Geoderma 149 (2009) 10–18

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

An assessment of the variation in soil properties within and between landform in the Amol region, Iran

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ARTICLE INFO

Article history:
Received 7 June 2008
Received in revised form 20 September 2008
Accepted 3 November 2008
Available online 13 December 2008

Keywords:
Frequency distribution
Landform
Log-transformed data
Factor analysis

ABSTRACT

Soil survey users require statistically valid information on the distribution and variability of soil attributes that are important for management and land use. Rigorous investigations of soil property distributions are rare, and statistical methodologies for soil survey applications are not commonly utilised. The objectives of our research were to: (i) evaluate the statistical distribution of soil properties for several landform elements, (ii) interpret these distributions in terms of pedogenic and other processes. Eight soil properties were measured for 57 pedons on 4 landform elements in the Amol region of Iran. Landforms were piedmont plain, levee, behind levee and lowland. The selection of samples was on the basis of distinct layers present in profiles. Clay concentration has a normal distribution for the soil samples from each of the four landforms whereas silt concentration is normally distributed only for the piedmont plain, $CaCO_3$ for lowland and CEC except for lowland. Concentrations of sand and organic carbon (for all landforms), EC (except for behind levee), $CaCO_3$ (except for levee) and CEC (lowland) followed lognormal distributions. However there were some soil properties for which a log transformation did not produce a normal frequency distribution. Care should be taken when applying statistical tests that are sensitive to departures from normality but asymmetric or misshapen distributions may still provide meaningful information. In order to investigate the distribution patterns of soil properties for the different landforms, factor analysis was performed on the data for each soil layer and this strongly differentiated the landforms. For the piedmont plain, attributes reflecting illuviation of clay dominate whereas for levee and behind levee soils original properties of stratified sediments are the dominant factors. For the lowland, variations in the factors indicate that pedogenic processes rather than sedimentary layering are dominant. The important contributions of both sedimentary sorting and pedogenesis to the distribution and properties of soils have been revealed by statistical analysis.

1. Introduction

The normal distribution is the most widely used distribution in statistics and many statistical tests are based on the assumption of normality. A normal distribution of data is assumed for many statistical analyses of soil properties. The statistical analysis of data from a regional-scale soil assessment requires an evaluation of the probability distribution and variability of the population to enable development of the appropriate estimators of population parameters (Upchurch and Edmonds, 1991). Most parametric univariate and multivariate statistical analyses require the data to be normally distributed and to have equal variance (Sharma, 1996). Violation of these assumptions can reduce the power of the statistical tests and may lead to incorrect conclusions. Many investigators of soil landscapes have assumed, either explicitly or implicitly, that their data are normally distributed and have applied statistical techniques based on that assumption. However, many soil properties may not be normally distributed. Miller et al. (1988) determined that subsoil organic C and pH are not normally distributed and that subsoil clay, subsoil sand, and surface soil thickness are normally distributed. Their samples were from transects in an area of low hills and dissected terraces where Chromoxererts and Xerochrepts had formed in sedimentary deposits of massive, interbedded sand, silt, and clay. The system heterogeneity was such that normal distributions might be expected. Non-normal distributions were not explained. Cambardella et al. (1994) reported that for one 36-ha field in Iowa, 25 of 27 soil properties were non-normally distributed, and in another 96-ha field, 4 of 14 soil properties were non-normally distributed. Eleven of 12 soil properties from 12 map unit transects in Missouri were non-normally distributed (Young et al., 1998) and 55 of 60 soil properties in a 40-ha

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doi:10.1016/j.geoderma.2008.11.016

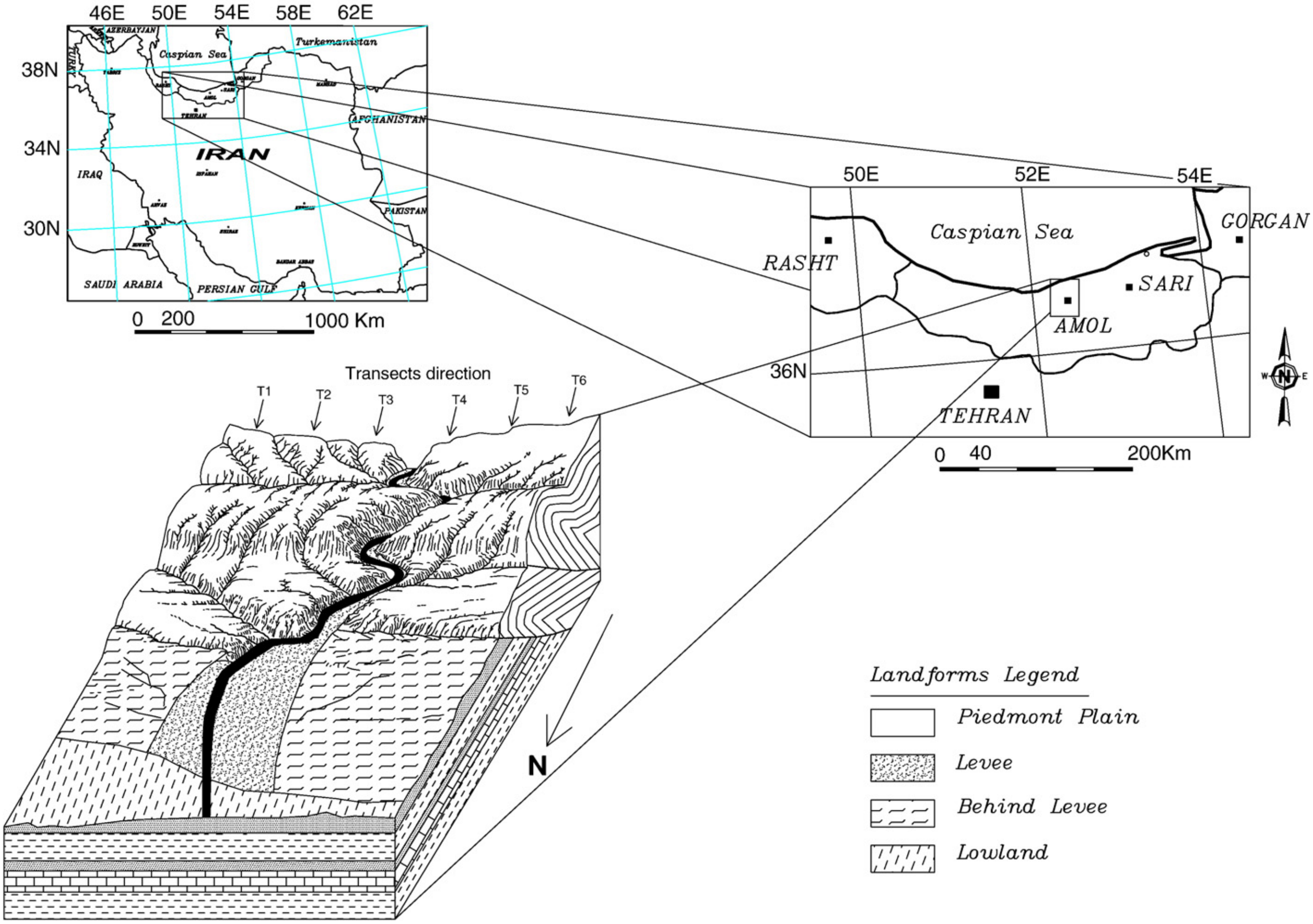

Fig. 1. Location of the Amol region and a schematic representation of the studied landforms. (1) piedmont plain, (2) levee (3) behind levee and (4) lowland.

field pasture were non-normally distributed (Young et al., 1999). The distribution and variability of soil properties are scale dependent (Beckett and Webster, 1971; Seyfried and Wilcox, 1995). As scale decreases, smaller scale sources of variability such as landform, landscape position and land-use may become subsumed into regional scale variability (Beckett and Webster, 1971; Seyfried and Wilcox, 1995). There is a need for similar statistical surveys of soil data for diverse soil–landscape associations. The nature of soil variation in the Amol region of Iran is not known and is the subject of this publication.

Our hypotheses were: (i) many soil properties are not normally distributed, and (ii) statistical distribution patterns provide information on variations in parent material and effects of pedogenic processes.

We have evaluated the normality of distributions of soil properties for different landforms and related the frequency distributions of selected soil properties to pedogenic processes and depositional layers.

2. Materials and methods

The Amol region of Iran is located between 52° 15′ to 52° 30′ east and 36° 22′ to 36° 30′ north in Mazandaran province, approximately 100 km northeast of Tehran (Fig. 1). Elevations vary between 197 m and −12 m above sea level. Mean annual temperature is 16 °C with average values in summer and winter of 25 °C and 7 °C respectively. Annual precipitation is 803 mm and is evenly distributed throughout fall, winter and spring. Summer is relatively dry. Landforms of the Amol region consist of piedmont plain, levee and behind levee with a small zone of lowland. Dominant natural plants at higher elevations are forest trees including *Punica granatum*, *Fraxinus excelsior*, *Alnus subcordata*, *Acer insigne* and on the alluvial plain are mainly *Rubus idaeus* and *Sambucus ebulus*. All Amol landforms are used for the cultivation of rice and oranges.

In this study, satellite images, geology maps and topography maps were used to classify landforms. A total of six representative transects were selected the length of transects varied between 12 and 17 km and slope gradient varied from 2–10%. All transects were from topslope to lower slope. Depending on the length of transects

Table 1
Summary statistics of soil properties for the Amol Region without stratifying in to landforms

Soil properties	Mean	Median	Variance	Skewness	Std. skewness
Sand, (%)	23.6	21	220	2.09**	0.13
Log sand, (%)	1.3	1.32	0.06	−0.52**	0.13
Silt, (%)	46.1	48	94	−1.43**	0.13
Log silt, (%)	1.64	1.68	0.02	−4.85**	0.13
Clay, (%)	30.2	29	135	0.12^{ns}	0.13
EC, (dS/m)	0.79	0.58	0.43	3.76**	0.13
Log EC, (dS/m)	−0.18	−0.23	0.06	0.92**	0.13
pH paste	7.48	7.59	0.15	−3.27**	0.13
Log pH paste	0.87	0.88	0.006	−3.95**	0.13
$CaCO_3$, (%)	13.6	12.7	60	1.43**	0.13
Log $CaCO_3$, (%)	1.05	1.1	0.07	−1.06**	0.13
CEC, ($cmol_c\ kg^{-1}$)	17.3	13	52.9	1.52**	0.18
Log CEC, ($cmol_c\ kg^{-1}$)	1.2	1.2	0.03	-0.11^{ns}	0.18
OC, (%)	1.15	0.87	3.49	11.5**	0.13
Log OC, (%)	−0.06	−0.06	0.09	0.46**	0.13

**: Significant at α=0.01 probability level.
ns: non significant at α=0.01 probability level.

Table 2
Frequency distribution of selected soil properties for different landforms in the Amol Region

Soil properties	Landform	Mean	Median	Variance	Skewness	Std. skewness
Sand, (%)	Piedmont Plain	14.2	14	53.6	2.40**	0.28
	Levee	28	24	287	2.03**	0.24
	Behind Levee	23.7	21	161	1.71**	0.20
	Lowland	31.3	24	391	1.79**	0.45
Silt, (%)	Piedmont Plain	42.1	42	38.6	−0.42ns	0.28
	Levee	46.3	49	118	−2.16**	0.24
	Behind Levee	48.7	49	84.0	−1.15**	0.20
	Lowland	42.4	44	118	−2.12**	0.45
Clay, (%)	Piedmont Plain	43.6	46	75.4	−0.42ns	0.28
	Levee	25.6	26	99.6	0.12ns	0.24
	Behind Levee	27.5	28	76.6	−0.17ns	0.2
	Lowland	26.1	25	154	−0.21ns	0.45
EC, (dS/m)	Piedmont Plain	0.94	0.71	0.58	2.30**	0.28
	Levee	0.61	0.50	0.09	1.55**	0.24
	Behind Levee	0.67	0.55	0.11	1.74**	0.20
	Lowland	1.75	1.26	1.94	1.67**	0.44
pH paste	Piedmont Plain	7.16	7.30	0.32	−1.56**	0.28
	Levee	7.60	7.63	0.02	−1.15**	0.24
	Behind Levee	7.60	7.64	0.03	−1.42**	0.20
	Lowland	7.21	7.26	0.41	−2.93**	0.44
$CaCO_3$, (%)	Piedmont Plain	8.26	7.40	44.5	2.68**	0.28
	Levee	13.3	13.1	21.3	2.00**	0.24
	Behind Levee	15.8	13.6	63.4	1.49**	0.20
	Lowland	16.6	14.6	123	0.49ns	0.44
CEC, ($cmol_c\ kg^{-1}$)	Piedmont Plain	24.4	23	51.7	0.48ns	0.39
	Levee	13.8	13	18.2	0.42ns	0.33
	Behind Levee	15.1	14	17.5	0.38ns	0.28
	Lowland	22.1	20.5	150	1.38**	0.59
OC, (%)	Piedmont Plain	1.26	0.95	1.04	2.00**	0.28
	Levee	0.82	0.80	0.16	0.51*	0.24
	Behind Levee	0.97	0.91	0.46	3.84**	0.20
	Lowland	3.10	1.29	36.6	3.81**	0.45

*: Significant at α=0.05 probability level.
**: Significant at α=0.01 probability level.
ns: non significant at α=0.01 probability level.

between northern hillside of Alborz and the coast of the Caspian Sea, several profiles were randomly selected from each transect to give a total number of 57 pedons consisting of 23 pedons from the behind levee landform, 16 from the levee, 13 from the piedmont plain and 5 from the lowland. The selection of samples from each pedon was on the basis of distinct layers and samples have been designated A, B, C, D, E, F and G in order of increasing depth. The nomenclature does not represent conventional pedological horizon symbols but instead distinct layers present in profiles. As will be demonstrated in this paper the apparent soil horizons are mainly distinct sedimentary layers. Thus the nomenclature is stratigraphic rather than pedological and the term layer will be used in this paper. A total of 320 samples

Table 3
Frequency distribution of normal distributed log transformed soil properties for different landforms of the Amol Region

Soil properties	Landform	Mean	Median	Variance	Skewness	Std. skewness
Log sand, (%)	Piedmont Plain	1.10	1.14	0.04	0.50ns	0.28
	Levee	1.38	1.38	0.05	−0.04ns	0.24
	Behind Levee	1.31	1.32	0.06	0.42ns	0.20
	Lowland	1.43	1.38	0.05	0.59ns	0.45
Log silt, (%)	Levee	1.64	1.69	0.03	−3.75**	0.24
	Behind Levee	1.67	1.69	0.01	−4.60**	0.20
	Lowland	1.58	1.64	0.07	−4.50**	0.45
Log EC, (dS/m)	Piedmont Plain	−0.13	−0.14	0.09	0.20ns	0.28
	Levee	−0.25	−0.30	0.03	0.45ns	0.24
	Behind Levee	−0.21	−0.25	0.03	0.71**	0.20
	Lowland	0.13	0.10	0.08	0.57ns	0.44
Log pH paste	Piedmont Plain	0.85	0.86	0.01	−1.71**	0.28
	Levee	0.88	0.88	0.01	0.44ns	0.24
	Behind Levee	0.88	0.88	0.01	−0.43ns	0.20
	Lowland	0.85	0.86	0.01	−3.57**	0.44
Log $CaCO_3$, (%)	Piedmont Plain	0.79	0.86	0.11	−0.15ns	0.28
	Levee	1.10	1.11	0.02	−1.65**	0.24
	Behind Levee	1.15	1.13	0.04	−0.15ns	0.20
Log CEC, ($cmol_c\ kg^{-1}$)	Lowland	1.28	1.31	0.05	0.17ns	0.59
Log OC, (%)	Piedmont Plain	−0.01	−0.02	0.10	−0.11ns	0.28
	Levee	−0.13	−0.09	0.05	−0.45ns	0.24
	Behind Levee	−0.08	−0.04	0.06	−0.24ns	0.20
	Lowland	0.11	0.08	0.28	0.67ns	0.45

**: Significant at α=0.01 probability level.
ns: non significant at α=0.01 probability level.

from the 57 pedons were analyzed for eight soil properties. Air dried soil samples were sieved through a 2-mm screen and analyzed for sand, silt and clay content using the pipette method (Anderson and Ingram, 1993), pH paste (McLean, 1982), total organic C (TOC) by the Walkley–Black method (Nelson and Sommers, 1982), calcium carbonate by neutralization with HCl and titration with NaOH (Nelson, 1982), cation exchange capacity (CEC) at pH 7 by ammonium acetate extraction was measured using the Bower method (Chapman, 1965) and electrical conductivity (EC) following Page (1982). The soils have been classified to subgroup level according to the soil classification system developed by the USDA (Soil Survey Staff, 2006). Most soils on the piedmont plain are Typic Epiaqualfs, on levee are Aeric Epiaquents, on behind levee are Typic Epiaquepts and Typic Epiaquents and for lowland are Typic endoaquepts. Assessment of frequency distributions and the normality test for data have been done using SPSS software (SPSS, Inc. 1990) and distributional symmetry (skewness) also was evaluated as the cube root of the deviation from the mean (Zar, 1974). To investigate the distribution pattern of soil properties within and between profiles for different landforms, factor analysis was performed on the data for each soil layer.

Factor analysis of data was carried out using Statistica Software (StatSoft, Inc. 2001). Each factor is a linear combination of the original variables. The first factor, associated with the largest eigenvalue, accounts for the maximum of the total variance; the second factor is the second linear combination, uncorrelated with the first, which accounts for the maximum of the residual variance, and so on until the total variance is accounted for. Usually, a small number of factors explain a high percentage of the total variance; that is, the data set can be described in a smaller-dimensional space (Ramos et al., 2007). In order to facilitate the interpretation of each component, Varimax Rotation was applied. The data were standardized to zero mean and unit variance before factor analysis.

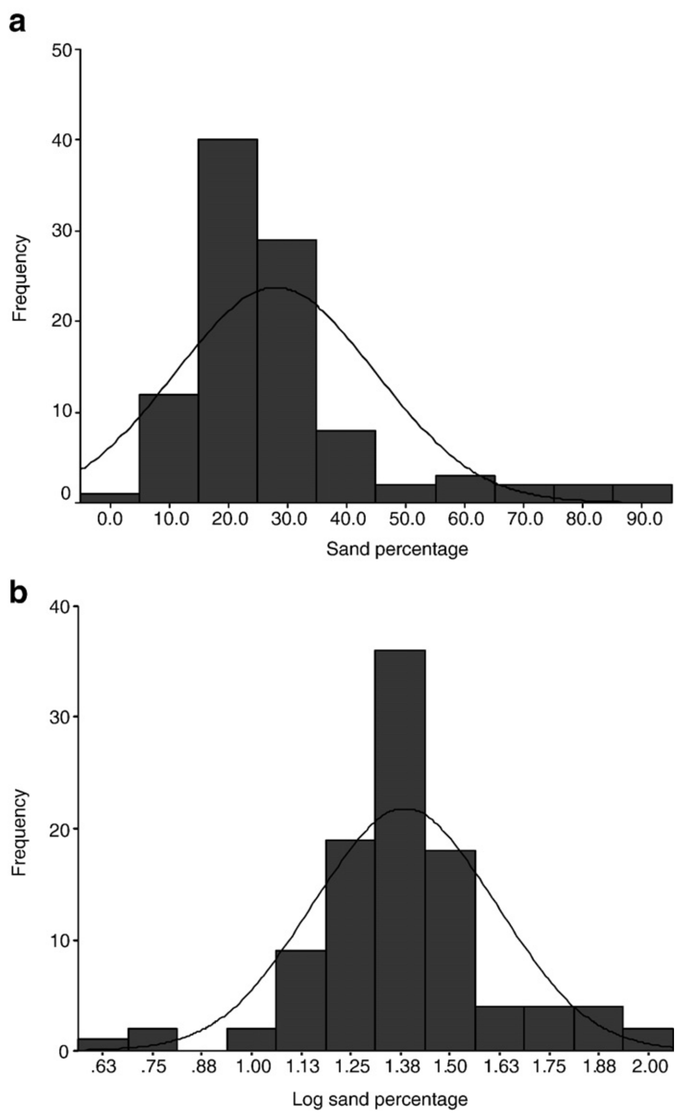

Fig. 2. Frequency distributions of sand percentage for the levee landform: (a) non-transformed data; (b) log-transformed data.

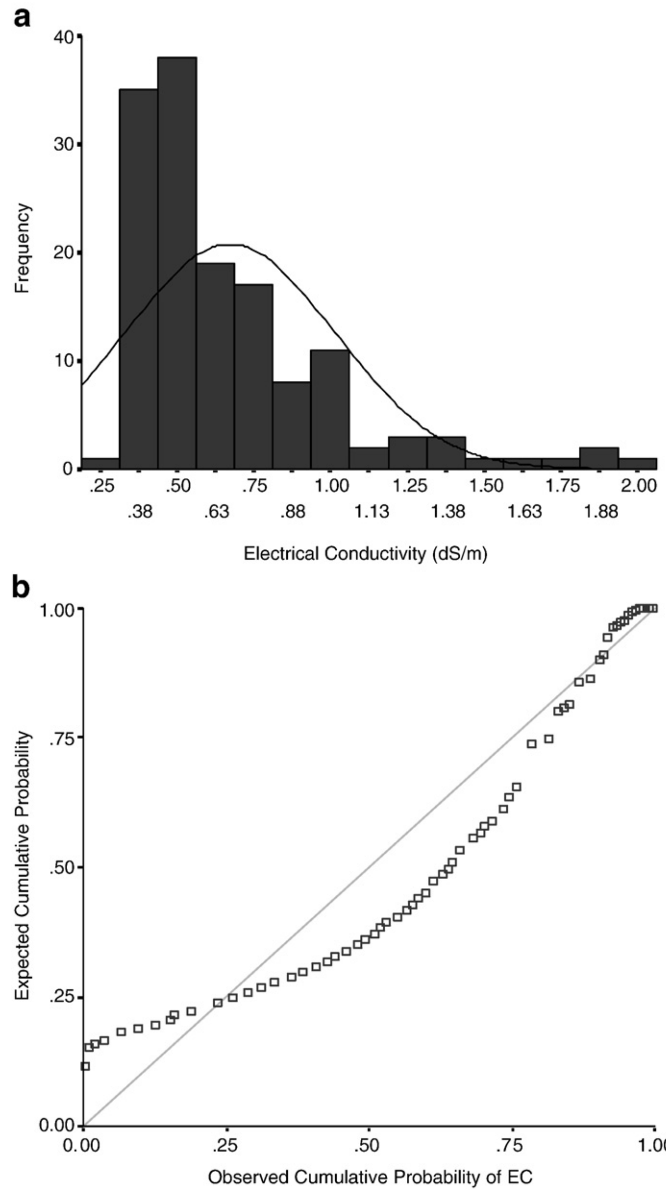

Fig. 3. Distributions of electrical conductivity values for the behind levee landform: (a) displayed as a histogram; (b) displayed as a probability plot.

3. Results

3.1. Frequency distribution of data

The frequency distribution of selected soil properties for the combined data from all landforms was calculated (Table 1). For both non-transformed and log-transformed data, only clay and log CEC have normal distributions. Stratifying soil properties by landform

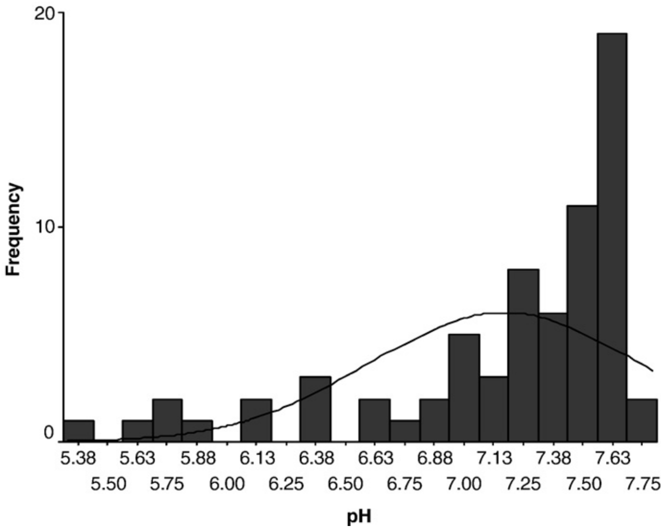

Fig. 4. Distribution of soil pH values for the piedmont plain landform.

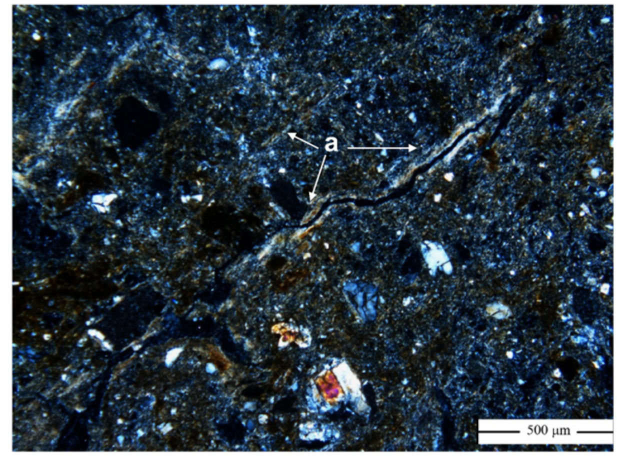

Fig. 6. Argillans (a) in voids and channels within the matrix of the D layer of a soil on the piedmont plain landform (XPL).

increased the number of normally distributed soil variables (Tables 2 and 3). Table 2 (without log-transformation), gives a normal distribution for clay (all landforms), silt (piedmont plain), $CaCO_3$ (lowland) and CEC (except for lowland). Transformation of these variables, showed that the normality of distributions could be improved. For example in Fig. 2, the distribution of sand percentage values in levee samples did not follow a normal distribution but for log-transformed data, the distributions are normal. Sand and organic carbon (for all landforms), EC (except for behind levee), $CaCO_3$ (except for levee) and CEC (only lowland) followed log-normal distributions (Table 3). These results show that distributions of values of soil properties differ significantly among landforms. Variations in soil properties result from variation in depositional environments and or differences in pedogenic or hydrologic processes for different landform positions. Soil properties may also be affected by the imposed drainage and agricultural practices including flood irrigation and the addition of fertilizer. These effects may cause data to depart from a normal distribution and cause skewness (positive or negative) for a soil mapping unit. Outliers may also be the result of asymmetric variation in pedogenic or hydrologic processes. For example, if we consider the right-tailed (positive) skewness for EC data for the behind levee landform (Fig. 3a), right-tailed skewness results from the presence of a few exceptionally large values, lengthening the right tail. In this instance, the high EC values represent pedons adjacent to saline rivers. The probability plot for this distribution allows identification of pedons that may be considered as outliers or inclusions (Fig. 3b). The relationship between observed and expected values would be linear for a normal distribution (the normal 1:1 line is shown in the plot). The pedon data that cause skewness are those that deviate from the 1:1 line in the right-hand part of Fig. 3b. Similarly the negative skewness of pH data, particularly for the piedmont plain landform, represents the nonuniform occurrences of leaching and erosion processes on this landform (Fig. 4).

3.2. Distribution of attributes for the piedmont plain landform

Results of factor analysis of standardized data for piedmont plain soils are given in Fig. 5a and b. Two factors explain about 60% of the variation in the data. This low value may be a consequence of the diverse nature of these soil materials. There are significant positive

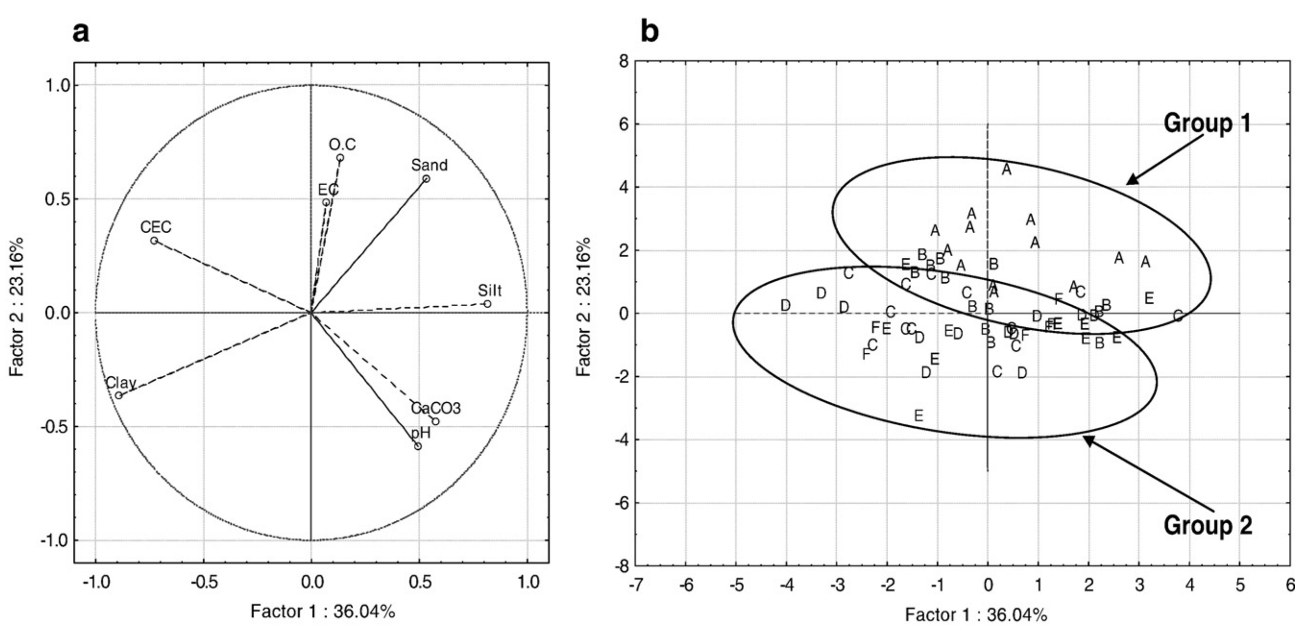

Fig. 5. Factor analysis of soil properties for the piedmont plain landform: (a) distribution of soil attributes; (b) distribution of soil samples.

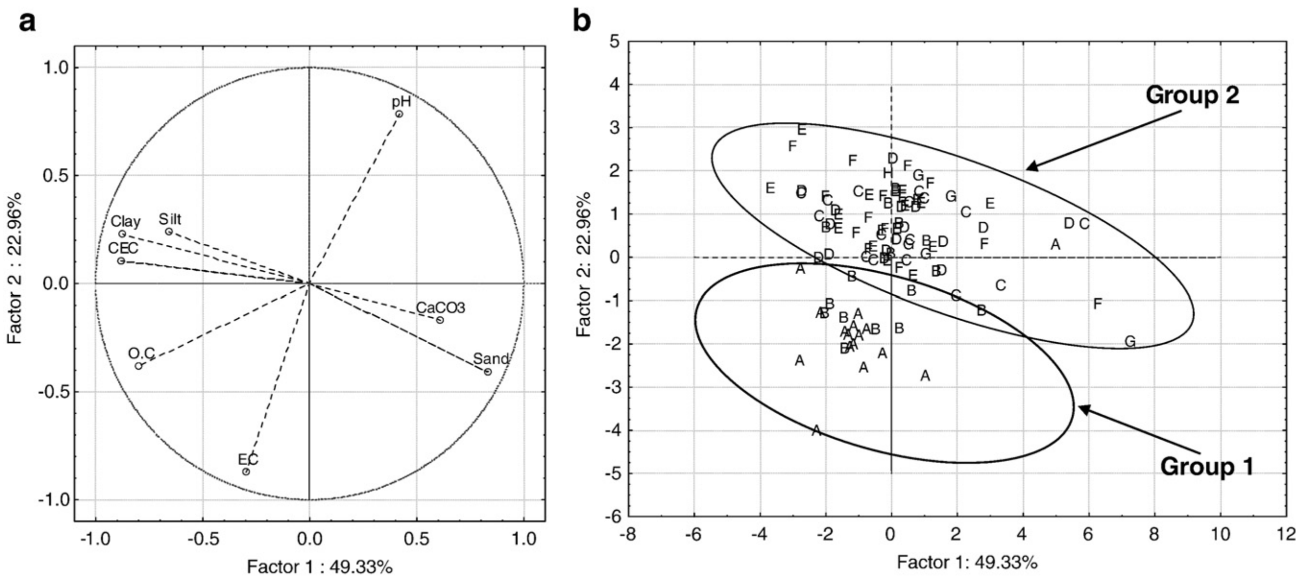

Fig. 7. Factor analysis of soil properties for the levee landform: (a) distribution of soil attributes; (b) distribution of soil samples.

relationships between pH and $CaCO_3$ and between OC and EC for this landform. There are negative relationships between clay and sand and between CEC and both $CaCO_3$ and pH. Cation exchange capacity is most closely related to clay content. The soil samples can be allocated to two main groups (Fig. 5b). The first group is composed of surface soil layers that have high OC, EC and sand concentrations. In the piedmont plain where land is used for rice and forest trees, soils accumulate high amounts of organic carbon in surface layers. The second group, is mainly composed of subsoil layers that have much higher percentage clay and CEC values. These groupings are a result of clay eluviation to subsurface layers with the formation of argillic horizons. Although these soils occur on sloping sites considerable pedogenesis has occurred. Argillans occur on ped surfaces and have been observed in the field and in thin sections (Fig. 6).

3.3. Distribution of attributes for the levee landform

Factor analysis of the attributes for the levee landform (Fig. 7a and b) shows that about 73% of the variation in the data is explained by two factors. Positive relationships exist between clay, silt and CEC and negative relationships between these attributes and sand and $CaCO_3$. Two main groups of samples can be recognized (Fig. 7b). The first group includes surface layers (first and second layers A, B) that have high EC and OC values and low pH. The second group mainly consists of the other soil layers with lower OC and EC values and higher pH. Soils of this group mostly have higher CEC, clay and silt values, some horizons have high $CaCO_3$ and sand values.

3.4. Distribution of attributes for the behind levee landform

Factor analysis (Fig. 8a and b) shows that 62% of the variation in the data for the behind levee landform is explained by two factors. Silt, clay and CEC are positively correlated and negatively correlated with sand. Also OC and EC are positively correlated and are negatively correlated with pH. Fig. 8b indicates that the distribution of samples in the behind levee landform is quite compact with one major group of soil samples (Group 1) with the different layers exhibiting similar properties, although there are some outlier data indicated in this figure. There is a quite systematic separation of samples on the basis of layer so that the major group can be divided to two subgroups. The

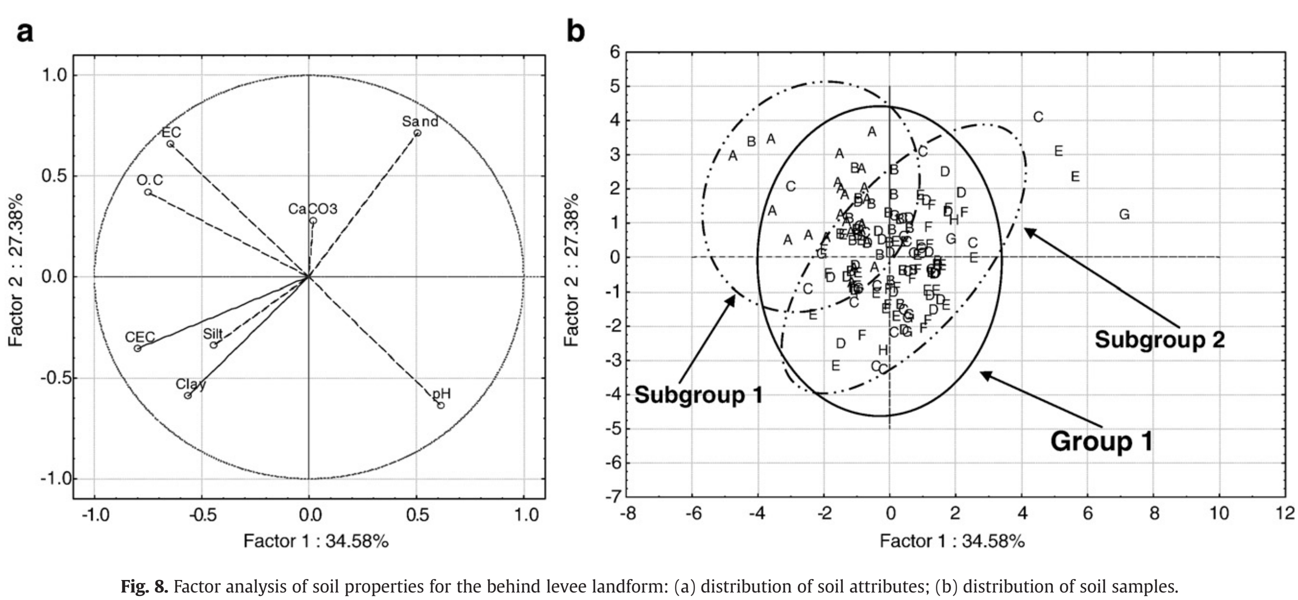

Fig. 8. Factor analysis of soil properties for the behind levee landform: (a) distribution of soil attributes; (b) distribution of soil samples.

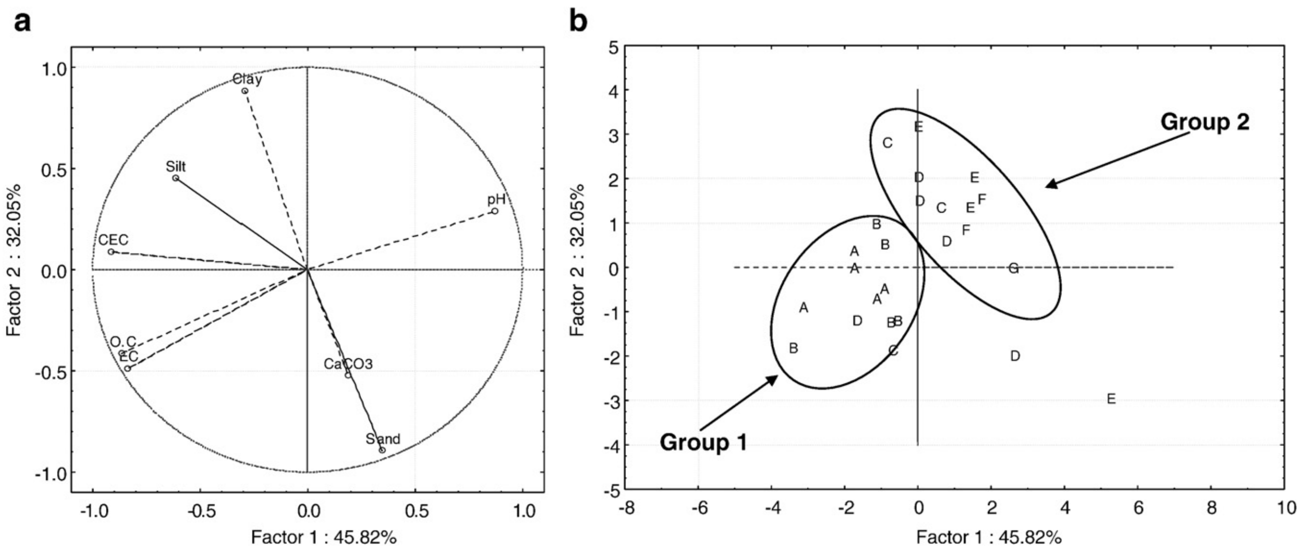

Fig. 9. Factor analysis of soil properties for the lowland landform: (a) distribution of soil attributes; (b) distribution of soil samples.

first subgroup, consists of samples with A and B symbols (surface layers) and the second subgroup mostly contains underlying layers but there is some overlap with the first subgroup.

3.5. Distribution of attributes for the lowland landform

About 78% of the variation in the soil property data for the lowland landform is explained by two factors (Fig. 9a and b). As for the other landforms, there is a strong positive relationship between EC and OC and these attributes have negative relationships with pH. Silt and clay are positively related to each other and negatively related to sand and $CaCO_3$. There are two main groups of soil samples for this landform that are quite different. The first group consists mainly of surface soil layers (A and B symbols) that have higher EC and OC values with lower pH. The second group consists mainly of subsurface samples that commonly have high clay and pH values.

There is a close relationship between EC and OC for the surface layer for lowland soils and indeed for all landform elements. High OC values commonly reflect the presence of roots and plant residues in surface layers but the high EC values may be related to fertilizer addition to topsoils by farmers and capillary rise of salt in soil solution from subsurface to surface layers during the dry season. Microbial activity is suppressed in salty soils which will promote the preservation of OC.

3.6. Variations in soil properties with depth and landscape position

Representative depth functions for mean factor 1 and 2 scores for soil properties for different landforms are shown in Fig. 10. For piedmont plain, variations in factors 1 and 2 with depth for most profiles show that some properties have been affected by pedogenic factors, for example T6P1, T5P1 and T1P4 show systematic trends with increasing depth. In these profiles, surface layers have high values for sand, silt, $CaCO_3$, pH, OC and EC, with increasing depth the values for clay and CEC increase. This situation indicates that the pedogenic processes of eluviation and illuviation have occurred and the presence of argillans in these soils supports this interpretation (Fig. 6). However, for some profiles on the piedmont plain, both factors 1 and 2 show an irregular variation with depth (e.g. T1P3), indicating that a major process affecting soil properties is the stratification of sedimentary parent material.

For the levee landform, for both factors, there are very irregular variations with depth in most profiles. For example, profile T3P10 contains layers that have diverse values of factor 1. These variations are due to stratification of the alluvial parent material in the profile. However, there are a few profiles such as T3P2 that have a systematic variation in factor 1 with depth and these may have been formed from uniform parent materials so that profile trends reflect pedogenesis.

For the behind levee profiles, it seems that there are both pedogenic and sedimentary effects on soil properties but that the original properties of sediments dominate. For example, in T6P5, pedogenesis in a quite uniform parent material has caused systematic variations in factors 1 and 2 with depth. However, for most profiles wide variations of factors 1 and 2 with depth indicate the presence of sedimentary layers.

For lowland profiles, variations in the factors mostly reflect pedogenic processes rather than sedimentary layering. This landform is mostly permanently inundated under current land management but previously experienced seasonal flooding and drought during which pedogenic processes occurred. In T1P11, factor 1 becomes more positive with depth as pH increases and EC and OC decrease whereas factor 2 (except in the bottom layer) becomes more negative as $CaCO_3$ and sand increase. The bottom layer contains more clay and silt which indicates that it is a discrete sedimentary layer.

4. Conclusions

Partitioning the soils of the Amol region by landform improved the normality of analytical data. Many soil properties are log-normally distributed (Parkin and Robinson, 1994). However, there were some soil properties for which a log transformation did not improve, or even worsened the degree of normality of the data. Additional research is needed to develop appropriate statistical analyses for these data (Brejda et al., 2000). Our results and those of Young et al. (1999) seem to indicate that normal distributions are less likely for more heterogeneous sedimentary parent materials. For example, the $CaCO_3$ distributions reported for levee soils, could be affected by stratified depositional layers “However” for some soil properties, the separate impacts of pedogenic, hydrologic and depositional processes on the normality of data are not clear. Skewed distributional tails that weaken statistical relationships may represent outliers or mapping inclusions and these pedons may respond differently to management (Young et al., 1999). This research has shown that the distribution of soil properties depends on depositional environment, landform and pedogenic processes. Distributions of analytical data provide important information, not only for statistical analysis, but for understanding and interpreting pedogenesis and applying appropriate

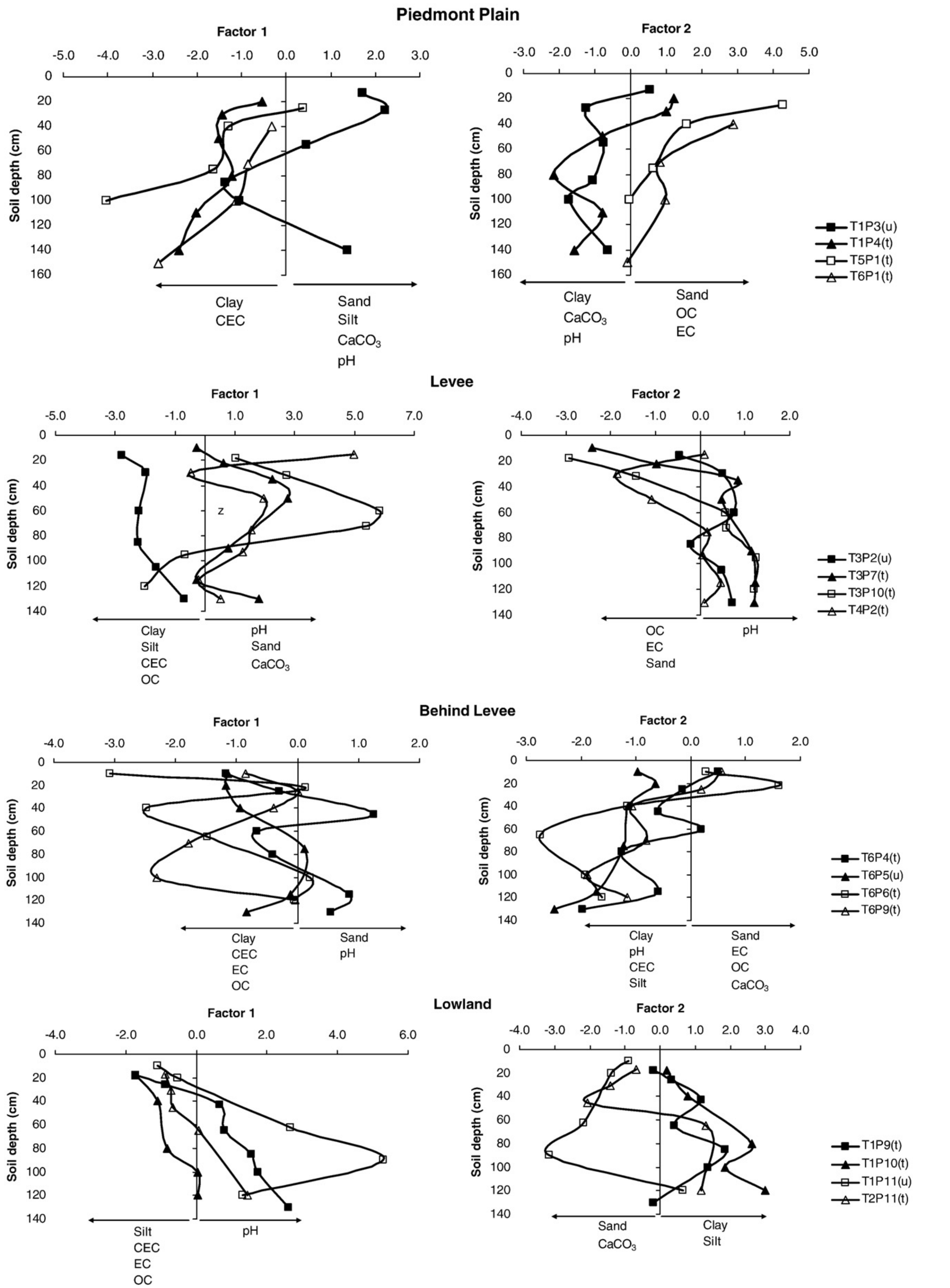

Fig. 10. Depth functions of 3 typical (t) and 1 unusual (u) profiles for factors 1 and 2 for piedmont plain, levee, behind levee and lowland landforms of the Amol region. (TnPx: *n* represents the number of the transect and *x* represents the number of the profile).

management. Factor analysis, has revealed the separate contributions of sedimentary sorting and pedogenesis on the distribution of soil properties.

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