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Outcomes of applying a geopedologic approach to soil survey in Iran

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Abstract

The paper reviews a set of soil surveys carried out in Iran using a geopedologic approach for different surveying aims in different scales. Most of these studies have implemented a similar survey method including the following steps: delineation of landforms from air photos using geomorphic and soil-landscape relationships, field check of the delineations, sample areas inventory with soils classified at the family level (USDA Soil Taxonomy), and extrapolation of the soil patterns from sample areas to the whole survey perimeter. The objectives of the paper was first to assess the accuracy and precision of this method via comparing the pedodiversity and similarity indices. Second, to find out at what level of detail or scale the geopedologic survey provides reliable information for extrapolation from visited to unvisited landscape units. The results in all types of analyses showed that differences between distribution of soil types and variables in training and extrapolation units of any landform increases with increasing scale and descending taxonomic and geomorphic categories. Therefore, it is proposed that the geopedologic soil surveys to be used not more intensive than semi-detail scales. It is concluded that the geopedologic approach is a suitable method for preparing proper foundation for pedometrics methods in all scales to study the basic and applied aspects of pedology.

***Keywords**:* Applicability; Geostatistics; Pedodiversity; Similarity index; Soil-landscape relationships

1. Introduction

The main parts of geopedologic approach are the following steps (Zinck, 1989): Image interpretation (landform mapping in the whole study area); selecting the sample area (the area containing portions of the total landform types); running a conventional soil survey with the required accuracy in sample area; extrapolating the soil patterns and information obtained from studied landforms to unstudied same landforms; checking the validity of extrapolated soil distribution with some new observations (in unstudied landforms). The geopedoloy method (Table 1) is based on specific geomorphic structure which is defined by Zinck (1989).

A critical assumption in conventional geopedologic approach believes that same landforms with the same evolutional history have more or less the same soil patterns and distribution within their boundaries. This seems to be in contrast with chaotic behavior and continuous variability of soils in nature. This paper is concerned with the weaknesses, constraints, impurities and disadvantages which may be elusive within polygon-based geopedologic soil survey approach. In our understanding, pedometric continuous raster-based soil surveying methods or any other approach which uses geomorphology (with or without using bases presented by Zinck (1989) for delineating the geoforms) to survey the soil-landscape relationship or map the soilscapes, are excluded from geopedologic soil survey methods.

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Table 1. Synopsis of the geoform classification system (Zinck, 1989)

Level	Category	Generic concept	Short definition
6	Order	Geostructure	Large continental portion characterized by a type of geologic macro-structure (e.g. cordillera, geosyncline, shield).
5	Suborder	Morphogeni environment	Broad type of biophysical environment originated and controlled by a style of internal and/or external geodynamics (e.g. structural, depositional, erosional, etc.).
4	Great group	Geomorphic Landscape	Large portion of land/terrain characterized by given physiographic features: it corresponds to a repetition of similar relief/molding types or an association of dissimilar relief/molding types (e.g. valley, plateau, mountain, etc.).
3	Subgroup	Relief/molding	Relief type originated by a given combination of topography and geologic structure (e.g. cuesta, horst, etc.). Molding type determined by specific morphoclimatic conditions and/or morphogenic processes (e.g. glacis, terrace, delta, etc.).
2	Family	Lithology/facies	Petrographic nature of bedrocks (e.g. gneiss, limestone, etc.) or origin/nature of unconsolidated cover formations (e.g. periglacial, lacustrine, alluvial, etc.).
1	Subfamily	Landform/ terrain form	Basic geoform type characterized by a unique combination of geometry, dynamics, and history.

1.1. Soil continuous variability

Based on ever-changing endogenous and exogenous factors, which are controlling the soil formation and evolution, soils inherently have a chaotic, complex, and vague character in space (Phillips, 2006). Therefore, the characteristics, quality, behavior and function of the soils in the realm of time and space show an ever-changing phenomenon. Soils, the objects of study in pedology, are historical objects, representing the result of natural experiments that have been ongoing for thousands to millions of years. The age and events, i.e. the historical contingencies (Phillips, 1998), that shape the soil mantle vary greatly from place to place, producing an almost infinite array of soils. It is possible that the factors that form any soil are unique and singular, and that replicates of any modern soil have not occurred in the past nor can they be repeated again in the future. This means that a unique soil would not occur repeatedly in the whole pedosphere (Phillips, 2006).

1.2. Geopedologic approach

Geomorphology is the study of landforms and the evolution of the earth surface. It attempts to explain the structures, materials, processes, and history of their evolution related to other natural features of the environment. It is well known that the structural patterns of geology, hydrology, geomorphology, pedology, and biology and their evolutional processes are interrelated (Grotzinger *et al.*, 2007). This highlights the intensity of structural interactions that existed during the formation and evolution of these naturally evolved features.

A number of attempts have been made to develop geomorphological hierarchical classifications (geomorphologic taxonomy). In these taxonomies, small features are nested within larger features; thus, different scaled spatial processes are described and differentiated (Rowentree *et al.*, 2000). Among morpho-genetic and hierarchical landform classification systems, the approach of Zinck (1989) has been called the geopedologic approach; it is used for soil surveying everywhere. The geopedologic approach truly uses the geomorphologic bases to differentiate the landforms having the same history of formation and evolution. The geopedologic soil survey approach differentiates the landforms and selects the representative landforms and, without internal delineation of soil bodies, characterizes the soils inside the landforms (intensity of study is referred to predefined scale) and finally extrapolates the soil properties and characteristics to unsampled landforms to create the soil map of concerned area. This means that a repeated zone of soils with the same property and character will be introduced to audience in studied area.

But how much precision and accuracy would result for a soil survey, when the bases of supervised classification (more used in remote sensing for classification of images) are used to extrapolate the characteristics of soils studied in landforms to the same but not studied ones? And considering our level of segregation ability, and the chaocity and complexity that soilscapes have in nature, how much this extrapolation is capable of keeping up with spatial soil variability is not clear. In this respect, the geopedologic soil survey approach faces two main obstacles: (a) the detail of the soil geomorphic units: how much in detail the geoforms are segregated and how much spatially homogeneous they are in different places? and (b) how much the extrapolation of data and information from a landform to the same unit in another sector of the landscape goes with the natural reality?

Some geopedologic soil surveys have been conducted in Iran for different purposes without using any judgment or validation criteria (Moameni, 1999; Toomanian *et al.*, 2006; Toomanian and Esfandiarpoor, 2012; Toomanian, 2013). Some establish comparisons with existing legislative soil surveys (Alijani *et al.*, 2013). Others, use scientific criteria to understand how much in detail the geopedologic approach goes with natural reality and variability (Esfandiarpoor *et al.*, 2009a; 2009b, 2009c, 2010). The objective of this research was to review the geopedologic studies done in Iran, and answer the above questions using the data provided by these studies and complementary data.

2. Materials and Methods

Data and information from investigations from several regions of Iran were used to assess the results of geopedologic soil maps (Toomanian *et al.*, 2006; Rashidi *et al.*, 2012 and 2013; Esfandiarpour *et al.*, 2009a, b, c; Esfandiarpour *et al.*, 2010). These studies were carried out or mostly supervised by the authors of these papers. The original data of published articles are taken from the authors to carry out the following analyses. In all cases, soil maps were based on geopedology to delineate the landscape and soil characterization in each representative landform was extrapolated to similar but unsampled landform. To investigate the magnitude of differences and similarities of the studied landforms (named training areas) and extrapolated ones (named extrapolation area) in defined conditions, the following analyses were done and compared on the representatives of the two kinds otherwise mentioned.

2.1. Pedodiversity analysis

Natural pedodiversity is a function of soil formation and evolution (McBratney and Minasny, 2007). Pedodiversity is used to measure the soil variation (McBratney, 1992). Pedodiversity may be considered as a framework to analyze spatial patterns of soils (McBratney, 1995). Pedodiversity is characterized through distributions of taxa abundances in a defined area by measuring soil diversity indices. The concept and the measurements of pedodiversity are described by Ibanez *et al.* (1995). These measurements can be used to show the increasing of pedodiversity indices in a descending order from high categories of soil or geomorphic taxonomy. Pedodiversity indices can be measured for a whole study area or within a landform surface (Toomanian *et al.*, 2006; Toomanian, 2013), and used to statistically compare the magnitude of pedodiversity of soils in training and extrapolation areas (Esfandiarpoor *et al.*, 2009b).

2.2. Similarity analysis

Communities can differ in species composition (taxa), total number of species, and the relative abundance of species. Numbers of indices are used to measure the similarity of two communities. Here, the objective was to evaluate the similarity of soil taxa developed in representative training and extrapolation areas of studies conducted in different regions. A variety of similarity coefficients is used to measure the magnitude of similarity of different soil taxonomic categories in the referred study conditions. The similarity coefficients are described by Meyer *et al.* (2004) and Esfandiarpoor *et al.* (2009b). In this study the similarity coefficients of Sorenson, the similarity coefficient of Jaccard (Chao *et al.*, 2005), the similarity coefficient of Manly (Manly, 2004), the Bray-Curtis similarity index (Bray and Curtis, 1957), and the percentage similarity (Krebs, 1999) are measured.

2.3. Statistical analysis

In the geopedologic approach, similar units should have the same quantitative characteristics without consideration of their geomorphic positions. Therefore, if we consider the soil as a collection of measurable land characteristics, we can use two quantitative approaches to compare two map units in a manner of: (a) single-characteristic, two delineations (univariate analysis) and (b) multi-characteristic, two delineations (multivariate analysis). Univariate comparison of mean values for two map units is the simplest quantitative method to study the soil map quality or delineation efficiency (Mohammadi, 2006). In order to know whether the two maps unit means are significantly different, a standard t-test is carried out (Esfandiarpoor *et al.*, 2010; Webster and Oliver, 1990; Manly, 2004). For univariate comparison of variation between two map units, with a single variable, the best known method is the F-test. Unfortunately, the F-test is known to be rather sensitive to the assumption of normality (Esfandiarpoor *et al.*, 2010; Manly, 2004). For this reason, we prefer to use a robust alternative to the F-test called Levene's (1960) test.

In the case of multivariate comparison of mean values for two map units, a more complicated situation is when we want to see how well the map separates the soils in multivariable space, i.e. considering the entire relevant variables together. One possibility is the Hotelling's T^2 test (Esfandiarpoor *et al.*, 2010; Hotelling, 1931). For the multivariate comparison of variation for two map units, a robust procedure can be constructed using the principle behind Levene's test (Esfandiarpoor *et al.*, 2010; Manly, 2004). The data values can be transformed into absolute deviations from sample means or medians. Testing the mean vectors is done using a Hotelling T^2 test. The t-student comparison may be used to evaluate the differences between pedodiversity or similarity indices calculated in representative training and extrapolation areas using the method presented by Esfandiarpoor *et al.* (2009b).

2.4. Geostatistical analysis

Geostatistics is not only used to describe spatial structures, but can also be used to understand or explore the underlying processes responsible for soil variation (Trangmar *et al.*, 1985). A fundamental tool for geostatistical analysis is the variogram (Journel and Huijbregts, 1978). According to Jongman *et al.* (1987), the development of variograms makes it possible to obtain valuable information about some hidden (not seen during direct observations) spatial structure and geographic distribution of the studied properties. With assumptions of geopedology, soils in a unique landform should have the same distribution of soil bodies with the same inherent character. Therefore, the models used in soil spatial variability analysis (geostatistics) are efficient tools to compare and reveal the hidden differences of soil property distributions in training and extrapolation areas. In this respect, to evaluate the magnitude of similarity or dissimilarity of soil geography within representative units, the following variogram parameters should be compared: (i) the fitted variogram model, (ii) the amount of nugget, (iii) nugget to sill ratio, (iv) the amount of range distance, and (v) range to total distance ratio.

3. Results and Discussion

The soil surveys provide essential data and information about the properties and characteristics of soil bodies continuously distributed in the environment. The spatial resolution of the data is concordant with the objectives and predefined level of design and planning which are related to the survey scale. The soil bodies are described in soil taxonomies being used worldwide. The most used taxon in soil surveys is soil series or sub-family. The intensity levels of soil survey (i.e., survey orders) and the purpose and expectation related to each scale are described in the soil survey manual (Soil Survey Staff, 1993). Semi-detailed and more intensive scales are designed to prepare detailed soil data and information by which decision makers are able to program applicable, precise projects or management systems in any applied disciplines. Lower scales of soil surveys are planned to get global and paternal information of nature to formulate country-level policies and programs. At these scales, full soil survey coverage is more important than detail of soil distribution. As a rule of thumb, the countries (some excluded) plan to increase the scale of their soil studies in a telescopic manner to study the soils at more and more detailed scales consistent with their need to prevent time and cost losses.

3.1. Pedodiversity analysis

It is well accepted that pedodiversity of soil taxa increases through descending categories of Soil Taxonomy and geopedologic categories (Toomanian, 2013; Toomanian and Esfandiarpoor, 2012; Esfandiarpoor *et al.*, 2009b). This fact is concordant with soil information and entropy theories describing soil evolution (Phillips, 1996). Therefore, intensive soil surveys must be more focused on chaotic and deterministic soil variations. Furthermore, increasing soil complexity through descending taxonomic categories is not spatially constant. This is obvious when the pedodiversities of the same kind of landforms (training and extrapolating) are calculated (Esfandiarpoor *et al.*, 2009b). As Table 2 shows, the pedodiversity differences of such comparison are high at family level. This is proved when a statistical t-student comparison between Shannon indices of training and extrapolation areas is made through descending taxonomic categories. Table 3 shows a significant difference (at 95 percent confidence level) between the pedodiversity indices of these two similar landforms, meaning that at least at family level the geopedologic extrapolation is not a wise action.

Table 2. Comparison of Shannon's diversity and mean taxonomic distance between training (Pi111a) and extrapolating (Pi111b) areas based on taxonomic hierarchy (Esfandiarpoor *et al.*, 2009b)

Taxonomic level	Location	N	S	H'	H'max	E	Q
Order	Pi111a	19	2	0.58	0.69	0.83	0.50
	Pi111b	15	2	0.67	0.69	0.97	0.50
Suborder	Pi111a	19	2	0.58	0.69	0.83	0.50
	Pi111b	15	2	0.67	0.69	0.97	0.50
Great group	Pi111a	19	3	0.75	1.10	0.69	0.76
	Pi111b	15	3	0.85	1.10	0.78	0.76
Subgroup	Pi111a	19	4	1.23	1.39	0.89	1.00
	Pi111b	15	4	1.17	1.39	0.84	1.00
Family	Pi111a	19	12	2.33	2.48	0.94	1.72
	Pi111b	15	7	1.710	1.95	0.88	1.69

N: Total samples, S: Richness, H': Shannon index, H'max: Maximum diversity, E: Evenness, Q: Mean taxonomic distance

Table 3. Statistical comparison of training and extrapolation areas based on Shannon index (H') (Esfandiarpoor *et al.*, 2009b)

Taxonomic levels	H'		Var H'		d.f	t
	Training area	Extrapolation area	Training area	Extrapolation area		
Order	0.576	0.673	0.012	0.005	31	0.740
Suborder	0.576	0.673	0.012	0.005	31	0.740
Great group	0.753	0.853	0.033	0.026	34	0.412
Subgroup	1.234	1.171	0.019	0.029	31	0.286
Family	2.333	1.710	0.032	0.043	32	2.276*

3.2. Similarity analysis

Soil similarity indices were calculated with three sampling intervals (study scales) for training and extrapolation areas in the Borujen area (Esfandiarpoor *et al.*, 2009c). The similarities of different taxonomic categories are shown in Fig. 1. As it is obvious from the figure, the similarity of soil taxa between these two similar landforms is drastically decreasing at subgroup and family levels to less than 40 percent. To find out how much of this is true, the same comparison was made within representative training and extrapolating similar landform data of studies conducted in different regions from reconnaissance to super-detailed scales. The pedodiversity indices of the same landforms were calculated to be crossed with the similarity indices. The comparison results are displayed in Table 4. It is clear that, compared with pedodiversity indices, similarity indices are inversely decreasing with increasing study scales. Four methods of similarity calculation (Sorenson, Jaccard, Manly, Bray-Curtis, and Percentage) showed the same decreasing sequence through studies with ascending scales.

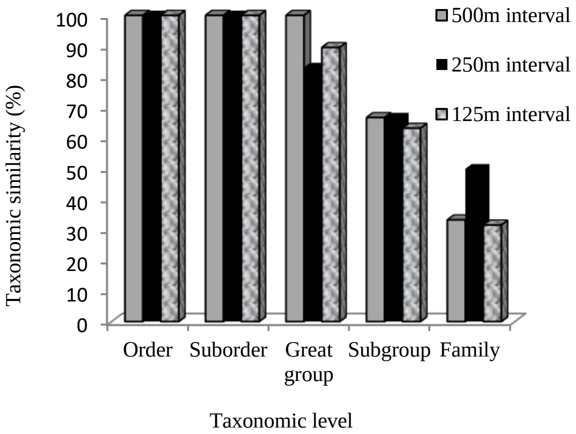

Fig. 1. Similarity indices calculated in soil taxonomic categories within training and extrapolation areas (Esfandiarpoor *et al.*, 2009c)

Table 4. Similarity and diversity indices calculated in representative training and extrapolation areas of studies with different scales

Studied by	Survey scale	Landform type[1]	Similarity index between training and extrapolating areas	Diversity index calculated in the same landforms
Toomanian *et al.* (2006)	Reconnaissance	Ap 111	0.75	1.11
Rashidi *et al.* (2012 and 2013)	Semi-detailed	Hi 111	0.66	1.33
Esfandiarpour *et al.* (2009a, b, c and 2010)	Detailed	Pi 111	0.50	1.60
Esfandiarpour *et al.* (2009a, b, c and 2010)	Super-detailed	Pi 111	0.39	2.33

[1]Ap: Alluvial plain, Hi: Hill-land, Pi: Piedmont

To find out the scale at which the similarity and the diversity of training and extrapolating landforms have balanced levels and the geopedologic soil survey method is applicable, two respective columns of Table 6 should be crossed. Fig. 2 shows that the crossing is on detailed soil surveys, which means that until detailed scale of soil survey the geopedologic method could be applied without considerable any limitations, but this method is not recommended in more intensive soil surveys.

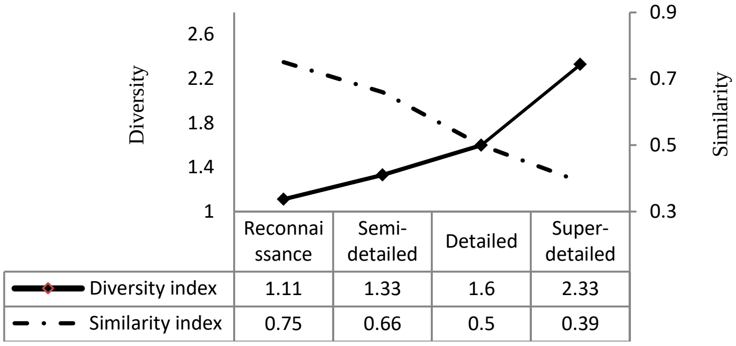

Fig. 2. Similarity and diversity indices crossed through different study scales

3.3. Statistical analysis

After intensive sampling, the distribution of some soil variables was analyzed by Salehi *et al.* (2013). This study was conducted to check the feasibility of geopedologic assumptions to extrapolate physical and chemical soil properties from a landform to a similar delineation in the north-west of the Faradonbeh region, Iran. The t-student test was done on the mean values of each delineation and found that all (pH excluded) the variables are significantly different in those areas (Table 5). They concluded that similar delineations of a geopedologic soil map unit could show different soil property variability as a result of different history, land-use, management, landform and/or pedological chaotic evolution.

Table 5. Statistical t-student test done on soil property values measured in training and extrapolation areas (Salehi *et al.*, 2013)

Soil properties	t-student test
pH	0.59
Total carbonates (%)	-2.20*
Rock fragments (%)	-4.62*
Organic matter (%)	-4.78*
Clay (%)	-3.82*
Sand (%)	4.62*
Bulk density (g cm^{-1})	3.56*

* Significant at 95% of confidence level

More or less the same results were obtained by Esfandiarpoor *et al.* (2010) with univariate and multivariate comparisons of mean values and variances in representative training and extrapolating areas. The results of t-student, Levene’s test and Hotelling’s T^2 test done on mean values of some soil variables have shown that, in general, the means of soil variables were similar (Tables 6 and 7). High differences between A horizon thickness variance in the training area and extrapolation area affect the significance of Levene's test in the univariate case (Table 2), and also in the multivariate test (Table 7). Therefore, results showed that the variability was not consistent within similarly named map units, indicating that the geopedological assumptions were not completely fulfilled in similar landforms.

Table 6. Univariate comparison of mean values and variances in Pi111 unit for both the training and the extrapolation areas (Esfandiarpoor *et al.*, 2010)

Soil property	Training area		Extrapolation area		t	
	Mean	Variance	Mean	Variance	Levene’s test	t-student test
A horizon thickness (cm)	16.84	2.14	19.93	43.78	-4.155*	-1.775
Organic matter (%)	0.80	0.06	0.85	0.08	-0.745	-0.572
Clay (%)	46.32	135.12	44.13	97.84	0.303	0.580
Rock fragments (%)	27.58	185.59	31.60	363.83	-1.730	-0.689
Total carbonates (%)	48.47	152.48	47.67	164.67	-0.397	0.186

* Significant at 95% confidence level.

Table 7. Multivariate comparison of mean values and variances in Pi111 unit for both the training and the extrapolation areas (Esfandiarpoor *et al.*, 2010)

Statistics	T^2	d.f1	d.f2	F
Mean values	8.95	5	28	1.57
Variances	22.23	5	28	3.89*

* Significant at 95% confidence level

3.4. Geostatistical analysis

It is well accepted that the variogram model and its parameters well describe the spatial dependency and distribution of studied area. If the training and extrapolating areas have the same soil pattern and distribution, they should have similar variographic parameters. A study was done by Esfandiarpoor *et al.* (2010) to geostatistically analyze the credibility of generalizing the results of the geopedological extrapolation from training to extrapolating area. Soil properties including contents of clay, rock fragments (2–75 mm), and total carbonates (in the soil family control section), organic matter (in the A horizon) and its thickness, were selected for analysis. To judge on the objective of the study, the similarity of spatial distribution extracted from variography of two landforms was compared. Tables 8 and 9 show the model and the parameters of the variogram prepared for defined soil variables in training and extrapolation areas. As seen, there are differences in model or parameter values in two sites with completely different spatial structure for both areas. After more intensively sampling, Salehi *et al.* (2013) obtained the same results.

Table 8. Soil variogram and its parameters extracted for properties of training area (Esfandiarpoor *et al.*, 2010)

Soil property	Model	Nugget	Partial sill	Range (m)	Nugget/Sill
A horizon thickness (cm)	Spherical	1.220	0.860	245	0.59
Log organic matter (%)	Spherical	0.009	0.003	278	0.75
Clay (%)	Spherical	110.500	38.400	261	0.74
Rock fragments (%)	Spherical	66.600	138.200	417	0.33
Total carbonates (%)	Spherical	116.500	36.500	359	0.76

Table 9. Soil variogram and its parameters extracted for properties of extrapolating area (Esfandiarpoor *et al.*, 2010)

Soil property	Model	Nugget	Partial sill	Range (m)	Nugget/Sill
A horizon thickness (cm)	Gaussian	27.460	24.590	575	0.53
Log organic matter (%)	Spherical	0.011	0.013	279	0.46
Clay (%)	Gaussian	13.200	88.000	259	0.13
Rock fragments (%)	Spherical	194.000	237.500	432	0.45
Total carbonates (%)	Spherical	145.200	81.000	417	0.64

4. Conclusion

To judge the geopedologic approach as a conventional soil survey method (against pedometrics methods) it is good to consider its advantages and disadvantages and see in what scale the weak points harm the results and decrease its applicability.

- *Advantages*

1- it is a time and cost effective method; 2- it may produce basic information for countries or regions without data; 3- it helps map unsampled or hard to sample areas; 4- it provides global and extensive data and information for decision makers; 5- it is applicable in near all scales of soil survey soil information above the family level; 6- it is useful method for natural resources studies which are dealt with more general scales studies.

- *Disadvantages*

1- extrapolation is denied in any pedometric approaches due to error propagation; 2- it maps landform units characterized by soils developed inside whereas objective of ordinary soil surveys is to map soil bodies (delineates the soil bodies); 3- the output is not concordant with the need of precision applications; 4- the soil delineations, if any, are not able to be extrapolated; 5- it is unable to describe the increasing noise created in data and information of intensive studies; 6- repeatability of soil polygons in nature is accepted.

The result of presented analyses are evidences proving that the extrapolation, a fatal step in geopedologic assumptions, is not concordant with the variability, continuity, complexity, disorderliness (chaotic) behavior of soil bodies and its attributes in nature. To overcome these constraints two ways may be recommended: (1) Although Fig. 2 limits the applicability of geopedologic approach to detailed soil surveys, but because the national or international data bases are fed by the outcomes of mostly semi-detail and more intensive soil surveys, and as defined in soil survey manual, starting point for producing data and information to apply the environmental management or agricultural production projects (minimum data and information is being provided by semi-detail scale surveys for such projects and data bases). Therefore, to consider complex and chaotic behavior of nature and ever-changing characteristics of the soilscape as an unavoidable environmental rule, we recommend putting the limit on semi-detailed soil survey as ultimate applicability of geopedologic soil surveys; (2) The geopedologic assumptions and bases are good scientific steps to consider all responsible sources for soil diversification and, upon ClORPT or SCORPAN paradigms, prepare the foundations of any pedometrics methods in all scale to study the basic and applied aspects of pedology.

Since using soil geomorphology in pedology and other environmental sciences is increasing, a comprehensive soil geomorphological taxonomy is sensed by different scientists (Mcmillan *et al.*, 2003; Phillips and Marion, 2007). The establishment of such taxonomy is recommended.

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References

Alijani, Z., F. Sarmadian, S. Musavi, 2013. Comparison of Traditional and geopedologic soil surveys; a case study in Kuhin, Iran. Iranian Natural Resources Journal, 67 (1); 93-102.

Bray, J.R., J.T. Curtis, 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecological Monographies, 27; 325-349.

Chao, A., R.L. Chazdon, R.K. Colwell, T.J. Shen, 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecology Letters, 8; 148-159.

Esfandiarpoor, I., M.H. Salehi, N. Toomanian, J. Mohammadi, 2009a. The Effect of Location of sample Area and Expert Knowledge on the Results of Geopedological Approach in Soil Mapping. Journal of Soil and Water Sciences, 49; 113-147.

Esfandiarpoor, I., N. Toomanian, M.H. Salehi, J. Mohammadi, 2009b. Assessing Geopedological Soil Mapping Results Using Diversity and Similarity Indices: A Case Study: Borujen Area, Chaharmahal-Va-Bakhtiari Province. Journal of Soil and Water (Science and Agricultural Industries Journal of Ferdossi Mashhad University), 23; 100-114.

Esfandiarpoor, I., N. Toomanian, M.H. Salehi, J. Mohammadi, R.M. Poch, 2009c. The effect of survey density on the results of geopedological approach in soil mapping: A case study in the Borujen region, Central Iran. Catena, 79; 18-26.

Esfandiarpoor, I., J. Mohammadi, M.H. Salehi, N. Toomanian, R.M. Poch, 2010. Assessing Geopedological Soil Mapping Results by Statistical and Geostatistical Methods: A Case Study in the Borujen Region, Central Iran". Catena, 82; 1-14.

Grotzinger, J., T. Jordan, F. Press, R. Siever, 2007. Understanding Earth (5th ed.), W.H. Freeman and Co., New York.

Hotelling, H., 1931. The generalization of Student's ratio. Annals of Mathematical Statistics, 2; 360-378.

Ibanez, J.J., S. De-Alba, F.F. Bermudez, A. Garcia-Alvarez, 1995. Pedodiversity: concepts and measures. Catena, 24; 215-232.

Jongman, R.H.G., C.J.F. ter Braak, O.F.R. van Tongeren, 1987. Data Analysis in Community and Landscape Ecology, (Pudoc, Wageningen).

Journel, A.G., C.H. Huijbregts, 1978. Minng Geostatistics. Academic Press, New York.

Levene, H., 1960. Robust tests for equality of variance. In: Olkin I., Ghurye S.G., Hoeffding W., Madow W.G., Mann H.B., editors. Contributions to Probability and Statistics. Stanford University Press, California, USA, p. 278-292.

Krebs, C.J., 1999. Ecological Methodology, 2nd ed. Addison-Wesley Educational Publishers, Inc

Manly, B.F.J., 2004. Multivariate Statistical Methods: A primer (3rd ed.). Chapman and Hall/CRC, London, p. 215.

McBratney, A.B., 1992. On variation, uncertainty and informatics in environmental soil management. Australian Journal of Soil Research, 30; 913-935.

McBratney, A.B., 1995. Pedodiversity. Newsletter of International Society of Soil Science working group on Pedometrics. Pedometron, 3; 1-3.

McBratney, A.B., B. Minasny, 2007. On measuring pedodiversity. Geoderma, 141; 149-154.

McMillan, R.A., T.C. Martin, T.J. Earle, D.H. McNabb, 2003. Automated analysis and classification of landforms using high-resolution digital elevation data: Applications and Issues. Canadian Journal of Remote Sensing, 29; 592-606.

Meyer, A.D.S., A.A.F. Garcia, A.P.D. Souza, 2004. Comparison of similarity coefficient used for cluster analysis with dominant markers in maize. Genetics and Molecular Biology, 27 (1); 83-91.

Moameni, A., 1999. Soil quality changes under long term wheat cultivation in the Marvdasht plain, south-central Iran [Ph.D. dissertation] Ghent University, Ghent, Belgium, 284 p.

Mohammadi, J., 2006. Pedometrics. I: Classical Statistics. Pelk Publication, Tehran, Iran.

Phillips, J.D., 1996. Deterministic complexity, explanation, and predictability in geomorphic systems. In: Bruce L. Roads and Colin E. Thorn (ed) The scientific nature of geomorphology: Proceedings of the 27th Binghamton symposium in

geomorphology held, 27-29 September, John Wiley & Sons Ltd.
Phillips, J.D., 1998. On the relation between complex systems and the factorial model of soil formation (with discussion). Geoderma, 86; 1- 42.
Phillips, J.D., 2006. Evolutionary geomorphology: thresholds and nonlinearity in landform response to environmental change. Hydrology and Earth System Sciences, 10; 731-742.
Phillips, J.D., D. Marion, 2007. Soil geomorphologic classification, soil taxonomy and effects on soil richness assessments. Geoderma, 141; 89-97.
Rowentree, K.M., R.A. Wadeson, J. O'Keeffe, 2000. The development of a geomorphological classification system for the Longitudinal Zonation of South African Rivers. South African Geographical Journal, 82; 163-172.
Salehi, M.H., Z. Safaei, I. Estendierpour-Borujeni, J. Mohemmedi, 2013. Generalisation of continuous models to estimate soil characteristics into similar delineations of a detailed soil map CSIRO Publishing. Soil Research, 51; 350-361.
Soil Survey Staff, 1993. Soil Survey Manual. U.S. Department of Agriculture, Handbook No. 18. U.S. Government Printing Office, Washington, D.C.
Toomanian, N., A. Jalalian, H. Khademi, M.K. Eghbal, A. Papritz, 2006. Pedodiversity and pedogenesis in Zayandeh-rudValley, Central Iran. Geomorphology, 81; 376-393.
Toomanian, N., I. Esfandiarpoor-Borujeni, 2012. Challenges of Pedodiversity in Soil Science. Eurasian Soil Science, 43 (13); 1486-1502.
Toomanian, N., 2013. Pedodiversity and Landforms. In: Ibanez J.J., Bockheim J., editors. Pedodiversity. Taylor and Francis Publication, 250 p.
Trangmar, B.B., R.S. Yost, G. Uehara, 1985. Application of geostatistics to Spatial Studies of soil properties. Advances in Agronomy, 38; 45-93.
Webster, R., M.A. Oliver, 1990. Statistical Methods in Soil and Land Resource Survey. Oxford University Press, New York, USA.
Zinck, J.A., 1989. Physiography and soils. Lecture-notes for soil students. Soil Science Division. Soil survey courses subject matter: K6 ITC, Enschede, The Netherlands.