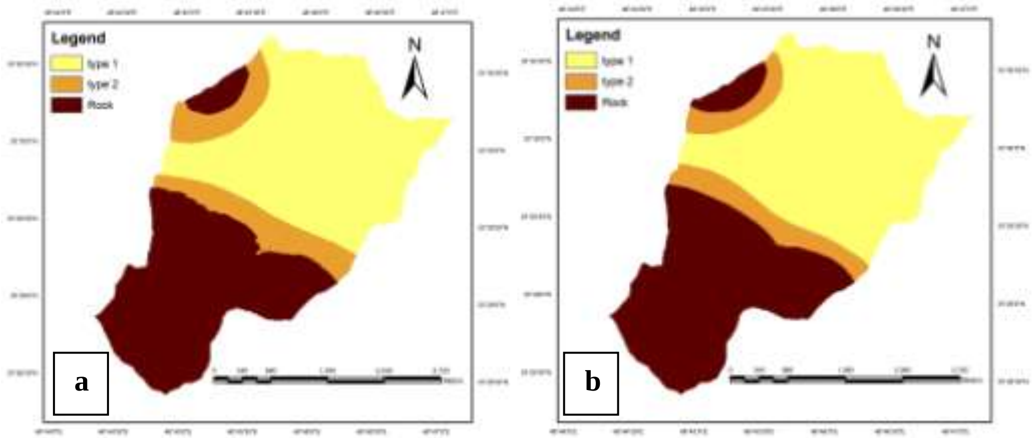


**Figure 7: a) The digital soil map, b) traditional soil map**

**Table 3: The error matrix of comparing maps drawn through traditional method and SIE model (area in terms of acres)**

| | | The SIE Map | | | | |
|---|---|---|---|---|---|---|
| | | Soil type 1 | Soil type 2 | Bedrock | Total | User's accuracy |
| The Manual Map | Soil type 1 | 434.5 | 6 | 0 | 440.5 | 98 |
| | Soil type 2 | 26.8 | 90.5 | 7.6 | 124.9 | 72 |
| | Bedrock | 0 | 1.8 | 366.3 | 368.1 | 99 |
| | Total | 461.3 | 98.3 | 373.9 | 933.5 | |
| | Producer's accuracy | 94 | 92 | 97 | | 95 |
| | Total accuracy: 95% | | | | | |

## RESULTS AND DISCUSSION

The final results indicate that the differences between Fine Mesic Typic haploxerept (soil type 1) and Fine Mesic Typicxerortent (soil type 2) is probably related to their parent ingredients. First type soil is of Inceptisols type and it is placed on the current time sediments in the low slope part of the field, thus they had time for evolution and formation of Bw genetic horizon. Second type soil is located on the hillside with a slope of 5 to 15 percent over lime formations. Due to bedrock material and also greater slope as compared with Inceptisols, this soil has had no opportunity for soil development. Thus, the geological layer has had a magnificent role in separating these 2 soil types during the inference process, and as one can see in figure 7-a (the map drawn through SIE model), the separation line between type 1 and type 2 is drawn by the geological layer, yet this separation is mostly subordinate to typography and homogenous units in the aerial image in traditional method. In separation process of soil type 2 and bed rock, elevation layers and slope have a dominant role. Thus, drawing a separating line between these two phenomena in the map drawn from the model has more accuracy. It is also less reliant on user's experience and accuracy.

The validation results represented in table 2 show a total accuracy of 95% which is an acceptable degree. Little accuracy on the side of the user and producer for soil type 2 (respectively 72% and 92%) compared to similar values for soil type 1 (respectively 98% and 94%) and bedrock (respectively 99% and 98%) can be justified by saying that soil type 2 has a common border with both soil type one and the bedrock, while the 2 units of soil type 1 and bedrock have a common border with only one unit (soil type 2).

As the input layers of SIE model are the digital model of elevation and layers derived from that, the output map scale is easily detectible due to the local separation power of the layers, and it has nothing to do with the scope of the area studied. As for traditional mapping, scale grows smaller as the scope of the area grows larger since collecting data about the whole are becomes increasingly harder. This causes the deletion of many details on the map. Another advantage of digital soil mapping is that we can map areas which are difficult to access. As the final results of this research confirm, the inference model can act as a good alternative for time-consuming, expensive traditional methods.

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