Evaluating the performance of concentration-number (C-N) fractal model for separation of soil horizon regarding vertical distribution and 3D models

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Abstract: This study aims to evaluate the efficiency of the concentration-number (C-N) fractal model for discrimination of soil horizon regarding the depth distribution profile. In this regard, soil parameters such as pH, organic carbon content, calcareous mineral content, electrical conductivity and available phosphorus of Ziarat forestland in Golestan Province, north of Iran, has been investigated. The C–N model of all parameters except EC reveals three distinct horizons, while EC indicates 4 horizons. Results of the distribution profile based on fractal thresholds for pH and available phosphorus accurately classified horizons in most of the samples. The result of vertical distribution of EC regarding the fractal method identified horizons correctly except for Z4 and Z7. In addition, horizons of Z1, Z3, Z6, and Z8 have been classified distinctly by using fractal thresholds of organic carbon content in this area. However, vertical distribution of the calcareous mineral content of the study area according to the fractal method was not applicable and soil horizons were not obtainable. In conclusion, based on the combination of results driven by fractal and vertical distribution, the closest model to soil horizons have been created by EC and pH distribution. The 3D model of soil horizon based on thresholds of fractal method shows a SE to NW trend in pH variation from acidic to basic.

Keywords: Concentration-number (C-N); Fractal model; Soil parameter; Vertical distribution profile; Ziarat Forestland.

1- Introduction

Recently, soil quality has been considered as a global issue because soils are closely related to food and water (McBratney *et al*., 2014). One of the most important environmental problems can be soil erosion which leads to soil depression and raising the level of sedimentation in the rivers and reservoirs (Bagherzadeh *et al*., 2013). Identifying horizons is the primary structure and concept in global soil taxonomic systems (Lebedeva *et al*., 1999). In many cases, horizons are recognized and classified based on the field surveys and lab properties of soil samples (Ahrens and Rourke, 2000). Many classification systems are proposed for classification of horizons [e.g. the Russian soil classification system (Shishov *et al*., 2001), and the IUSS Working Group WRB (2006)].

The spatial variability of soil properties has been connected strongly with parameters such as texture, organic matter content, pH, and soil electrical conductivity (Goovaerts, 1997). Spatial data can help scientists to make a decision for identifying suitable locations (Li *et al*., 2009). Vanwalleghem *et al*., (2010) studied spatial variability of soil horizon depth in natural soil. They focused on loess-derived soils to pay attention to C horizon.

Recently researchers have applied different approaches such as Portable X-ray Fluorescence Spectrometry (Weindorf, 2012) and optical methods (Ben-Dor, 2008) for classifying soil profiles in the field. In addition, some new technologies such as Vis–NIR in remote sensing and proximal sensing are used in this field (Fajardo *et al*., 2016).

Recently, the application of numerical methods has gained a considerable reputation for classification of soil horizons (e.g. Rayner, 1966). Fractal methods are among numerical methods and have been applied in various branches of earth sciences. Fractal models were initially proposed by Mandelbrot (1983) from the Latin word fractus, meaning broken. The existence of fractal structures in geological data was explained by Meng and Zhao (1991). Application of the fractal method for calculation of different geochemical populations has been presented by Cheng *et al*., (1994). Decomposition of geochemical patterns is a basic object of applied geochemistry (Zuo and Wang, 2015). Various fractal models have been suggested in geochemical analysis consisting of Number-Size (N-S) by Mandelbrot (1983), Concentration-Area (C-A) proposed by Cheng *et al*., (1994), Concentration-Distance (C-D) by Li *et al*., (2003), Concentration-Volume (C-V) by Afzal *et al*., (2011) and Concentration-Number (C-N) by Hassanpour and Afzal (2013). Previously, many scientist have been used fractal methods and models in various fields of geosciences for instance separating geochemical anomalies (Afzal and Ebadi, 2010; Parsa *et al*., 2017a, b, c), delineation of gold mineralized zones(Afzal *et al*., 2013a, b), covering a wide area by spatial Cu-soil anomaly and multifractal modeling (Jesus *et al*., 2013), separation of alteration zones (Soltani *et al*., 2014), mapping multi-element soil anomalies(Asadi *et al*., 2014) and estimating changes in soil properties (Gao *et al*., 2014).

Even though quite a few studies have focused on the spatial distribution and soil horizons according to soil parameters, there are only a few reports on the application of the fractal theory to 3D modeling of soil properties (i.e. combine the results of the fractal method with vertical distribution in soil science). This study is focused on a combination of concentration-number fractal and vertical distribution of some soil parameters of Ziarat soil such as acidity (pH), Electrical Conductivity (EC), Calcium carbonate (Calc%), Organic Carbon (OC), and Available phosphorus (AP). The results presented in this paper are based on the soil parameter traits determined in the Ziarat forestland according to results of the Natural Resources and Watershed Office data of Gorgan. The dataset consists of 58 samples that are taken from 8 boreholes in the Ziarat forestland, northern Iran. The objective of the present study is to use the C-N fractal model to identify different horizons in soil profiles and examine the depth distribution of soil horizons based on populations which are separated by the fractal model. In fact, this study aims to examine the fractal nature of soil horizons.

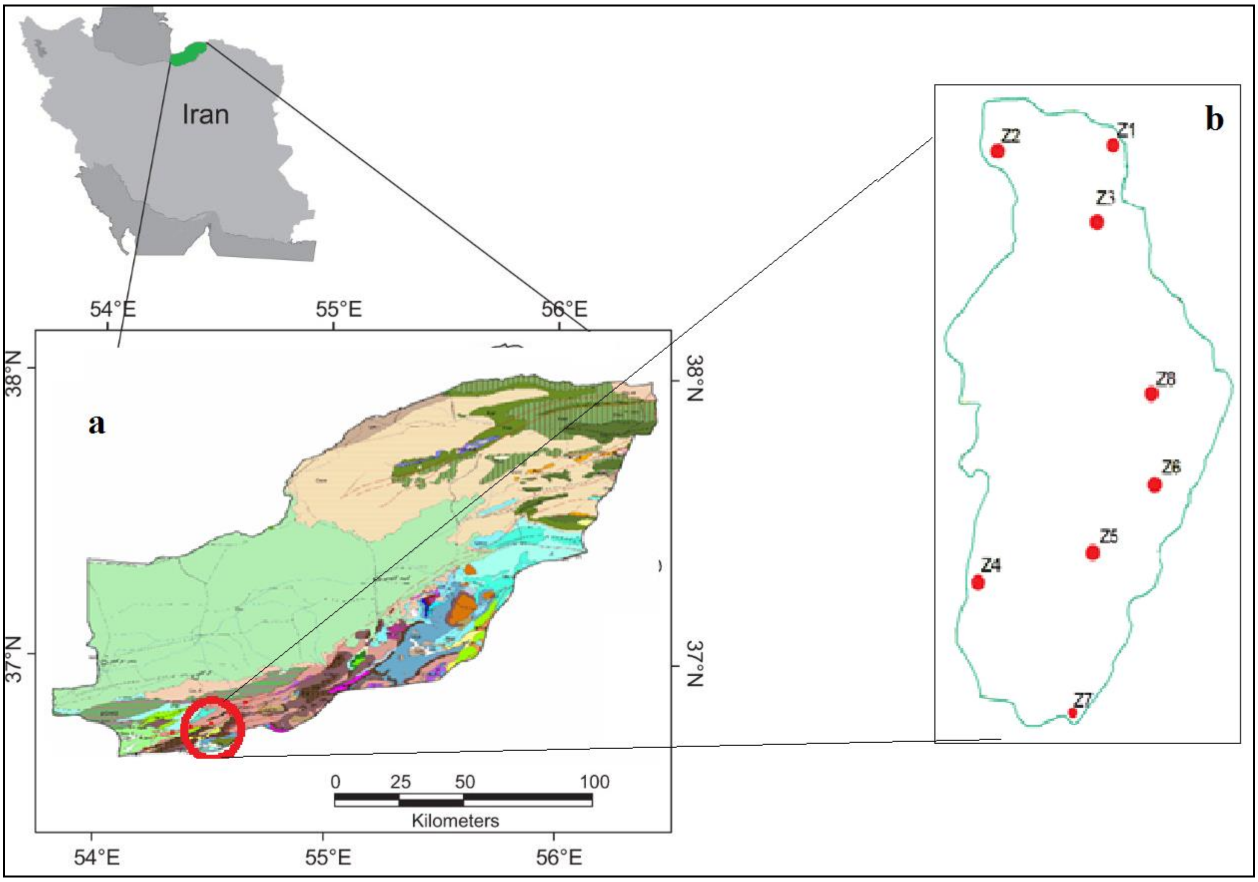
2- Study area

This study focuses on the southern to the western part of Golestan province, from Ziarat jungle to Qareh Sou. The Ziarat forestland is located in the south of Gorgan, Golestan province, Iran (Fig. 1a). The Ziarat forestland is situated between 54◦ 23’ 53’ and 54◦ 31’ 11’ E and 36◦ 36’ 51’ and 36◦ 43’ 59’ N, with an altitudinal range between 756 and 3020 m a.s.l. with a mean annual rainfall of 452 mm and mean annual temperature of 10.78 centigrade.

Two stratigraphic units play a major role in the lithology of Ziarat: the Precambrian and Mesozoic sediments. Precambrian sediments are mainly composed from metamorphic schist (mica schist, chlorite schist, quartzite, marble, and slate), which is dark green and bright and is a known Gorgan green schist. Mesozoic sediments consist mainly of limestone and dolostone with layers of marl in the upper Jurassic. In some places, there are sandy loose sediments of Quaternary.

Due to the presence of unique plant species, this area is under the protection of the natural resources of Iran. Also, this area includes species such as Beech, Oak, Alder, Maple, Plum, Elm, Linden, Acer, Walnut, and also other unique species like Cypress and Yew trees.

Figure 1) Location map and sampling area; a) Golestan province, b) sampling location in Ziarat forestland.



3- Datasets

Based on the territorial and sub-territorial units, 8 core samples (from depths of 0 –150 cm) were collected after removing visible plant roots, large debris, and other waste materials from the top soil. Soil sampling was conducted at irregular intervals. The locations of the sampling sites are illustrated in Figure 1b. Water checker portable meter (hatch model HQ40D53000000) was used for measurement of Electrical conductivity (EC) and pH in the field. In the lab, the soil samples were air–dried and then pulverized in a swing mill. In order to assess soil organic matter (SOM) content, the Nelson and Sommers (1982) method was used which is based on Walkley-Black (1934) acid digestion method and the weight loss on ignition method using furnace and then soil organic carbon (SOC) was evaluated based on SOC = 0.58 SOM. The calcium carbonate equivalent was measured by Bernard's calcimeter method based on a volumetric method (Karchegani *et al.*, 2012) by using the auto calcimeter measures and geo-data (made in France). Available P was extracted with HCl-NH_4F and using the spectrophotometer (Bray and Kurtz 1945) and available K was extracted with 1.0 M CH_3COONH_4 (Carson 1980) and the flame spectrophotometer (model Sherwood flame photometer 410) in the Natural Resources and Watershed Office of Gorgan.

4- Materials and methods

4.1- C-N fractal method

Mandelbrot (1983) proposed the concept of number-size (N-S) fractal method and can be applied in delineation and separation of geochemical populations. In contrast with several geochemical data analysis method, this method does not require the data to be pre-processed. This model demonstrates the relationship between parameters and their cumulative numbers of samples (Mandelbrot, 1983). The fractal methods have many applications, especially in geochemistry, for example, Monecke *et al*., (2005) used the N-S fractal model to determine enrichment of elements accumulated with metasomatic processes in the Waterloo massive sulfide deposit. The N-S model has been developed and the concentration-number (C-N) model has been proposed by Hassanpour and Afzal (2013). The C-N model has the general form as follows (Eq. 1).

$$N(\geq\rho) = F\rho{-}D \quad \text{Eq. 1}$$

Where ρ represents concentration, N (≥ρ) indicates a cumulative number of samples with concentration values more than or equal to ρ, F is a constant and D is the fractal dimension of the distribution of concentrations (Deng *et al*., 2010; Hassanpour and Afzal, 2013).

Table 1) Descriptive information on soil samples in Ziarat forestland

sample	Petrology	Depth (cm)	Horizon	pH	EC (mili.mohs/Cm)	Calc %	OC %	AP (ppm)
Z1	calc- schist- sandstone- slate- shale	0 - 10	A	7.8	1.24	4.5	5.8	27.1
		10 - 40	B_1	6.33	0.25	3.1	0.48	0.49
		40 - 150	B_2	7.42	0.58	15.2	3.4	10.8
Z2	calc- schist- sandstone- slate- shale	0 - 20	A	6.45	0.46	3	5.8	15
		20 - 45	B_1	7.3	0.36	3.5	0.59	4.6
		45 - 150	B_2	7.75	0.6	23.6	1.36	10.4
Z3	calc	0 - 20	A	7.5	0.75	7.6	0.75	10.6
		20 - 45	C	7.46	0.72	1.47	6.1	15
Z4	calc - schist	0 - 15	A	7.31	0.56	6.5	3.7	8.2
		15 - 40	B_1	7.82	0.39	17.5	0.96	6.5
		40 - 140	B_2	7.9	0.32	25	0.59	0.22
Z5	calc - schist- sandstone- slate	0 - 10	A	5.8	1.19	7.1	6.3	50
		10 - 50	B_1	6.29	0.2	3.1	0.8	4.9
		50 - 130	B_2	7.73	0.55	22.9	0.98	0.82
Z6	calc - conglomerate- schist	0 - 20	A	7.33	0.42	72.6	2.2	14.42
Z7	calc - marl calc - sandstone	0 - 25	A	6.19	0.56	5	5.3	54
		25 - 50	C	7.11	0.47	20.6	4.8	11
Z8	calc - conglomerate	0 - 15	A	6.7	0.37	40.2	6.8	49

Fractal dimension becomes a helpful measurement to quantitatively characterize soil properties (Xia *et al*., 2015; Wei *et al*., 2016). Usually, the fractal dimension of various communities is different. So by distinguishing the number of fractal dimension of samples, number of communities can be identified (cheng *et al*., 1994). Then a logarithm should be taken from Eq. 1.

$$\text{Log}(N>=p) = - D \log(\rho) + \log(F) \quad \text{Eq. 2}$$

According to the above equation (Eq.2), the fractal dimension could be calculated based on the regression slope in the log-log plot of concentration vs. the number of samples (C-N). If there were various communities, results indicate some different line with different slopes which the breaking point can be considered as the threshold of separating the communities.

In order to determine the number of populations and their threshold (using C-N method), firstly, data should be classified. The number of classes has been determined by using Sturges method. One of the best rules for determining the desirable number of groups into which a distribution of observations should be classified is Sturges method as follows:

$$K= 1 + 3.32 \text{ Log } n$$

Where n is the number of observations. The descriptive information of soil parameters in this study is presented in Table 1. As shown, the petrology of this area includes Calc, schist, marl, sandstone, slate, shale and conglomerate which show that the metamorphism rock and siliciclastic sedimentary are dominant in this area. Based on the depth of sampling and available horizon, as presented, samples Z1, Z2, Z4, and Z5 have horizon B¬1¬ and B2 whereas samples Z3 and Z7 just have the C horizon.

5- Results and discussion

5.1- C-N fractal results

According to the results of Sturges method, there are 7 classes in this case study, for which the frequency were determined. Then logarithmic plot of each parameter (i.e. pH, OC, AP …) were plotted (Fig. 2). Finally, the best lines were fitted on data using the least squares method. As mentioned, according to C-N method, the fractal dimension of populations is different and the value of breaking point indicates the threshold of separation of populations. According to the log-log plots, there are three or four soil populations for the samples which are presented in Figure 2. For instance, for pH, three lines have been estimated by the least squares method on data. The equation of lines and their correlation coefficients of each parameters have been presented in Table 2. The slopes of these lines (based on Eq. 2) indicate fractal dimension of data which each dimension presents one different population.

Table 2) Equation and correlation coefficient of fitted line of parameters

Parameters	Equation	
pH	y = -1.6034x + 2.9509	R^2 = 0.9985
	y = -15.616x + 14.921	R^2 = 1
	y = -75.882x + 67.482	R^2 = 1
EC	y = -1.0313x + 1.0939	R^2 = 1
	y = -3.3687x + 0.2147	R^2 = 0.9971
	y = -8.044x + 0.5634	R^2 = 1
	y = -1.4662x + 0.5014	R^2 = 0.9851
Calc%	y = -2.3236x + 4.1202	R^2 = 0.9956
	y = -3E-14x + 0.4771	R^2 = #N/A
	y = -6.789x + 12.423	R^2 = 1
AP	y = -0.2618x + 1.2834	R^2 = 0.9779
	y = -1.2534x + 2.3411	R^2 = 1
	y = -3.3589x + 5.7468	R^2 = 0.9917
OC%	y = -0.2613x + 1.5257	R^2 = 1
	y = -0.9656x + 1.8203	R^2 = 0.9954
	y = -16.496x + 13.129	R^2 = 1

Results obtained by the C-N plot present threshold values for each parameter separating the soil parameters population which have been shown in Table 3. As shown, except EC, other parameters present two thresholds (three distinct horizons) but EC indicates three thresholds (four separate horizons). Fractal analysis has been considered as a first step toward improving the characterization of the vertical distribution of soil horizons.

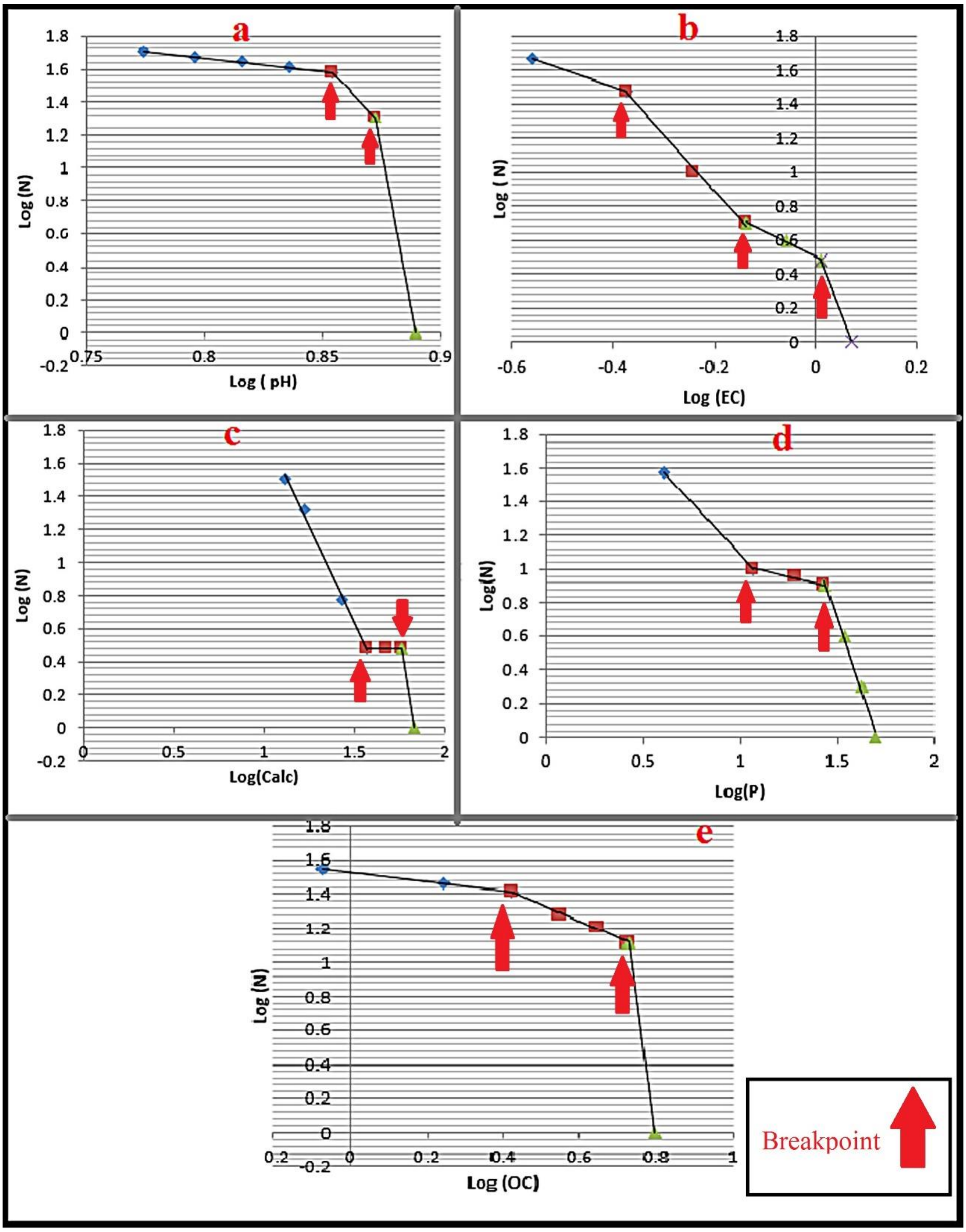


Fig. 2. C–N Log–log plots of soil parameters; a) pH, b) EC, c) Calc%, d) AP and e) OC%

5.2- Vertical distribution

In order to carry out a correlation of obtained threshold values by the C–N model and the soil horizons, vertical distribution of soil parameters were examined (Fig. 3). Considering that the vertical distribution of soil parameters is the key to making a decision for management and planning, soil depth influences vegetation growth (Meyer *et al*., 2007) and is a key factor when dealing with soil properties (Lacoste *et al*., 2016).

Table 3) Threshold values of soil parameters based on C-N fractal.

Parameter	Threshold 1	Threshold 2	Threshold 3
pH	7.15	7.45	-
EC	0.425	0.725	1.025
Calc%	37.1	57.5	-
AP	11.75	27.15	-
OC%	2.65	5.35	-

As shown in Figure 3a, in Z1 and Z3, by increasing depth, soil acidity changes from alkaline to acidic while in Z5 and Z2, soil acidity changes from acidic to alkaline. According to the fractal method, three populations have been considered for this soil. In samples Z1 and Z2 (three horizons), Z6 and Z8 (one horizon), the number of horizons have been detected correctly. But in samples Z3 and Z7 separating horizons C and A was not possible. In addition, in samples Z4 and Z5, the vertical distribution based on the fractal was not able to recognize B1 and B2.

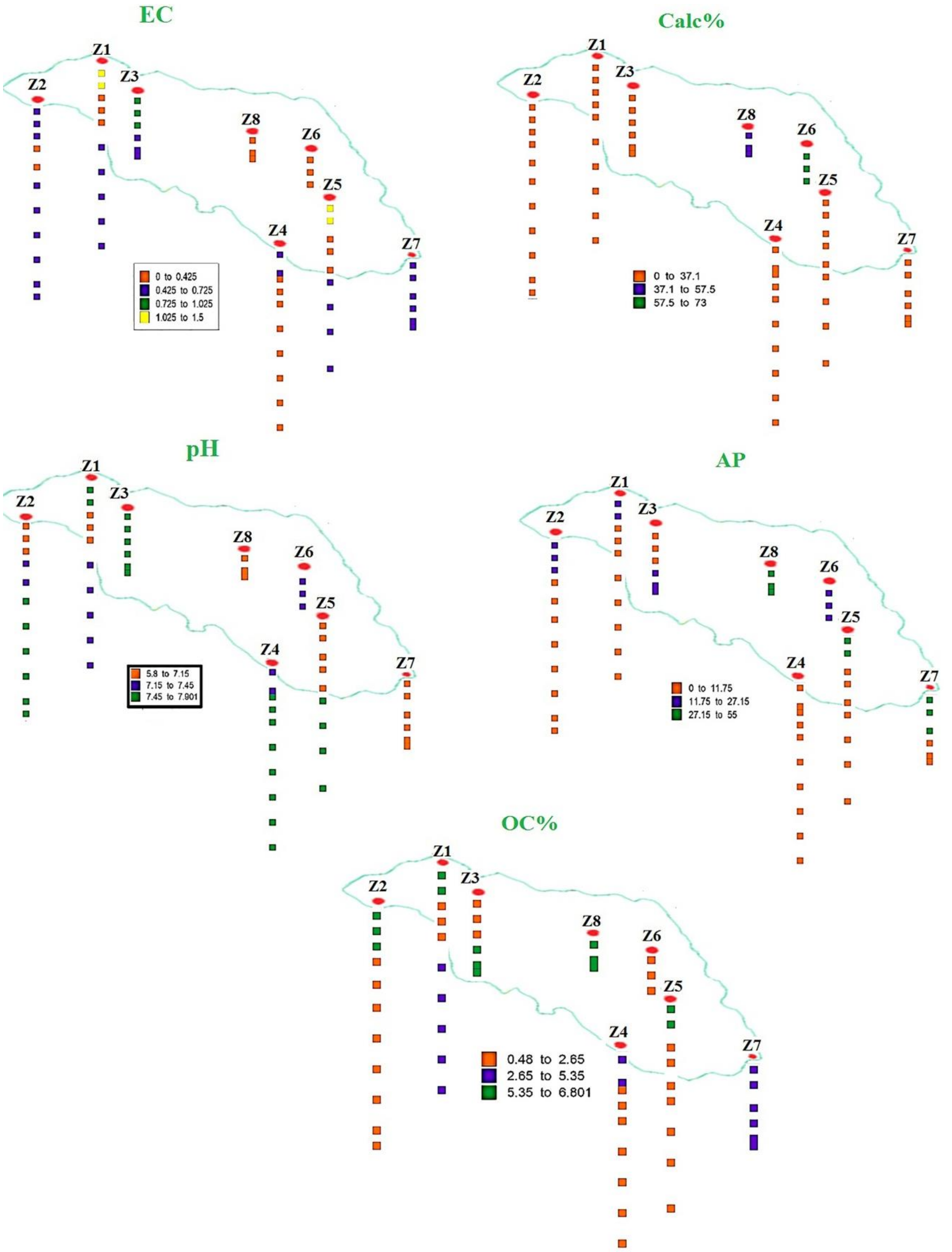


Figure 3) Vertical distribution of soil parameters toward the depths according to fractal threshold for pH, EC, Calc%, AP and OC %).

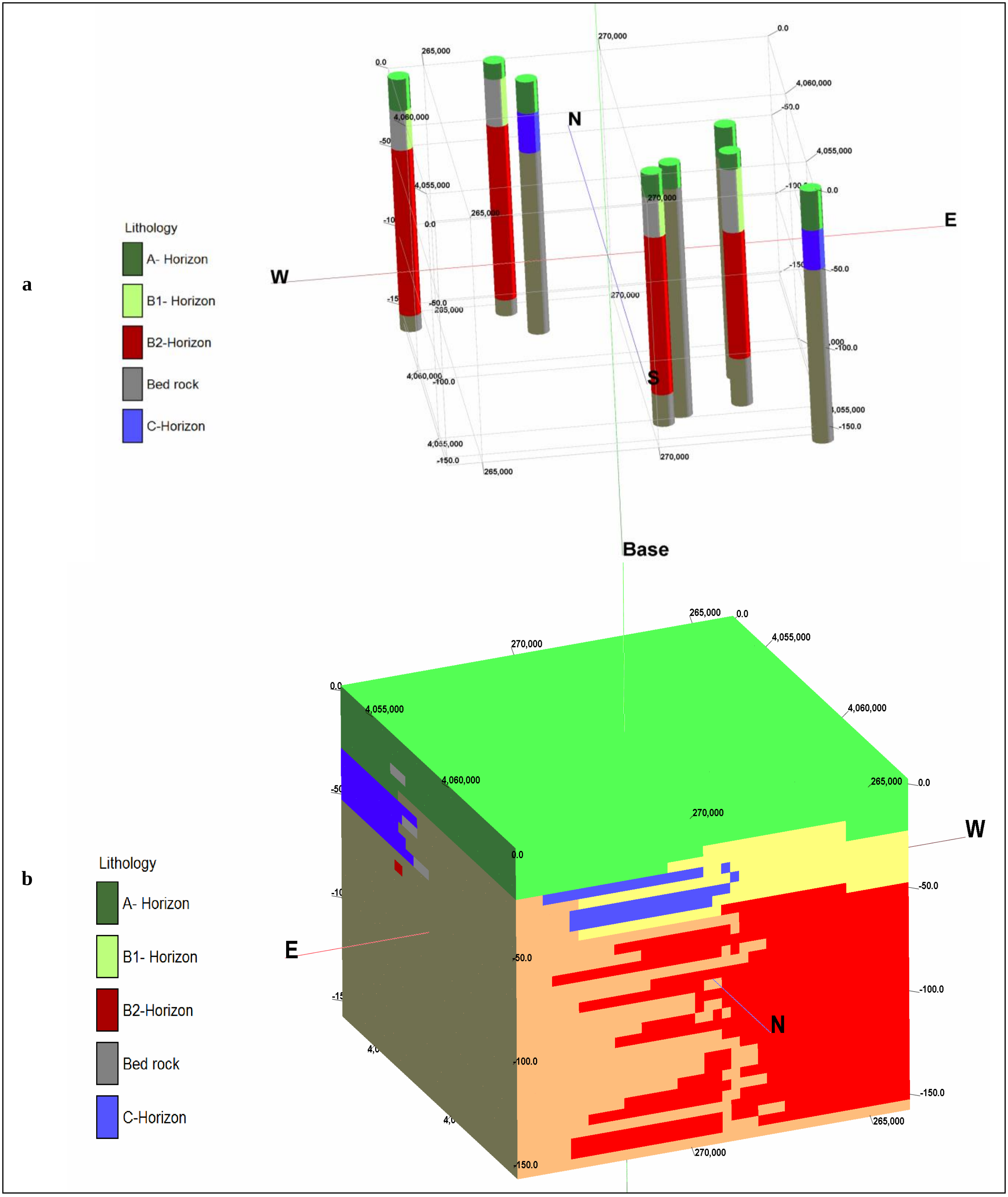


Figure 4) Model of Ziarat forestland soil horizon; a) 3D log plot of core samples, b) 3D blocking model from NE to SW.

As depicted in Figure 3b, for Z1 and Z5 the electrical conductivity is decreased with increasing depth, the electrical conductivity is decreased while it was reverse in Z2. Results of the depth distribution of samples based on the EC population which was separated by the fractal threshold indicates four populations. Except for Z4 and Z7, the soil horizons were distinguished accurately. In sample Z4, the model was not able to separate B1 and B2 and in sample Z7, the horizon C was not separated.

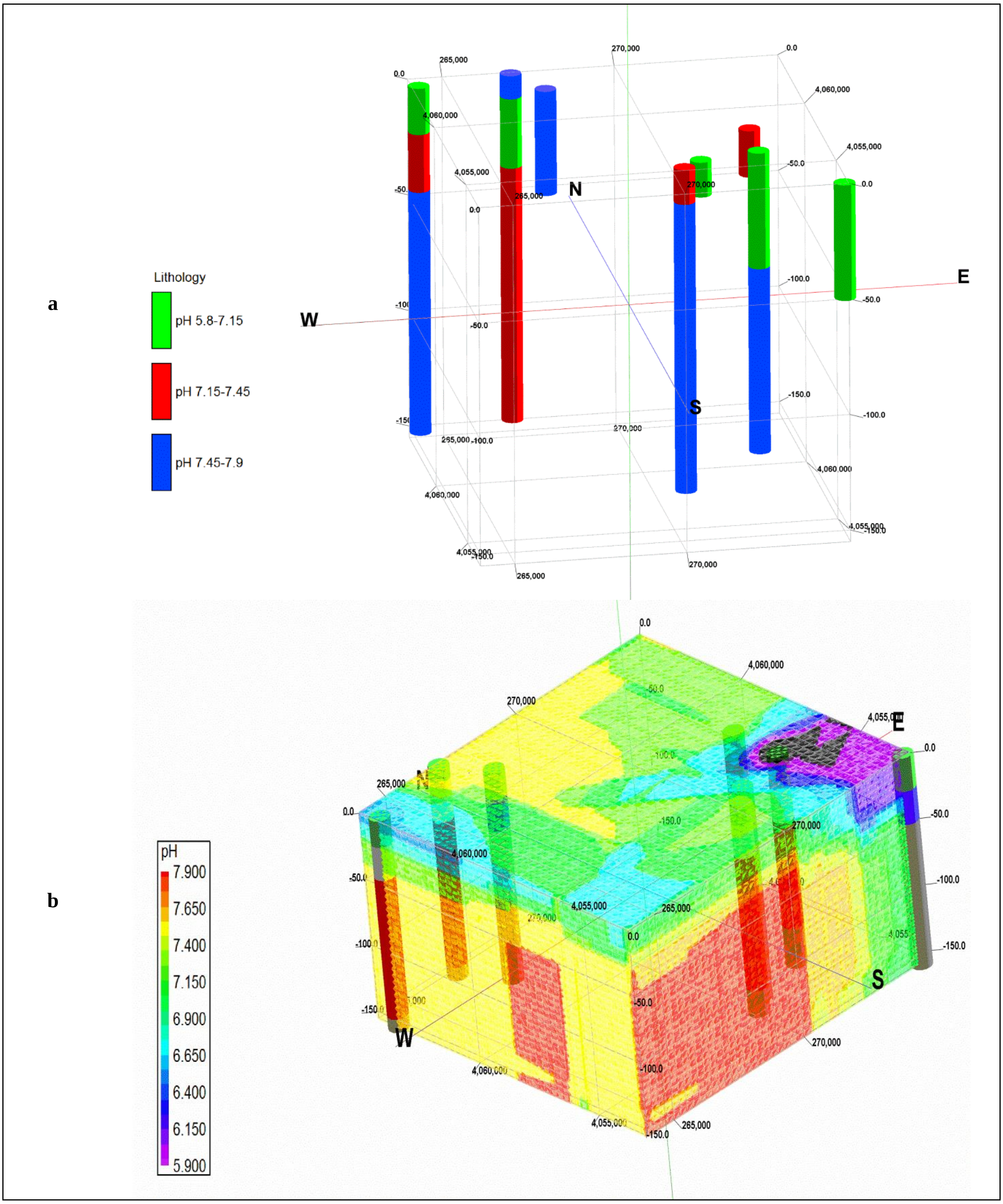


Figure 5) Model of pH of Ziarat forestland soil based on fractal model; a) 3D log plot of core samples, b) 3D blocking model.

Vertical distribution of the calcareous mineral content of the study area according to the fractal method has been presented in Figure 3c. As shown, there is no separation in the samples and this method does not work properly for this parameter in this area.

Distribution of available phosphorus toward depth based on fractal thresholds has been demonstrated in Figure 3d. In most samples, the AP has been detracted toward the depth. As shown in samples Z3, Z6, Z7 and Z8, using this method indicates good results but in samples which contain horizons B1 and B2, such as Z4, Z1, Z2, and Z5, the fractal was not successful in separating the population based on horizons.

The average organic carbon content in horizon A is more than horizon B and C (Fig. 3e). Regarding the fractal thresholds, three populations have been considered for this soil. In sample Z1 (three horizons), Z3 (two horizons), Z6 and Z8 (one horizon), existing horizons have been separated distinctly.

In order to achieve a conceptual model of soil horizon, a 3D model of core samples was created and then based on this cores, the 3D model of the horizons was made. Based on Figure 4, it seems presence of horizon C and the trend of bed rock following the topography of study area. In order to evaluate the C-N fractal Model in detail, a 3D model based on pH threshold (which presented in Figure 2 and Table 3) was created. At first the 3D log plot for pH of samples was made and then the 3D model of pH was created. As results of 3D model of pH according to the C-N fractal model shown (Fig. 5), by considering the block model, from Southeast to Northwest and towards to the depths, the pH changes acidic to basic.

6- Summary and Conclusion

In this study, the concentration–number (C–N) fractal model was used to identify soil horizons in the Ziarat Forestland, north of Iran. In order to evaluate the efficiency of this method, the distribution of soil horizons toward depth, regarding the fractal thresholds for each parameter, have been demonstrated. The C–N model based on pH, calcareous mineral content, available phosphorus and organic carbon content indicates three distinct horizons with two breakpoint thresholds. In fact, these models were supposedly not able to distinguish divergence in horizon B between B1 and B2. The results of C-N model of electrical conductivity reveals four separate populations which are indicative of four different horizons. Indeed, we can guess that B1 and B2 have been separated regarding the diversity of EC.

Vertical distribution of pH regarding the fractal method reveals three populations which indicate three horizons in Z1 and Z2 and one horizon is determined correctly in Z6 and Z8. However, separating horizon A and C in samples Z3 and Z7 was not successful. Results of the distribution pattern of available phosphorus toward depth according to the fractal thresholds presents successful segregation for Z3, Z6, Z7 and Z8 and unsuccessful results for Z4, Z1, Z2, and Z5. In addition, three horizons in Z1, two horizons for Z3 and one horizon in Z6 and Z8 were separated distinctly by using fractal thresholds of organic carbon content in this area. Moreover, the soil horizons were identified correctly by using fractal thresholds of EC except for Z4 and Z7. Even though using the fractal thresholds presents acceptable results for many of parameters, vertical distribution of the calcareous mineral content of the study area according to the fractal method was not applicable and soil horizons were not obtainable.

In order to study the horizons and fractal method in detail, the 3D model of soil horizons and pH of soil were created based on fractal threshold which presents an acidic to basic trend for pH from SE to NW and toward the depth. All in all, according to the combination of results driven by fractal and vertical distribution, the distribution of EC and pH represents soil horizons better than the other parameters.

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