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Examination of Relationship between Species Diversity and Environmental Variables in Arid and Semi-arid Rangelands of Iran

ABSTRACT

The necessary recommendations for environmental management can be provided by measuring diversity and distribution of plant species. The relationship between species diversity and environmental variables affecting Furg rangelands, in the East of Iran was examined. A systematic-random approach was employed to sample vegetation and soil characteristics. Vegetation sampling was conducted using a 10×10 m quadrate (10 quadrate per vegetation type). According to the rooting depth of plants, soil samples were taken from 0-30 cm depth and analyzed through standard laboratory approaches to determine physical and chemical properties. Species diversity was measured using the indices Simpson, Shannon-Wiener and Fisher's alpha. To determine factors affecting species diversity, the Canonical Corresponding Analysis (CCA) and Principal Component Analysis (PCA) were utilized. The vegetation type Ar.au-Ac.sp (type III) had the highest diversity, which was mainly located on the soils with higher quantities of EC, Ca, Na, Gypsum and sand content. The vegetation type Ar.au-La.or-Co.er (type I) with the lowest diversity was mainly placed on the soils where sand content was higher and soil pH, moisture content, TNV, silt content and slope were lower, as compared with those in other vegetation types. Generally, it could be established that in the studied region, the species diversity of plants was more impacted by soil properties, as compared with topographic characteristics.

Key words: *Canonical corresponding analysis (CCA), ordination, principal component analysis (PCA), plant species diversity, soil variable, topographic factors*

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INTRODUCTION

Iran's vast territory with a variety of climates and soils consists of habitats of many species. Therefore, by knowing the factors affecting the growth of plant species, spending extra money and wasting time in rangelands reclamation can be prevented. To this end, the identification of native plants and effective factors in their establishment is necessary. Environmental factors effectively play a significant role in determining the habitats of plants (*Escudero et al. 2000*). Furthermore, species diversity is one of the most important indicators for rangelands evaluation and determining the status of ecosystem (*Mesdaghi 2008*). Several studies have been carried to establish relationships between environmental factors and species diversity. For instance, *Mirdavoodi and Zahedipour* (*2005*) in their study determined an appropriate model for estimating species diversity of plant communities of Meighan Desert in Iran and the impact of some ecological factors on it was investigated, as well. Results showed that among the variables studied, six main soil variables including electrical conductivity (EC), the amount of magnesium ions (Mg^{2+}) and gypsum, organic carbon content, soil texture and also the distance between water table and roots had the most correlation with species diversity alterations in the studied region. *Azarnivand et al.* (*2007*) in their study about environmental factors affecting the distribution of plant species in Damaghan, Iran stated that altitude, rainfall and slope are as the main factors affecting changes in vegetation cover. *Fahimipour et al*. (*2010*) in examining the relationship between some pasture plant species with environmental factors in a part of rangelands of central Taleghan, Iran came to this conclusion that slope, altitude, soil texture, depth, phosphorus and nitrogen had the most impact on the species growth and diversity in the studied area. *Khadem Al-Hosseini* (*2009*) by comparing the numerical indices of species diversity in three habitats (with different grazing rates) showed that all diversity indices had the highest values in exclosure area and the lowest amount in heavy grazing area. *Sang* (*2009*) also showed that topographic characteristics of the habitat with a major impact on the amount of rainfall, temperature and physico– chemical characteristics of the soils always play a fundamental and crucial role in changing the pattern of plant diversity. *Yibing et al.* (*2004*) and *Sang* (*2009*) analyzed the relationship between distribution of vegetation cover and soil factors in the deserts of China using Canonical Corresponding Analysis (CCA). Soil moisture, organic matter, salinity and soil pH had different effects on short shrubs and meadows. *Motaharifard et al.* (*2012*) evaluated the indicators of species diversity in exclosure and heavy grazing areas of Margun region, Iran. Results revealed that exclosure rangeland had a higher diversity and species richness as compared with a heavy grazing rangeland. Other similar works such as *Pinke et al.* (*2010*) and *Small and McCarthy* (*2005*) have confirmed a significant relationship between soil variables and species diversity, as well. Thus, according to the reviewed studies and regarding to the importance of species diversity in the management of sustainable development in the areas with natural vegetation cover, this study was carried out to evaluate the indices of species diversity and factors influencing species diversity in Furg rangelands within Southern Khorasan province of Iran.

MATERIALS AND METHODS

Furg watershed of Darmian is 113 km southeast of Birjand city (**Figure 1**). The study area is a sub-basin of the Khaf salt marsh basin in Darmian region, located at 59° 42' 38''E to 59° 55' 33''E and 32° 46' 36''N to 32° 54' 31''N. This watershed has a total area of 11,136 ha with a maximum altitude of 2,746 m and minimum 1,904 m and an average of 2,141 m above sea level. The average slope of watershed is 53.5%, which indicates a high topographic condition. According to meteorological studies, the amount of average annual rainfall in the area is 253.7 mm; the average temperature is 5.9°C with a wet duration of 5.5 months from mid-November to late April. The watershed climate is classified within cold semi-arid climate condition, according to the Emberger method (*Abkhizgostar Shargh Co. 2008*). Furg watershed includes three types of vegetation (**Table 1**). The vegetation type II with an average slope of 45.6% occupies 58% of the watershed area. Type I occupies 33% of the watershed area which locates on the lands with the slope gradient of 48.5%. The smallest watershed surface (1.5%) with a slope gradient of 47 % has been covered by the vegetation type III.

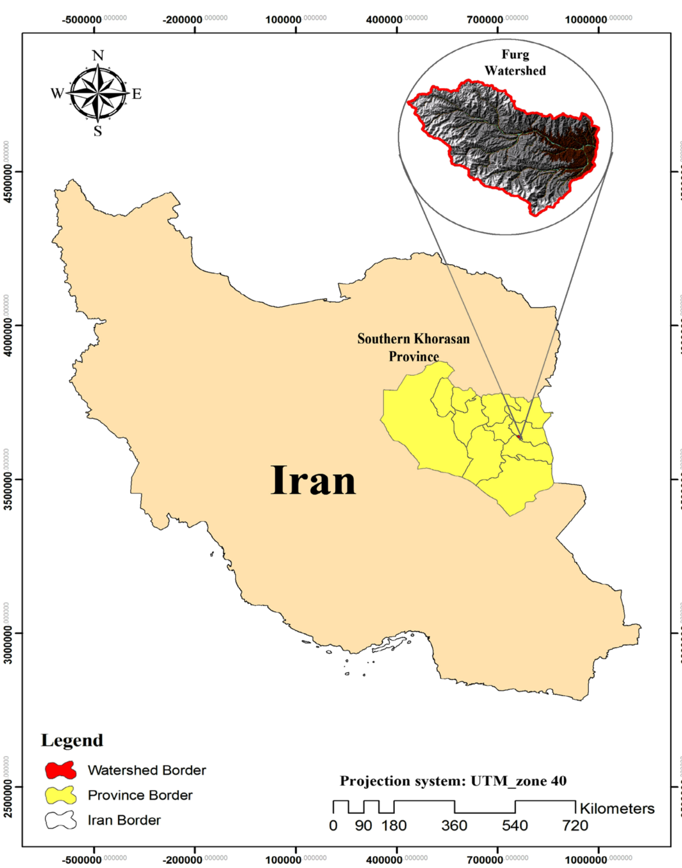

Figure 1. Geographic location of the study areas.

Research Method

The topographic, geology and geomorphology, aerial photos, meteorological data, land use and other required information were collected and vegetation types were mapped based on the geomorphologic units. A total of 10 plots were sampled in each type according to the type and distribution of vegetation in the study area. The size of each plot was determined to be 10 × 10 m^2 (*Mesdaghi 2008*).

In each plot, list of plant species, canopy cover, stone, pebble and bare soil fractions were determined. Soil samples were taken from the depth 0-30 cm, according to the rooting depth of plant species. At each point, the Global Positioning System (GPS) was utilized to record latitude, longitude and altitude. The slope and aspect values were measured with inclinometer. Soil samples were sieved by a two-mm sieve after drying and according to the weight of samples before and after sieving and the weight of crossed soil from the sieve, stone and pebble fractions were determined. Then, physical and chemical testing for determining soil texture, soil moisture content in saturated status, pH, electrical conductivity (EC), organic matter (OM), lime (TNV), gypsum ($CaSO_4.2H_2O$) and minerals [Sodium (Na), Potassium (K), Calcium (Ca) and Magnesium (Mg)] was performed on particles smaller than two millimeters. Soil texture was determined using the Baykas gauging method (*Gee et al. 1986*). Soil moisture was measured using prepared saturated clay through the weighting approach. After preparation of the saturated distillate, soil acidity was determined by the pH meter and to assess soil salinity, an EC meter was utilized. The OM was measured by Walkley-Black method (*Walkley and Black 1934*). TNV was calculated by the calcimetry approach and $CaSO_4.2H_2O$ was calculated by the Bauer approach (*Hawkins and Kunze 1965*). The cations of Na and were determined by the Flame photometry (*Gee et al. 1986*) and the complexometric

Table 1. Plant covers percentage and diversity indices in each vegetation type.

Type	Dominant Species	Coverage (%)	Altitude (m)	Evenness	Fisher's Alpha	Simpson	Shannon-Weiner	Species Richness
I	*Artemisia aucheri, Lactuca orientalis, Cousinia eryngioide*	11.5	1919-2260	0.307	1.323	0.346	0.87	17
II	*Artemisia aucheri, Asteragalus heratensis, Serratula latifolia*	24.8	2100-2767	0.437	2.311	0.534	1.309	20
III	*Artemisia aucheri, Acanthophyllum sp.*	17.1	2000-2530	0.678	3.413	0.668	2.128	23

titration approach was employed to measure Ca and Mg (*Gee et al. 1986*). To determine species richness, the total number of species was counted in each vegetation type. Species diversity indices of Shannon-Wiener, Simpson, and Fisher's alpha (*Mesdaghi 2011*) were calculated based on the frequencies of plant species in each vegetation type using the EstimateS win9.1 software (*Colwell 2013*). Principal Component Analysis (PCA) and CCA techniques in PC-ORD software (*McCune and Mefford 1999*) were used to determine the most important factors affecting species diversity. The PCA has also been used in the field of science in order to identify the most important parameters in separation of the various phenomena. Complex relationships that influence plant growth can be explored by PCA, which has high accuracy and ability to analyze environmental factors affecting habitat (*Mesdaghi 2011*). However, it should be noted that there is a possibility of bias in data analysis due to the different units of measurements for each variable (*Mesdaghi 2011*). Therefore, data were standardized before using PCA. The PCA is a statistical method to define new variables in terms of linear combination of the initial variables. The purpose of PCA is extracting the main components of a set of basic variables. New components are independent to each other and their variance is downtrend. The first extracted component has maximum variance among initial set of data and subsequent extracted components have lower variance among initial set of data and total variance of extracted components is equal to the total variance of data (*Jolliffe 2002; Mesdaghi 2011*). In PCA analysis, sites classification and separation is performed based on the maximum variance of principal components (*Jolliffe 2002*). To determine the most effective environmental factors (including different variables of soil and topography) on the distribution of plant species, CCA (*Jongman et al. 1995*) was run and relationships between plant species with environmental factors were illustrated by diagramming.

For analysis of ordination charts obtained by principal component analysis and justifying the spatial distribution of vegetation types, the following points were considered: the distance between points representing vegetation types from each other as well as the distance of points from axis of coordinates indicate the strength or weakness of relationships. The bigger the length of the vector representing the vegetation types and the smaller the angle with the main axis, the higher the correlation between vegetation types with the variables of that axis will be. Whatever indicator points of habitats get closer; those types will have more similarity with each other which indicates a similar environmental situation (*Wildi 2010; Mesdaghi 2011*); and to interpret the ordination chart, the algebraic signs of correlation coefficients between environmental variables and principal components.

RESULTS

In this study, 45 plant species and 25 genera belonging to nine families were identified. The *Asteraceae* with 19 species *and Poaceae, Apiaceae* and *Lamiaceae* each with 5 species were the most important plant families. The *Fabaceae*, *Caryophyllaceae, Plumbaginaceae, Chenopodiaceae and Zygophyllaceae* had lower importance with less number of plant species. The destruction of plant cover in the study area is the most important reason of the abundance of the family *Asteraceae.* Most of plant species in this family are categorized in the growth form of Hemicryptophyte, which are attuned to cold and mountainous condition (*Archibold 1996)*.

The frequencies of plant species listed was based on a flora categorization scheme (**Figure 2**). This study provided

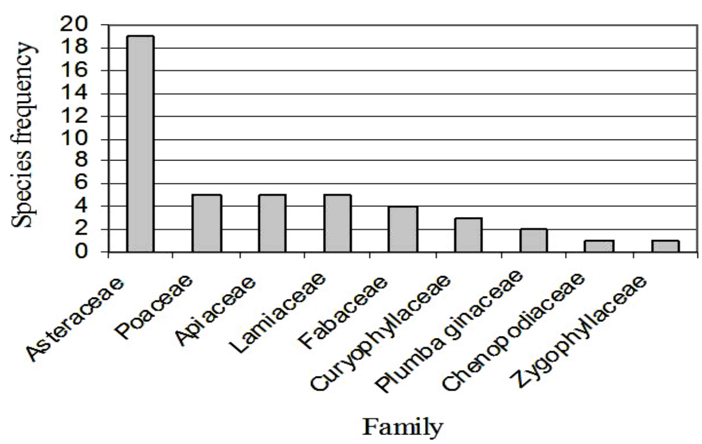

Figure 2. Frequency of plant species in different families.

a floristic list of the study area (**Table 2**) and the index values of species diversity in different vegetation types, as well as the physical and chemical properties of soil and topographic factors in different vegetation types (**Tables 3** to **5**).

PCA

To determine the most important environmental factors which lead to changes in species diversity, PCA method was used. Principal component transformation on 17 environmental factors was examined in three vegetation type. In this method, components are chosen until eigenvalues are greater than the index BSE: Broken Stick Eigenvalue. This condition was fulfilled in the first, second and the third component and these components justified 58.382 % of species diversity (**Table 6**). The importance of the first component was more, in a way that 28.301 % of

Table 2. Floristic list of rangeland species in the study area.

Species	Family	Life form	Plant form	Degree of palatability	Usage
Artemisia aucheri	Asteraceae	P	Sh	III	Forage
Artemisia diffusa	Asteraceae	P	Sh	III	Forage
Artemisia scoporia	Asteraceae	P	Sh	II	Forage
Artemisia sieberi	Asteraceae	P	Sh	II	Forage
Amberboa nana	Asteraceae	A	F	II	Forage
Astragalus heratensis	Fabaceae	P	Sh	II	Protector
Astragalus aureus	Fabaceae	P	Sh	III	Protector
Astragalus podolobus	Fabaceae	P	Sh	II	Protector
Astragalus brevidens	Fabaceae	P	Sh	II	Protector
Acanthophyllum spp	Caryophyllaceae	P	Sh	III	Protector
Acanthophyllum glandulosum	Caryophyllaceae	P	Sh	III	Protector
Acanthophyllum microcephalum	Caryophyllaceae	P	Sh	III	Protector
Acantholimon acmostegium	Plumbaginaceae	P	Sh	III	Protector
Acantholimon sp	Plumbaginaceae	P	Sh	III	Protector
Bromus tectorum	Poaceae	A	G	III	Forage
Bromus danthoniae	Poaceae	A	G	II	Forage
Cousinia eryngioides	Asteraceae	P	Sh	III	Invader
Cousinia	Asteraceae	P	Sh	III	Protector
Cousinia microcarpa	Asteraceae	P	Sh	III	Invader
Cousinia sp	Asteraceae	P	Sh	III	Invader
Centaurra virgata	Asteraceae	P	F	III	Invader
Centaurra bruguierana	Asteraceae	P	F	III	Invader
Centaurra ibrica	Asteraceae	P	F	III	Invader
Cirsium congestum	Asteraceae	P	F	III	Invader
Dorema ammoniacum	Apiaceae	P	F	III	Invader
Eryngium billardieri	Apiaceae	P	F	III	Invader
Eryngium coucasicum	Apiaceae	P	F	III	Invader
Echinops leucographus	Asteraceae	P	F	III	Invader
Ferula szowitsiana	Apiaceae	P	F	III	Invader
Ferula ovina	Apiaceae	P	F	II	Invader
Gundelia tournefortii	Asteraceae	P	F	III	Protector-Forage
Hymenocrater calycinus	Laminaceae	P	Sh	III	Invader
Hymenocrater bituminosus	Laminaceae	P	Sh	III	Invader
Hordeum bulbosum	Poaceae	P	G	I	Forage
Hordeum glaucum	Poaceae	P	G	II	Forage
Launea acanthodes	Asteraceae	p	F	III	Invader
Lactuca orientalis	Asteraceae	A	F	III	Protector
Melica persica	Poaceae	A	G	III	Forage
Nepeta persica	Laminaceae	P	F	III	Invader
Nepeta pungens	Laminaceae	P	F	III	Invader
Noaea mucronata	Chenopodiaceae	p	F	III	Invader
Peganum harmala	Zygophyllaceae	p	F	III	Medicinal
Serratula latifolia	Asteraceae	P	F	IIIó	Protector-Forage
Scariola orientalis	Asteraceas	P	F	II	Forage
Thymus transcaspicus	Laminaceae	P	F	III	Medicinal

changes were related to the variables of the first component. 16.969 % of changes were related to the variables of the second component and 13.112 % of changes were related to the variables of the third component.

According to the absolute value of coefficients, the first component included slope, pH, EC, Ca, Na, TNV, sand and silt and the second component included variables of slope, altitude, pH, Ca, K, OM, clay, stone and pebble and the third component comprised aspect, pH, soil moisture content, Na, sand and clay (**Table 7**). Thus, the first and the second components had a major contribution to alterations in vegetation of the study area (**Figure 3**). Tn the first and second components. As discussed above, the first component included soil moisture content, pH, EC, Ca, Na, TNV, sand and silt contents, and the second component included slope, altitude, pH, Ca, K, OM, clay, stone and pebble fractions (**Figures 4** to **6**). Considering the positive and negative coefficients of variables (**Table 7**), in the first principal component from left to right, pH, saturated soil moisture content, TNV, silt, and slope gradient decreased, while EC, Ca, Mg, Na, $CaSO_4.2H_2O$ and sand content increased. In the second component from bottom to top, slope gradient, altitude, clay content, and stone and pebble fraction decreased, while pH, Ca, K, and OM increased.

Given the diversity indices (**Table 2**), the vegetation type Ar.au-Ac.sp with a Shannon-Wiener value of 2.13 had the highest diversity and it was scattered in the fourth quarter of ordination chart on the soils with higher quantities of EC, Ca, Na, $CaSO_4.2H_2O$ and sand content (**Figure 4**). The vegetation type Ar.au-La.or-Co.er with the lowest diversity (Shannon-Wiener index=0.87) was scattered in the first and second quarter of ordination chart and has been grown on the soils in which sand content was higher and soil pH, moisture content, TNV, silt content and slope were lower, as compared with those in other vegetation types (**Figure 5**). The vegetation type Ar.au-As.he-Se.la (with a Shannon-Wiener value of 1.31) was scattered in the third quarter of ordination chart and has been grown on the soils with relatively higher amounts of pH, Ca, K and OM (**Figure 6**).

CCA

To determine the most effective environmental factors on the distribution of plant species, the CCA approach was used. Canonical correspondence analysis on 17 environmental factors was examined in 30 plots with 45 species. The first axis with an eigenvalue of 0.671 justifies 24.1 % of changes in vegetation. The second axis with the eigenvalue of 0.367 justifies 13.2 % of changes in vegetation (**Table 8**). Based on correlation coefficients of variables with principal axes, the first axis showed the most correlation with variables of slope, altitude, saturated soil moisture content, K, $CaSO_4.2H_2O$, and sand content and the second axis had the most correlation with the variables aspect, saturated soil moisture content, Ca, TNV, sand and silt contents. According to the correlation coefficients between the variables and principal axes (**Table 9**), in the first component from left to right, the amount of saturated

Table 3. Soil and topographic properties of different plots in the vegetation type I.

Environmental factor	Plot Number									
	1	2	3	4	5	6	7	8	9	10
Aspect*	South	West	West	West	West	East	East	East	East	East
Slop (%)	17	9	21	13	4	17	7	2	23	11
Altitude (m)	2218	2093	2097	2113	2067	2084	2118	2121	2187	2105
pH	8.21	7.42	8.12	7.75	8.08	7.75	7.68	8.16	8.06	8.21
EC ($mmhos.cm^{-1}$)	0.43	1.52	1.32	1.16	1.38	1.16	1.73	1.18	1.1	1.73
Moisture Saturation Percentage (SP%)	31.04	30.8	30.7	41.5	26.7	30.7	29.1	32.9	24.3	25.5
Calcium ($meq.L^{-1}$)	1.5	3.8	4.4	3.0	4.1	3.0	3.2	3.5	1.4	4.4
Magnesium ($meq.L^{-1}$)	1.55	2.9	2.6	3.2	3.7	2.8	2.2	2.4	1.8	6.0
Sodium ($meq.L-^{1}$)	0.71	8.5	5.7	5.3	5.1	4.5	11.9	5.5	7.5	6.7
Potassium ($meq.L^{-1}$)	0.21	0.17	0.13	0.09	0.11	0.11	0.17	0.14	0.11	1.21
Lime percentage (TNV)	17.9	15.3	16.9	16.2	15.3	15.9	14.7	17.4	14.8	18.2
Gypsum (%)	1.11	1.25	1.24	1.39	1.38	1.35	1.47	1.12	1.35	1.14
Organic matter (%)	0.16	0.11	0.17	0.14	0.14	0.12	0.09	1.13	0.15	0.13
Sand (%)	46.5	50	59.1	44.9	71.1	64.9	68.9	63.1	75.1	73.1
Silt (%)	36.2	27.5	26.6	35.3	18.6	25.3	21.3	26.6	12.6	12.6
Clay (%)	18.5	22.5	14.3	19.8	10.3	9.8	9.8	10.3	12.3	14.3
Soil texture	L	SL	SL	L	SL	SL	SL	SL	SL	SL
Stone and pebble fraction (%)	5.9	3.5	10.3	25.2	7.7	31.4	26.3	6.8	8.1	5.7

L: Loam; SL: Sandy Loam

*: Every aspect was imported to the software as an azimuth angle

Table 4. Soil and topographic properties of different plots in the vegetation type II.

Environmental factor	Plot Number									
	1	2	3	4	5	6	7	8	9	10
Aspect*	Southwest	South	West	West	West	West	Southwest	Southwest	West	Southwest
Slop (%)	20	25	37	45	12	31	35	29	49	30
Altitude (m)	2392	2258	2395	2352	2291	2386	2346	2355	2285	2375
pH	7.81	8.09	7.57	8.22	8.01	7.87	7.62	7.72	7.89	8.19
EC ($mmhos.cm^{-1}$)	1.39	0.44	1.28	1.61	0.27	1.13	0.96	1.12	0.32	0.33
Moisture Saturation Percentage (SP%)	31.7	27.5	32.5	24.3	21.4	28.3	26.9	25.1	34.1	25.3
Calcium ($meq.L^{-1}$)	4.4	1.5	2.8	5.5	0.85	2.4	2.8	2.2	1	1.01
Magnesium ($meq.L^{-1}$)	3.4	1.55	3.2	4.8	0.87	2.9	2.0	2.6	1.02	1.07
Sodium ($meq.L^{-1}$)	5.8	0.93	6.5	5.5	0.48	5.6	4.7	5.7	0.68	0.55
Potassium ($meq.L^{-1}$)	0.14	0.12	0.15	0.17	0.08	0.11	0.07	0.13	0.11	0.15
Lime percentage (TNV)	17.7	15.1	14.2	18.5	18.2	16.9	15.1	16.3	17.3	18.1
Gypsum (%)	1.09	1.41	1.35	1.07	1.14	0.96	1.11	1.24	1.15	1.11
Organic matter (%)	0.13	0.14	0.12	0.11	0.11	0.14	0.11	0.14	0.11	0.13
Sand (%)	62.9	58.2	56.9	75.1	54.6	62.9	70.9	72.9	52.1	40.1
Silt (%)	23.3	28.5	17.3	8.6	34.5	17.3	13.3	13.3	30.1	50.1
Clay (%)	13.8	14.5	25.8	16.3	12.8	19.8	15.8	13.8	18.5	10.4
Soil texture	SL	SL	CL	SL	SL	SL	SL	SL	SL	L
Stone and pebble fraction (%)	27.2	15.2	30.8	6.2	20.1	25.9	31.3	29.4	10.4	25.7

L: Loam; SL: Sandy Loam; CL: Clay Loam

Table 5. Soil and topographic properties of different plots in the vegetation type III.

Environmental factor	Plot#									
	1	2	3	4	5	6	7	8	9	10
Aspect*	Northwest	Southeast	Southeast	Southeast	Southeast	Southeast	Southeast	Southeast	Southeast	Southeast
Slop (%)	30	20	15	17	35	43	35	30	20	17
Altitude (m)	2181	2178	2200	2215	2234	2241	2225	2221	2221	2210
pH	8.14	8.17	8.13	7.68	7.82	7.67	8.09	7.88	8.01	7.82
EC ($mmhos.cm^{-1}$)	1.43	1.29	1.21	1.29	1.25	1.12	1.36	1.44	1.32	1.12
Moisture Saturation Percentage (SP%)	34.2	28.1	23.1	24.1	29.3	22.8	28.1	35.1	34.1	31.2
Calcium ($meq.L^{-1}$)	4.9	4	2.8	3.4	3	3.4	4.8	3	3.2	3.6
Magnesium ($meq.L^{-1}$)	2.4	3.5	2.0	4.2	4	3	2.4	4.2	4.2	2.4
Sodium ($meq.L^{-1}$)	6.8	5.1	4.0	5.1	5.3	4.5	6.8	7.1	7.1	5.1
Potassium ($meq.L^{-1}$)	0.13	0.12	0.09	0.11	0.13	0.09	0.13	0.11	0.12	0.07
Lime percentage (TNV)	16.6	17.4	15.1	14.9	15.5	15.2	16.9	17.1	17.4	16.6
Gypsum (%)	1.19	1.12	1.31	1.33	1.28	1.41	1.24	1.13	1.12	1.24
Organic matter (%)	0.17	0.14	0.11	0.14	0.11	0.13	0.17	0.11	0.14	0.09
Sand (%)	53.1	69.1	70.9	74.9	60.9	78.9	54.2	50.9	50	60.9
Silt (%)	28.6	18.6	10.6	11.3	17.3	9.3	30.1	13.3	13.4	19.3
Clay (%)	18.3	12.3	11.8	13.8	21.8	11.8	19.1	35.8	36.2	19.8
Soil texture	SL	SL	SL	SL	CL	SL	SL	SL	SL	SL
Stone and pebble fraction (%)	4.	5.5	20.3	28.9	31.2	30.7	16.5	15.5	16.2	35.3

L: Loam; SL: Sandy Loam; CL: Clay Loam

soil moisture content, K and $CaSO_4.2H_2O$ increased, while sand content, altitude and slope gradient decreased.

The species *Echinops leucographus*, *Peganum harmala*, *Nepeta persica*, and *Melica persica* were placed in the first quarter of ordination chart and due to the proximity to the first principal axis, the variables saturated soil moisture content, K, $CaSO_4.2H_2O$ and silt content showed a

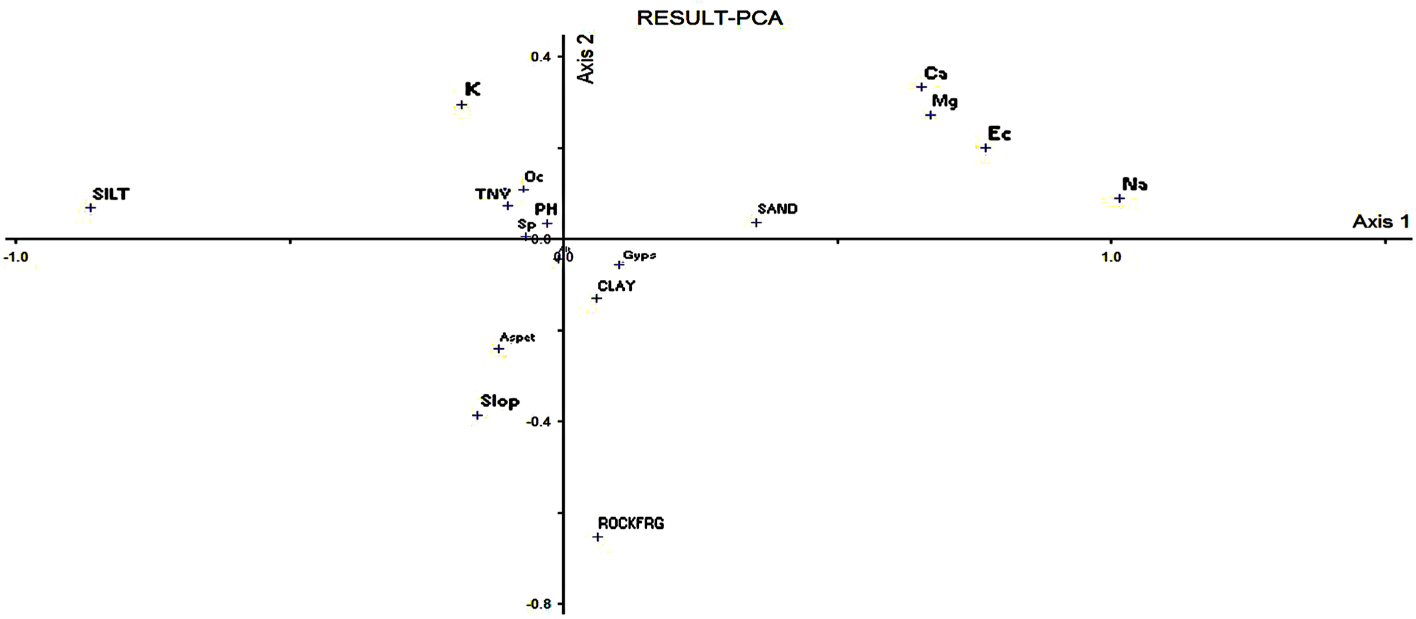

Figure 3. Environmental variables plotted on the first and second principal components.

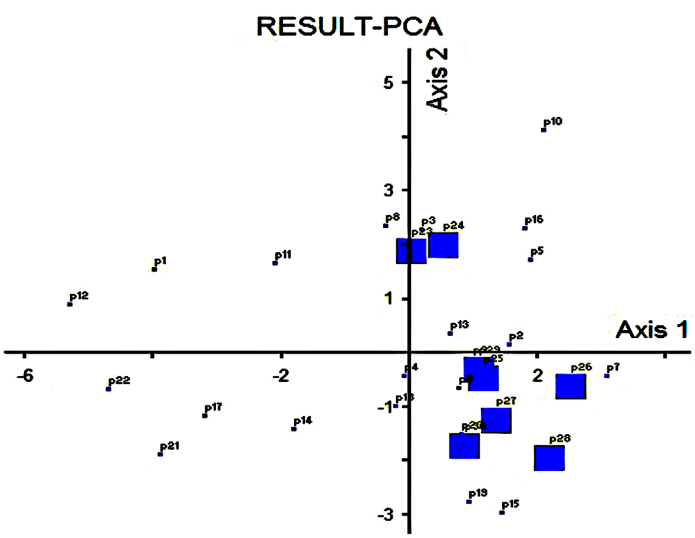

Figure 4. Ordination chart of the vegetation type III.

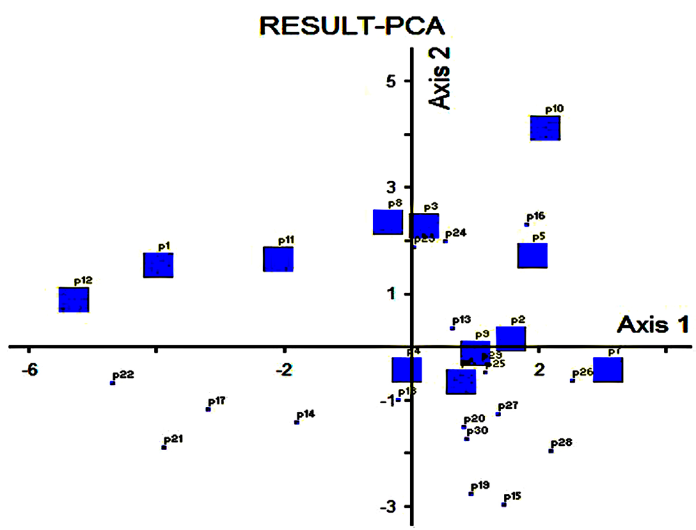

Figure 6. Ordination chart of the vegetation type II.

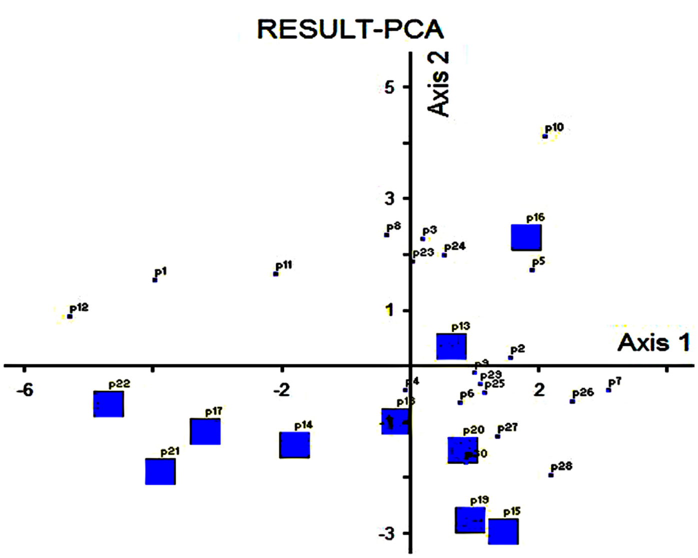

Figure 5. Ordination chart of the vegetation type I.

Table 6. Eigenvalues and variance percentage of each component analyzed by PCA.

Component	Eigenvalue	Cumulative variance (%)	Variance (%)	BSE
1	4.811	28.301	28.301	3.440
2	2.885	45.270	16.969	2.440
3	2.229	58.382	13.112	1.940
4	2.066	70.537	12.156	1.606
5	1.165	77.389	6.851	1.356
6	0.935	82.866	5.497	1.156
7	0.731	87.185	4.299	0.990
8	0.622	90.845	3.660	0.847
9	0.466	93.587	2.742	0.722
10	0.288	95.281	1.694	0.611

Table 7. Eigenvalues of environmental variables in each component analyzed by PCA.

Environmental factor	Component Number					
	1	2	3	4	5	6
Aspect	-0.0386	-0.1287	0.3444	0.1268	0.5362	-0.4860
Slop	-0.0621	-0.2536	0.0751	-0.4337	0.1494	0.4142
Altitude	-0.0471	-0.3114	-0.0393	-0.4825	0.2158	-0.0652
pH	-0.2237	0.4008	-0.2024	-0.0934	0.0724	0.1056
EC	0.4125	0.1795	0.1489	-0.0343	-0.0587	0.0061
Moisture Saturation Percentage	-0.0895	0.0122	0.5409	0.1716	-0.1718	0.3537
Calcium	0.3254	0.2780	0.1116	-0.1242	-0.0703	0.1956
Magnesium	0.3231	0.2196	0.1299	-0.2358	-0.0885	0.0417
Sodium	0.3806	0.056	0.2018	0.0903	-0.0084	-0.0884
Potassium	-0.1260	0.3325	0.1512	-0.0041	-0.0486	-0.3271
Lime percentage (TNV)	-0.2692	0.3182	0.0192	-0.3106	-0.2453	-0.0815
Gypsum	0.2020	-0.1842	-0.0888	0.4745	0.0320	0.2309
Organic matter	-0.0979	0.2442	-0.0001	0.0904	0.5938	0.4701
Sand	0.3501	0.0610	-0.3533	-0.0728	0.1565	-0.1092
Silt	-0.3819	0.0518	0.1260	0.2372	-0.1382	0.0328
Clay	0.0363	-0.1302	0.5180	-0.2287	0.0085	-0.0255
Stone and pebble fraction	0.0235	-0.4144	-0.0911	-0.0139	-0.3643	0.0485

Table 8. Eigenvalues and variance percentage in each axis analyzed by CCA.

Principal axes	Eigenvalue	Variance (%)	Cumulative variance (%)	Correlation coefficient*
1	0.671	24.1	24.1	0.99
2	0.368	13.2	37.3	0.897
3	0.216	7.8	45.1	0.824

*Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables.

Table 9. Correlation coefficients between environmental variables and principal axes analyzed by CCA.

Environmental factor	Axis Number		
	1	2	3
Aspect	0.009	-0.208	0.186
Slop	-0.696	0.063	0.121
Altitude	-0.820	-0.155	0.075
pH	0.016	0.206	0.062
EC	0.079	0.062	-0.199
Moisture Saturation Percentage	0.452	-0.403	0.023
Calcium	0.121	-0.331	-0.281
Magnesium	-0.012	-0.094	-0.279
Sodium	0.075	0.215	0.044
Potassium	0.314	-0.182	0.138
Lime percentage (TNV)	0.008	-0.386	0.092
Gypsum	0.288	0.269	-0.016
Organic matter	0.268	0.077	0.261
Sand	-0.373	0.483	-0.081
Silt	0.479	-0.521	0.223
Clay	-0.004	-0.223	-0.047
Stone and pebble fraction	-0.302	-0.173	-0.231

direct relationship with these species (**Figure 7**). Therefore, it could be revealed that the species *Echinops leucographus*, *Peganum harmala*, *Nepeta persica*, and *Melica persica* were mostly distributed on the soils with higher amount of moisture, K, $CaSO_4.2H_2O$ and silt.

The plant species *Artemisia scoporia, Astragalus aureus, Astragalus podolobus, Acanthophyllum spp., Acantholimon acmostegium, Acantholimon sp., Cousinia sp., Lactuca orientalis, Hymenocrater microcarpa, Cousinia eryngioides,* and *Cousinia calycinus* were located in the second quarter of ordination chart. Therefore, these have a direct relationship with the variables sand content, slope and pebble fragments. Thus, it was evident that these species were mostly located on the soils with higher amount of sand, stone and pebble fragments and higher degree of slope (**Figure 8**). According to correlation coefficients between variables and principal axes (**Table 9**) in the second component from bottom to top, the magnitude of saturated soil moisture content, Ca, TNV, sand and silt contents decreased while sand content increased. The plant species *Astragalus heratensis, Artemisia diffusa, Cousinia, Bromus tectorum, Bromus danthoniae, Centaurea virgata, Acanthophyllum glandulosum, Acanthophyllum microcephalum, Dorema ammoniacum, Centaurea ibric, Centaurea bruguierana, Cirsium congestum, Eryngium billardieri, Eryngium coucasicum, Ferula sowitsiana, Ferula ovina, Hordeum bulbosum, Hordeum glaucum, Serratula latifolia, Noaea mucronata,* and *Thymus transcaspicu*s were placed in the third quarter of ordination

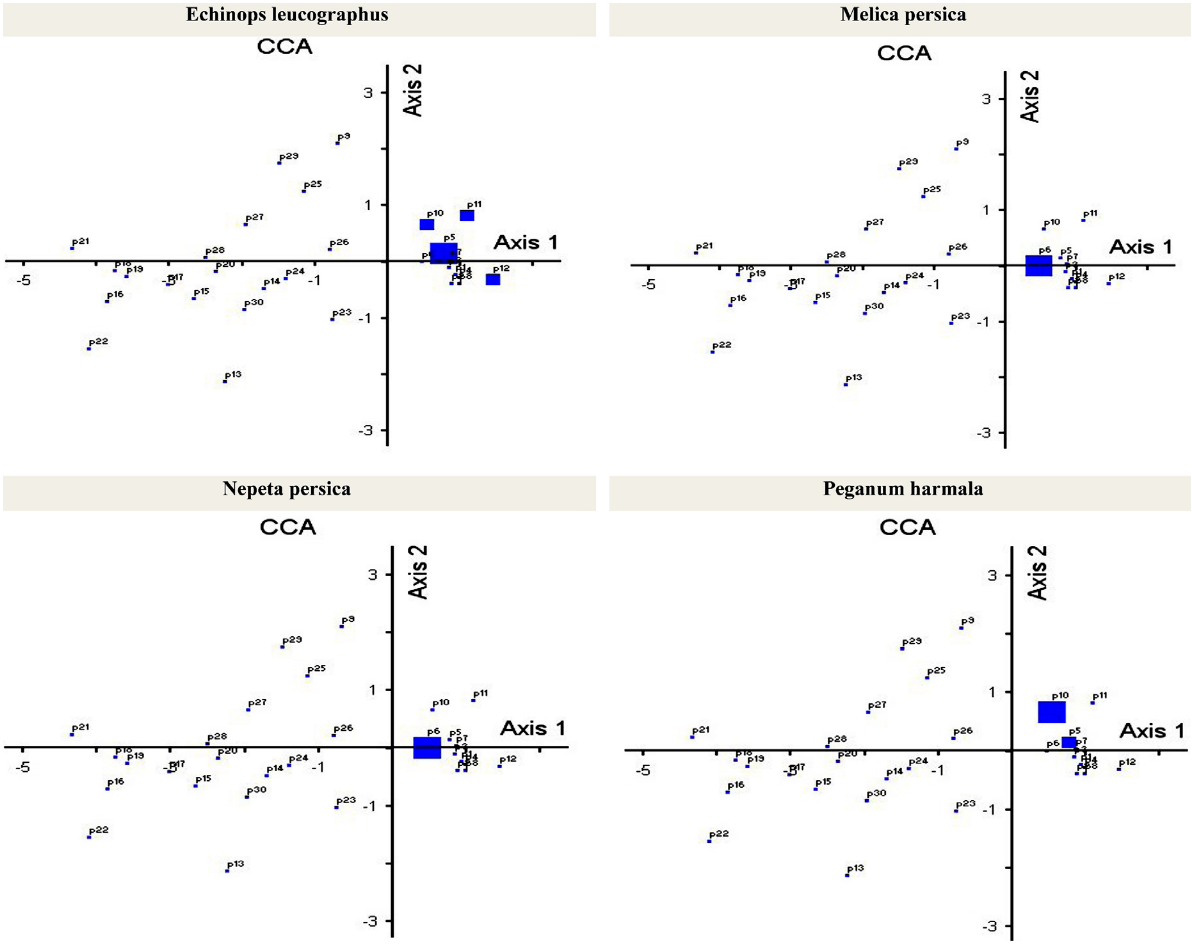

Figure 7. Plant species, scattered on the first quarter of ordination graph.

chart and showed direct relationship with altitude and pebble fragments (**Figure 9**). Eventually, the fourth quarter of ordination chart mostly involved the species *Artemisia aucheri*, *Artemisia sieberi, Amberboa nana, Astragalus brevidens, Gundelia tournefortii, Hymenocrater bituminosus, Launea acanthodes, Nepeta pungens,* and *Scariola orientalis*. These species showed a higher relationship with the variables TNV, silt content and K (**Figure 10**).

DISCUSSION

In the study area, species diversity changed marginally which can be due to the constancy or little alterations of climatic and topographic factors. In Furg watershed, rainfall depth alteration (as the most important driver of climatic alterations) is in a range of 235-260 mm, which confirms a constancy in climatic condition. However, soil factors had the most impact on the diversity of plant species in different vegetation types. *Fahimipour et al.* (*2010*) expressed that if soil properties of a geographic region which has same climatic and topographic characteristics get known well, important factors affecting species diversity would easily be recognized.

The most important factors that had a greater impact on species diversity were pH, EC, Ca, Na, Mg, TNV, sand and silt contents which according to the PCA results could justify about 45 % of changes in species diversity. In vegetation type III, according to ordination chart from left to right, the amount of sand content increased while pH, slope, TNV and silt content decreased. Thus, it could be revealed that the vegetation type III had a direct relationship with EC, Ca, Mg, Na, $CaSO_4.2H_2O$ and sand content and an indirect relationship with pH, slop, TNV and silt content. In type III, given that the most of plant species were halophyte (from families of *Asteraceae, Chenopodiaceae, Caryophyllaceae*), they had a distribution near the first axis of ordination chart. This vegetation type tended to inhabit on soils with a coarser texture. The most important species of the vegetation type III is *Artemisia aucheri* which grows in climatic conditions of cold and semi-humid steppe. *Zare Chahooki et al.* (*2008*) also confirmed that *Artemisia aucheri* scatters on inclined slopes with a coarse texture of soil and higher amount of EC. As established by researchers (*Zare Chahooki et al. 2008*), soil texture is among the factors which significantly affects the species diversity, especially in arid regions. Changes in soil texture result in some alterations in soil available moisture content to plant

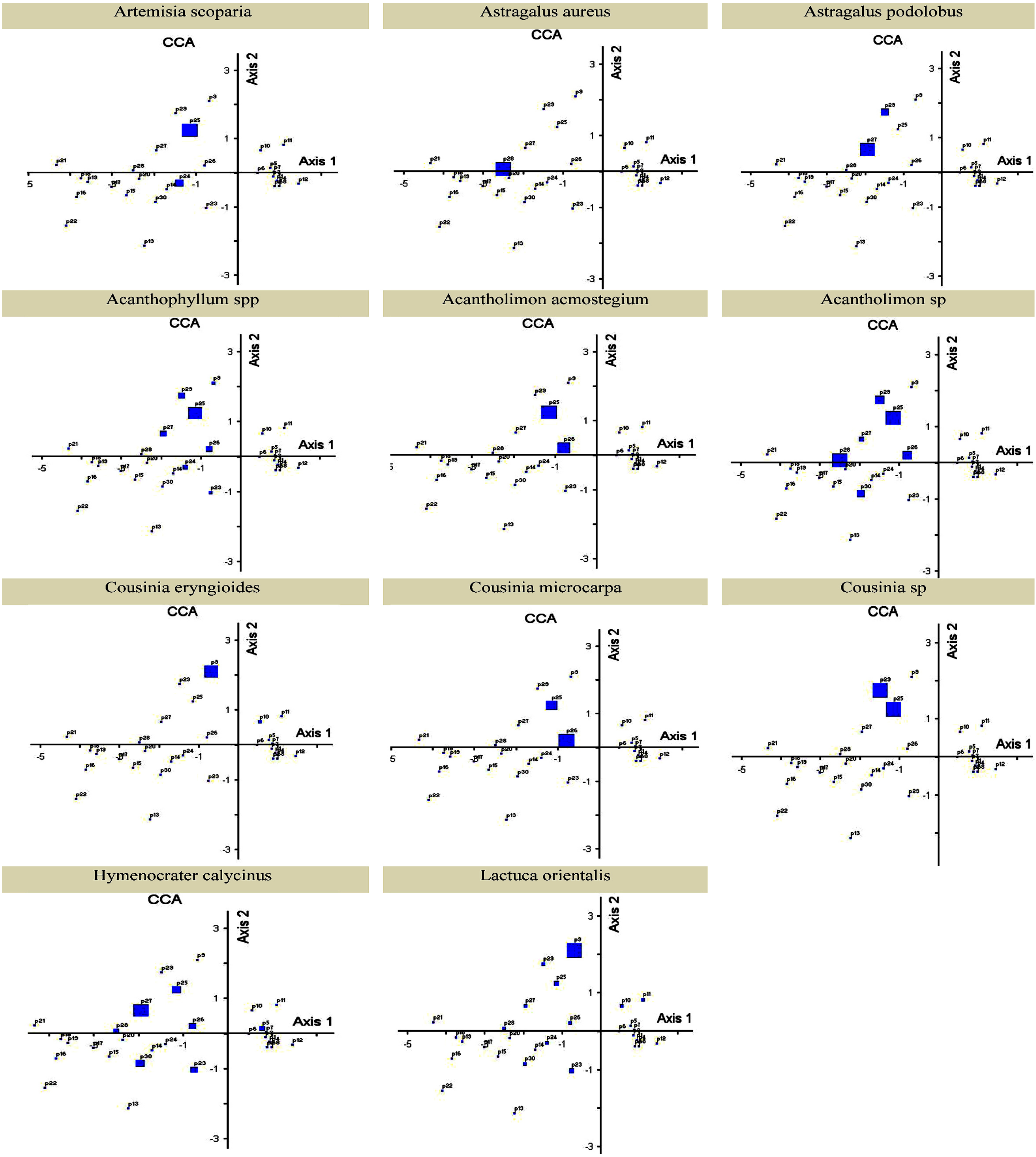

Figure 8. Plant species, scattered on the second quarter of ordination graph.

and consequently affect the distribution of plants and species diversity in different are*as. This fact was also established by Haghian et al. (*2009). According to *Grytnes and Vetaas* (*2002*), maximum diversity can be seen in moderate altitudes and the plant species diversity decreases with increasing in altitude. This statement is in conformity with the findings in this research, as well. In vegetation type I, according to ordination chart from left to right, sand content increased while pH, slope, TNV and silt content decreased. This type showed a moderate relationship with EC, Ca, Mg, Na, $CaSo_4.2H_2O$ and sand content and relatively a weaker relationship with pH, slope gradient,

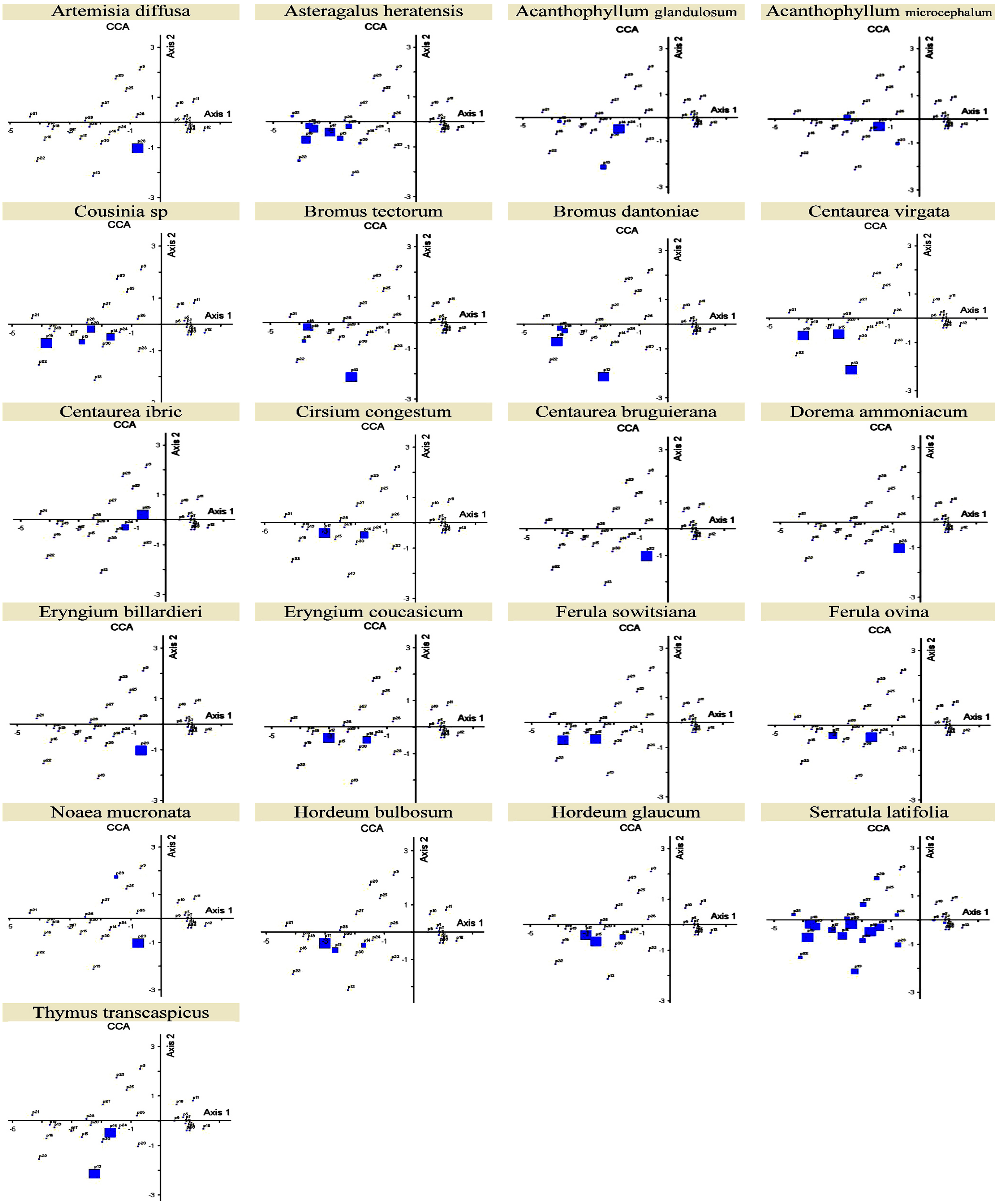

Figure 9. Plant species, scattered on the third quarter of ordination graph.

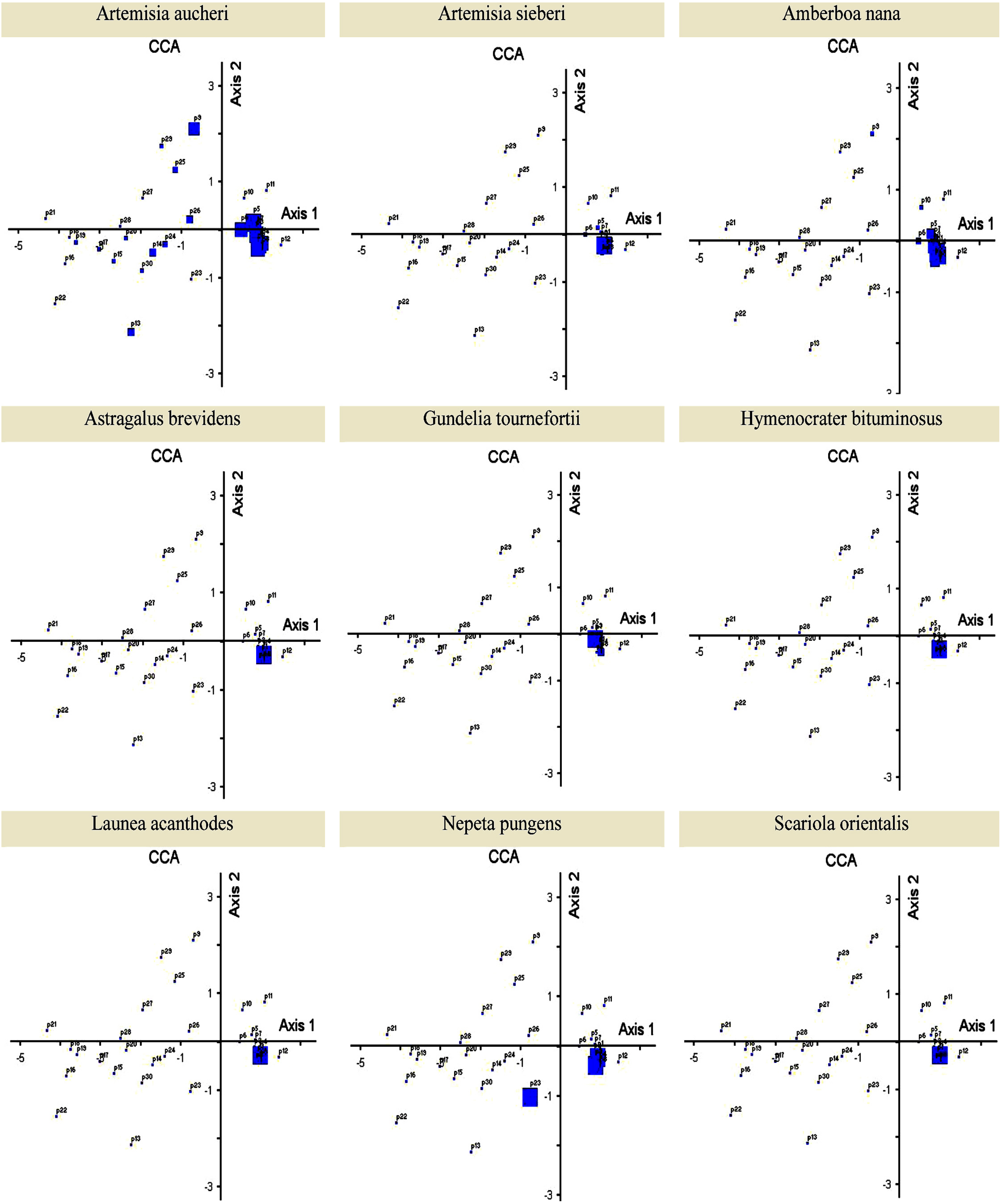

Figure 10. Plant species, scattered on the fourth quarter of ordination graph.

TNV and silt content. Most plots of the vegetation type I scattered around the first principal axis but with a distance of that. In this type, slope gradient was among the factors which had indirect impacts on plant species. The mineral sodium (Na) was another factor which limited the species diversity in vegetation type I. *Mirdavoodi and Zahedipour* (*2005*) expressed that excessive concentration of solute such as cations of Na, Mg and Ca increases osmotic pressure and creates a physiological dryness for plants. Consequently, water absorption by plant is disrupted and growth stops. In vegetation type II, according to ordination chart from bottom to top, slope gradient, altitude, clay content, stone and pebble fraction decreased, while pH, Ca, K and OM increased. Thus, the vegetation type II had a weak relationship with slope gradient, altitude, clay content, and stone and pebble fractions and relatively a stronger relationship with pH, Ca, K and OM. In Furg watershed, the vegetation type II had a moderate diversity which would be due to the influence of pH, Ca and K minerals and OM. Organic matter improves soil structure, increases storage capacity and changes soil acidity. These findings were supported by *He et al.* (*2007*), as well. After the minerals N and P in terms of importance, K has a vital role in the regulation of photosynthesis, transmission of carbohydrates and protein synthesis. *Zare Chahuki et al.* (*2008*) also introduced potassium mineral as one of the key factors affecting species diversity of rangelands in Yazd state, Iran.

Considering the fact that the most regions of the vegetation types II and III were extended on the slopes with southern direction, it could be claimed that the aspect was another reason for the increase of plant diversity in these vegetation types. *Teymouri et al.* (*2011*), in an examination of aspect impact on species diversity, found that the southern directions included the highest diversity and flat areas involved the highest uniformity.

TNV has a low solubility in water but creates a strong alkali if it is turned to a solution and creates some limits for the plants which need acidic soil to growth. Thus, TNV is an inhibitor factor for plants growth except for the plants that were adapted to higher contents of TNV. It reduces the availability of micronutrients such as Zn and Mg for plant (*Alizadeh et al. 2012*). Evidently, a few of the plant species in this area, such as *Artemisia aucheri, Amberboa nana, Serratula latifolia, Scariolia orientalis, Nepeta pungens, Lactuca orientalis, Hordeum bulbosum, Bromus tectorum, Launea acanthodes,* and *Hymenocrater bituminosus* have become compatible with higher levels of TNV in soil as seen and confirmed in the work of *Hante and Zare Chahuki* (*2011*).

CONCLUSION

Arid and semi-arid vegetation communities are strongly influenced by various environmental factors. However, all environmental factors are not of the same importance in the diversity of plant communities. In the studied area, soil properties had the most effect and topographical factors had much less impact on the diversity of plant species. Thus, it could be established that the formation and the change in species diversity were mainly caused by the variety of soil factors. By the examination of environmental factors contributing to the change in species diversity, suitable measures can be taken in efficient management and sustainable development of natural fields and also reclamation of similar degraded rangelands. According to the results of this research, it must be considered that for rangeland reclamation in vegetation type III, the managers should select the plant species which are compatible with higher quantities of EC, Ca, Na, Gypsum and sand content. However, rangeland reclamation in vegetation type I needs the selection of plant species which are compatible with higher sand content and lower soil pH, moisture content, TNV and silt content, as compared with those in the vegetation type II.

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Providing a GIS-based Combined Model Applied to Evaluate Urban Environment Carrying Capacity in Shemiran City, Iran

ABSTRACT

Urban ecosystems evolve over time and space, as the outcome of dynamic interactions between Socio-economic and biophysical processes operating over multiple scales. If the urban population and human activities expand infinitely and exceed the "limit of urban capacity", local urbanites would no longer perceive prosperity, but be troubled by the overall deteriorations in Socio-economic and ecological aspects. On this basis, the present study aims to suggest a GIS-based model, combined of TOPSIS along with Fuzzy modeling, in GIS environ as a Spatial Decision Support System (SDSS), to evaluate Urban Environment Carrying Capacity. Suggested model was planned on basis of desirable and the maximum accepted limits of chosen indicators, used to determine Hot spots widths. The study area was Shemiran City (according to data collected at 2013) with 43%, 44% and 10% had Degree 2 (low pressure), Degree 3 (median pressure) and Degree 4 (Maximum pressure) of carrying capacity, respectively; also only 3% was at critical state. None of the studied districts has desirable degree of Carrying capacity.

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Key words: *Urban Environment Carrying Capacity (UECC); GIS- based Model; TOPSIS; GISFM; Evaluation; Shemiran City*

INTRODUCTION

Urban ecosystems evolve over time and space as the outcome of dynamic interactions between Socio-economic and biophysical processes operating over multiple scales (*Alberti 1999*). Cities are complex ecological systems dominated by humans. The human elements make them different from natural ecosystems in many ways. From an ecological perspective, urban ecosystems differ from natural ones in several respects; including their climate, soil, hydrology, species composition, population dynamics and flows of energy and matter (*Alberti 2008*).

With rapid urbanization across the world, many megacities have become showcases for a host of concomitant diverse urban problems. The "urban diseases" frequently besetting these cities include traffic congestion, housing shortage, lack of amenity, environmental pollution, and others, which has posed actual challenges and impediments for sustainable development (*Wei et al. 2015*). If the urban population and human activities expand infinitely and exceed the "limit of urban capacity", local urbanites would no longer perceive prosperity, but be troubled by the overall deteriorations in Socio-economic and ecological aspects. The immediate cause for these problems is the overdevelopment or over-concentration of population and Socio-economic activities in urban areas, which has greatly exceeded the inherent UCC (Urban Carrying Capacity) of cities (*Oh et al. 2002; Shi et al. 2013*).

In terms of urban planning, carrying capacity is the determined ability of the natural and artificial environment to support the demands of various uses (*Godschalk and Parker 1975*). In addition, carrying capacity is defined as the ability of natural and man-made systems to absorb population growth or physical development without serious decline or damage (*Schneider et al. 1978*). As a social science concept, carrying capacity is defined as the economic scale that the natural system of an area can sustain (*Lee 1999*). Furthermore, the urban carrying capacity can be defined as the level of human activities, population growth, patterns and extent of land use, physical development and etc., which can be sustained by the urban environment without causing serious degradation and irreversible damage (*Oh et al. 2005*).

These concepts is based on the assumption (*Kozlowski 1990*) that there are certain environmental thresholds that when exceeded can cause serious and irreversible damage to the natural environment. These approaches concerning carrying capacity can be useful when the thresholds are identified ahead of time. The determination of the capacity of urban space is straightforward when managing such human activities as population, traffic and land-use (*Lee et al. 2009*).

Environmental Carrying Capacity (ECC) is crucial to the speed and scale of a regional economic and Socio development and the continuous improvement of the ECC is a must for the sustainable development (*Zhang and Xu 2010*).

A review of several urban carrying capacity studies conducted in this field suggests that urban pressure indicators for studying urban sustainability consist of 8 main items including: air, energy, green areas, noise, transport, waste, water and territorial/demographic data (*European Commission-Eurostat 2001*). From 1996, ISTAT has collected the data related to 22 major Italian cities through environmental survey on major cities. The selected analytic framework is the well-known driving-pressures-state-impact-responses model, which is widely used for environmental indicators. In some cases, due to the lack of statistical data, indicators have been selected on the basis of availability and comparability criteria. Some of the main indicators were population density, possession of land, green space and transportation area, access to green space, emission of CO_2, NO_x, VOC, PM_{10}, Pb, water consumption per capita, sewage COD/BOD, soil contaminant, municipal waste per capita and energy consumption (*Tehrani and Makhdoum 2013*). *Godschalk and Axler* (*1977*) suggested soil, slope, vegetation, wetlands, scenic resources, natural hazards, air and water quality, and energy availability as factors affecting environmental carrying capacity. *Onishi* (*1994*) employed factors such as water supply, sewage, waste treatment, railway, road, and housing. *Liu* (*2012*) developed an UCC evaluation model whit 12 measurable indicators that focus on the physical factors, such as land, water, transportation and environment. *Tehrani and Makhdoum* (*2013*) employed factors such as natural state, population, resources consumption, waste/emission production and urban facilities. *Wei et al.* (*2015*) suggested key indicators that determine the UCC of an urban area are grouped into five main UCC components, i.e., environmental impacts and natural resources, infrastructure and urban services, public perception, institution setting and society supporting capacity.

Despite plenty of discussions and explanations, UCC still lacks a widely accepted definition and standardized assessment method (*Shi et al. 2013; Wei et al. 2015*).

Some of methods that directly or indirectly used to estimate the urban environment carrying capacity include: IPAT equation (*Chertow 2001*), energy analysis model (*Zhao et al. 2005*), ecological footprint model (*Du et al. 2006*), uni constraint model, graphical model, Pressure-State-Response model (*Guwahati 2012*) and spatial-Temporal models (*Tehrani and Makhdoum 2013*; *Wang et al. 2014*).

The present study addressed 28 indicators emphasizing on principal aspects of urban environment (ecological-economic-Socio) in 10 key subjects, including climate quality, underground water, earth shape, natural disasters, population; urban land use planning; consumption of matter and energy; production of wastes and traffic), in order to evaluate Urban Environment Carrying Capacity using a GIS-Based combined model.

Study Area

Shemiran City, located at the center of Shemiranat County, the most northern point of Tehran Province-Iran. Stretched in 51° 23´ to 51° 32´ eastern longitude and 35° 46 ´to 35° 50´ northern latitude, the study area is located at Alborz slope of the south (**Figure 1**). Composed of 10 districts, totally 46 km^2, Shemiran City includes approximately 461,714 people (According to last statistics of 2013). Because of high divers natural, economic and Socio attractions, in two recent decades, population increased and as a result, constructions especially in mountain area, as well as the heights upper than 1,800 m, beside river valleys and faults, which consequently resulted in instability and irreversible damages.

MATERIALS AND METHODS

This study applied a GIS-based model, combined of TOPSIS along with Fuzzy modeling, in GIS environ as a Spatial Decision Support System (SDSS), to evaluate Urban Environment Carrying Capacity. Combination of GIS with mentioned technique results in a useful tools in Spatial Planning (*Jankowski, 1995; Malczewiski, 1999*).

Suggested model was planned on basis of the desirable and maximum accepted limits of the selected indicators. However, due to difference of selected indicators, as well as their changes throughout the studied extent, evaluation of socio-economic and ecological Urban Environment Carrying Capacity is carried out separately, and results are compiled finally (**Figure 2**).