

Application of Watershed Dimensionless Half Profiles for Climate Recognition

¹Marzieh Foroutan and ^{1,2}Mazda Kompanizare

¹Department of Desert Regions Management, School of Agriculture, Shiraz University, Shiraz, Iran

²Department of Geography and Environmental Management, University of Waterloo, Waterloo, Canada

Abstract: DEM analysis and profile extraction being used for finding many changes and phenomena in different regions, in this study dimensionless transverse half profile in two areas with different climates, in Fars province, Iran, were analyzed and compared. DEM data from 10 m intervals for 268 profiles selected from Jooyom and Doroodzan watersheds with respective warm arid and cold semi-arid climates. Profiles were selected from along main channels in each watershed with an average distance of 100 m. Dimensionless half profiles were clustered by the Discriminate method. Results demonstrated that the dimensionless half profiles in a warm and arid climate had more fluctuations and deviations of elevations from their means along profiles compared with those in warm climate and it could be a good way for comparing regions and climate recognition. It also shows that not just even too far weather conditions can be reflected in profiles but even two different regions in a same mountain chain but different weathers can clearly create different forms of watersheds.

Keywords: Climate regime, DEM analysis, dimensionless profiles, Iran, watershed topography, zagros mountains

INTRODUCTION

The transverse profile of a valley or a watershed can be defined as distance-elevation along a line orthogonal to the direction of the main stream. Different directions various sizes of profiles, can be regarded as evidence demonstrating the history of geomorphologic processes history, climate regimes, lithology and surface processes in a region. Longitudinal profile shapes have been used to study the evolutionary stage of a watershed, channel sediment and bedrock characteristics, tectonics, climate and sea-level changes (Yatsu, 1955; Seidl and Dietrich, 1992; Snyder *et al.*, 2003; Goldrick and Bishop, 2007). Transverse profiles have been studied to detect dominant processes of erosion (Svensson, 1959; Laity and Malin, 1985; Baker, 1990; Schumm *et al.*, 1995). In some studies a series of transverse and longitudinal profiles, designed in a watershed, have served to illustrate the detailed structure of valley formation within a watershed (Lin and Oguchi, 2006). Analyzing both transverse and longitudinal profiles demonstrates the geomorphological complexity of a watershed and shows that this does not always decrease with increasing relief because differences in bedrock erodibility also affect watershed topography (Lin and Oguchi, 2009).

Traditional field-based sampling of profiles can be a time-consuming, costly and challenging endeavor when large areas need to be investigated, or where terrain is remote and difficult to access and where the topography and landforms are highly variable over

short distances. Topographic maps are not necessarily very precise and it can be hard to interpolate data from them. Using Digital Elevation Model (DEM) and GIS software land surface profiles can easily be extracted and analyzed (Zaprowski *et al.*, 2001; Wohl and Achyuthan, 2002; Hayakawa and Oguchi, 2006; Lin and Oguchi, 2006).

The effect of climate on processes affecting land surface and watershed geomorphology were studied by White and Blum (1995) and Wolman and Gerson (1978) From analysis of field data, it was reported that the weathering of Si and silicate-derived Na are primarily controlled by climatic factors and the effectiveness of climatic events on both hill slopes and rivers is not separable from gradient, lithology or other variables that control both thresholds of activity and recovery rates.

In this study comparisons were made between dimensionless half transverse profiles of watersheds in two mountainous areas, Jooyom and Doroodzan. These areas constituted the same geological structures and formations but had different climate regimes (Fig. 1). The half profiles were classified then distributions of each class in watersheds of different areas and upstream and downstream parts were investigated.

MATERIALS AND METHODS

Study area: In this study, watersheds in two areas of Fars province of Iran were selected. The selected watersheds were on the Folded Zagros Zone, in the

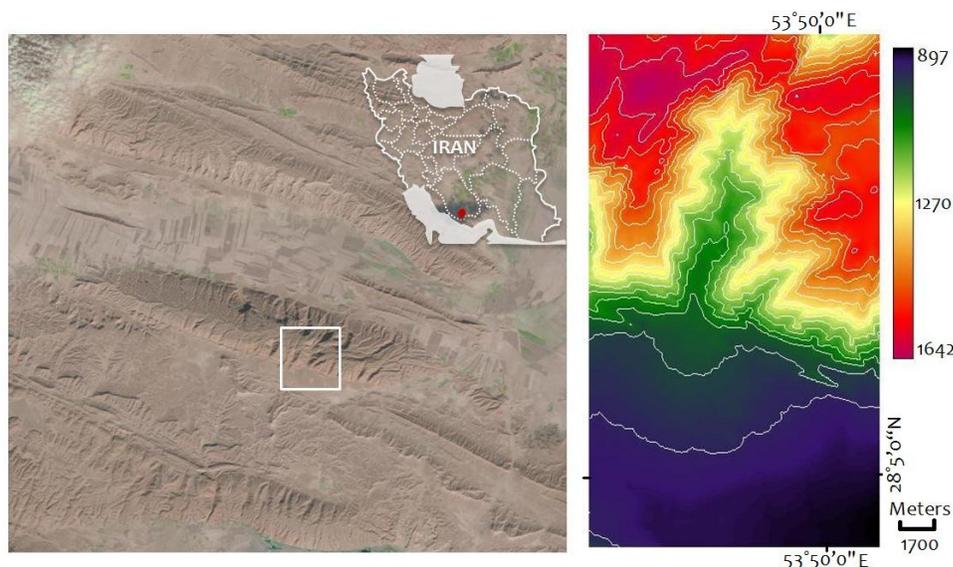


Fig. 1: Google earth image and DEM of the JM with 10 m intervals

southwest of Iran. These areas were Jooyom (JM), with a warm arid climate and Doroodzan (DN), with a cold semi-arid climate.

In JM the area located between 776315 and 778925 longitude and 3108755 and 3113055 latitude, in Zone 39. The area consisted of a large main watershed divided in to 10 sub-watersheds (Fig. 1). In this area profile areas of elevations were in the range of 897 to 1642 m and the surface slopes were between 0 and 79°. Figure 1 shows the digital elevation model and Google Earth image, as can be seen in these figures the JM watershed is a drop-shaped style basin, typical of that in a high mountainous area, developed from Asmari limestone formation. There is no permanent river in this area. The average wind speed in this area is about 10 m/s and the annual precipitation is about 182-256 mm with about 28 rainy days per year. Maximum and minimum annual temperatures are about 48° and -4.5°, respectively. In the JM area the average annual temperature is 22°C and relative humidity is in a range of 42-49% (Fig. 2).

DN, the second selected area, drains from the Kor River in the south west of Iran and is located in a cold semi-arid mountainous region. Ten watersheds were selected in this area. Elevation of the selected watersheds in the DN area is in the range of 902 to 1650 m and the slope is between 0 and 75°. Watersheds in this area were located between 615630 to 623940 longitudes and 3356460 to 3369640 latitude, in Zone 39. There were several permanent rivers downstream of the watersheds in DN. The average wind speed in this area is about 11 m/s and annual precipitation is about 427-550 mm with approximately 48 rainy days/year.

Maximum annual temperature is about 23° and the minimum -9.5°. The average temperature and the humidity percentages of the DN area are 14.5 and 42-44%, respectively (Fig. 2). As can be seen in Fig. 1 and 2 DN and JM areas were located in different climate conditions but in the same type of geological zone with same deformation rate. The DN area's Google Earth image and its DEM are illustrated in Fig. 2. These figures illustrate that watersheds in the DN region were in a mountainous area and in an area of Asmari limestone formation.

The selected watersheds in both areas are located in the central part of the Folded Zagros Belt with the same deformation rate and geology properties in Fars province (Fig. 3). The FZB consists of alternating anticlines and synclines with northwest-southeast trends that cover the entire region and create ranges and basins (Fig. 3). These outstanding anticlines are created by formation fractures such as Asmari Limestone Formation with Oligo-miocene age and Sarvak limestone formation with Mesozoic Ages. The alternation of feature forming limestone formations, such as Sarvak and Asmari Formations and fine grained marly and evaporate formations, such as Pabdeh-Gurpi and Gachsaran formations lead to perfect exposure of feature forming formations such as anticlines in southwestern Iran. The watersheds selected for this study were developed on the southwestern flanks of anticlines, with a northwest-southeast axis trend, formed in Asmari limestone (Fig. 3). In DN and JM areas the Pabdeh-Gurpi Marly formation at the core of anticlines are less exposed and the whole watersheds are in an area of Asmari limestone and watersheds in both areas have an alluvial fan on their outlets.

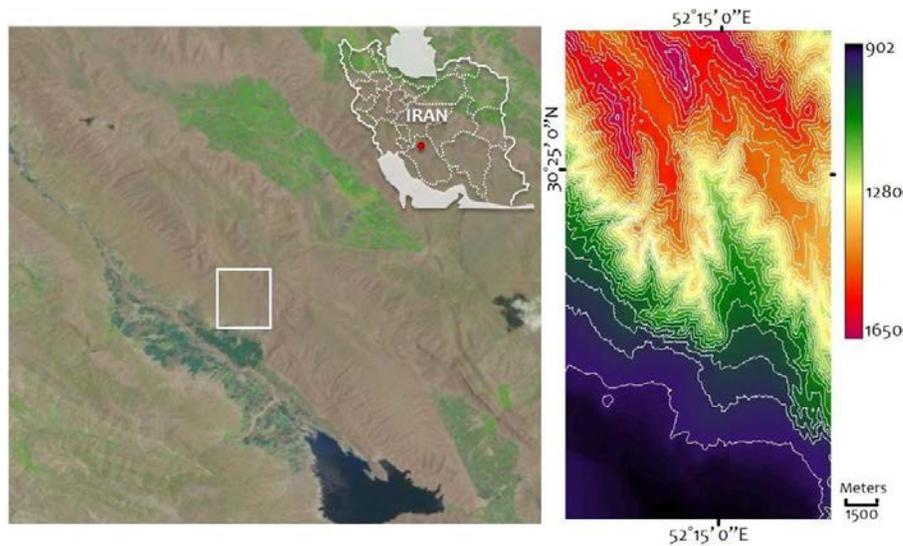


Fig. 2: Google earth image and DEM of the DN with 10 m intervals

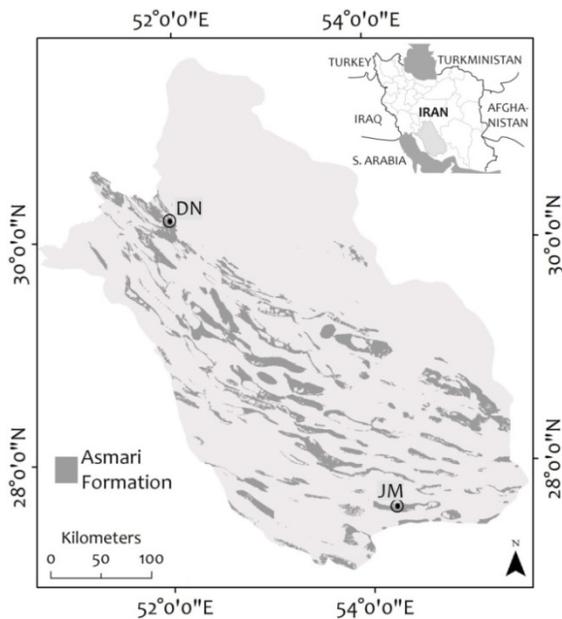


Fig. 3: Asmari formation in Fars province along Zagros mountain chain and location of two study areas on this limestone formation

Methods: In this study for all twenty selected watersheds in JM and DN areas, transversal profiles were selected in directions perpendicular to main drainage paths and with intervals of about 100 m (Fig. 4). Elevations along selected profiles were then determined. Profiles covered the entire widths of their corresponding main drainage valleys. Elevations along profiles were extracted from DEM data with 10 m intervals. Then average slopes between each successive

elevation point were determined and assigned to a midpoint between the two points. To make better comparisons, elevations along profiles were determined for a certain number of points with constant intervals. For new elevation points dimensionless elevations and dimensionless distances were determined from a profile crest. These dimensionless elevations and distances were calculated and plotted for half of each profile. A half profile is a transverse profile from a valley crest to a drainage path in the longer valley side of a drainage area. Both analysis were done using MINITAB 15. A flowchart of steps taken in the study is shown in Fig. 5.

Watershed profiles extraction: In each sub-watershed the mainstream path was delineated on the DEM mesh with 10 m interval. On the DEM mesh the path of the main stream was shown by a vector connecting the centers of DEM cells through which the main stream was passing, Fig. 4 schematically illustrates the main channel of one watershed as an example and transverse profile perpendicular to the channel with 100 m intervals that extracted by GIS software.

An elevation of each cell's center through which the profile line passed was extracted by selecting a profile on a DEM. Elevations of twenty points with equal intervals along each half profile was determined using MATLAB software that interpolated the extracted elevation points.

Dimensionless elevation versus dimensionless distance for the half profiles: To better classify shapes of half profiles in watersheds, dimensionless profiles, or the dimensionless elevation versus dimensionless

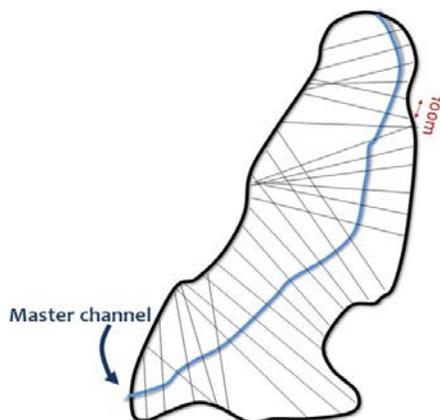


Fig. 4: Schematic image of an example watershed boundary and its transverse profiles with 100 m that have been extracted by GIS software

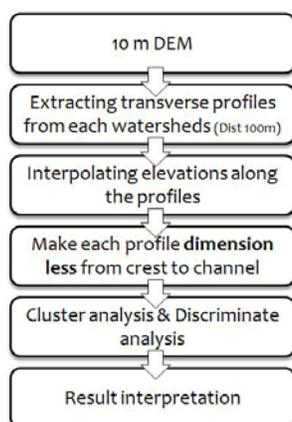


Fig. 5: Study steps flow chart

distance for the half profiles were calculated and drawn. A dimensionless distance is the ratio between the horizontal distance between a given point and the channel to the horizontal distance between the channel and the crest in a half profile. And the dimensionless elevation is the ratio between the elevation difference between the given point and the channel to the elevation difference between the crest and channel in a given half profile. The dimensionless elevations and distances were determined for each of the twenty points with equal intervals along each half profile.

Cluster and discriminate analysis: The dimensionless half profiles were clustered according to the dimensionless elevation in twenty points. The cluster analysis was done using the Ward method and linkage criteria. In the Ward method the sum of squared deviations from points to centroids were minimized within-cluster sum of squares.

Table 1: Results of discriminate analysis on dimensionless half profiles in DN (group 1) and JM (group 2) areas

Group	1	2
	212	56
Summary of classification		
	True group	

Put into group	1	2
1	182	23
2	30	33
Total N	212	56
N correct	182	33
Proportion	0.858	0.589

N: 268; N correct: 215; Proportion correct: 0.802

Ward's linkage uses the incremental sum of squares; that is, the increase in the total within-cluster sum of squares as a result of joining two clusters. The within-cluster sum of squares is defined as the sum of squares of distances between all objects in the cluster and the centroid of the cluster. The equivalent distance was determined as follows:

$$d^2(r, s) = n_r n_s \frac{|\bar{x}_r - \bar{x}_s|^2}{(n_r + n_s)} \quad (1)$$

where,

$||^2$: Euclidean distance

\bar{x}_r & \bar{x}_s : The centroids of clusters r and s , as defined in the centroid linkage

Discriminate analysis uses training data to estimate the parameters of discriminate functions of predictor variables. Discriminate functions determine boundaries of predictor spaces between various classes. In this study discriminate analysis was used to classify observations in to two or more groups; if there was a sample with known groups.

RESULTS AND DISCUSSION

The dimensionless half transverse profiles were analyzed by discriminate and cluster analysis as discussed below.

Discriminate analysis of the dimensionless half profiles: Discriminate analysis was conducted on the dimensionless elevations versus dimensionless distances for the half transverse profiles in both JM and DN areas. Results of analyses are presented in Table 1. Results show that the half profiles of JM and DN areas are identifiable by a correctness proportion of about 80%. This means that 80% of the measured half profiles can be correctly classified according to two classes, those of JM and DN areas based on their dimensionless elevations at 20 points with equal intervals along their lengths.

Table 2: Number of profiles in each class and within and between class distances

	Number of observations	Within cluster S.S.	Avg. distance from centroid	Max. distance from centroid
Cluster 1	81	4.7552	0.2327	0.4451
Cluster 2	64	9.4773	9.4773	0.8032
Cluster 3	62	9.1653	9.1653	0.8705
Cluster 4	27	9.3165	9.3165	0.9833
Cluster 5	27	1.0531	1.0531	0.3097
Cluster 6	7	1.4360	1.4360	0.7632

Max.: Maximum; Avg.: Average; S.S.: Sum of square

Table 3: Distances between the cluster centroids

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Cluster 1	0					
Cluster 2	0.4342	0				
Cluster 3	0.3675	0.7708	0			
Cluster 4	0.4499	0.6166	0.6452	0		
Cluster 5	0.2859	0.4047	0.4938	0.7093	0	
Cluster 6	1.2516	1.6684	0.9573	1.2439	1.437	0

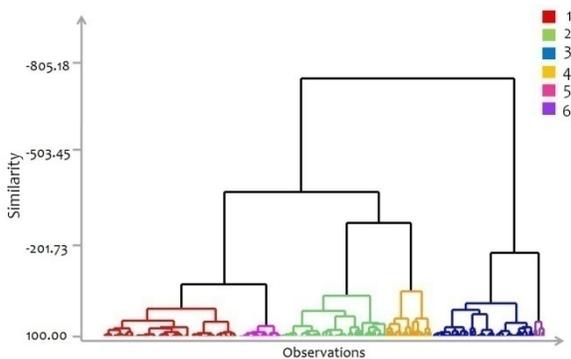


Fig. 4: Dendrogram of the cluster analysis conducted on the dimensionless half-profiles of DN and JM areas

Cluster analysis of the dimensionless half profiles:

Dimensionless half profiles were classified according to dimensionless elevations at 20 points along profiles using a cluster analysis with the Wards method and the Euclidian distance. Profiles were classified in to 6 clusters. Results of the analysis are presented in Fig. 6, 7, 8 and Table 2 and 3. The dendrogram of the clusters in Fig. 6 shows clusters of groups 1, 5, 2, 4, 3 and 6, respectively, from left to right. The dendrogram shows that the highest similarities are between cluster pairs 1 and 5, 2 and 4 and 3 and 6. Table 2 and 3 show that numbers of profiles in different classes are in the range of 7 to 81. These Tables also show that average and maximum distances from the centroid are almost the same for all clusters. Table 3 illustrates that distances between cluster centroids are also in the same ranges except for cluster number 6 with a larger distance than that of the other clusters.

In Fig. 7 the average dimensionless half profiles according to average elevations at 20 points along their lengths are drawn for all six clusters. To better illustrate the curvatures in Fig. 9, the averages of profiles for each of the six classes are compared with a reference

profile, Ref, with constant slope. Based on the shape of profiles and the dandrogram shown in Fig. 6, the average profile in Fig. 7 can be divided into three groups (Fig. 8). Group 1 presents clusters 2 and 5 that have convex upstream parts. Group 1 probably has rock exposure on its upstream and a debris slope with a constant slope on its downstream part. The difference between clusters 2 and 5 is a smaller scarp in their upstream part and shallower stream erosion at their downstream part in cluster 2.

Group 2 (Fig. 8c), including clusters 4 and 6, are profiles with large scarps and concave slopes on their upstream parts. In cluster 6 there is a steeper slope or higher scarp on the upstream part and a flat slope on the downstream part followed by a small depression near the downstream channel or depression. But in cluster 4 the upstream scarp is gentler with limited extention. Also in the downstream part of cluster 4, the gentle sloped part ends in a deep down-cutting or depression at its down-slope side.

Group 3 (Fig. 8b), with an almost linear upstream part, includes clusters 1 and 3. Cluster 1 is in the form of a constant gradient slope and seems to be a debris slope with a small stream depression at its downstream end. And cluster 3 is in the form of an almost constant gradient debris slope with a small scarp on its upstream and a small projection near its downstream side.

Distribution of half profile classes in watersheds:

Distribution of six half profile clusters within the watersheds was investigated by dividing the watersheds into three parts; upstream, mid-stream and downstream. In each part of a watershed in DN and JM areas the percentages were determined of half profiles belonging to different clusters (Table 4). As can be seen in Table 4, (30, 24 and 23%, respectively) of profiles were from clusters 1, 2 and 3, respectively. And the cumulative frequency percentage of profiles from clusters 4, 5 and 6 was about 23%. In the

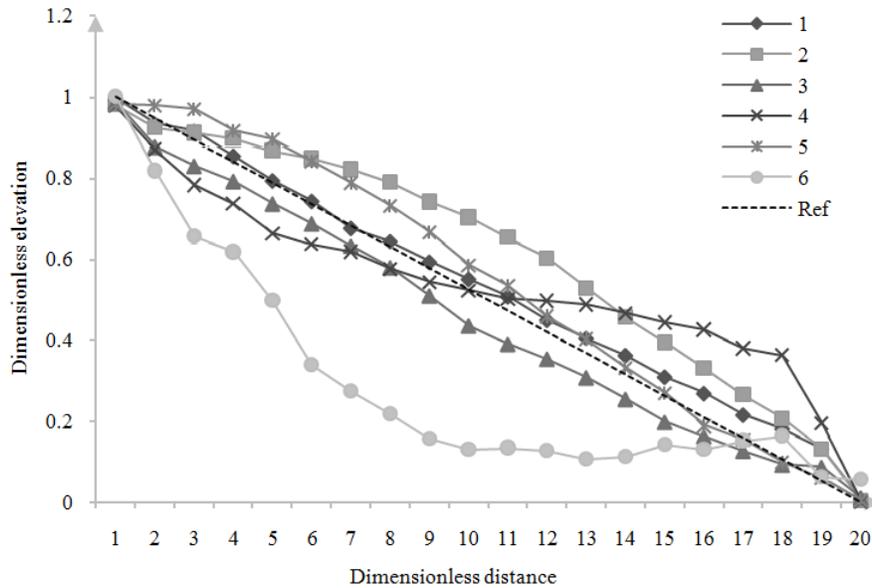


Fig. 5: Average dimensionless half profiles of the six classes determined through cluster analysis

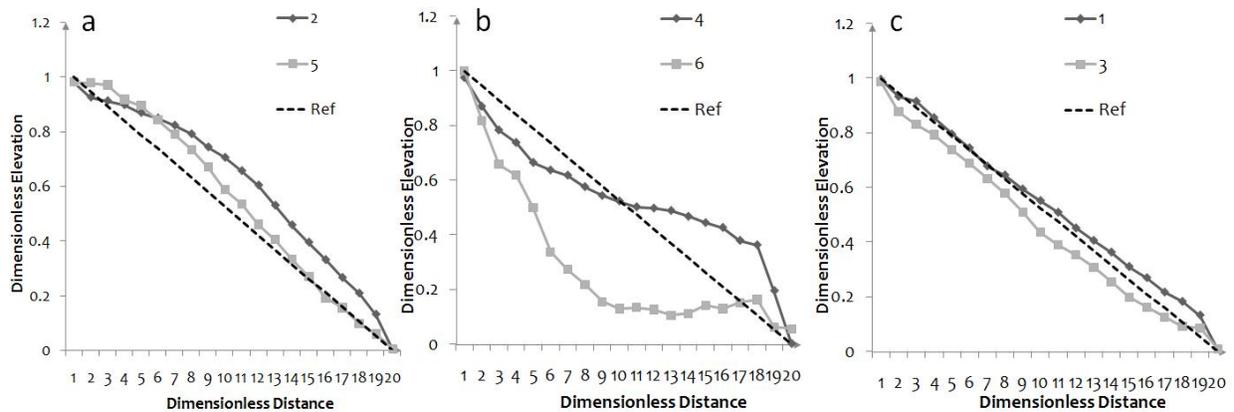


Fig. 6: The three main cluster groups 1 (a), 2 (b) and 3 (c), based on the dendrogram of Fig. 6 and the similarity between profile shapes in each classes

upstream part of almost all watersheds, the relative frequency of cluster 4 was higher and comparable with cluster 3. It means that debris slopes were less frequent and scarp slopes had higher frequency in upstream parts compared with mid and downstream parts. In the mid-stream part of a watershed the relative frequency of profiles from clusters 4 and 6 were less than those of other clusters, showing lower frequency of scarp slopes in mid-stream profiles.

The difference between averages of profile frequencies in DN and JM watersheds is also presented in Table 4. As can be seen in this Table the main difference, more than 10%, is between the average

frequency percentages in DN and JM of +11% and -12% in clusters 1 and 4, respectively. Maybe that is because of more frequent scarp profiles in JM and more dominant debris and constant slope profiles in DN. On the upstream parts the major difference is in cluster 2 with 11% higher relative frequency in the DN area. It shows that profiles with convex rock outcrops and small scarps on their upper part are more frequent in upstream parts of the watersheds in the DN area. In mid-stream profiles, DN area clusters 1 and 5 show 18% higher frequency and in JM area cluster illustrates 29% more frequency compared with DN. It means that in the midstream part of DN watersheds the

Table 4: The frequency percent of profiles from different clusters in up-, mid- and down-stream parts of DN, JM and the whole watersheds

		Up stream						Mid-stream					
Cluster		1	2	3	4	5	6	1	2	3	4	5	6
DN	DN1	35	65	0	0	0	0	41	59	0	0	0	0
	DN2	100	0	0	0	0	0	71	7	21	0	0	0
	DN3	75	25	0	0	0	0	38	50	0	0	12	0
	DN4	0	37	16	16	16	16	26	26	0	0	47	0
	DN5	40	0	50	10	0	0	70	10	20	0	0	0
	DN6	31	23	12	0	35	0	54	12	35	0	0	0
	DN7	5	47	32	16	0	0	42	26	0	0	32	0
	DN8	30	40	10	0	10	10	0	50	0	0	50	0
	DN9	0	16	5	79	0	0	32	0	37	32	0	0
	DN10	0	27	18	41	0	14	9	15	50	0	27	0
JM	DN	29	27	17	16	7	4	37	25	17	3	18	0
	JM1	50	0	0	50	0	0	50	50	0	0	0	0
	JM2	0	0	50	50	0	0	0	0	100	0	0	0
	JM3	50	05	0	0	0	0	50	0	50	0	0	0
	JM4	0	50	50	0	0	0	0	100	0	0	0	0
	JM5	75	0	25	0	0	0	0	0	100	0	0	0
	JM6	14	0	0	43	43	0	72	0	0	28	0	0
	JM7	0	0	0	0	60	40	0	20	0	60	0	20
	JM8	0	60	40	0	0	0	0	60	40	0	0	0
	JM9	0	50	0	50	0	0	0	0	100	0	0	0
Difference	JM10	60	0	40	0	0	0	0	0	100	0	0	0
	JM	23	16	25	21	11	4	20	23	46	9	0	2
Total		6	11	-8	-6	-4	1	18	2	-29	-6	18	-2
		28	25	18	17	8	4	34	25	23	4	14	0
		Down stream						Total					
Cluster		1	2	3	4	5	6	1	2	3	4	5	6
DN	DN1	29	71	0	0	0	0	35	65	0	0	0	0
	DN2	21	14	21	21	21	0	64	7	14	7	7	0
	DN3	0	38	38	0	25	0	38	37	13	0	12	0
	DN4	37	32	16	16	0	0	21	32	11	11	21	5
	DN5	40	0	50	10	0	0	70	10	20	0	0	0
	DN6	19	12	69	0	0	0	35	15	38	0	12	0
	DN7	5	47	32	16	0	0	42	26	0	0	32	0
	DN8	40	10	30	0	20	0	23	33	13	0	27	3
	DN9	16	16	53	16	0	0	16	11	32	42	0	0
	DN10	45	0	14	14	0	27	18	14	27	18	9	14
JM	DN	30	21	30	6	10	3	32	25	21	8	12	2
	JM1	50	0	0	50	0	0	50	17	0	33	0	0
	JM2	100	0	0	0	0	0	33	0	50	17	0	0
	JM3	0	100	0	0	0	0	33	33	33	0	0	0
	JM4	0	0	50	50	0	0	0	50	33	17	0	0
	JM5	0	0	25	75	0	0	25	0	50	25	0	0
	JM6	43	43	0	14	0	0	43	14	0	29	14	0
	JM7	0	40	0	0	0	60	0	20	0	20	20	40
	JM8	0	0	40	60	0	0	0	40	40	20	0	0
	JM9	0	0	50	50	0	0	0	0	100	0	0	0
Difference	JM10	0	60	40	0	0	0	20	20	60	0	0	0
	JM	21	25	20	29	0	5	21	21	30	20	4	4
Total		8	-4	11	-23	10	-3	11	3	-9	-12	8	-1
		28	22	28	10	8	3	30	24	23	10	10	3

smoothed rock outcrops and debris slopes are more frequent but the debris slopes with a small scarp on its upstream end is more frequent in the midstream part of JM watersheds. In downstream parts of the watersheds in the DN area the frequencies of clusters 3 and 5 are 11 and 10% more than those for the JM area and the frequency of cluster 4 in JM is 23% more than that for DN. It means that in the downstream parts of the watersheds in DN the smoothed rock exposure and the

debris slope with the small scarps on its upstream is more frequent and the profiles with upstream scarps and down-cutting in the downstream parts are more prevalent in JM.

The average dimensionless half profiles of DN and JM areas are shown in Fig. 9. In this Figure the average profiles of the two areas show that there is a small difference between the average profiles of the two areas. But small differences, such as a small depression

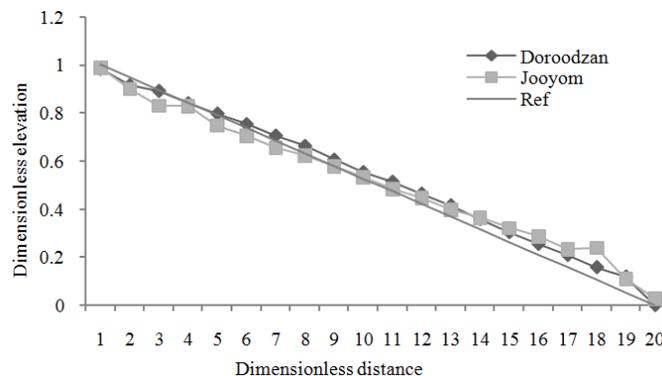


Fig. 7: Average dimensionless profiles of DN and JM.

near the downstream, can be seen in the JM average profile.

CONCLUSION

To determine the effect of climate on the shape of dimensionless transverse half profiles elevations along the 268 transverse profiles perpendicular to the main drainage paths of each 20 selected watersheds in DN and JM areas with wet-moderate and hot-arid climates, respectively, were extracted from the DEM map with a 10 m resolution.

Analysis of the dimensionless half profiles reveals that they can be divided in to two clusters of DN and JM according to profile forms with a correction proportion of about 80%. The dimensionless half profiles can also be divided in to three main classes of debris slope with upstream rock exposure and convex surface, with upstream scarps and concave surfaces and without scarps or rock exposure and with sloped plain surfaces.

Occurrences in clusters 3 and 4 of profiles with small scarps on their upstream parts are more in JM especially in middle and downstream parts of the watersheds, respectively. It means that in JM the relative height of an upstream scarp along a profile increases toward the downstream part of a watershed.

Clusters 1 and 5 with debris slope on their mid and downstream parts are more abundant in DN. The profiles of these classes are more abundant in the middle stream of the watersheds in DN. Maybe this was because in upstream and downstream parts of watersheds the rock exposure and deep incisions caused by drainage serves to prevent evolution of a debris slope in these two regions, respectively. The higher standard deviations of elevations along the average dimensionless profiles show that deviations of elevations from their means are about 2.5 times greater in JM compared with DN.

Previous studies from Lin and Oguchi (2006) show that the formation of transverse profiles is affected by

active erosion processes and creates different valley formations with a characteristic slope angle. Variations in local channels formed in watersheds also play a subordinate role in characterizing transverse profiles. Other research has been done using transverse profiles to describe landscape characters and to identify erosion processes (e.g., Svensson, 1959; Sugden and John, 1976; Hirano and Aniya, 1988).

This study for the first time shows that different climate regimes exert a profound influence on transverse dimensionless half profiles perpendicular to a main channel in a watershed. An evaluation of this influence is recognizable in the DEM map with 10m resolution. Maybe studying transverse profiles in a DEM with 5 m resolution or less would result in better discrimination of profiles in different climates.

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