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Morphometric analysis and soil characterization of dolines in the Gorazbon district of Kheyrud-Kenar Experimental Forest (northern Iran)

Analyse morphométrique et caractérisation des sols des dolines dans le district de Gorazbon de la Forêt expérimentale de Kheyrud-Kenar (nord de l'Iran)

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Résumé: Une doline est une dépression superficielle fermée dans des paysages karstiques, généralement circulaire ou subcirculaire et avec une dimension jusqu'à des centaines de mètres de diamètre. Cette forme du relief karstique, très distinctif et commun, peut apparaître dans une variété de formes et de tailles. La distribution spatiale, la description morphologique et l'évolution des dolines ont été étudiées dans le district de Gorazbon de la Forêt expérimentale de Kheyrud-Kenar (nord de l'Iran). Des mesures morphométriques et une collecte systématique d'échantillons de couverture du sol ont été effectuées pour chaque doline observée au cours du travail sur le terrain. Les paramètres morphométriques tels que la longueur, la largeur, les pentes latérales et le périmètre de la doline ont été mesurés. Ensuite, l'aire, la profondeur, l'indice de circularité, le rapport longueur/largeur et le rapport longueur/profondeur ont été calculés et utilisés pour la caractérisation morphométrique de chacune des dolines. Par la suite, deux autres paramètres ont été utilisés pour déduire le degré de karstification de la zone de la zone étudiée: la densité spatiale des dolines en nombre et la densité spatiale des dolines en aire occupée). La détermination en laboratoire des propriétés physiques (couleur, texture) et chimiques (pH, CaCO3, matière organique) du sol a été effectuée sur les échantillons prélevés. Les résultats obtenus indiquent la présence de dolines principalement dans la zone d'étude avec une distribution spatiale irrégulière, ainsi qu'un degré général élevé de karstification. Les dolines étudiées montrent les axes de longueur et de largeur avec une certaine asymétrie, résultant en une forme de sub-circulaire à elliptique. La caractérisation des sols rappelle l'hypothèse d'un éventuel début de développement de cavités peu profondes, pas encore visibles en surface, au fond des dolines, probablement liées au système karstique souterrain (des fissures élargies et/ou même des grottes). Les axes plus longs des dolines semblent alignés sur les principaux éléments géologiques structurels au niveau régional. Toutes ces données pourraient indiquer la présence d'un stade précoce dans l'origine des dolines d'effondrement, avec des implications évidentes en termes de risques naturels. Dans ce contexte, nous pensons qu'une prise de décision appropriée en matière de gestion forestière et dans des politiques spécifiques de planification environnementale devrait toujours tenir compte de ces informations quantitatives karstiques (et de cette approche) sur la relation mutuelle entre le développement des peuplements forestiers et les reliefs naturels qui caractérisent cette zone d'étude.

Mots-clés: Karst, Solution doline, Morphométrie, Propriétés du sol, Risques naturels, Gestion forestière.

Abstract: A doline is a natural superficial enclosed depression of karst landscapes, usually circular or subcircular in plan and with a few to a hundred meters in diameter. This very distinctive and common karst landform can appear in a variety of shapes and sizes. The spatial distribution, description and evolution of dolines were investigated in the Gorazbon district of Kheyrud-Kenar Experimental Forest (northern Iran). Morphometric measurements and systematic collection of soil cover samples were performed for each observed doline during field survey. Morphometric parameters such as doline's length, width, side slopes and perimeter were measured. Afterward, the area, depth, circularity index, length/width ratio and length/depth ratio were also calculated and used for the quantification of the individual dolines. Two other parameters were instead used to infer the degree of karstification of the study area: i.e., the spatial density of dolines and the pitting index. The laboratory determination of physical (color, texture) and chemical (pH, $CaCO_3$, organic matter) soil properties were conducted on the collected samples. The obtained results indicate the presence of mainly solution dolines in the study area with an irregular spatial distribution, as well as a general high degree of karstification. The studied dolines show the axes of length and width with a certain asymmetry, resulting in a shape from sub-circular to elliptical. Soil characterization point out to the hypothesis of a possible incipient develop of subcutaneous shallow holes (pipes - not yet visible on surface) at the dolines bottoms, probably linked to the underground karst system (enlarged fissures and/or even caves). Doline's longer axes seem aligned with to the major regional structural geological elements. All these data could indicate the presence of an early stage in the origin of collapse dolines, with obvious implications in terms of natural hazards. In this context, we believe that a proper decision-making in forest management, and in specific environmental planning policies, should always consider this karst quantitative information (and approach) on the mutual relationship between the forest stand development and the natural landforms that characterize the study area.

Keywords: Karst, Solution doline, Morphometry, Soil properties, Natural hazards, Forest management

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INTRODUCTION

Karst is a peculiar topography/landscape in which rock dissolution by natural waters is one of the most important geomorphic processes, occupying ca. 20% of the earth's ice-free continental area (JENNINGS, 1985; FORD & WILLIAMS, 2007; among others). In this landscape, a doline correspond to any small to intermediate natural superficial enclosed depression and is considered as diagnostic karst landform, although their eventual absence does not necessarily mean that karst is not developed (e.g., CVIJIĆ, 1893; FORD & WILLIAMS, 2007; KRANJC, 2013; GUTIÉRREZ *et al.*, 2014). A doline can appear in a variety of shapes and sizes, sometimes even like a "crater" connected to a cave or fissures at the bottom that allows the underground drainage of the water (e.g., LI *et al.*, 2008; FORD & WILLIAMS, 2007; GUTIÉRREZ 2016). It is usually circular or subcircular in plan, with few to hundreds of meters in diameter and a form that range from saucer-shaped to funnel-shaped - or even cylindrical. The bottom and sides (when gently sloping) are commonly covered by soil and/or siliciclastic sediment (KRANJC, 2013). Six main endmembers of doline's type were classified from a genetic point of view: solution, collapse, subsidence (including suffosion and dropout), buried and caprock (more detailed in FORD & WILLIAMS, 2007; GUNN, 2004; KRANJC, 2013; and references herein). In particular, and in according with the last cited authors, the bowl-shaped form indicates a typical solution doline where the main process involved in its genesis and evolution was the dissolution or corrosion of the bedrock.

The morphometric studies of karst have a long tradition, beginning with the classical doline shape measurements conducted by CVIJIC (1893) and followed by a set of works during the first half of 20th century, enabling a quantitative analysis of karst landscape (see the reviewed in GUNN, 2004; FORD & WILLIAMS, 2007). According to several authors, geo-environmental factors such as lithology, topographic elevation, slope, soil type, vegetation or climatic type (among others) may show some correlation with certain morphometrically parameters (BONDESAN *et al.*, 1992; BATORI *et al.*, 2014; among others). A large variety of morphometric parameters that mainly depend on karst genesis and evolution can be measured or calculated (LAVALLE *et al.*, 1967; WILLIAMS, 1972).

Traditionally, the morphometric studies of karst landscapes were based on topographic maps, remote sensing technology (air photographs and satellite imagery) and digital elevation models (DEM), using also the support of Geographic Information System (GIS) tools (OGDEN, 1988; GUTIERREZ-SANTOLALLA *et al.*, 2005; PODOBNIKART *et al.*, 2008; NEWBY, 2012; DE CARVALHO *et al.*, 2013; VERBOVSK & GABOR, 2019). However, the greatest disadvantages of remote sensing imagery and DEM are their insufficient resolution and accuracy, especially in forested karst territories (such as the study area), particularly for the detection of some specific morphometric parameters proposed in literature - e.g., doline's length and width (TELBISZ *et al.*, 2009; BASSO *et al*, 2013; KOBAL *et al.*, 2015; ÖZTÜRK *et al.*, 2018).

The main objectives of this investigation were the identification of dolines and the description of their morphometry, as well as the characterization of the respective soil cover, in the mixed beech forests of northern Iran. The Iranian beech belt is connected to the European forests regarding plant composition and, at this level, it has many similarities with Balkan forests. However, beech forests of Iran are unique because of the presence of subtropical elements. Iranian beech forest has not been influenced by glaciers and the evolution of these communities has been stable since the Pliocene. Even though this forest is located on the Alborz Mountains (in natural forests of Iran), little comprehensive research about geomorphology (including karst evolution) has been carried out yet. Furthermore, the aim of this paper is also to add new quantitative data to the literature in order to support a more effective and sustainable forest management and planning frameworks.

STUDY AREA

In this work the forested Kheyrud-Kenar mountainous areas (northern Iran) was chosen as study area taking in consideration its natural environmental characteristics, especially in terms of the occurrence of karst features (Alborz karst). This territory is 100% covered by *Fagus orientalis*, *Carpinus betulus*, *Acer velutinum*, *Alnus subcordata* and *Quercus castanifolia* (BI NAM, 2006). The investigation was carried out within the Gorazbon section of the Kheyrud-Kenar Experimental Forest (Fig. 1), which is owned and managed by the University of Tehran for educational, research and conservation purposes. The forest covers a total area of almost 8,000 ha and is located within the 36°27'N to 36°40'N of latitude and the 51°32'E to 51°43'E of longitude.

The climate is sub-Mediterranean with a mean annual temperature of 9 °C and a total annual precipitation of 1380 mm (MARVIE MOHADJER *et al.*, 2009). Selected forest communities occupy plateaus, or moderately inclined slopes, at an altitude from 1150 m to 1250 m, dominated by moderately acidic to alkaline brown forest soils with deep organic A-horizon. Geologically, Middle Jurassic to Upper Cretaceous limestone formations are the most prominent lithologies (BI NAM, 2006). All the meteoric water sinks directly into the dolines. The topography does not show any traces of surface rivers network. Only very small superficial channels for the transfer of rainwater to dolines were observed in the field.

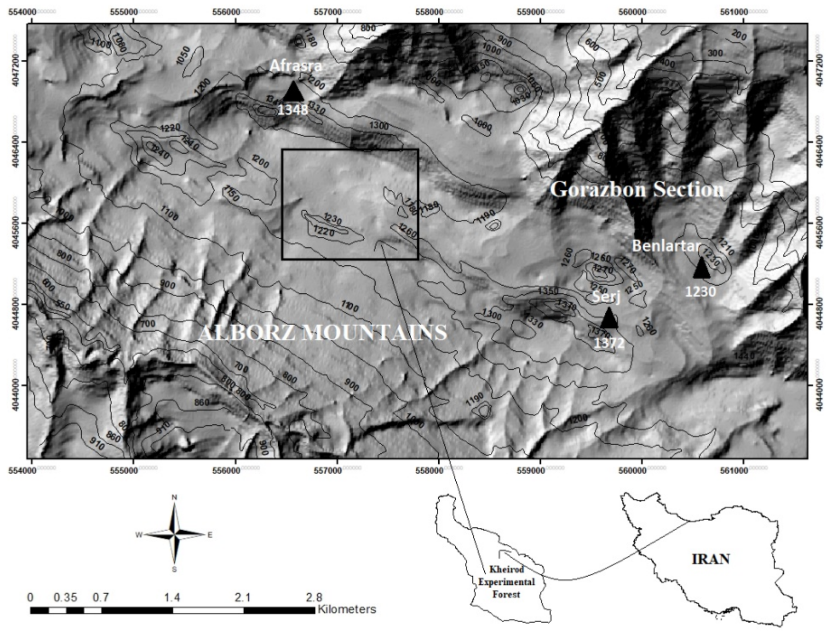


Fig. 1 - Location of the study area in the Kheyrud-Kenar Experimental Forest.

MATERIALS AND METHODS

Morphometric analysis

About morphometric analysis, the main problem was the lack of suitable topographic maps of the study area with enough resolution. For this reason, among a great number of morphometric parameters proposed by various authors in literature, only those directly measurables in the field (or calculated using the field measurements) were included in this investigation.

The field data collection took-placed during the summer of 2018 in an area of 42 ha. In order to perform the field observations, a 100×100 m regular grid of control points was established and a circular zone of 0.1 ha (plot area) was considered for some randomly selected points. In each plot area the observed dolines were described and localized using a global position system (84 dolines in 42 plot areas) (Fig 2).

Morphometric parameters such as doline's length (L_d), width (W_d), side slopes (S_d) and perimeter (P_d) were measured during field survey. The area (A_d), depth (D_e), circularity index (C_i), length/width ratio (L_d/W_d) and length/depth ratio (L_d/D_e) were calculated and used for the quantification of the individual dolines. In addition, doline density (D_d) and pitting index (P_i) were also used to infer the degree of karstification for the study area.

The pitting index represents a simple measurement of the surface karstification (BAUER, 2015) and is defined as the ratio between the study area (A_k) and the sum of dolines area (ΣA_d):

$$P_i = \frac{A_k}{\sum A_d}$$

The doline density was calculated as the ratio between the total number of dolines (N_d) and the study area (BAUER, 2015):

$$D_d = \frac{N_d}{A_k}$$

The circularity index of a doline was taken as the measure of the deviation of a doline shape from a perfect circle (BAHTIJAREVIC, 1996; DE CARVALHO *et al.*, 2013; BAUER, 2015). It is the ratio between the doline area and the area of a hypothetical circle of the same perimeter:

$$C_i = \frac{A_d}{\left[\pi\left(2\frac{A_d}{P_d}\right)^2\right]}$$

Fig 2 – Some examples of dolines, in the study area, during field measurements.

Using the length/width ratio (BASSO *et al.*, 2013), the dolines were classified into 4 nominal groups regarding their form in plan: circular and sub-circular ($L_d/W_d \leq 1.21$), elliptical ($1.21 < L_d/W_d \leq 1.65$), sub-elliptical ($1.65 < L_d/W_d \leq 18$) and elongated ($L_d/W_d > 1.8$).

The length/depth ratio was considered as internal shape index (see Table 1) and used to find the origin of dolines (BONDESAN *et al.*, 1992; DAY, 1976). Depths were simply obtained as the difference between the highest elevation of dolines and the lowest (bottom) points.

Table 1 – Definition of both compared objects and geometrical forms based on the doline length/depth ratios (L_d/D_e).

L_d/D_e ratio	Similar objects	Geometrical forms
$L_d/D_e > 5$	Plate	Trunk of cone
$5 > L_d/D_e > 2$	Bowl	Hemisphere
$2 > L_d/D_e > 1.5$	Funnel	Cone
$1.5 > L_d/D_e$	Pit	Cylinder

Soil analyses

Soil samples were systematic collected, at a depth of 15 cm, from two specific sections of each doline (walls and bottom) during field survey. The initial assumption was that the soil properties must be different in these two distinct parts of the dolines. In order to test this hypothesis, sixteen dolines within different plots areas were randomly chosen. In total 32 soil samples were taken and analyzed in laboratory.

After collection, the soil samples were air-dried and sieved using 2-mm-mesh to remove the living roots and rock fragments. Color, texture, pH, $CaCO_3$ content and organic matter amount were determined. In particular, soil color was described for each sample through the Munsell Soil Color Charts. For the determination of soil texture the hydrometer method was adopted (FOLK, 1974). The hydrogen-ion activity in each sample was obtained using a pH-meter device. Titration procedure and acid neutralization allowed to determine the $CaCO_3$ content (LOEPPERT & SPARKS, 1996). Soil samples were ignited for 4 h at 550 ºC in a muffle furnace to remove organic matter and to concentrate the remaining mineral residue (DOUGLAS, 2010). The proportion of organic matter was then estimated as the weight difference between before and after the sample burning.

RESULTS AND DISCUSSION

Dolines morphometric parameters

Dolines occupy about 35% of the study area (Fig 3). The total area in the individual dolines range from 12.62 m² (plot 27) to 2355.79 m² (plot 33) (see Table 2). Furthermore, the dolines area and perimeter values are positively correlated (Fig 4). Dolines length range from 2 m to 40 m, the depths from 1 m to 14 m and the side slopes from 4° to 47°.

Table 2 - Number of observed dolines for each plot area and respective average values of dolines area, perimeter, pitting index, density and circularity index.

Plot area	Number of dolines	Dolines area (m^2)	Dolines perimeter (m)	Pitting index	Dolines density	Circularity index
2	2	881.40	142.12	1.2	1.97	1.8
4	1	680.36	93.13	1.5	0.98	1.02
7	1	1388.27	132.65	1.1	0.98	1.01
8	1	94.91	35.49	10.7	0.98	1.06
9	2	127.71	53.53	8.0	1.97	1.79
10	3	522.41	132.12	1.9	2.95	2.66
11	1	25.15	19.10	40.5	0.98	1.15
14	1	75.61	31.35	13.5	0.98	1.04
15	1	83.28	32.34	12.2	0.98	1
16	1	266.90	58.28	3.8	0.98	1.01
17	2	112.69	53.11	9.0	1.97	1.99
18	1	316.04	63.54	3.2	0.98	1.02
19	1	13.50	13.04	75.3	0.98	1.00
20	5	332.68	128.76	3.1	4.91	3.97
21	3	435.05	116.07	2.3	2.95	2.47
22	2	638.13	108.52	1.6	1.97	1.47
23	3	945.22	194.58	1.1	2.95	3.19
24	1	268.47	58.11	3.8	0.98	1.00
25	1	86.66	34.81	11.7	0.98	1.11
26	1	82.82	33.55	12.3	0.98	1.08
27	1	12.62	12.59	80.6	0.98	1.00
28	2	482.80	111.28	2.1	1.97	2.04
29	5	1093.70	244.73	1.3	4.91	4.36
30	6	1972.21	317.91	1	5.90	4.08
31	1	678.24	92.96	1.5	0.98	1.01
32	2	1589.63	202.94	1.4	1.97	2.06
33	3	2355.79	299.39	1.1	2.95	3.03
34	3	1183.78	208.00	1	2.95	2.91
35	3	716.78	164.10	1.4	2.95	2.99
36	2	420.92	87.95	2.4	1.97	1.46
37	4	1107.46	223.13	1.1	3.93	3.58
38	2	475.71	108.67	2.1	1.97	1.98
39	4	1612.74	233.72	1.2	3.93	2.70
40	2	728.71	115.05	1.4	1.97	1.45
41	5	946.09	210.84	1.1	4.91	3.74
42	4	131.27	79.14	7.8	3.93	3.80

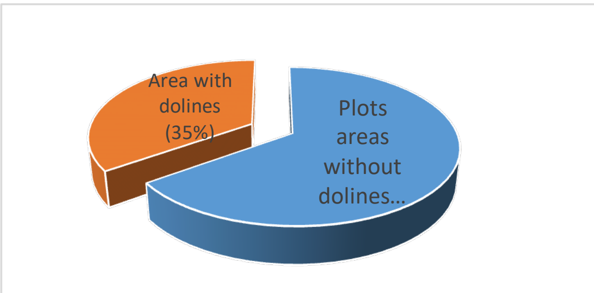
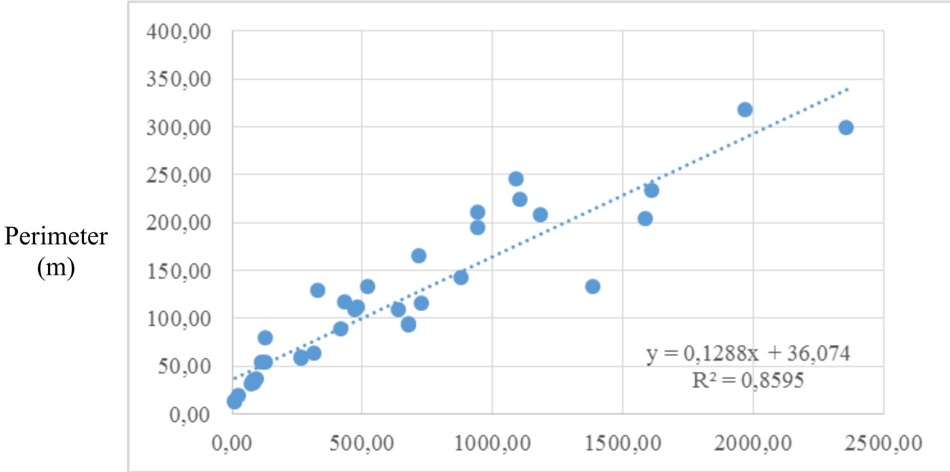


Fig. 3 - Proportions of the plots areas with and without dolines.

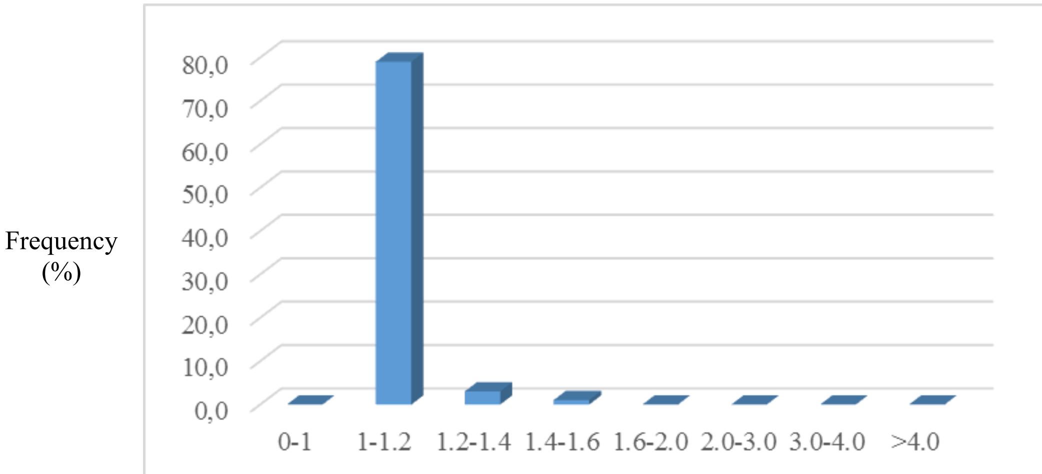


Area (m^2)

Fig. 4 – Correlation between dolines area and perimeter.

The pitting index varies from 1 to 80.6, with an average of 2.1 (see Table 2). It is important to note that lower values of pitting index indicate a high degree of karstification (theoretically, value of 1 is for a completely karstified area).

The circularity index ranges between 1.00 and 4.36. Most dolines are nearly circular in plan with the major modal ratio class between 1 and 1.2. Approximately 80% of the total dolines population shows a circularity index smaller than 1.2 (Fig 5).



Circularity index

Fig. 5 - Frequency distribution of doline circularity index.

The classification results of dolines according to the elongation ratio (L_d/W_d) allows to identify 58% of the dolines as sub-circular, 35% as elliptical, 6% as sub-elliptical and 1% as elongated (Table 3 and Fig 6). The dolines length and width values are positively correlated (Fig 7).

Table 3 – Average values of dolines length/width ratio (L_d/W_d) and length/depth ratio (L_d/D_e).

Plot area	L_d/W_d	L_d/D_e	Similar object	Plot area	L_d/W_d	L_d/D_e	Similar object
2	1.17	2.60	bowl	**30**	2.48	5.20	plate
2	1.14	2.28	bowl	**30**	1.59	7.41	plate
4	1.19	3.57	bowl	**30**	1.02	7.38	plate
7	1.15	14.06	plate	**30**	1.32	2.71	bowl
8	1.40	5.65	plate	**30**	1.42	7.88	plate
9	1.47	1.50	funnel	**30**	0.84	3.70	bowl
9	1.06	5.71	plate	**31**	1.19	4.57	bowl
10	1.70	5.62	plate	**32**	1.32	10.31	plate
10	1.08	5.75	plate	**32**	1.33	5.00	plate
10	1.37	6.36	plate	**33**	1.32	5.81	plate
11	1.73	3.73	bowl	**33**	1.68	4.20	bowl
14	1.30	5.09	plate	**33**	0.88	4.50	bowl
15	1	3.22	bowl	**34**	1.29	9.00	plate
16	1.18	2.50	bowl	**34**	1.05	17.69	plate
17	1.12	1.30	pit	**34**	1	13.64	plate
17	0.97	1.70	funnel	**35**	1.07	8.00	plate
18	1.20	5.24	plate	**35**	1.04	5.15	plate
19	0.93	2.00	bowl	**35**	1.22	11.00	plate
20	1.16	4.17	bowl	**36**	1.08	2.71	bowl
20	1.14	4.55	bowl	**36**	0.96	13.58	plate
20	1.26	4.15	bowl	**37**	0.65	5.10	plate
20	1.13	4.64	bowl	**37**	1.06	4.29	bowl
20	1.36	7.83	plate	**37**	1.26	11.43	plate
21	0.93	4.00	bowl	**37**	1.38	5.47	plate
21	1	5.91	plate	**38**	1.07	11.54	plate
21	1.44	2.88	bowl	**38**	1.22	12.22	plate
22	1.45	2.75	bowl	**39**	1.22	7.15	plate
22	1.64	4.50	bowl	**39**	1.12	6.15	plate
23	1.07	2.67	bowl	**39**	1.34	4.55	bowl
23	1.76	6.43	plate	**39**	0.95	13.33	plate
23	1.53	10.74	plate	**40**	1.05	2.09	bowl
24	0.95	6.00	plate	**40**	1.17	3.49	bowl
25	1.60	5.30	plate	**41**	1.07	3.77	bowl
26	1.50	5.71	plate	**41**	0.68	2.52	bowl
27	1.00	3.64	bowl	**41**	1.07	3.44	bowl
28	0.77	6.41	plate	**41**	1.09	3.60	bowl
28	1.24	5.53	plate	**41**	0.98	2.66	bowl
29	1.28	3.40	bowl	**42**	1.32	3.15	bowl
29	1.04	12.54	plate	**42**	1.76	5.69	plate
29	1.47	6.88	plate	**42**	1.10	6.00	plate
29	0.90	4.42	bowl	**42**	0.82	2.31	bowl
29	0.90	8.64	plate				

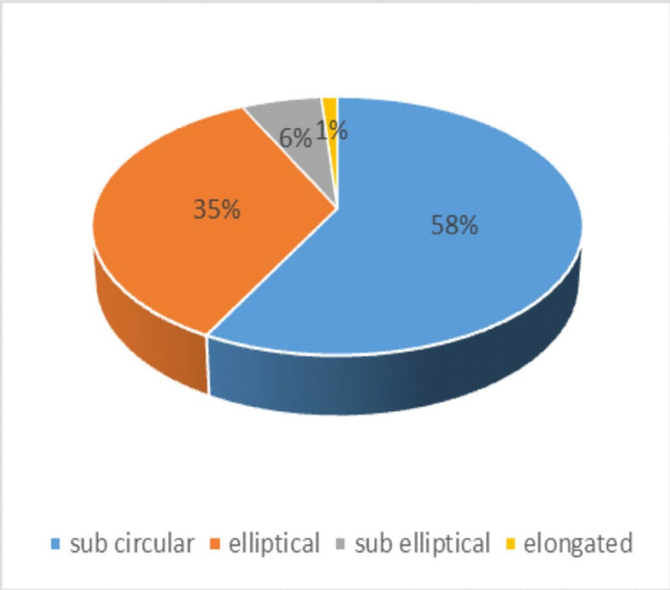


Fig. 6 - Proportions of doline's form types.

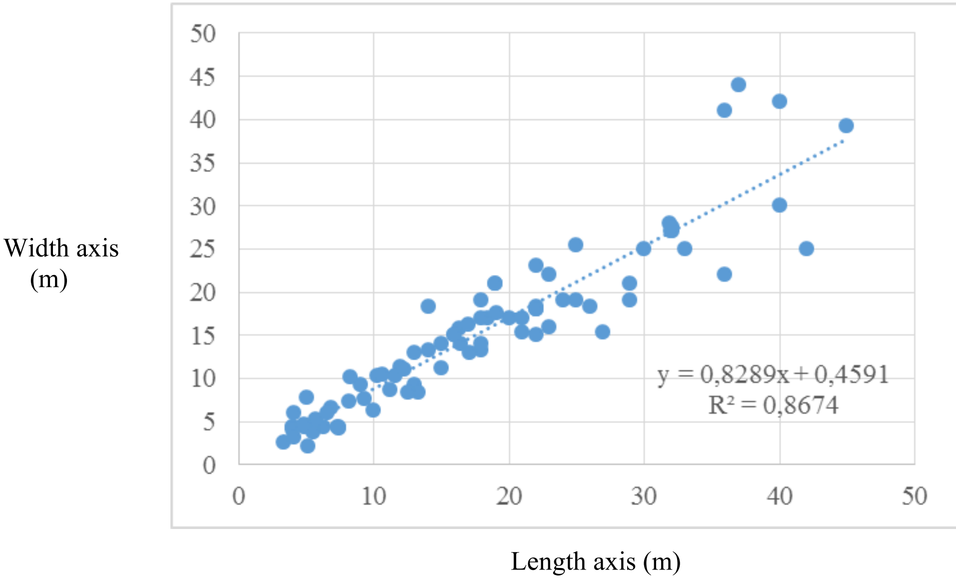


Fig. 7 - Correlation between dolines length and width.

According to the length/depth ratio values, the plate (53%) and bowl (43%) are the most common shapes of the observed dolines (Table 3 and Fig. 8), indicating that dissolution (or corrosion) of the bedrock were the main process involved in its genesis and evolution (i.e., solution dolines). The funnel (3%) and pit (1%) dolines are very rare in the study area.

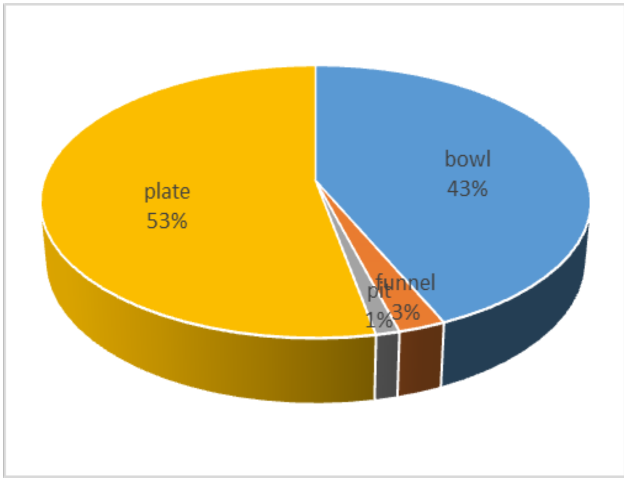


Fig. 8 - Proportions of doline's shape types.

In the study area the distribution of dolines respect to the topographic altitude is irregular, showing most of them localized between 1214 m and 1288 m (Fig. 9). There is not a clear relation between the altitude and the number of dolines.

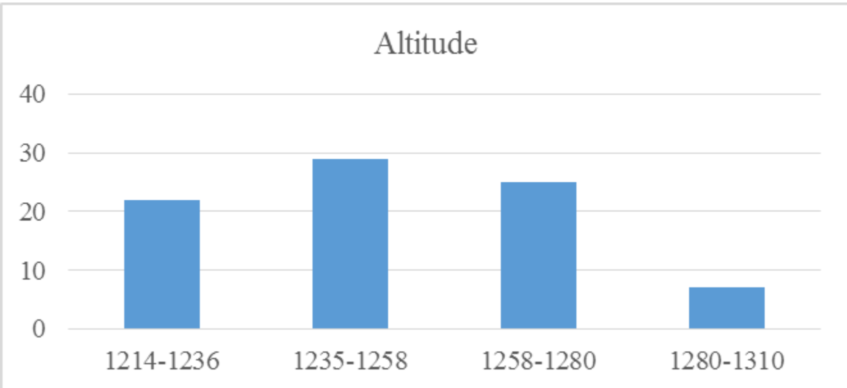


Fig. 9 - Frequency distribution of dolines with respect to topographic altitude.

Soil characteristics

The greatest soil thicknesses were observed on the walls of dolines. Alfisol was the common soil-type detected in the studied dolines, which is very rich in clay. These soils can be found mainly under broad-leaved forest and have a subsurface horizon in which clay has accumulated. Alfisol occurs in temperate humid and sub humid regions and (generally) a clayey texture developed on gentle slopes limestones (Soil Survey Staff, 1999).

Analyzed soil have a texture of clay loam, or sandy clay loam and clay. The texture is relatively homogeneous in both walls and bottoms, but generally the clay amount on the walls is greater than in the dolines bottom (see Table 4). The content of sand varies significantly among the two different sections of the dolines, with more accumulation in the bottom.

The surficial humus-rich horizons are thin on the walls (1-4 cm) and thick in the bottom of dolines (5-25 cm). The content of humus radically decreases just in the walls. Higher levels of organic matter were observed in dolines bottom and least amount in dolines walls (see Table 4).

Table 4 - Physical and chemical soil properties in two distinct sections of selected dolines.

		Organic matter (%)	Soil texture (%) Sand	Silt	Clay	pH	$CaCO_3$ (%)	Munsell color
Doline 4	Bottom	16	76	9	15	5.54	1	10YR2/1
	Walls	6	50	15	35	5.85	2.50	10YR7/2
Doline 9	Bottom	10	82	6	12	5.56	1.25	10YR2/3
	Walls	5	64	11	25	5.89	2.75	10YR7/2
Doline 10	Bottom	25	81	7	12	5.05	1.25	10R3/2
	Walls	11	42	27	31	5.83	2.25	10YR7/2
Doline 14	Bottom	41	88	1	11	5.10	1.2	10R2/2
	Walls	9	45	24	31	5.19	2.25	10YR7/2
Doline 15	Bottom	8	83	3	14	5.32	1	10YR2/3
	Walls	3	44	17	39	6.35	2.75	10YR6/2
Doline 19	Bottom	25	66	12	22	5.59	0.75	10YR2/2
	Walls	9	48	23	29	5.72	2.50	10YR6/2
Doline 20	Bottom	7	69	7	24	5.58	1.5	10YR2/3
	Walls	3	44	27	29	6.19	2.38	10YR7/1
Doline 21	Bottom	10	69	6	25	5.49	1.25	10YR1/7
	Walls	3	26	55	19	6.31	2.45	10YR7/2
Doline 23	Bottom	15	78	4	18	5.55	1.13	10YR4/1
	Walls	4	75	4	21	6.12	2.75	10YR6/3
Doline 24	Bottom	12	65	15	20	5.76	0.75	10YR2/2
	Walls	6	45	29	26	5.27	2.28	10YR6/2
Doline 25	Bottom	14	80	1	19	5.53	1	7/5YR2/3
	Walls	3	37	27	36	5.64	2.50	10YR6/2
Doline 26	Bottom	15	86	2	12	5.43	0.5	10YR2/1
	Walls	6	45	27	28	4.72	3.25	10YR6/3
Doline 28	Bottom	12	63	14	23	5.47	1.25	10YR2/1
	Walls	7	37	27	36	5.88	2.25	10YR4/1
Doline 35	Bottom	6	88	3	9	5.79	1.25	10YR5/1
	Walls	2	77	4	19	5.89	2.50	7/5YR6/3
Doline 36	Bottom	8	78	3	19	5.37	1.25	10YR4/1
	Walls	2	36	29	35	5.75	2.70	10YR7/2
Doline 41	Bottom	10	75	6	19	5.81	1	10YR2/4
	Walls	2	44	27	29	5.86	2.25	7/5YR7/2

The pH ranged from 4.72 to 6.35 in the doline walls and from 5.05 to 5.79 in the bottom (see Table 4). The highest variability of soil pH values was determined in the doline walls of plot area 21 (6/31) and plot area 20 (6/19). According to the pH values, the soils are considered acidic and strongly acidic in the bottom of dolines. Soil pH and organic matter strongly affect soil functions. Specifically, the pH influences the solubility and the organic matter decomposition. Furthermore, soil organic matter improves the water holding capacity, the microbial decomposition, the plant foliage and the decreases of pH in very long term (DELGADO & FOLLETT, 2002; LAL *et al.*, 1998; EFE, 2010).

Content of $CaCO_3$ were found in both dolines bottom and walls, without significant detected differences. $CaCO_3$ range from 0.5 % to 1.5 % in the dolines bottom and from 2.25 % to 3.25 % in the dolines walls (see Table 4).

One of the reasons for the difference in soil properties from the dolines walls and bottom may depend on the current amount of vegetation and organic remnants that characterize these two distinct sections. Successful tree and bush growth are occurring on doline slopes where the soil is found in the fissures of the bedrock. On the other hand, the roots grow into the fissures of the bedrock thereby enlarging them. After heavy rain, the waters that fall directly into the dolines, together with the channeled one, infiltrates beneath the soil and tends to increase the size of dolines by dissolution (Fig 10). Furthermore, infiltrating water creates widened joints, eventually connected with more deep caves. The presence of subcutaneous and incipient shallow holes (pipes) at the bottoms of dolines, whereby the fine soil fraction is evacuated in the karstified bedrock by water, can be also inferred.

Fig. 10 – Examples of very small superficial channels that drain the rainwater into the dolines.

CONCLUSIONS

In the Gorazbon district of Kheyrud-Kenar Experimental Forest (northern Iran), the dolines are the prominent superficial natural karst landforms, showing a certain asymmetry in plan (shape from sub-circular to elliptical) and the longer axes aligned to the major regional structural geological elements. There are hundreds of dolines with and irregular spatial distribution, in an area with a general high degree of karstification. The morphometric analysis and soil characterization of dolines allows to classify them mainly as solution dolines, with a possible incipient development to collapse dolines.

In broadly terms, the motivation for such research comes from the strong belief that in this specific region the geomorphic systems were developed under the influence of various natural processes in the old-growth forest. These new quantitative data can contribute to define a reference-state for the geomorphology, because come from a "virgin" natural territory which was not under significant human impact. However, preventive actions are now necessary in this region in terms of natural hazards, especially considering the possibility indicated by this investigation in which collapse dolines are in an early stage of development. Finally, a proper decision-making in forest management, and in specific environmental planning policies, should always consider this karst quantitative information (and approach) on the mutual relationship between the forest stand development and the natural landforms that characterize the study area.

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