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Research and Full Length Article:

Effects of Mining Activities on Structure and Function of Rangeland Ecosystem Using the Landscape Function Analysis (LFA) (Case study: Copper Mine in Dareh Zereshk, Yazd province, Iran)

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Abstract. This study was conducted to evaluate the effect of copper extraction on the structure and function of rangelands ecosystem around the mine area in Dareh Zereshk, Yazd province, Iran. Three study sites were considered at the specified intervals of the mine (0-200, 200-500 and 500-1000m). This research was conducted from 2012 to 2013. In each location, three linear transects with a length of 50 m were deployed in the slope direction. The structural characteristics were measured for ecological patches and inter patches space along each transect, and the landscape organization indices for each ecological unit (distance from the mine) were calculated. For each patch and inter patch, five measurement areas (replicates) were considered over each transect. In addition, 11 soil surface indices were evaluated and categorized. Using the soil surface indices scoring, the functional characteristics of each ecological unit including stability, permeability and nutrient cycle were calculated for each patch and inter patch in three locations. Based on the results, there were significant differences between the nearest (0-200m) and far (500-1000m) ones from the mine for indicator and functional traits ($P<0.05$). But there was no significant difference between the mid distance of the mine (200-500m) and two other sites, near and far from the mine ($P>0.05$). On the other hand, the function of different types of ecological patches was significant at different distances from the mine ($P<0.05$). So, the combined patches and inter patches had the highest and lowest values of functional indicators, respectively. The results demonstrate the efficiency of the landscape function analysis method to assess the post-mining damages and any subsequent reconstruction of rangeland in the around area.

Key words: Ecological patches, Inter patch areas, Soil properties, Dare Zereshk mine

Introduction

Today, many natural areas have undergone mining operations. Exploration and extraction activities of mines have a wide and varied impact on the environment including soil and vegetation as a result of ecosystem health. Because the ecosystems of arid regions are very fragile in the event of the destruction of the plant communities in these areas, their recovery will be very slow. For this reason, in order to ensure the health of these ecosystems, assessment of structural and functional changes in these areas is necessary (Tongway and Hindley, 2004). In the section of structure ecosystem, there are some cases such as layering and vegetation type, vegetation form, percentage of canopy cover and vegetation density, and in the section of ecosystem function such as energy flow, food cycle, and water and soil infiltration status.

Although the function study does not simply examine the structure of the ecosystem, it is possible to study it using existing methods such as the nutrient cycle, energy flow and soil health and its infiltration (Tongway and Hindley, 2000). In recent years, the use of various indicators for assessing the ecosystem function in order to assess the degradation process is under development. For this purpose, the CSIRO Institute in Australia has devised a methodology called the Landscape Function Analysis (LFA). This method is a monitoring methodology that has been devised to evaluate the impact of mines in Australia and has been used extensively throughout the world in various ecosystems, and in general, it evaluates the function of surface soils using 11 indicators (Tongway and Smith, 1989). This method is used in natural and rehabilitated landscapes after mining, in the range from arid areas to rainforests adjacent to the equator in Indonesia, in a variety of uses from the traditional exploitation of rangelands to meadows that previously had mineral exploitation and also in ecosystems for the conservation of biodiversity (Tongway and Hindley, 2004). Using this method, They studied the remediation trend in Australian mining ranges. They found a speedy, low cost, and simple tools for assessing the surface of the soil in field operations that are the advantages of this method, which has doubled the importance of using this method (Tongway and Hindley, 2000). In Zimbabwe, using the LFA method, the effects of copper mine on the structure and function of the ecosystem of the region has been investigated (Dowo *et al.*, 2013). Tongway *et al.* (2003) examined the indices provided by the LFA method to determine the sustainability, permeability and nutrient indices in nine regions of Australia. They found that the process of erosion and sedimentation in the mining area of golden granite is active. Maestre and Puche (2009) used the LFA method to study the ecosystem function and monitoring the desertification process in Australia. They found that stability indices, permeability and nutrient cycles have a significant correlation with soil variables and this method has a good potential for desertification monitoring. They used the LFA method to study the ecosystem performance and monitoring the desertification process in Australia. They found that indices of stability, permeability and nutrient cycles have a significant correlation with soil variables and this method has a good potential for desertification monitoring (Maestre and Puche, 2009).

Jozaghyan *et al.* (2016) conducted a research on the effects of clay and gypsum mining on vegetation and soil conditions in dryland ecosystems in Segzi plain of Isfahan province, Iran using the LFA method. Their results showed that soil in the mined areas had less stability than the reference area. Also, vegetation and soil conditions indicated that the rate of desertification was more in the mining area. Some researchers such as Dunwoody (2015), Mayor *et al.* (2012) and Gaitan *et* *al.* (2013) had integrated the function of ecosystems in different scales by integrating the LFA method with remote sensing techniques.

The purpose of this study was to investigate the effect of mining on soil surface characteristics and rangeland functional characteristics using LFA method in rangelands around copper mine of Zarshak valley located in Yazd province, Iran.

Materials and Methods

The study area

Dareh Zereshk area is located at 60 km southwest of Yazd and 45 km southwest of Taft along the Yazd-Shiraz road and 10 km away from Ali Abad copper mine, Iran between 53°45′ to 53°54′ eastern longitude and 31°29′ to 31°36′ northern latitude (Figure 1). This copper mine is near the Dareh Zereshk with 2400 m elevation above sea level. It is surrounded by mountain of Kaleh Kaftar with the altitude of 2935 m above sea level in the west and Tambehmar Sookhteh Mountain with the altitude of 2700 m above sea level in the east (Figure 2). The copper deposit of Dareh Zereshk is located in one of the active tectonic zones of central Iran and in the western margin of Shirkouh granite. Due to its location in Shirkouh slopes, this region is relatively cooler than Yazd city (National Iranian Copper Industry Co, 2011; Dalvand *et al*., 2015).

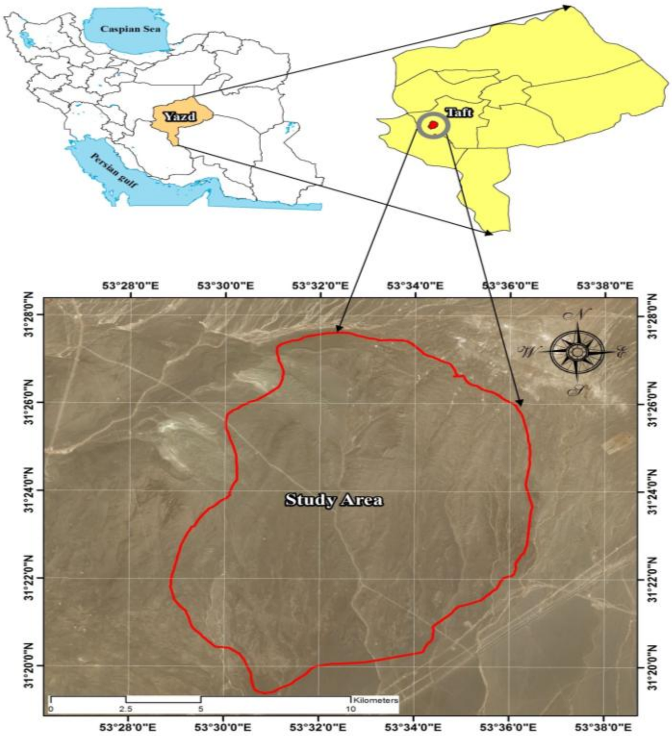

Fig. 1. The map of site location in Yazd province and Taft city, Iran

Research Method

This study was carried out in three range sites located at the specified intervals from the Dareh Zereshk mine (0-200, 200-500, 500-1000m). So, the regions in terms of elevation, slope and aspect were relatively similar. The site characteristics as vegetation cover condition and plant composition are presented in Tables 1 and 2. The reason for choosing these intervals is to reduce the effects of mining at distances beyond the center of the crisis (Monemi *et al*., 2018). The location of each site on Google Earth images is presented in Figure 2.

Table 1. Vegetation cover of study sites in rangelands around Dareh Zereshk copper mine

Distance from mine	The dominant plant type	Cover %	Litter %	Rock %	Soil %	Rangeland condition [a]		Range trend [b]	
						Score	Class	Score	Tendency
0-200 m	*Ar. sieberi -As.myriacanthus*	10	2	50	38	14	Very poor	+1	Positive
200-500m	*Ar.sieberi -As.myriacanthus*	21	5	32	42	24	poor	-1	Negative
500-1000m	*Ar.sieberi -As.myriacanthus*	28	8	25	39	30	poor	-1	Negative

a=based on four factorized modification

b=based on trend balance method

Table 2. Plant composition of study sites in rangelands around Dareh Zereshk copper mine

Distance from mine	Plant composition
0-200 m	*Artemisia sieberi-Astragalus myriacanthus- Artemisia aucheri- Hertia angutifolia- Lactuca serriola- Euphorbia connate- Noae macronata- Boissiera squarrosa*
200-500 m	*Astragalus myriacanthus- Artemisia aucheri- Hertia angutifolia- Lactuca serriola- Euphorbia connate- Noae macronata- Boissiera squarrosa- Stachys inflate*
500-1000 m	*Astragalus myriacanthus- Artemisia aucheri- Hertia angutifolia- Lactuca serriola- Euphorbia connate- Noae macronata- Boissiera squarrosa- Stachys inflate- Stipa barbata- Acantholimon heratense*

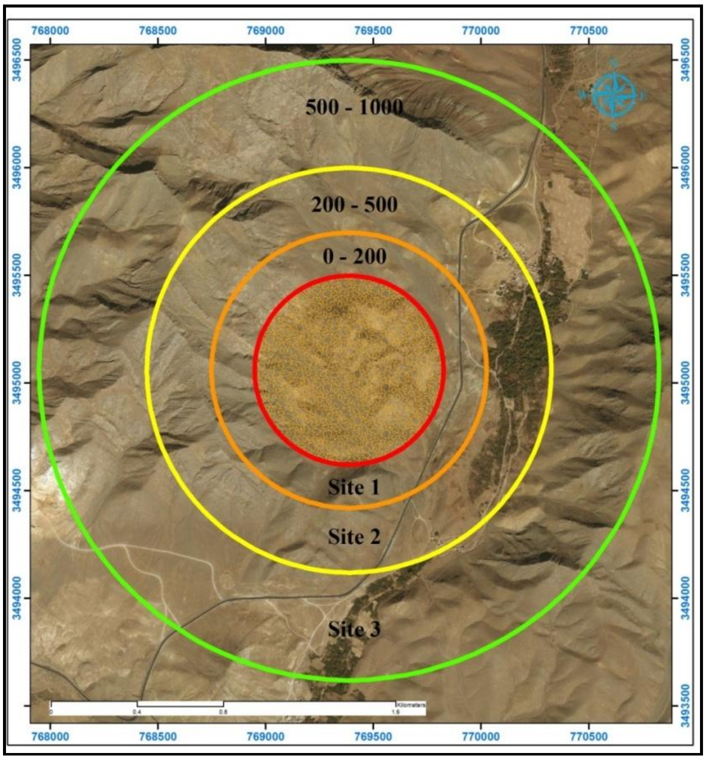

Fig. 2. Location of study sites in rangelands around Dareh Zereshk copper mine

Based on LFA method, at each site, three 50 m transects (depending on the conditions of the area and the type and distance of the vegetation) were laid out randomly along the slope and for each ecological patch, five replications were considered. In each transect, data on the length and width of patches were collected for bushes, grasses, forbs, and biological components patches and inter-patches (bare soil).

In each replication, 11 soil parameters were assessed based on the LFA method instruction such as rain splash protection, perennial vegetation cover, litter, cryptogam cover, crust brokenness, soil erosion types and severity, deposited materials, soil surface roughness, surface nature (resistance to disturbance), slake test and texture (Tongway and Hindley, 2004). In Table 3, a brief explanation is given about the soil surface indices, the number of classes and the relationship of each of them with the functional characteristics of stability, infiltration and nutrient cycling.

To evaluate three functional characteristics including stability, infiltration and nutrient cycling and to calculate 11 soil surface indicators, the LFA software designed in the Excel was used. The means of functional characteristics were compared using One-way ANOVA.

Table 3. Relationship between 11 characteristics with stability indicators, infiltration and nutrient cycle (Tongway and Hindley, 2004)

Row	Indicators	Stability	Infiltration	nutrient cycle	Number of classes
1	Rain splash protection-surface cover percentage to evaluate the level of soil protection against rain drops	×			5
2	Perennial vegetation cover-percentage of perennial vegetation cover (Calculate through the length of transect). The objective is to estimate the basal cover and/or canopy cover of bushes, trees and perennial grass		×	×	4
3	Litter including percentage of annual grasses and ephemeral herbage, To assess the amount, origin and degree of decomposition of plant litter	×			10
4	Cryptogam cover-including cover of fungi, algae, lichens, mosses and liverworts along the transect		×	×	4
5	Crust brokenness, the degree of surface crust that is broken, with the aim of assessing the amount of soil that has the potential for erosion	×			4
6	Soil erosion type and severity, determining the type of erosion (rills and gullies, terracettes, sheet erosion, scalding, pedestalling) and its severity in the assessment area	×			5
7	Deposited materials-percentage of soil and litter materials that exposed to erosion. The objective is to assess the nature and amount of alluvium transported to and deposited on the query zone that implies stability	×	×	×	4
8	Soil surface roughness, soil surface micro topography for its capacity to capture and retain water, prop gules, topsoil and organic matter.		×	×	5
9	Surface nature (resistance to disturbance). determine the hardness of the soil through finger pressure or pen to evaluate soil resistance to erosion	×	×		5
10	Slake test-assess the stability of natural soil fragments to rapid wetting	×	×		5
11	Soil texture-determine texture of the surface soil to determine infiltration		×		4

Results

A. The structure of vegetation at different distances from mine

The results showed that mining had a significant impact on vegetation structure and caused the loss of a major part of the vegetation in the area close to mine. The results of means comparison using Duncan's test showed a significant difference between three area distances from the mine for the length and width of ecological patches, the percentage of patch coverage, the number of patches/10 m, total patches area, patch area index and landscape structure index ($p<0.05$). As the distance from the mine increases, the vegetation of structure factor such as Total length of the patch, coverage percent, and number of patches/10 m, etc. significantly increase (Table 4). It should be noted that the inter patch includes the bare soil, litter and plant humus and annual plants.
Different letters represent a significant difference at the level of $P <0.01$ with Duncan's test.

Table 4. The mean structural properties of ecological patches and inter-patches spacing at different intervals of the mine

Distance from the mine	Ecological patch						
	Total length of the patch (m)	Coverage percentage	No of Patches/10 m	Total surface area (m^2)	Patch Surface index	Landscape Organization Index	Inter-patch spacing (m)
0-200m	4.30±0.51[b]	15.80±0.11[c]	4.30±0.03[c]	3.81±0.17[b]	0.02±0.01[b]	0.15±0.76[b]	1.62±0.42[a]
200-500m	7.14±0.21[ab]	28.34±0.37[b]	4.77±0.32[b]	9.71±0.39[ab]	0.05±0.04[ab]	0.29±0.12[ab]	1.12±0.46[ab]
500-100m	10.27±0.66[a]	37.46±0.50[a]	5.01±0.12[a]	25.55±0.38[a]	0.13±0.12[a]	0.40±0.09[a]	0.78±0.16[b]

B. Evaluation of 11 soil surface indices

The soil surface cover in the mining area and closer to the mine was the lowest and by increasing distance from the mine, the amount of vegetation cover was increased. As moving into the mine area, the amounts of vegetation in particular, perennial plants, litter and cryptogam cover were reduced. A decline in soil crust brokenness at distances away from the mine was observed but near the mine, its value was increased. In addition, the amount of erosion and sediment deposited near the mine increased (Table 5). Far from the mine (500-1000m), Surface roughness was higher than two other sites. It decreased near the mine, mostly the hollows were in a class of 3-8 mm and a further distance (8-25 mm class). In the manipulated area surrounding the mine, the mechanical strength of the soil increases due to the movement of machinery and compact soil surface and soil stability decreases according to the stability test index (Table 5).

Table 5. Score points for assessing soil surface indices at various distances from the mine

Soil surface indices	Distance from the mine		
	0-200m	200-500m	500-1000m
Soil cover (%)	1.9	2.8	3.9
Perennial plant cover (%)	1.8	2.23	3.35
Litter cover (%)	6.1	8.5	10.2
Cryptogam cover (%)	1	1.1	1.8
Soil crust brokenness	1.45	1.65	2.46
Erosion type & severity	2.93	2.1	1.95
Deposited materials	3.5	3.12	2.45
Soil surface roughness	2.6	2.8	3.5
Soil surface resistance to disturb	3.15	3.1	2.6
Slake test	2.3	2.5	3.4
Soil texture	2.3	2.54	2.72

C. Means of the functional properties of ecological patches at three sites

In this part of the study, ecological patches were compared in terms of function regardless of the number and level of ecological patches in each site. There were three vegetative forms including grass species, forbs and bushes in rangelands that created different ecological patches. Duncan's test results showed that there was a significant difference between the various ecological patches and inter patches areas in the site far from the mine in terms of stability and nutrient cycle but in terms of infiltration, significant differences were not observed between ecological patches. However, in terms of infiltration, there were significant differences between the ecological patches and inter patches space.

The complex(plants in a patch can be single or complex) ecological patches had the highest value of functional indicators (stability, infiltration and nutrient cycle) and inter patches had the least values. In addition, there was a significant difference between ecological patches in three sites(Table 6). Different letters represent a significant difference at the level of P <0.01 with Duncan's test.

Table 6. Comparison of the functional properties of ecological patches at different distances from the mine

Distance from the mine	Ecological patch	Stability	Infiltration	Nutrition cycling
0-200m	Grass	37.13±0.16[b]	21.29±0.13[b]	19.32±0.51[b]
	Forb	41.05±0.63[ab]	31.16±0.26[a]	22.81±0.24[ab]
	Shrub	40.53±0.34[ab]	29.33±1.36[ab]	20.69±1.10[b]
	Compound patch	51.22±1.36[a]	32.09±0.29[a]	28.70±0.46[a]
	Inter-patch	25.18±0.36[c]	15.629±0.43[c]	13.12±0.41[b]
200-500m	Grass	31.32±0.30[b]	24.26±0.32[b]	17.29±0.10[b]
	Forb	34.46±1.6[ab]	30.71±0.03[ab]	21.76±1.33[ab]
	Shrub	37.73±0.92[ab]	29.27±0.15[ab]	17.68±2.02[b]
	Compound patch	51.32±1.67[a]	34.14±0.30[a]	29.48±0.33[a]
	Inter-patch	20.82±0.30[c]	19.26±0.32[c]	11.20±0.50[c]
500-1000m	Grass	36.41±3.30[b]	26.21±0.31[a]	19.40±0.66[b]
	Forb	39.46±1.03[b]	28.12±3.40[a]	24.66±0.14[ab]
	Shrub	46.60±0.98[ab]	29.95±0.28[a]	25.51±0.62[ab]
	Compound patch	52.32±0.14[a]	31.54±1.13[a]	34.21±0.01[a]
	Inter-patch	21.41±0.83[c]	20.21±031[b]	1.84±0.16[b]

D. Comparison of total functional indices at different distances from the mine

The functional indices of stability, infiltration and nutrient cycle were significant between two sites far from the mine (500- 1000 m) and near the mine (0-200m) while intermediate distance from the mine (200- 500 m) with two other sites had no significant difference (Table 7). Different letters represent a significant difference at the level of P <0.01 with Duncan's test.

Table 7. Comparison of total functional indices at different distances from the mine

Distance from the mine	Stability	Infiltration	Nutrition cycling
0-200m	31.64±0.66[b]	21.22±0.61[b]	18.61±0.38[b]
200-500m	38.62±0.66[ab]	26.26±0.18[ab]	21.43±0.09[ab]
500-1000m	45.17±0.17[a]	29.14±0.36[a]	24.13±0.14[a]

Discussion and Conclusion

Mining is one of rangeland degradation factors that can lead to changes in structure, function and efficiency of ecosystem in different ways. The results of this research showed that mine extraction may lead to changes in rangeland structure around the mine and much of the vegetation surrounding the mine was disappeared.

As the distance from the mine increases, the amount of vegetation cover increases. There was a significant difference of vegetation cover percent at different distances from the mine. The higher vegetation cover percent and the possibility of ecological patches far away from the mine can be attributed to lack of manipulation, maintenance of soil surface moisture and litter accumulation. According to the results, the presence of perennial plants far from the mine caused the formation of numerous patches. Also, in the handicapped areas near the mine, vegetation consisted mostly of annual plants and due to the lack of perennial plants, the number of patches was the least.

In this regard, plowing and manipulating the rangeland have been mentioned as an important factor in reducing the plant number (Arzani *et al.*, 2007). In the vicinity of the mine, along with manipulation and soil degradation, the number of patches and their surface area decreased, which is an indicator of the destruction of the landscape due to human activities.

Noymeir (1973) described this and explained the function of the landscape and the improvement of the environmental conditions in the storage of water and resources by patches. Patches far from the mine (500-1000m) are distributed almost uniformly. Therefore, increasing the indicator of the organization of the landscape and in other words, the level of capability and potential of the landscape far away from the mine is justifiable. Also, with the start of mining, the existing stones and pebbles have been eliminated as an obstacle to erosion, and it increases the sensitivity of the area to erosion. As a result, the cover structure and the index of landscape system near the mine as compared to the two distances (middle and far distance) have significantly decreased. Holm *et al.* (2002) showed that the indices of vegetation patches affect the level of structural indices. These results are consistent with the published data (Boer and Sargent, 1998; Jouzagyan *et al*., 2016; Azimi *et al*., 2018).

According to the results, there was a significant difference for length of ecological patches at different distances from the mine. So, soil consistency at a distance away from the mine was low. While the mining areas were completely free of any cover. The complete removal of vegetation in the mining areas had accelerated the erosion process. Tongway and Ludwig (2002) also point out that the removal of vegetation in mineralized logic is one of the most destructive activities that can occur in an ecosystem. Generally, habitats with the widespread and continuous bare soil have inadequate structure than habitats with less continuous soil (Gould, 1982). It is clear that patches are effective in improving landscape function as compared to the inter patch.

Changing soil surface indices showed that mining increased rangeland degradation. Soil cover far from the mine had a higher score due to the relatively good vegetation cover of perennial plants that is in accordance with Kavianpour *et al.* (2015). The amount of litter was increased far from the mine due to the perennial vegetation and decreased in the surrounding area of the mine.

Far from the mine due to habitat stability and proper flow pattern, surface erosion was less than that expected for the habitat, but in the near distance to the mine, surface erosion became more severe as a result of soil manipulation and compaction due to the stability. The lower erosion far away from the site led to lower amount of sedimentation material. Near the mine, roughness of the soil decreased due to the crossing of heavy machinery while in the more distance from the mining area due to the presence of perennial plants, trenches and soil peaks resulted in high surface roughness. This surface roughness allows for greater permeability and can provide a safe environment for seed and litter accumulation. In the mine area by heavy vehicles, the surface soil becomes very rigid and requires a lot of mechanical force to excavate it, and with decreasing soil organic matter and vegetation, soil stability decreases and with increasing distance from the mine and increasing vegetation and litter and organic matter from their decomposition, soil stability is increased. It was in agreement with Kavianpour *et al.* (2015).

The results showed that ecosystem structure (vegetation patches) had different and significant effects on soil stability, Permeability, and nutrient cycle due to shape, percentage of area, height and percentage of vegetation and litter. Bradshaw *et al.* (1984) in their study of dryland grasslands stated that different vegetative forms have different effects on soil stability and permeability due to differences in root structure and permeability, and vegetative forms having larger dimensions have more effect on soil stability.

In the study area, the combined patches had the highest values in terms of stability, permeability and nutrient cycle indices. Mesdaghi and Ghobadi (2010) in studies on the effect of different vegetation forms on soil surface characteristics stated that the presence of combined patches increased both shoot and leaf area per unit area, thus providing an opportunity for decomposition of plant residues that increased the three indices studied. Heshmati *et al.* (2007) also reported that composite patches integrate the properties of different shapes; as a result, canopy cover, litter and root volume increase, resulting in stability, permeability and nutrient cycling. The results of the studies by Tangway and Hindley (2004) and Jafari *et al.* (2015) about the role of more blended patches on soil parameters are consistent with the results of this study. Also, the lowest percentage of soil function indices was due to the inter patches and the lack of effective vegetation, litter and physical barrier.

The diversity and increasing number of ecological patches in remote rangelands, the irregular pattern and disruption of water flow in them, and also the existence of small and separate patchy spaces have increased the stability index far from the rangelands. The results of this study are in agreement with those of Karami *et al.* (2018), Arzani *et al.* (2007), Mesdaghi and Ghobadi (2010) and Arab Sarbijan *et al.* (2016). Also, the presence of perennial plants and litter in low and high altitudes and short water flow patterns significantly increased the permeability and cycle of nutrient far from the mine. The relative decrease in function in the vicinity of the mine can be attributed to the compression of the soil by the movement of heavy machinery, the stagnation of the soil, the reduction of vegetation and surface roughness and the removal of vegetation, which reduced the return of organic matter to the soil and more precisely with reduction in organic matter, the aggregate stability decreases, and after the soil compacted, the permeability and cycle of the elements are reduced.

According to the results of this study, soil surface indices were well indicative of rangeland degradation in mining areas that could be used to determine rangeland degradation thresholds. Consequently, the effect of human activities on the function and structure of the ecosystem can be investigated using the LFA method.

In general, although the activity of mines causes destruction, mines in rangelands cannot be ignored. Therefore, laws that are more stringent should be put in place by governments to force miners to modify soil and cover after harvest and to monitor the government as well.

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اثر بهره‌برداری از معادن بر ساختار و عملکرد اکوسیستم مراتع با استفاده از روش تحلیل عملکرد چشم‌انداز (LFA) (مطالعه موردی: معدن مس دره زرشک در استان یزد)

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چکیده. به‌منظور ارزیابی اثر استخراج مس از معدن دره زرشک واقع در استان یزد، بر ساختار و عملکرد اکوسیستم مراتع اطراف معدن سه مکان مطالعاتی، در فواصل مشخص از معدن (۲۰۰-۰، ۵۰۰-۲۰۰ و ۱۰۰۰-۵۰۰ متر) در نظر گرفته شد. این تحقیق از سال ۱۳۹۲ الی ۱۳۹۳ صورت گرفت. در هر مکان، سه ترانسکت خطی به‌طول ۵۰ متر در جهت شیب منطقه، مستقر شدند. ویژگی‌های ساختاری لکه‌های اکولوژیک و فضای بین‌لکه‌ای در طول هر ترانسکت، اندازه‌گیری و شاخص سازمان‌یافتگی چشم‌انداز برای هر واحد اکولوژیک (فاصله از معدن)، محاسبه شد. برای هرکدام از لکه‌ها و فضای بین لکه‌ای در طول هر ترانسکت، پنج ناحیه سنجش، در نظر گرفته شد و با استفاده از دستورالعمل شاخص‌های ارزیابی سطح خاک، تعداد ۱۱ شاخص سطح خاک، امتیازدهی و تعیین طبقه شدند. بر مبنای نتایج حاصل از امتیازدهی شاخص‌های سطح خاک، ویژگی‌های عملکردی رویشگاه شامل؛ پایداری، نفوذپذیری و چرخه عناصر غذایی برای هر یک از لکه‌ها و فضای بین‌لکه‌ای و به‌تبع آن برای هر واحد اکولوژیک، محاسبه شد. بر اساس نتایج، شاخص سازمان‌یافتگی چشم‌انداز و ویژگی‌های عملکردی، در فاصله نزدیک به معدن (۲۰۰-۰ متر)، با فاصله دور از معدن (۱۰۰۰-۵۰۰ متر)، اختلاف معنی‌دار داشت($p<0/05$). اما بین فاصله متوسط از معدن (۵۰۰-۲۰۰ متر) با دو مکان دیگر (فاصله کم و فاصله زیادتر)، تفاوت معنی‌داری مشاهده نشد($p>0/05$). از طرف دیگر، عملکرد انواع لکه‌های اکولوژیک، در فواصل مختلف از معدن، دارای تفاوت معنی‌دار بودند($p<0/05$). به‌طوری‌که از لحاظ شاخص‌های عملکردی، لکه‌های ترکیبی بیشترین مقدار و فضای بین لکه‌ها، کمترین میزان را دارا بود. نتایج بیانگر کارایی روش تحلیل‌عملکرد چشم‌انداز به‌منظور ارزیابی تخریب‌های ناشی از معدن‌کاوی و پیگیری هر نوع بازسازی متعاقب آن می‌باشد.

کلمات کلیدی: لکه‌های اکولوژیک، فضای بین‌لکه‌ای، خصوصیات خاک، معدن دره زرشک