DESERT 2022, 27(1): 141-152
DOI: 10.22059/JDESERT.2022.88600

RESEARCH PAPER

Landscape Function Analysis along Precipitation Gradient in the Rangeland of Southern Al-Jabal Al -Akhdar, Libya

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Received: 6 December 2021, Revised: 12 December 2021, Accepted: 3 February 2022

Abstract
The southern slope of Al-Jabal Al-Akhdar in northeastern Libya is a model for the desertification process, as it witnesses a sharp deterioration due to the prevailing climatic conditions and irrational human activities. We conducted the present research in the rangeland of southern Al-Jabal Al –Akhdar to investigate the effects of annual precipitation gradient on landscape function and soil surface condition. The study area was divided into three levels of annual precipitation (high, medium, and low precipitation). We randomly selected 10 sites for each precipitation level. Three line transects were taken for each site. Landscape Function Analysis methodology (LFA) was applied to assess soil surface condition. The Least Significant Difference (LSD) test was also used. The results showed the significant effect of annual precipitation on all the soil surface condition indices. The highest SSI was at the high level with a mean of 49.8% and the lowest was at the medium level with an average of 44.6%, with a highly significant difference (P=0.000). The WII was low in all the precipitation levels, and highly significant differences were found; the same results could apply to NCI. LOIs of the three levels were reasonably close (0.063, 0.042, and 0.058) without any significant differences. A decrease was observed in PN with the direction to the south. The results revealed that landscape functioning in the study area was significantly different from the impact of rainfall. It is necessary to develop different plans for each area according to its climatic conditions in order to combat erosion and conserve soil, as an essential natural resource.
Keywords: LOI, SSI, WII, LFA, Libya

Introduction

Libya spreads over an area of 1.7 million Km^2, approximately 90% of which is desert. Rangelands constitutes 148,330 Km^2 , and forests and woodlands cover 3,380 Km^2 of Libya (Mahmoud *et al*., 2021). About 12,672 km^2 of the Libyan rangelands are considered to be critical areas, in which about a half million people are affected (Bai *et al*., 2008). According to the Arab Organization for Agricultural Development, many regions in Libya have begun to show signs of degradation in rangelands and are also exhibiting reduced plant cover. Land degradation can have a disastrous impact on the entire ecosystem. The decreased vegetation cover, lack of flora variety, dominance of unpalatable plant species, reduction in wildlife, leaching of minerals from the soil, crusting and compacting of soil, collection of water, sedimentation, and an increase in the saline content of both household and farm water supplies, are a number of the undesirable effects caused by degradation (Kapalanga, 2008; Zucca *et al*., 2015).

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The southern slope of Al-Jabal Al –Akhdar (the Green Mountain), in northeastern Libya, is a model for the desertification process, as it witnesses a sharp deterioration. The ecosystem in the region is at risk of desertification due to the prevailing climatic conditions and irrational human activities. Rugged terrain and slopes, and the spread of fragile rock formations highly susceptible to water erosion made its soil structurally susceptible to deterioration due to the confinement of the natural vegetation cover, nature of the hilly land, and the increase in water runoff, especially during the winter season, which indicates the presence of water erosion (Mahmoud *et al*., 2008). Removing the natural vegetation cover and replacing it with annual crops provides less protection for the top soils and dramatically increases the rate of water run-off, which leads to accelerated soil erosion. The overloaded range over the logging vegetation cover and plantation of marginal land, on which grain crops with low productivity are grown, has tilted the precarious balance of semi-arid and arid areas, causing a further increase in the spread of desert and erosion of soil (Gebril and Saeid, 2012). Uncontrolled grazing and all-season presence of plants have led to the loss of the necessary soil protection. The incidence and rates of soil erosion in Al-Jabal Al –Akhdar are controlled mainly by different types of land use and soil cover; however, it dependents on the topography and annual precipitation (Aburas *et al*., 2001; Ali, 1995). Most of the natural environment-related factors have a role in creating a very fragile and sensitive environment for erosion under irrational human use. Al-Jabal Al –Akhdar is located in a transitional area between the coast and the Sahara, making it more susceptible to climate changes. Despite the increase in land degradation in the Jabal Al-Akhdar region, accurate documentation of its spread and future impact requires further effort and investigation. Therefore, through this research, the soil surface condition and the effects of the annual precipitation rate on landscape functions in the southern slope of Al-Jabal Al –Akhdar were assessed, which enables us to have a more comprehensive understanding of the erosion problem at the local level. It also assists decision-makers in making the right decisions to combat erosion and conserve and preserve soil, as a very important natural resource.

Materials and Methods

Study area

As shown in Figure 1, the study area is located on the steppes southern slope of Al-Jabal Al-Akhdar, northeast Libya, between 32°N, and 21°E, covering an area of about 2000 km^2. The climate in the area is arid to semi-arid. The rainy period starts in September and continues until February, which is characterized by fluctuation and irregularity. The annual precipitation ranges from about 50 to 250 mm / year (Figure 2). The average temperature ranges from 0°C in January to up 35°C (Mahmoud *et al*., 2016). The dominant winds are northwestern in summer and northeastern in winter, and from southeast (Gibli), winds blow over the region, which are hot winds accompanied by sand waves. The average wind speed is 10-25 km/hr. and on a number of occasions, it reaches 60 km/hr. The permanent vegetation cover is dwarf shrub-steppe consisting of *Artemisia herba-alba* and *Haloxylon scoparium*, which occupy the low hills and the undulating and narrower alluvial plains (Mahmoud *et al*., 2021).

Methods

The study area was divided into three levels based on the annual precipitation, namely high (>200mm/year), medium (100 – 200mm/year), and low precipitation (50-100mm/year), using the annual precipitation maps in Libya, which were collected and matched from several trustworthy references (ARC-ICARDA, 2008; Blanchet *et al*., 2021; Deitch *et al*., 2017; El-Tantawi, 2005; Hamad, 2012; Mahmoud, 2016). The annual precipitation gradually decreases to the south direction towards the Sahara Desert. We randomly selected 10 sites for each level of precipitation (Appendix A).

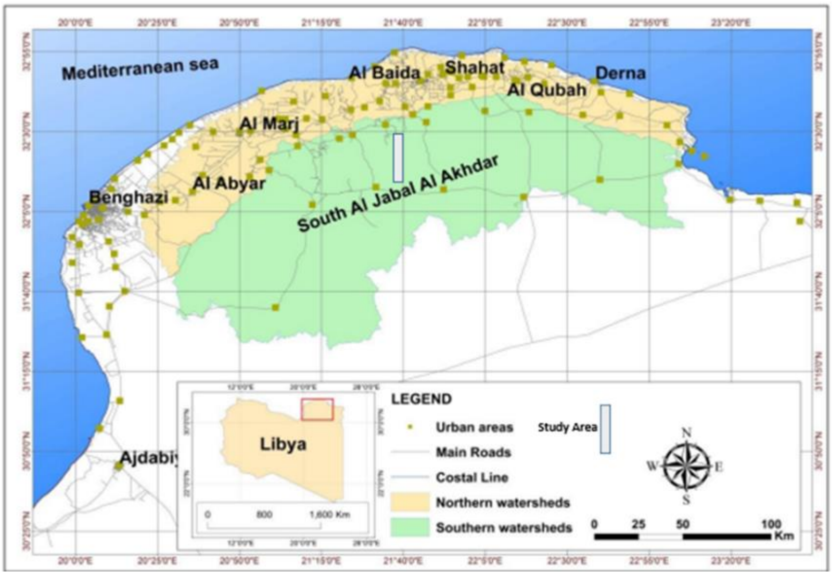

Figure 1. Geographical location of the study area (Hamad, 2019)

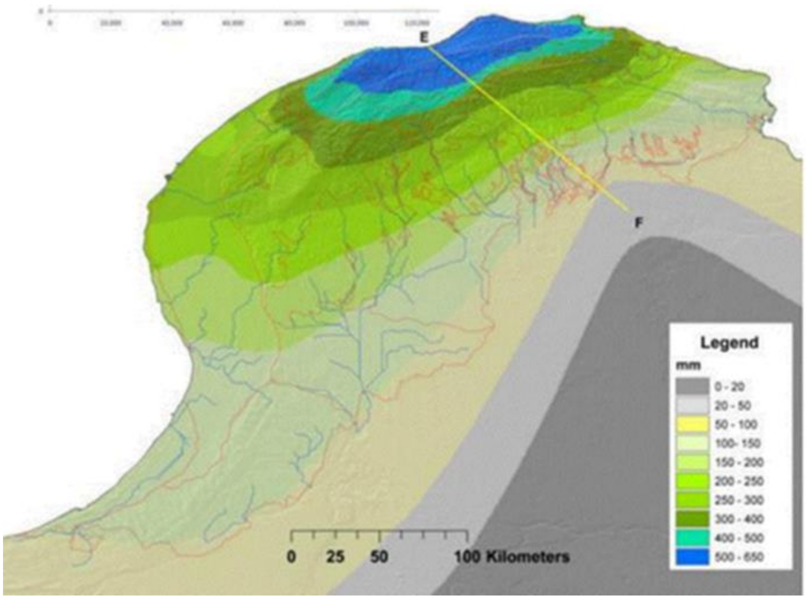

Figure 2. Distribution of the annual rainfall in northeastern Libya (ARC-ICARDA, 2008)

Soil Surface Condition Assessment, and Patch and Interpatch Structure

Landscape Function Analysis methodology (LFA) was applied (Mahmoud *et al*., 2014; Russell, 2007). Field data were collected using quadrate 1m^2 on a line transect (100m length) oriented in the direction of the water runoff. Three-line transacts were taken for each site. We collected 11 field indicators of soil surface data, as follows: litter over, ground cover, cryptogam cover, litter origin, the resistance of soil surface to distribution, erosion features, deposited materials, nature of soil surface, soil micro topography, soil texture, and slake test. The field data summarized three major soil surface condition indices, namely (1) Soil Stability Index (SSI), (2) Water Infiltration Index (WII), and (3) Nutrient Cycling Index (NCI) (Lau *et al*., 2008). Patch and interpatch data were collected along the line transect for each site. After entering the data into an LFA data-entry spreadsheet, the following indices were obtained: the number of Patches/10 m (PN), Total Patch Area (TPA), and the Landscape Organization Index (LOI) (Table1).

Table1. Landscape function and soil surface assessment indices

Index Name	Code	Units	Assessment
Soil Stability Index	SSI	0 - 100	Soil Surface Assessment
Water Infiltration Index	WII	0 - 100	Soil Surface Assessment
Nutrient Cycling Index	NCI	0 - 100	Soil Surface Assessment
Number of Patches	PN	n/10m	Landscape Heterogeneity
Total Patch Area	TPA	m^2	Landscape Heterogeneity
Landscape Organization Index	LOI	0 - 1	Landscape Heterogeneity

Statistical Analysis

The Least Significant Difference (LSD) test was applied using SPSS software, where the precipitation level was an independent factor and landscape function indices were dependent variables. The level of significance was 5 %.

Results

Soil Surface Condition Assessment

Surface stoniness is the most common in a high level of precipitation, where it is mainly found in hilltop and slopes. In numerous sites, stones cover more than half of the surface (Appendix B). However, the surface cover of rocks is considerably less in wadis. Surface crusts are found in most sites with crust hardiness varying from low to high. Numerous cracks often fragment the crust, usually more than 2mm wide, which permit water infiltration. The results showed the significant effect of annual precipitation level on all the soil surface condition indices. SSI was below 50% at the three levels (Figure 3) as it was slightly lower than the average in the three levels of annual precipitation; the highest SSI was in the high level with a mean of 49.8% and the lowest was in the medium level with an average of 44.6%, with a highly significant difference (P=0.000). According to the results, the WII was low in all the precipitation levels, and highly significant differences were found between the averages of the high level and the other two levels. On the other hand, there were no significant differences between the medium and low levels (P=0.403); the same results apply to the NCI (Table 2). Nevertheless, the highest average of all the soil surface condition indices belonged to the high level of precipitation.

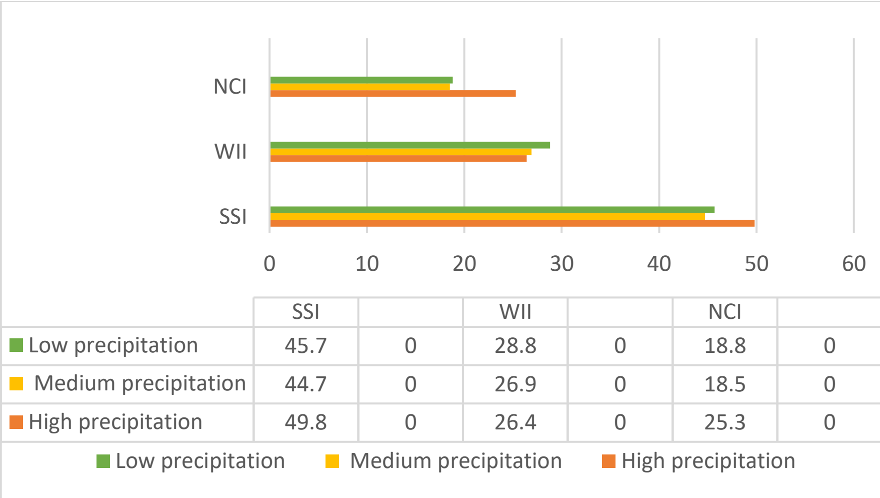

Figure 3. Descriptive statistics results of soil surface condition indices

Table2. Multiple comparisons between the means of SSI, WII, and NCI

Dependent Variable		(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	P Value
SSI	LSD	1.00	2.00	5.14667*	.42390	.000
			3.00	4.10667*	.42390	.000
		2.00	1.00	-5.14667*	.42390	.000
			3.00	-1.04000*	.42390	.016
		3.00	1.00	-4.10667*	.42390	.000
			2.00	1.04000*	.42390	.016
WII	LSD	1.00	2.00	6.73333*	.62608	.000
			3.00	6.20667*	.62608	.000
		2.00	1.00	-6.73333*	.62608	.000
			3.00	-.52667	.62608	.403
		3.00	1.00	-6.20667*	.62608	.000
			2.00	.52667	.62608	.403
NCI	LSD	1.00	2.00	6.84333*	.62780	.000
			3.00	6.50000*	.62780	.000
		2.00	1.00	-6.84333*	.62780	.000
			3.00	-.34333	.62780	.586
		3.00	1.00	-6.50000*	.62780	.000
			2.00	.34333	.62780	.586
			3.00	.00500	.01149	.664

*. The mean difference is significant at the level of 0.05.
1= high precipitation; 2= medium precipitation; 3= low precipitation.

Landscape Heterogeneity

LOI was very low in all the precipitation levels without any significant differences; the mean values of the three levels were reasonably close (0.063, 0.042, and 0.058, respectively) (Figure 4). The results revealed a significant increase in Total Patch Area (TPA) in the high level of precipitation compared to the medium and low levels (P= 0.003 and 0.000, respectively). Generally, TPA was very low in all the precipitation levels. As for PN, an apparent decrease was observed with the direction to the south, where rainfall rate drops, with highly significant differences (Table 3).

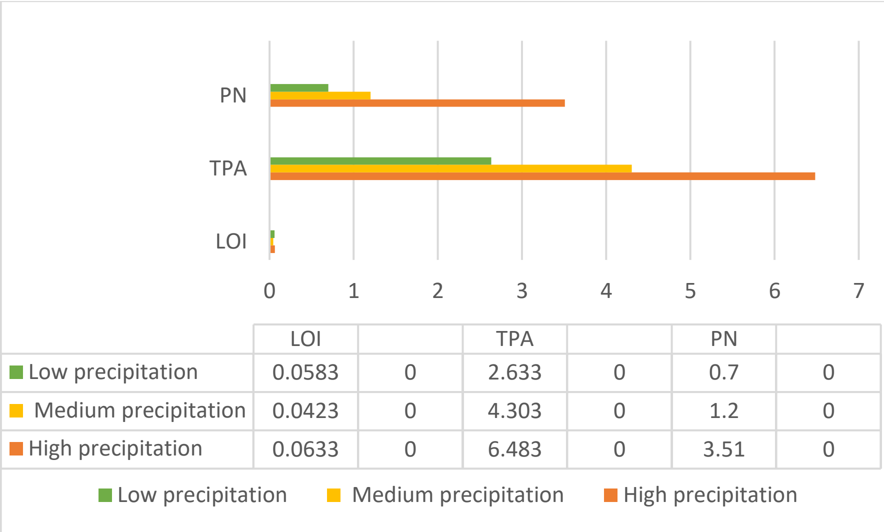

Figure 4. Descriptive statistics results of landscape heterogeneity indices

Table 3. Multiple comparisons between the means of landscape heterogeneity indices

Dependent Variable		(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	P Value
LOI	LSD	1.00	2.00	.02100	.01149	.071
			3.00	.00500	.01149	.664
		2.00	1.00	-.02100	.01149	.071
			3.00	-.01600	.01149	.167
		3.00	1.00	-.00500	.01149	.664
			2.00	.01600	.01149	.167
TPA	LSD	1.00	2.00	2.18000*	.71724	.003
			3.00	3.85000*	.71724	.000
		2.00	1.00	-2.18000*	.71724	.003
			3.00	1.67000*	.71724	.022
		3.00	1.00	-3.85000*	.71724	.000
			2.00	-1.67000*	.71724	.022
PN	LSD	1.00	2.00	2.31000*	.19610	.000
			3.00	2.85000*	.19610	.000
		2.00	1.00	-2.31000*	.19610	.000
			3.00	.54000*	.19610	.007
		3.00	1.00	-2.85000*	.19610	.000
			2.00	-.54000*	.19610	.007

*. The mean difference is significant at the level of 0.05.
1= high precipitation; 2= medium precipitation; 3= low precipitation.

Discussion

Since there are no breaks between the three studied areas, no boundaries are separating them. Still, the change is gradual with the direction to the south; thus, by comparing the northern (high precipitation), middle (medium precipitation) and southern (low precipitation) parts of the region, clear differences were observed, which give an idea of the extent of this change as a result of the difference in geographical location, where conditions become more severe with the direction towards the south.

The study results indicated significant effects of the annual precipitation gradient on most soil surface indices. This effect decreases with the similarity of soil mechanical composition, where the soil texture is similar in the areas of medium and lower levels of precipitation

(Appendix C). However, it should be noted that considerable variations in the LFA-SCA indices existed between the three levels of precipitation. The variations still lacked consistency between the medium and low levels. Therefore, no significant differences were found between the averages of some indices associated with the two levels (WII, NCI, and LOI). For the current research study area, the bio-crust cover (cryptogam cover) is relatively low (below 1% in all the study sites) (Appendix B) since the establishment of bio-crust communities is not affected by strong winds and the sandy texture of the soil. This resembles conclusions from factors, such as the creation of desert pavements, which are widespread in the study area due to predominance of wind erosion that tend to facilitate the stability of soil within such ecosystems. Moreover, the high percentage of silt in the mechanical structure of soil may have helped the reduction in the effects of erosion factors (Appendix C). Therefore, the locations with diverse vegetation cover can attain identical stability index values in certain situations where the existing desert pavements can provide stability while others rely on vegetation covers. The results of the statistical analysis previously listed showed a medium SSI in the three levels of precipitation. Accordingly, the soil was in a medium level of stability, which is due to low vegetation coverage. On the other hand, silt, which was medium in the soil, may have a role in this, as it is the most important soil particle that work on soil granule cohesion according to Mahmoud (2008)**.** In dry-lands, the proportion of mineral colloids is usually low until it allows the formation of soil granules that improve its texture. The silt particles have no colloidal properties, but they are so soft that they can fill all the gaps inside the soil, whether large or small, and reduce the aeration and infiltration and thus soil fertility. Furthermore, the low percentage of organic matter in the soil may reduce the stability of the secondary particles as stated by Kemper and Koch (1966).

WII means were close and slightly below the average, which may be due to soil texture. The latter is supported by the findings of Catarina and Clasandström (2000), where they found that among many factors studied, including soil texture, vegetation cover, slope, and type of land use, it was found that vegetation cover and soil texture were the most important factors affecting soil infiltration. At a high level of rainfall, the indices showed higher infiltration. WII predicted bare-soil infiltration rate and hill slope runoff better than simple soil functioning indicators, such as soil organic carbon, stone cover, crusted bare-soil cover, bulk-density, and plant cover (Mayor and Bautista, 2012). Bartley *et al*. (2006) concluded that the loss of sediment from the hillsides was low due to below-average rainfall, meaning that the annual precipitation factor may be more influential than the topography factor. The bare patches significantly affect runoff and soil loss from hill slopes. It is also an indication that the hill slopes must have medium to high patches of cover to entrap and store sediment and reduce the adverse effects of rainfall on soil properties. The correlation factor was positive between TPA and runoff (Muñoz-Robles *et al*., 2011). Patches and inter-patches are functional units from an eco-hydrological perspective within semi-arid rangelands, which affect soil hydrology and erosion irrespective of vegetation condition. Franlab (1975) concluded that for many reasons, the infiltration of surface water in the study area would be more favorable than the above-ground storage. Further research of some sites in various water-shed areas could be recommended. The highest NCI was obtained in the high level of precipitation. On the other hand, the results indicated that NCI in the medium and low levels is very low, which may be because most of the selected sites in these regions tend to lead towards the southern direction (Ata Rezaei *et al*., 2006). The values of NCI for all the study sites represented the harsh climate conditions of the location as NCI was seen to decrease in the southern study area. Furthermore, the noticeable reduction in the percentage of organic matter in the soil was expected due to the severe decline in vegetation cover that characterizes the study area, as well as the low humidity and high annual average temperature; this is consistent with what most local previous studies have reported (Mahmoud *et al*., 2021;

SWECO, 1986; Zatout, 2014). The positive and negative effects of cattle-grazing patterns on NCI can be seen. The positive impact is observed as a result of adding organic matter to the soil. The negative effect indirectly arises with the decrease in or removal of vegetation cover, which will decline nutrient cycling. However, without grazing management and control, the adverse effects of overgrazing will immediately overpower the results of the positive impacts; this phenomenon could be observed in many of the sites in the study area.

In general, LOI was found to have decreased in the low and medium levels of precipitation while in the high level, it increased insignificantly. The variation in LOI was very low (very low Standard Deviation). The large patches at the medium level can be attributed to the low grazing intensity. However, the patch size was reduced with the increase in grazing intensity (Mahmoud *et al*., 2021; Mirreh and Diranai, 2014). With the rise in grazing intensity, a decrease in fertile patches is inevitable. A reduction in the number of patches is a sign of landscape degradation attributable to inappropriate management activities (Yari *et al*., 2012). Moreover, an increase in degradation will lead to a substantial reduction in the width of palatable patches. The low value of the Landscape Organization Index reflects the harsh conditions of the southern location, and indicates that the area is undergoing the process of desertification.

TPA converged a lot between the high and medium levels of precipitation despite the apparent increase in the high level (visibly), and this could be due to shrub size and distribution, where it was close and small in the high level; meanwhile, it was further and larger in the medium level. As for the low level, it had a very low TPA compared to the other levels, and in general, it can be said that the TPA and PN are reduced with the direction to the south; the same trend could be observed for biodiversity (Gadalla, 2014). This is due to the decrease in the annual precipitation with the direction to the south. Nevertheless, the inter-patch area was higher than the patch area. In addition, the three LFA indices were significantly lower in the low level of precipitation. The results implied that the study area landscape functioning was considerably owing to the impact of rainfall. The natural vegetation cover in the low and medium levels of precipitation is very sparse; what exists is usually restricted to dry wadi-beds, rocky pockets, and various depressions. However, a reasonably dense vegetation cover can be found on the wadi alluvial fans to the south, benefiting from run-off water. This cannot be attributed only to the low average rainfall; overgrazing also similarly affects soil surface condition and the southern part of the study area, which receives a low average precipitation compared to the northern part, was also observed to have a large number of grazing animals. The vegetation in the high annual precipitation level is also sparse and does not cover the entire soil surface. Meanwhile, it is more differentiated and contains a higher proportion of herbs. The natural vegetation cover is severely degraded by over-grazing and cultivation activities.

The spatial discrepancy in the amounts of rain is one of the apparent phenomena that characterizes the rain in the study area. It may happen those quantities of rain fall over one area while not a single drop falls in the other nearby areas that are only a few kilometres away (SWECO, 1986). The geographical location of the study area affects the amount of annual precipitation; the location of the area behind the northern slope on the south slope and its distance from the sea, has put it in the rain shadow area. Active northern winds drop most of their load of rain as they ascend to the northern slope, and therefore, these winds do not reach the southern slope unless most of their load has been unloaded. Thus, the northern and western regions with rainy winds are more humid compared to the south.

Conclusion

In general, the results of our research revealed the apparent effect of annual precipitation on landscape functions and soil surface condition in the southern slope of Al-Jabal Al-Akhdar. Through the results, it could be said that landscape functions deteriorate with a decrease in the annual precipitation. Still, it seems as if other factors have an effect on soil surface condition in the study area, such as soil texture, topography, and wind. Accordingly, the focus should be on wind erosion in the southern part and water erosion in the northern part; for example, the use of water harvesting techniques could be extended in the areas with a high precipitation level while in those with a low precipitation level, controlling cattle grazing by installing exclosures (fenced areas) could be done in order to minimize over-grazing. On account of the vast area of southern Jabal Al-Akhdar rangeland, extensive research is required to give us a more comprehensive understanding of erosion processes so that appropriate programs could be developed, which combat this phenomenon and reduce the speed of the desertification process and the encroachment of Sahara sand. Developing other plans for each region according to its climatic conditions is essential to combat erosion and conserve soil, as a vital natural resource.

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Appendices

Appendix A. Sites coordinates

Precipitation Level	Site	GPS	
		N	E
High	1	32°.26'.711"	21°.18'.801"
	2	32°.26'.711"	21°.18'.704"
	3	32°.26'.298"	21°.18'.604"
	4	32°.26'.291"	21°.18'.511"
	5	32°.26'.208"	21°.18'.444"
	6	32°.26'.641"	21°.18'.151"
	7	32°.26'.461"	21°.18'.787"
	8	32°.26'.466"	21°.18'.879"
	9	32°.26'.523"	21°.18'.953"
	10	32°.26'.468"	21°.18'.840"
Medium	11	32°.03'.294"	21°.11'.385"
	12	32°.03'.987"	21°.11'.556"
	13	32°.03'.725"	21°.11'.657"
	14	32°.03'.730"	21°.10'.971"
	15	32°.03.589"	21°.11'.561"
	16	32°.03'.389"	21°.10'.980"
	17	32°.03'.497"	21°.11'.379"
	18	32°.03'.736"	21°.11'.545"
	19	32°.04'.407"	21°.11'.956"
	20	32°.04'.476"	21°.11'.957"
Low	21	32°.01'.060"	21°.17'.063"
	22	32°.01'.000"	21°.18'.013"
	23	32°.01'.163"	21°.17'.399"
	24	32°.01'.129"	21°.17'.342"
	25	32°.01'.119"	21°.17'.473"
	26	32°.00'..353"	21°.30'485"
	27	32°.01'.221"	21°.29'004"
	28	32°.01'.894"	21°.26'.872"
	29	32°.01'.822"	21°.26'.650"
	30	31°.92'.188"	21°.31'.084"

Appendix B. The means of field indices used for soil surface assessment

Precipitation Level	Site	Soil Cover %	Litter Cover %	Cryptogam Cover %	Crust Broken-ness	Erosion Features	Soil Micro-Topography mm	Deposited Materials %
High	1	1 - 15	< 10	< 1	Slight	Slight	3 - 8	5 – 20
	2	1 - 15	< 10	< 1	Slight	Extensive	3 - 8	5 – 20
	3	1 - 15	10 - 25	< 1	Slight	Moderate	3 - 8	0 – 5
	4	1 - 15	< 10	< 1	Slight	Slight	3 - 8	5 – 20
	5	15 - 30	25 - 50	< 1	Slight	Slight	3 - 8	0 – 5
	6	1 - 15	10 - 25	< 1	Slight	Slight	3 - 8	0 – 5
	7	1 - 15	< 10	< 1	Slight	Moderate	3 - 8	5 – 20
	8	1 - 15	10 - 25	< 1	Moderate	Extensive	3 - 8	5 – 20
	9	1 - 15	< 10	< 1	Moderate	Extensive	3 - 8	5 – 20
	10	1 - 15	< 10	< 1	Moderate	Extensive	3 - 8	5 – 20
Medium	11	1 - 15	< 10	< 1	Slight	Slight	3 - 8	20 - 50
	12	1 - 15	1 - 10	< 1	Slight	Slight	3 - 8	20 - 50
	13	1 - 15	< 10	< 1	Slight	Insignificant	3 - 8	5 - 20
	14	1 - 15	1 - 10	< 1	Slight	Insignificant	3 - 8	0 - 5
	15	1 - 15	< 10	< 1	Slight	Insignificant	3 - 8	5 - 20
	16	15 - 30	1 - 10	< 1	Slight	Insignificant	3 - 8	0 - 5
	17	< 1	< 10	< 1	Extensive	Slight	8 - 25	0 - 5
	18	1 - 15	< 10	< 1	Moderate	Moderate	< 3	20 - 50
	19	1- 30	10 - 25	< 1	Moderate	Moderate	3 - 8	0 - 5
	20	1 - 15	< 10	1 - 10	Moderate	Extensive	< 3	>5
Low	21	< 1	10 - 25	< 1	Slight	Insignificant	< 3	0 - 5
	22	1 - 15	10 - 25	< 1	Slight	Insignificant	< 3	0 - 5
	23	1 - 15	10 - 25	< 1	Slight	Insignificant	< 3	5 - 20
	34	< 1	< 10	< 1	Moderate	Insignificant	< 3	5 - 20
	25	1 - 15	< 10	< 1	Slight	Insignificant	< 3	0 - 5
	26	< 1	< 10	< 1	Extensive	Moderate	< 3	0 - 5
	27	1 - 15	< 10	< 1	Moderate	Insignificant	< 3	0 - 5
	28	< 1	< 10	< 1	Slight	Insignificant	< 3	0 - 5
	29	1 - 15	< 10	< 1	Extensive	Moderate	< 3	0 - 5
	30	< 1	< 10	< 1	Extensive	Moderate	< 3	0 - 5

Appendix C. Means of some physical properties of the soil in the study areas

Level of Precipitation	Field soil Humidity %	Mechanical Analysis %			Organic Matter %	
		Clay	Silt	Sand	Patch	Interpatch
High	4.74	44.31	40.05	15.18	4.40	2.47
Medium	2.62	36.27	34.31	29.12	3.84	3.05
Low	2.17	27.68	29.5	41.15	3.51	2.72

(Mahmoud *et al.*, 2021)