

Use of morphometric analysis and self-organizing maps for alluvial fan classification: case study on Ostorankooch altitudes, Iran

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Abstract. The aim of this study is to classify alluvial fans formed by high-gradient braided streams and torrents that discharge into the Ostorankook altitudes in the Lorestan province, Iran. The morphology of the fans and their watershed is quantitatively described through estimated morphometric parameters. For relationships between geomorphological features of the fans and their drainage basins, self-organizing maps (SOM) were used. In SOM, according to both qualitative data and morphometric variables, the clustering tendency of alluvial fans was investigated using 15 alluvial fans parameters. The results of the analysis showed that several morphologically different fan types were recognized based on their geomorphological characteristics in the study area. A strong positive relationship was found between the drainage basin area and size of the fan with a simple power function. In addition, the relationship between fan slope and drainage area was found to be negative and moderately strong with a simple power function.

1. Introduction

Alluvial fans are created on steep high power channels where reduced stream power and serve as a transitional environment between a degrading upland area and adjacent lowland [1]. The morphology of a fan resembles a cone segment with concave slopes that typically range from less than 25° at the apex to less than 1° at the toe [2]. The analysis of the main controlling factors on past and present fan processes (debris flows and stream flows) is a major concern in order to distinguish between the two dominant sedimentary processes on alluvial fan formation and evolution [3].

Alluvial fans occur in any climatic environment, such as temperate mountain areas [4], humid temperate [5] and humid tropical environments [6]. Several studies have explored the relationship between the size of fans and their contributing basins to understand the mechanisms of fan construction [7]. Other studies on fan-basin morphometric focus on differentiation between debris flow and fluvial dominated fans [4-8].

Alluvial fan morphometry has been studied since the early 1960s, with a number well-researched relationships developed, such as a drainage basin area to alluvial fan area. Denny [9] and Hooke [10] have described classic alluvial fan form process variables using morphometry. More recent morphometry



research used geography information system (GIS) to explore alluvial fan morphology for determination of fans location and fast and accurate analysis [11,12]. Volker et al. [12] investigated formative surface processes using morphometry to identify formative surface processes generated by alluvial fan flows. Fan morphometry typically evaluates a number of alluvial fan control variables to demonstrate the impact of each of these variables on fans [12]. They used topographic maps, aerial photographs and derived equations, but were seldom paired up with a field analysis of landforms [13].

Self-organizing maps (SOM) have been applied as a clustering and projection algorithm for high dimensional data [14]. Modeling utilizing SOM has recently been applied to a wide variety of geomorphology fields. It was employed to cluster volcanic ash arising from different fragmentation mechanisms [15], assess sediment quality, and define mortality index on different sampling sites [16]. In addition, Ferentinou et al. [17] used SOM to classify marine sediments. Karymbalis et al. [18] also used SOM to investigate the clustering tendency of alluvial fans.

The aim of this study is to perform the classification of alluvial fans, located in the Oshtorankooch altitudes in the Lorestan province, Iran, according to their morphological features, using morphometry and SOM. The investigation will use 15 morphometric variables for each fan as described in Table 1.

Table 1. Morphometric parameters of the fan deltas and their corresponding drainage basins measured for this study [19].

Symbol	Morphometric parameter
A_b	Drainage basin area
P_b	Perimeter of the drainage basin
ΣL_c	Total length of 20 m contour lines within the drainage basin
C_b	Basin crest
R_b	Basin relief
L_c	Total length of the channels within the drainage basin
Ap_f	Fan apex
D_b	Drainage basin density
S_b	Drainage basin slope ($S_b = e \Sigma L_c / A_b$, where e is the equidistance)
Cir_b	Drainage basin circularity ($Cir_b = 4\pi A_b / P_b^2$)
M	Melton's ruggedness number ($M = R_b A_b^{-0.5}$)
L_f	Fan length
A_f	Fan area
S_f	Fan slope
p_f	Fan concavity

2. Material and methods

2.1. Study area

The study area is the Oshtorankooch altitudes in the Lorestan province, Iran. This area is located at 33° 9' to 33° 22' N and 49° 12' to 49° 23' E with an area of 3,260.62 km² (Figure 1). The lowest and highest elevations in this area are 885 and 4,049 m respectively. Rainfall displays high inter-annual and seasonal variability, with the annual long-term precipitation of the study area being 425 mm.

This study is based on quantitative and qualitative data depicting the morphology and morphometry of fans and their catchments derived from fieldwork. In order to determine the role of the fluvial sediment supply for the evolution of the fan deltas, the correlation between geomorphological features of the drainage basins and features of their fan deltas was estimated.

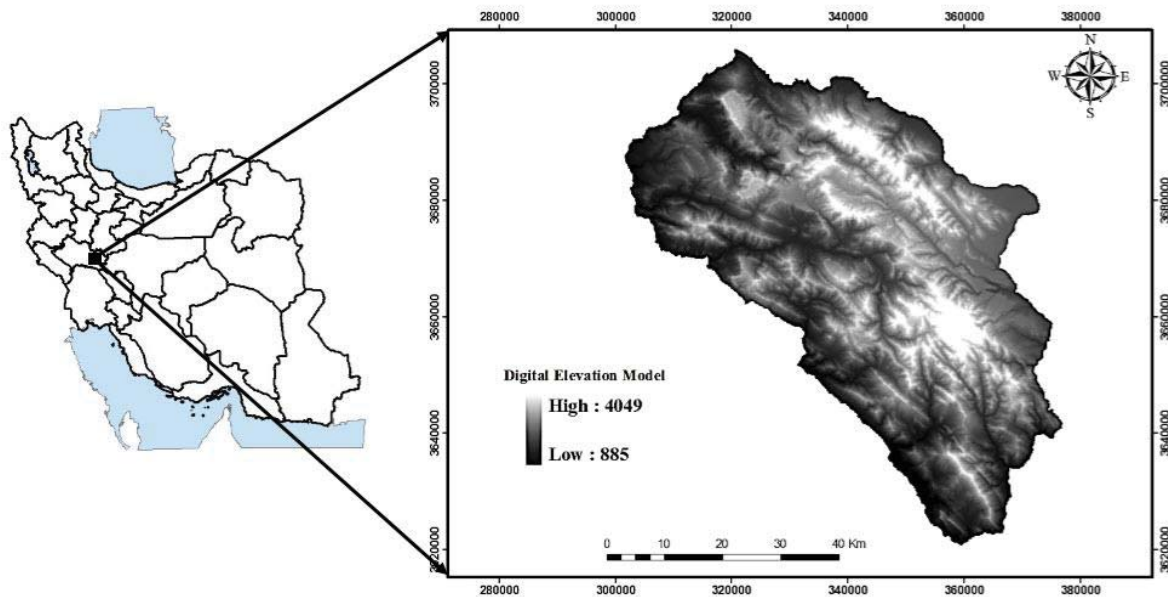


Figure 1.Location of the study area.

Drainage networks were delineated from aerial photograph interpretation and topographic maps with a scale of 1:50,000. The same maps, with 20 m contour lines, were used for the measurement of the morphometric parameters of the drainage basins.

In the study area, there are several sub-basins, with each having an alluvial fan (Figure 2). Their respective measured morphometric parameters are shown in Table 2. Maximum, minimum and mean elevations were calculated for each drainage basin using zonal statistics with the mapped basins and filled DEM as inputs.

Table 2. Morphometric parameters measured for the alluvial fans.

Fan	$A_b(\text{km}^2)$	$P_b(\text{km})$	$\sum L_c(\text{km})$	C_b	R_b	$L_c(\text{km})$	A_{pr}	D_b	S_b	Cir_b	M	L_f	$A_f(\text{km}^2)$	P_f	S_f
1	23.66	21.03	530.07	3006	1159	22.15	2006	0.94	0.45	0.67	0.24	1.47	0.44	2.95	0.32
2	43.61	27.09	1140.38	3509	1750	34.46	2509	0.79	0.52	0.75	0.26	1.51	0.42	3.03	0.23
3	32.90	23.46	601.72	2644	947	32.38	1644	0.98	0.37	0.75	0.17	0.81	0.16	1.62	0.25
4	6.09	10.64	113.97	2086	666	5.58	1086	0.92	0.37	0.68	0.27	1.44	0.40	2.88	0.46
5	20.26	19.50	389.26	2774	1310	18.37	1774	0.91	0.38	0.67	0.29	1.14	0.25	2.28	0.36
6	9.26	13.53	135.61	2362	718	12.05	1362	1.30	0.29	0.64	0.24	0.92	0.17	1.85	0.43
7	13.52	14.38	255.82	2893	1255	14.37	1893	1.06	0.38	0.82	0.34	0.93	0.19	1.86	0.41
8	18.74	18.90	374.16	2844	1522	19.42	1844	1.04	0.40	0.66	0.35	1.55	0.44	3.10	0.39
9	25.54	20.03	593.39	3200	1843	20.21	2200	0.79	0.46	0.80	0.36	1.51	0.46	3.02	0.27

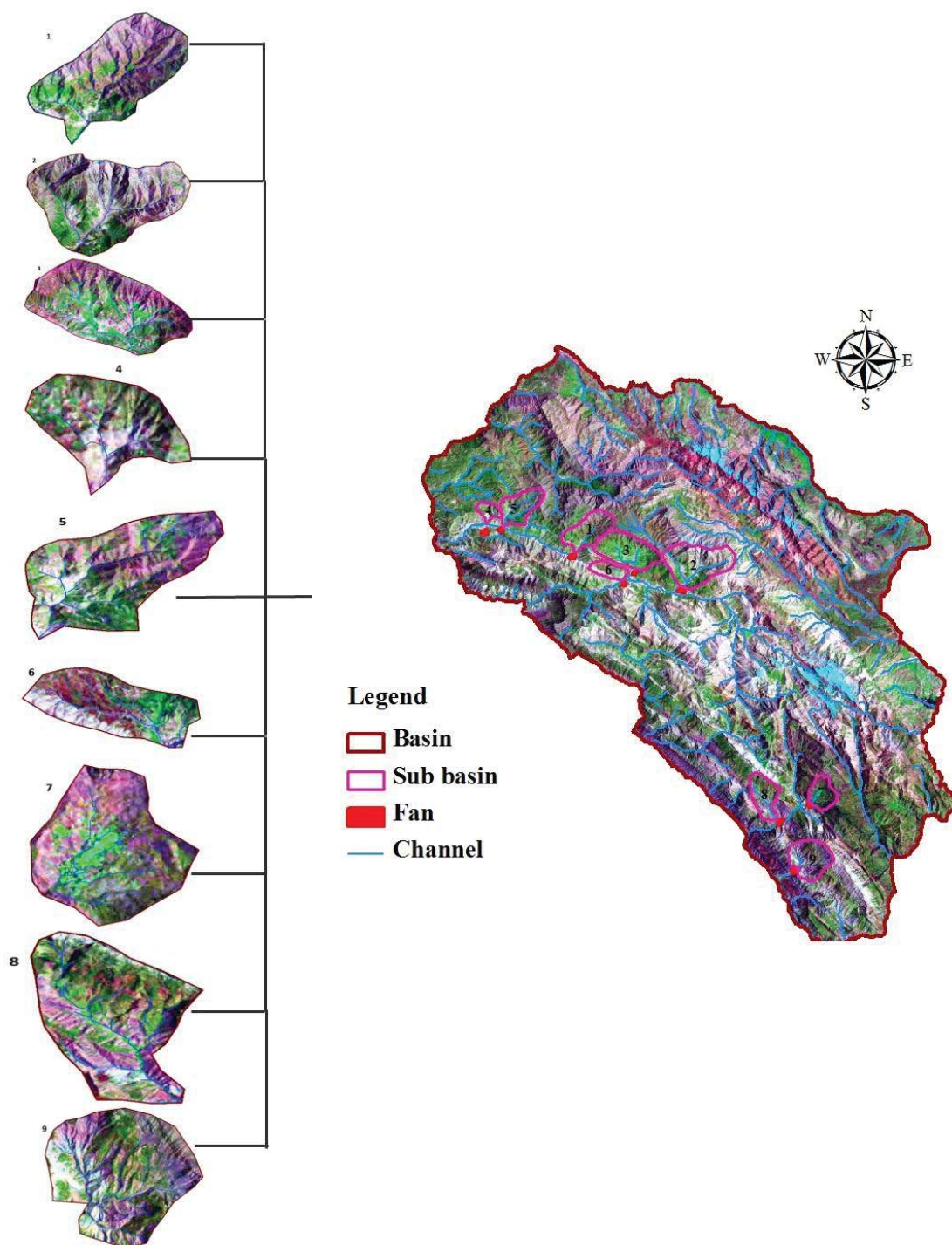


Figure 2. The sub-basins in the study area.

2.2. SOM

Artificial neural networks (ANNs) are non-linear mapping structures based on the function of the human brain, and are powerful tools for modelling when the underlying data relationship is unknown. ANNs can identify and learn correlated patterns between input data sets and corresponding target values, after which can be used to predict the outcome of new independent input data. ANNs imitate the learning process of the human brain and complex data even if the data is imprecise and hence, are ideally suited for the modeling of alluvial fan data, which are known to be complex and often non-linear. ANNs have great

capacity in predictive modeling, whereby all the parameters describing the unknown situation can be presented to the trained ANNs [20].

SOM are unsupervised ANNs formed from neurons located on a regular, usually, two-dimensional regular planar array grid (Figure 3). It is based on unsupervised learning, which means that no human intervention is needed during the learning and little needs to be known about the characteristics of the input data. SOM offers a solution to use a number of visualizations linked together [21]. When several visualizations are linked together, scanning through them is very efficient because they are interpreted in a similar way. The U-matrix produced from SOM visualizes distances between neighboring map units and thus shows the cluster structure of the map. Samples within the same cluster will be the most similar according to the variables considered.

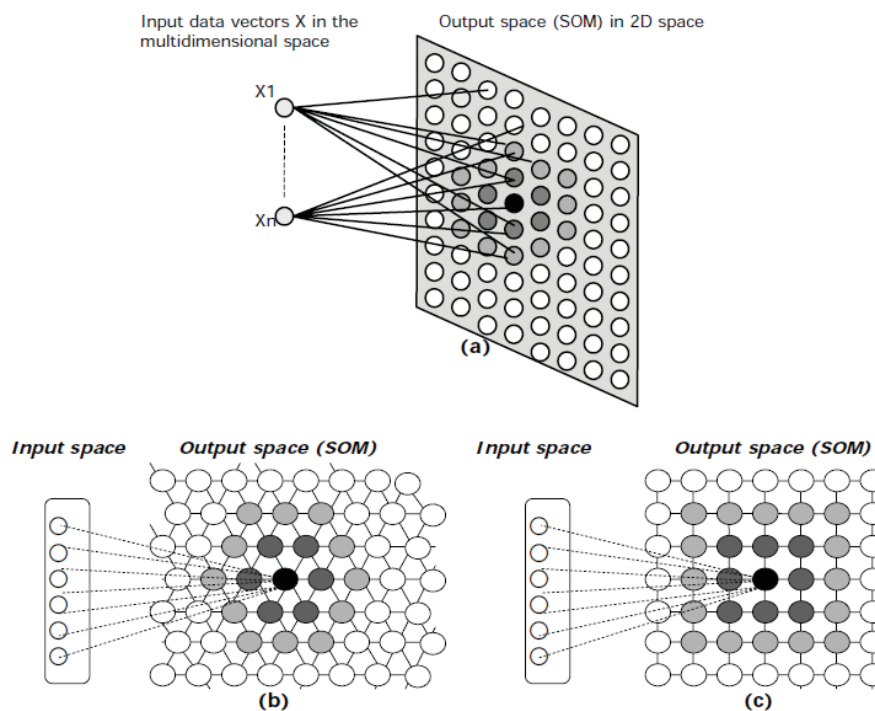


Figure 3. The structure of a SOM network: (a) Selection of a node and adaptation of neighboring nodes to the input data. The SOM grid can be (b) hexagonal or (c) rectangular. The black object indicates the node that was selected as the best match for the input pattern[22].

3. Results and discussion

3.1. SOM

SOM was applied for the study area to describe the alluvial fan morphometry. The visualization in Figure 4 consists of 16 hexagonal grids, with the U-matrix in the upper left, along with the 15 component layers (one layer for each morphometric parameter examined in this study).

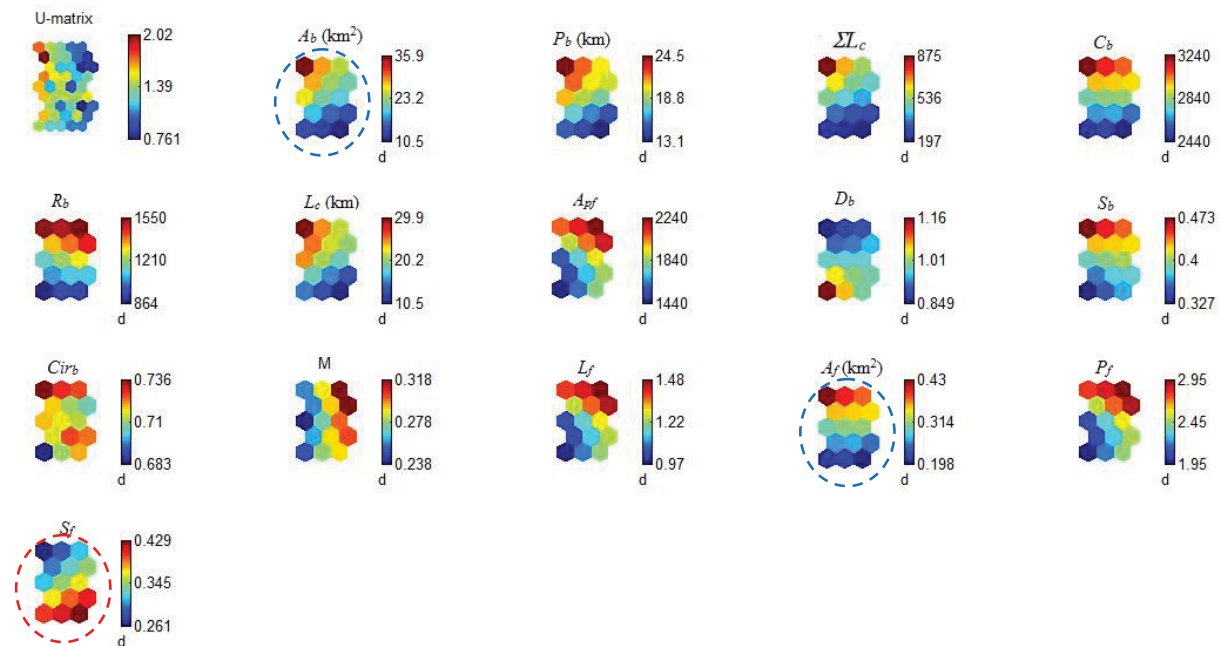


Figure 4. SOM visualization through U-matrix (top left) and 15 component layers (one layer for each morphometric parameter examined).

The warm colours in the layers represent the boundaries of the clusters, while cold colours represent the clusters themselves. In Figure 5, the same visualization is presented through hit numbers and post-it labels. The hit numbers in the polygons represent the record number of the dataset that belongs to the same neighborhood (cluster). Based on this, two clusters were generated. The records that belong to the same cluster are mapped closer and have the same colour.

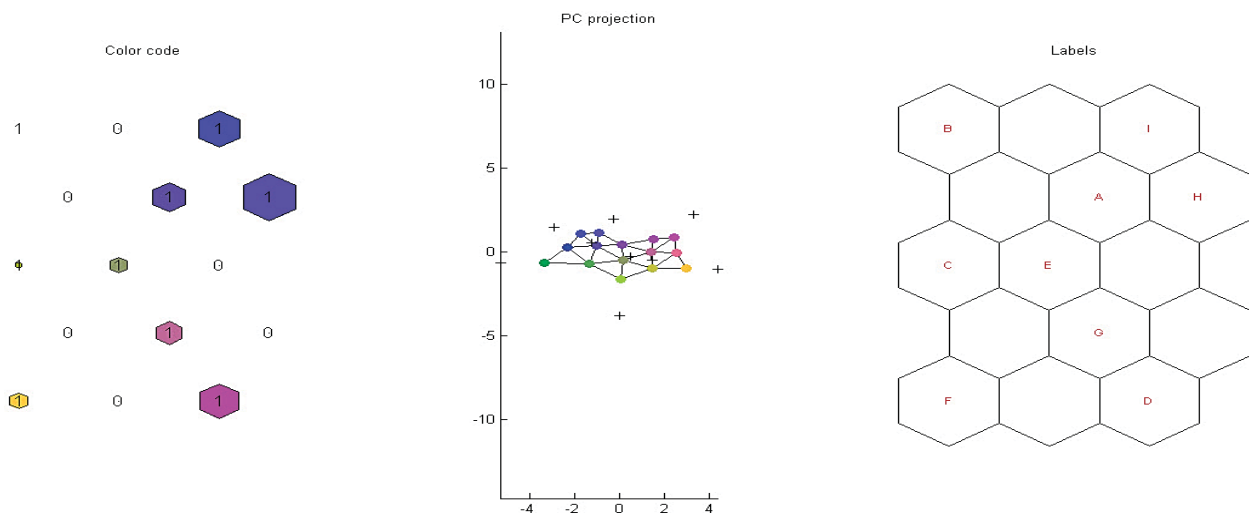


Figure 5. Different visualizations of the clusters obtained from the classification of the morphological variation through SOM: (a) Color code. (b) Principal component projection. (c) Label map with the names of the alluvial fans.

Based on the clusters for relationship between drainage basins and alluvial fans, it is found that:

- Drainage basin area A_b is correlated with fan area A_f .
- Fan slope S_f and drainage basin area A_b are inversely correlated.

Analysis of each cluster is then carried out to extract the rules that best describe each cluster by comparison of the component layers. The rules to predict the generation of alluvial fans are extracted by mapping the clusters presented in Figure 4 using the input morphometric parameters (component layers) in Figure 5. Using the SOM method, the fans in the study area are divided into two groups (Figure 6). The characteristics of each group of fans are provided in the Table 3.

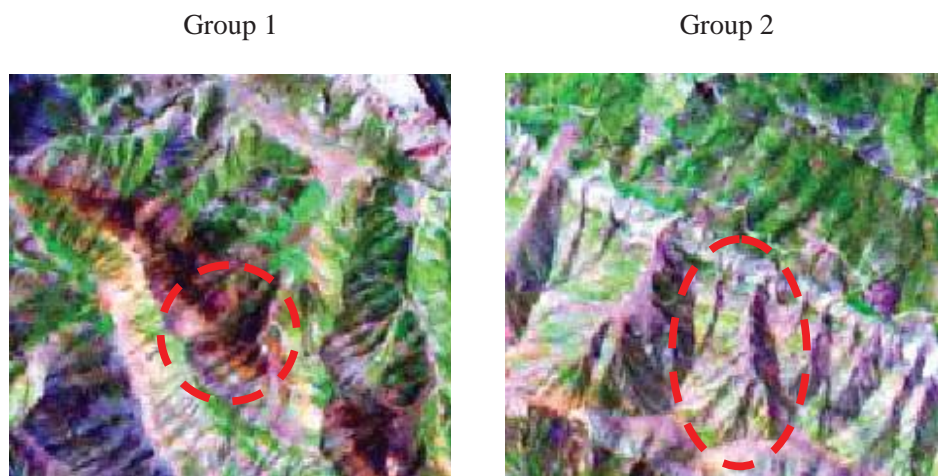


Figure 6. The two groups of fans in the study area.

Table 3. Characteristics of each group of fans in the study area.

Parameters	Group 1	Group 2
Fan area A_f (km ²)	0.19	0.43
Fan concavity P_f	1.9	3
Fan length L_f	0.95	1.5
Fan slope S_f	0.36	0.33

3.2 Morphometric relationships

The correlations between the geomorphic features of the studied fans and drainage basins include relationships between drainage basin area and fan area, drainage basin area and fan slope.

3.2.1. Drainage Area A_b and Fan Area A_f

Bull [23] was the first to describe quantitatively that as drainage basin area increases, the size of the alluvial fan also increases. He quantified the relationship with a simple power function of the form:

$$A_f = cA_b^k \quad (1)$$

where A_f is alluvial fan area, A_b is drainage basin area and c is an empirical derived coefficient representing the area of an alluvial fan with a drainage basin area of 1.0. The exponent k is the slope of the regression line and measures the rate of change in the fan area with increasing drainage basin area. By representing the relationship between these two parameters (Figure 7), it becomes clear that the data fits into a single exponential function:

$$A_f = 0.21A_b^{0.1096} \quad (2)$$

with a high correlation coefficient of 0.83, so there is a strong positive relation between A_b and A_f .

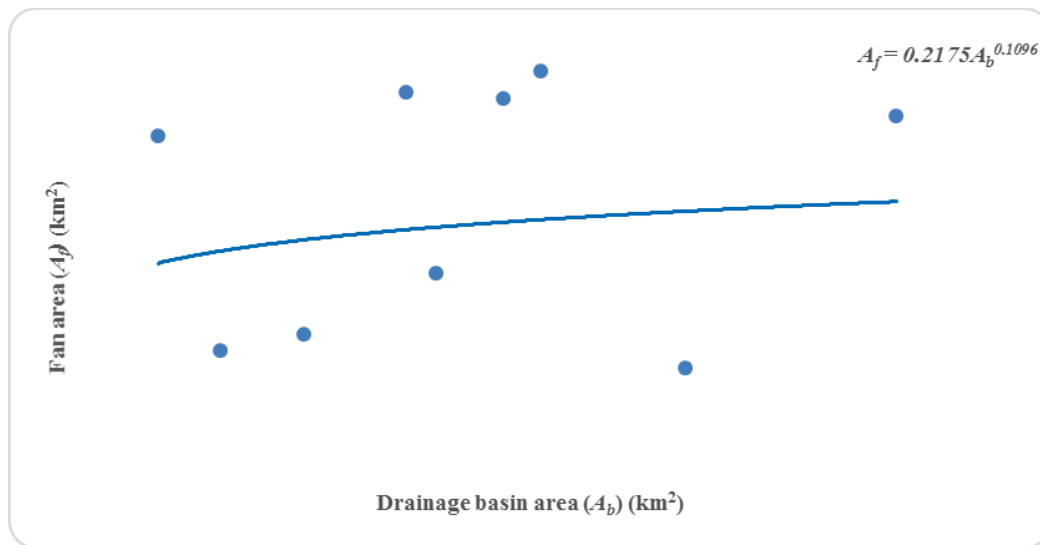


Figure 7. Correlation between drainage basin area A_b and fan area A_f for the studied fans and drainage basins.

The coefficient c , which according to Harvey [24] ranges from 0.1 to 2.2, has the value of 0.21 for the study area, similar with the value calculated for the coast of Gulf of Corinth, Greece [18]. In the literature, the different values of c and k for humid and sub humid area fans have been reported [25]. Table 4 includes values of c and k in the power law relationships between A_b and A_f from research works in various morphoclimatic environments. The value of the exponent for the study area agrees with the typical value for arid regions (about 0.9) [10] and 0.88 [18], and is higher than those derived from humid (0.58) and polar (0.65) regions. This value shows that the fans increase little in extension when the drainage area increases.

3.2.2. Drainage Area A_b and Fan Slope S_f

The relationship between the drainage basin area A_b and fan gradient S_f was investigated by Hooke [10] and Harvey *et al.* [1]. This relation is quantified with a simple power function of the form:

$$S_f = cA_b^k \quad (3)$$

Table 4. Values of coefficient c and exponent k in the power law relationship ($A_f = cA_b^k$) between drainage area and fan area from previous research works performed in various environments.

Location	c	k	Reference
Dellwood, North Carolina, USA	0.23	0.53	26
Roan Mountain, North Carolina, USA	0.38	0.76	27
General River Valley, Costa Rica	0.92	1.01	6
Banff, Alberta, Canada, fluvial fans,	0.48	0.32	28
debris-flow fans	0.17	0.48	28
single-group of fans	0.15	0.77	4
Japan	2.23	0.40	29
Central Alps, Northern Italy	0.29	0.33	25
Gulf of Corinth, Greece	0.13	0.88	18

The coefficient k is negative, indicating that increase of A_b results in decrease of S_f . In the study area, this relationship (Figure 8) can fit into the following function:

$$S_f = 1.0142A_b^{-0.377}$$

$$(4) S_f = cA_b^k S_f = 1.0142A_b^{-0.377}$$

The value of the exponent k (-0.377) falls within the range of values of -0.40 to 0, as given by Harvey [24]. In the coast of Gulf of Corinth, Greece, the calculated values of c and k are 0.14 and -0.45 respectively [18].

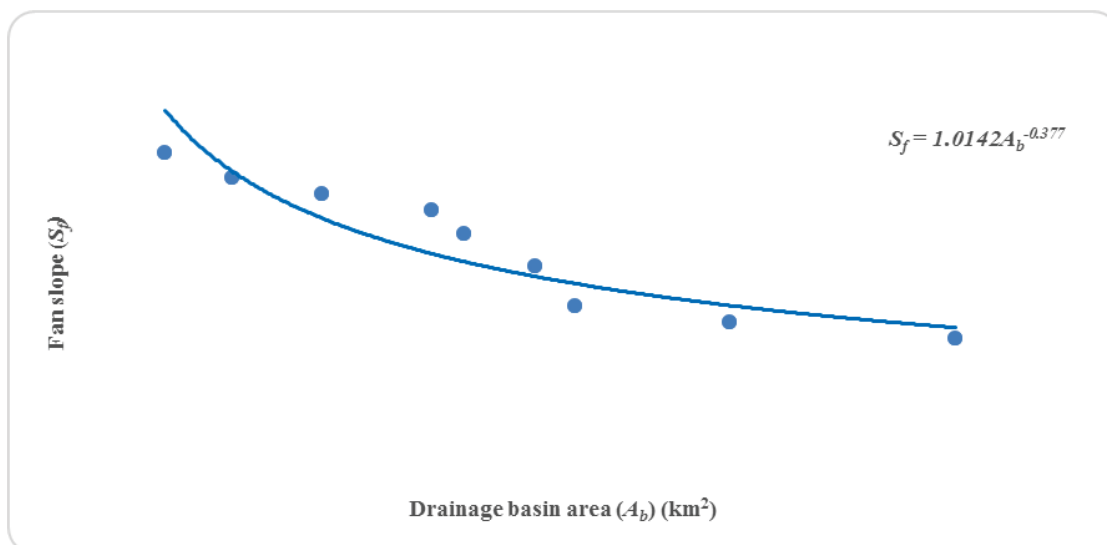


Figure 8. Correlation between drainage basin area A_b and fan slope S_f for the studied fans and drainage basins.

The values of exponent k from previous studies are 1.00 [18] and hence, Church & Mark [7] postulated that a general linear relationship exists for S_f versus M . For the study area, the value of k (0.26) indicates that the fan slope increases more rapidly than the ruggedness of the basin. According to De Scally & Owens [8] and Karymbalis et al. [18], debris-flow fans are supplied by basins with a higher value of M while the fans are steeper, smaller and less concave. This relationship provides an initial assessment of debris-flow potential for the broader study area, but this needs to be supported by field investigation of debris flows and sediment supply conditions in the basin.

4. Conclusion

The aim of this study is to determine the effectiveness of SOM as a clustering tool in the field of applied geomorphology. In this research, the geomorphological characteristics of alluvial fans in the Oshtorankooch altitudes were investigated. Qualitative observations, quantitative geomorphological analysis and application of SOM led to the definition of two main types of fans with different morphological features and the identification of certain correlation schemes between the studied parameters. Comparison of the geomorphological map and SOM showed that the applied methodology is a promising method for the mapping of drainage network channels. This method could be applied as a generic tool of alluvial fan classifier to larger datasets, in order to assess and interpret dominant formation processes through the study of multiple morphometric features describing alluvial fans and corresponding drainage basins. SOM provides an efficient scalable tool for the analysis of geomorphometric features as meaningful landform elements, leading to better understanding complex geomorphological systems.

5. References

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