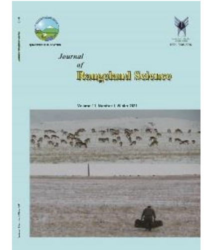

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**Research and Full Length Article:**

# Rangeland Restoration Analysis on the South Slope of Al-Jabal Al-Akhdar, Northeast Libya

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**Abstract.** This study was conducted on the south slope of Al-Jabal Al-Akhdar (the Green Mountain) rangelands, northeast Libya to investigate changes in perennial plant species richness, landscape function and soil surface condition in order to determine whether exclosures are effected strategy for the improvement and rehabilitation of rangeland ecosystem at the regional level. Four study sites were positioned along a strong north-south rainfall gradient. A total of 28 monitoring sites were reinstalled and assessed between May and December 2014, the sites were then initially installed and assessed between the period of May and December 2006. The monitoring site layout was based on the Western Australia Rangeland Monitoring System (WARMS). The response variables measured were those included in the protocols of Landscape Function Analysis technique (LFA). Based on the results, LFA indices were in the low and medium scales in all of the monitoring sites within the exclosures. Notably, it is considered a good comparison tool for what it is currently occurring in the target grazing areas. No changes in perennial plant species richness amid the study areas, with the exception of the Thahar Altair area. Overall, in estimation, at least 10 years of protection from grazing is required in the higher rainfall area (Maduar Zetun), and a considerably longer period in the lower rainfall areas to the south before vegetation cover and soil surface conditions recover sufficiently to be re-exposed to grazing. Consequently, grazing should be controlled to conserve national forage resources.

**Key words:** Ajramiah, Libyan rangelands, Exclosures, LFA, NCI, WII

## Introduction

Rangelands are among the most important resources to support the national economy, and are an essential foundation to support and develop the animal products industry. Sustainable and renewable, if used correctly. Rangelands cover an area of over 37.5 million $km^2$ or almost 61% of all the dry lands all over the world, however, the estimation of the land areas considered rangelands vary from 18% to 80% (Lund, 2007; Middleton and Thomas, 1997). Nevertheless, rangelands face constant threats due to human encroachment, erosion, wearing, and the effects of drought.

Rangelands in the western part of North Africa are situated in the region between the Sahara desert and marine coastal areas, where harsh conditions of the environment prevail. Low and erratic rainfall, high temperatures with high rates of evaporation, and shallow and poor soils make up the environmental conditions in these regions. Management of the mentioned range lands in terms of sustainable forage production remains a major challenge.

Libya, with an area of 1.7 million $Km^2$, 148,330 $Km^2$ is rangeland, and 3,380 $Km^2$ covers forests and woodlands. The South Al-Jabal Al- Akhdar Project in Northeast Libya commenced in 1973 and currently is continuing under the name Pasture Development Project (PDP). This major governmental project is attempting to improve the condition of large areas of the range lands via a variety of strategies, including seasonally controlled grazing, construction of numerous check damns, digging of channels and the establishment of cereal and fodder farms. This project has recently established a series of exclosures, many of which are planted with exported species such as, *Atriplex rosea*, *Atriplex vesicaria*, *Eucalyptus sp* and *Acacia cyanophylla*. There are also exclosures where natural vegetation recovery is being allowed to occur. This provided an opportunity to assess and analyze rangeland recovery, as well as degradation, within both protected and open areas for grazing.

Extensive grazing by sheep, goats and camels occurs in the southern slope of the Al-Jebel Al-Akhdar rangelands. Severely degraded soil and vegetation are widespread (Gebril and Saeid, 2012; Mahmoud *et al.*, 2008). The amount of grazing animals in the region is considered so large, that the natural range land area cannot provide livestock with its full requirement of forage. This amount has increased from 119,800 in 1980, to 152,930 in 2008 (Abdalrahman *et al.*, 2010). The Al-Jabal Al-Akhdar ecosystem is at risk of desertification due to the prevalent climatic conditions of Libya. Though the rangelands are situated to the south of the Al Jabal Al Akhdar zone, they are still in a pristine state, and self-sustainable enough to deal with minor ecosystem problems.

Degradation effects are propagated through processes of commencing with inappropriate or unsustainable land use practices, which eventually result in a substantial, near permanent decline in ecosystem health and productivity. Signs of degradation in the south of the Al Jabal Al Akhdar include marked reduction or complete loss of vegetation cover, accelerated soil erosion, increases in dust storms, edaphic drying, reduced biodiversity, as well as reduced habitat diversity and primary productivity. In a comprehensive study, Swedish Environmental Consultancy (SWECO) reported that pasture yield in the study's rangelands falls somewhat below the average for the Mediterranean Basin (SWECO, 1986). Forage Production was low in the grazing rangeland when compared with exclosures in the study area (18.69 and 6.66 g $m^{-1}$, respectively), as reported in 2006 (Sanosi, 2008).

## Importance of the Study

Approximately 90% of the area occupied by Libya is a desert with the exception of the Al-Jabal Al-Akhdar region and the coastal strip. Al-Jabal Al-Akhdar (the green mountain), is a range in northeastern Libya in Cyrenaica, a province long renown for verdant mountains, spectacular Mediterranean coastline and well-preserved ancient Greek architecture. It is the highest range in northern Libya. It forms board promontory in the Mediterranean Sea, bound to the west by Wadi Al Bab and the east by the Bay of Bombah (SWECO, 1986).

According to World Conservation Monitoring Centre, the total species number of existing plants tends to 2059. It cannot be categorized as rich flora when compared to the country at large. The Maquis is the natural vegetation, occupies the Al-Jabal Al-Akhdar region. Even though the region represents almost 1% of the area covered by the country, it still forms Libya`s richest part with respect to biodiversity. Over 50% of the total plant species present in this region, which is over 1100 different plant species, 75 of which are endemic (El-Darier and El-Mogaspi, 2009). It should also be noticed that this region is home to a variety of medicinal and aromatic plant flora.

## Previous Work in the Study Area

The Food and Agricultural Organization (FAO) has been working in Libya since 1950, the FAO tested 860 forage species for re-seeding of degraded native species. Between 1954 and 1960, the United States (US) Technical Assistance Program was active in Al- Jabal Al- Akhdar. Work by US technicians included establishing methods for improved range and pasture management through increased forage production and controlled grazing, re-vegetation techniques and natural recovery through protection of areas. This program was then managed by the Libyan government from 1960 (F.A.O, 1964).

The Libyan Agricultural and Livestock Research Centre (ARLC) was established in 1976. Rangeland research was undertaken by the Range Management Unit of the Natural Resources Division of ARLC (with FAO assistance) in a number of fields. These included seeding, fertilizer trials, forage production, and the planting of fodder shrubs and trees, and the chemical analysis of fodder. The work also included the genetic conservation of the most valuable indigenous forage plants such as *Medicago* species and other rangeland shrubs. Between 1981 and 1986, SWECO, a Swedish Environmental Consultancy, undertook a very comprehensive survey of over one million hectares of Al- Jabal Al-Akhdar. The work included topographic surveying, mapping of soil and vegetation, pasture land improvement study (SWECO, 1986). The work is very well documented and is essentially detailed range ecology and management study of this region, providing much useful background information.

In 2004, a preliminary study by Omar Mukhtar University commissioned by the management of Al-Jabal Al-Akhdar Project Authority. The study documented the status of soil, forests, pastures and rangelands in the region, covering about 300,000ha, using 54 sites represented a range of conditions from good to poor, including areas affected by fire, plantation of *Pinus halepensis* and *Eucalyptus spp*. The study report makes a number of more specific recommendations and also identifies the need for the integration of socio-economic factors in future natural resource management plans. Follow up studies are proposed. In the period of 2005 and 2011, cooperation occurred between Omar Mukhtar University and the south Al-Jabal Al-Akhdar project from the Libyan side, along with the Curtin University of Technology and Centre for the Management of Arid Environments from

Western Australia. The Australian side presented a work proposal (Russell, 2006). The project took six years, and included three component projects: Plant Species Diversity, Landscape Function Analysis (the first time the LFA method had been applied in the North African Rangelands), and Soil Surface Condition and forage production (Gadallah, 2014; Mahmoud *et al.*, 2008; Sanosi, 2008).

Zatout (2014) conducted a study on plant species' richness and biodiversity at the study site, and revealed that the impact of livestock had caused the collection of surface soil due to overgrazing, thus causing a change in the region's biodiversity. Consequently, these steps caused the deterioration and degradation of land quality. The dominance and explosive growth of certain varieties of plants able to grow in dry climates and rangelands, along with palatable species like *H. scoparia*, *Piturauthos tortuosus*, *Anabasis articulata*, *Artemisia herba alba* and *Retama raetam*, were witnessed (Gebril and Saeid, 2012; Mahmoud *et al.*, 2008; Zatout, 2014).

In this study, we aim to investigate changes in perennial plant cover, landscape function and soil surface conditions in open grazing and protected areas at the study site, in order to discover whether the exclosures (fenced areas) are an effective method for the regeneration and rehabilitation of range land conditions at the regional level.

## Materials and Methods

### The Study Area

The study area as shown in Fig. 1 is located on the southern slope of the Al-Jabal Al-Akhdar area, northeast Libya located approximately 32° N, and 21° E, with an area of about 3000 km².

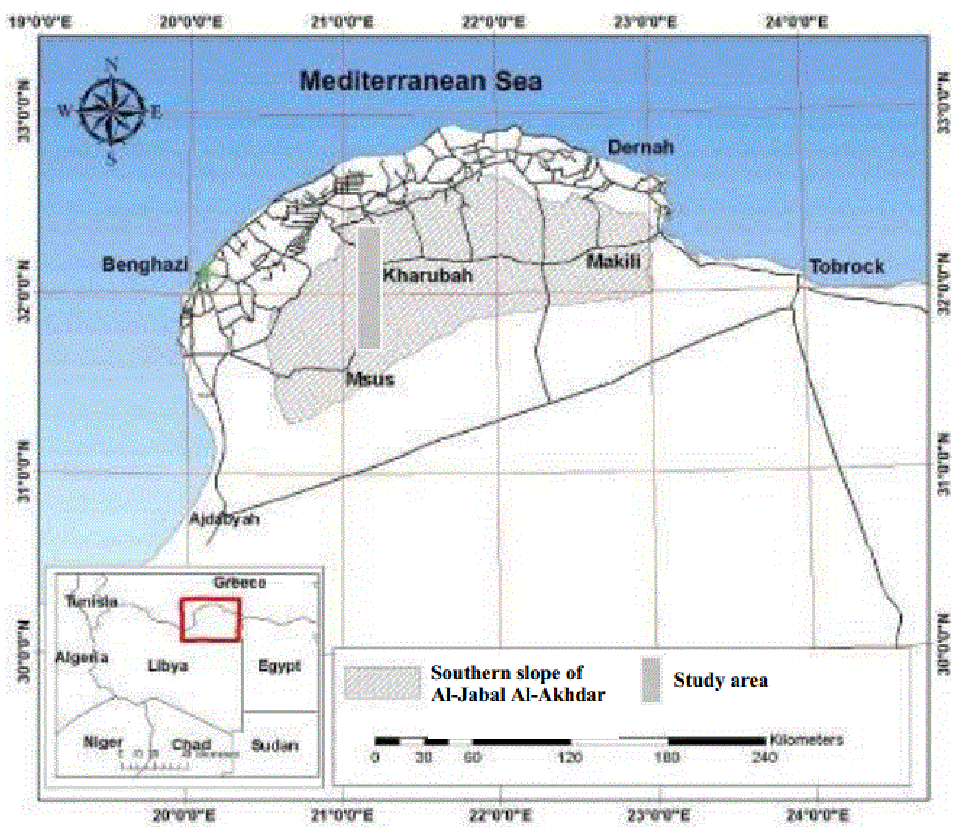


**Fig. 1**. Southern Al-Jabal Al-Akhdar map show the location of study area (Hamad, 2012)

### Description of Research Localities

Four research areas exhibiting moderately to severely degraded soil and vegetation, namely Madur Zetun (MZ), Omguzlan (OG), Thahar Altair (TT) and Ajramiah (AJ), were selected along a strong north-south rainfall gradient. (Table 1 and Fig. 2). Exclosures are situated at the three northern locations only. The AJ location is an open area for grazing that experiences overgrazing. Furthermore, the area receives very low average of rainfall. In 2006, two monitoring sites were selected in the AJ area, which boarder the Sahara Desert, and five an indicator in regards to the desertification process in the area. Monitoring sites were re-installed in order to monitor the changes in soil and vegetation cover under these harsh environmental conditions, over an eight year period.

**Table 1.** Summary Description of Study Areas

| Study Area Name | Study Area Code | Exclosure Area ha | Installation date | Average Rainfall mm/year |
|---|---|---|---|---|
| Maduar Zetun | MZ | 125 | 2001 | 250 |
| Omguzlan | OG | 220 | 1993 | 150 |
| Thahar Altair | TT | 25 | 2002 | 100 |
| Ajramiah | AJ | Open area | - | <50 |

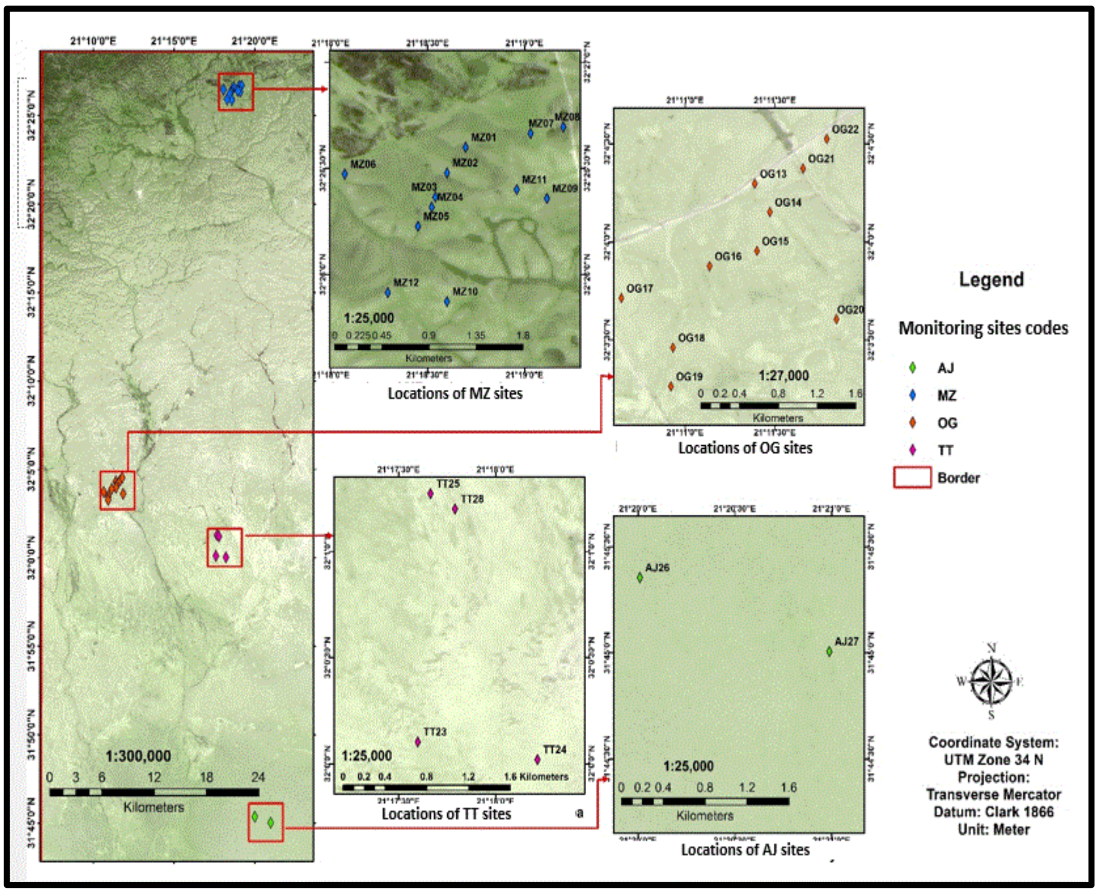


**Fig. 2.** The Selected Research Areas

## Location, Physiographically, Climate and Vegetation

Al-Jabal Al-Akhdar forms the northeastern extent of the Libyan plateau. The range forms an arcuate upland plateau approximately 250km long (E-W) by 100km wide (N-S) with the highest elevation (882m above sea level) occurring in the vicinity of the village al Faidiyah at approximately longitude 21°50' E, and latitude 32°40' N, just southern the city of Al Baida. The terrain is rugged. The plateau rises abruptly, step-like, from a narrow coastal plain as a series of deeply dissected escarpment, then from the plain intersected by vales and eventually to flat alluvial plains with wide outwash fans delivering seasonally intermittent flood water to several large flat areas depressions, at about 150 m above sea level. The climate is Mediterranean characterized by winter rainfall (November to March or April) generated by southeast migrating cold fronts arising in central and western Europe and long dry summers (May to October) typified by the hot dry northward moving Ghibli wind from the Sahara and associated dust storm. The rainfall range in the region is <50 to 550 mm per year and temperatures reach below Zero in January and up to 35°C in July and August. Fog is a common in the winter month.

At lower elevations and reduced rainfall, a belt of dwarf shrub steppe consisting of *Artemisia herba-alba* and *Haloxylon scoparium* occupies the low hills, and the undulating and narrower alluvial plains. Further south, a steppe of stem and leaf succulents occupy the board flat alluvial plains and drier undulating plains. Species in this formation include *Haloxylon scoparium*, *Anabasis articulata*, *Suaeda pruinosa*, and *Salsola tetrandra* (SWECO, 1986).

## Perennial Plant Species Richness Index

Perennial plant species richness' signifies the number of perennial plant species at each exclosure site (Russell, 2007). Initially, a large area assessment of perennial vegetation change has taken place from the rangeland monitoring sites in Libya. Results are derived from four areas located within roughly 3000 $km^2$ of arid shrub lands in the southern slope of Al-Jabal Al-Akhdar.

A list of all the perennial plant species (grasses, shrubs and trees) in the study area have been used as a reference within the exclosures at each of the research localities (Table 2). The list is a result of an inventory survey conducted by our Libyan-Australian team in 2006 as part of a plant species diversity study (Gadallah, 2014). Colleagues from the Faculty of Natural Resources and Environmental Sciences (Omar Al- Mukhtar University), accompanied by an expert on perennial plant species, took part in the survey.

**Table 2.** List of Perennial Plant Species in the Exclosure area of Madur Zetun and Omguzlan

| Madur Zetun Area | | | Omguzlan Area | | |
|---|---|---|---|---|---|
| No. | Species name | Family | No. | Species name | Family |
| 1 | *Pituranthos tortuosus* | Apiaceae | 1 | *Pituranthos tortuosus* | Apiaceae |
| 2 | *Thapsia garganica* | Apiaceae | 2 | *Periploca augustifolia* | Asclepiadaceae |
| 3 | *Achillea santolia* | Asteraceae | 3 | *Artemisia herba-alba* | Asteraceae |
| 4 | *Artemisia herba-alba* | Asteraceae | 4 | *Atractylis serratuloides* | Asteraceae |
| 5 | *Atractylis serratuloide* | Asteraceae | 5 | *Phagnalon graecum* | Asteraceae |
| 6 | *Echinops cyrenaicus* | Asteraceae | 6 | *Anabasis articulata* | Chenopodiaceae |
| 7 | *Phagnalon graecum* | Asteraceae | 7 | *Atriplex halimus* | Chenopodiaceae |
| 8 | *Scorozorera undulate* | Asteraceae | 8 | *Atriplex rosea* | Chenopodiaceae |
| 9 | *Varthemia sp.* | Asteraceae | 9 | *Atriplex vesicaria* | Chenopodiaceae |
| 10 | *Helianthemum virgatum* | Cistaceae | 10 | *Hamada scoparia* | Chenopodiaceae |
| 11 | *Anabasis articulata* | Chenopodiaceae | 11 | *Salsola tetrandra* | Chenopodiaceae |
| 12 | *Atriplex halimus* | Chenopodiaceae | 12 | *Suaeda pruinosa* | Chenopodiaceae |
| 13 | *Hamada scoparia* | Chenopodiaceae | 13 | *Ephedra altissima* | Ephedraceae |
| 14 | *Nonaea mucronats* | Chenopodiaceae | 14 | *Andrachne telephioides* | Euphorbiaceae |
| 15 | *Suaeda vermiculata* | Chenopodiaceae | 15 | *Retama raetam* | Fabaceae |
| 16 | *Salsola tetrandra* | Chenopodiaceae | 16 | *Salvia triloba* | Lamiaceae |
| 17 | *Astragalus caprnius* | Fabaceae | 17 | *Acacia cyanophylla* | Mimosaceae |
| 18 | *Iris sisryncum* | Iridaceae | 18 | *Acacia karroo* | Mimosaceae |
| 19 | *Marrubium vulgare* | Lamiaceae | 19 | *Eucalyptus sp* | Myrtaceae |
| 20 | *Teucrium polium* | Lamiaceae | 20 | *Limonium thouninii* | Plumbaginaceae |
| 21 | *Phlomis floccosa* | Lamiaceae | 21 | *Limonium tubiflorum* | Plumbaginaceae |
| 22 | *Thymus capitatus* | Lamiaceae | 22 | *Cynodon dactylon* | Poaceae |
| 23 | *Asparagus stipularis* | Liliaceae | 23 | *Polygonum equisetiforme* | Plumbaginaceae |
| 24 | *Stipa parviflora* | Poaceae | 24 | *Ziziphus lotus* | Rhamnaceae |
| 25 | *Poa bulbosa* | Poaceae | 25 | *Reaumuria vermiculata* | Tamaricaceae |
| 26 | *Stipa lagascae* | Poaceae | 26 | *Fagonia cretica* | Zygophyllaceae |
| 27 | *Dactylis glomerata* | Poaceae | 27 | *Peganum harmala* | Zygophyllaceae |
| 28 | *Limonium tubiflorum* | Plumbaginaceae | | | |
| 29 | *Emex spinosus* | Polygonaceae | | | |
| 30 | *Polygonum equisetiformi* | Polygonaceae | | | |
| 31 | *Ziziphus lotus* | Rhamnaceae | | | |
| 32 | *Sanguisorba minor* | Rosaceae | | | |
| 33 | *Reaumuria vermiculata* | Tamaricaceae | | | |

## Monitoring Site Layout and Installation

A total of 28 monitoring sites were reinstalled and assessed between May and December 2014. The sites were initially installed and assessed between May and December 2006, and were installed within the exclosures and other open areas. The chosen sites displayed plant cover of less than 30%, a decreased functionality, and apparent indicators of degradation. The monitoring site layout is based on the Western Australia Rangeland Monitoring System (WARMS) (Watson *et al.*, 2007), usually consisting of a photographed area or photo plot to provide a permanent visual record of change, and a series line transects. In Australia, three line transects per each monitoring site were set; but in the Libyan range land, we modified this by adding two additional lines to reduce experimental errors, since the vegetation cover is more sparse compared to that in Western Australia. Each line exhibited dimensions of 100 m length by 4 m width (area of 400 $m^2$), with a combined area of 2,000 $m^2$ (Fig. 3).

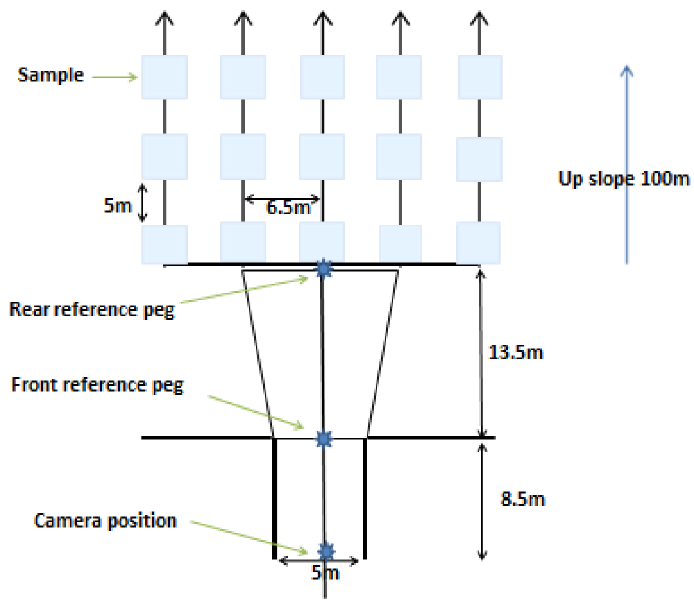


**Fig. 3.** The Monitoring Site Layout

Post-installation, the latitude and longitude aspect and orientation of each monitoring site, as well as the slope implementing a Clinometer, were determined using a GPS device. The landform, vegetation type, and soil type were described for each monitoring site as well.

## Landscape Function Analysis, Soil Surface Condition Methodology

To achieve the objectives of this research, we put forward LFA methodology (Tongway and Hindley, 2004). Regarding LFA, data were collected on a line transect oriented in the direction of the resource flow. Soil surface data were composed in different combinations to reflect three major soil habitat quality indices, namely: (1) Soil Stability Index (SSI), (2) Water Infiltration Index (WII) and (3) Nutrient Cycling Index (NCI) (Fig. 4).

Amid each site, five line transects were used to collect field data. Eleven indicators of soil surface data are implemented as follows: litter cover, ground cover, cryptogam cover, litter, resistance of the soil surface to distribution, erosion features, deposited materials, nature of soil surface, soil micro topography, soil texture and slake test. In addition, the Soil Surface Condition index (SSCI) was utilized in this research. This index, developed by Russell based on the work by Tongway, forms part of his doctoral research (Russell, 2007). SSCI is the sum of SSI, WII, and NCI, reflecting the overall soil surface health. Perennial vegetation cover and arrangement presents a vital indicator of whether landscapes lose or retain soil resources. Consequently, the LFA method characterizes landscape organization, measure patch and inter-patch structure. Patches are long-lived features that obstruct or divert water flow, and collect or filter out material from run-off such as perennial plants, rocks > 10 cm and tree branches in contact with the soil (Tongway and Hindley, 2004). Once data have been inserted in specialized software, it summarizes the landscape organization, including the number of Patches/10m, total patch area (TPA), average inter patch length (m), range inter patch length and lastly, landscape organization index.

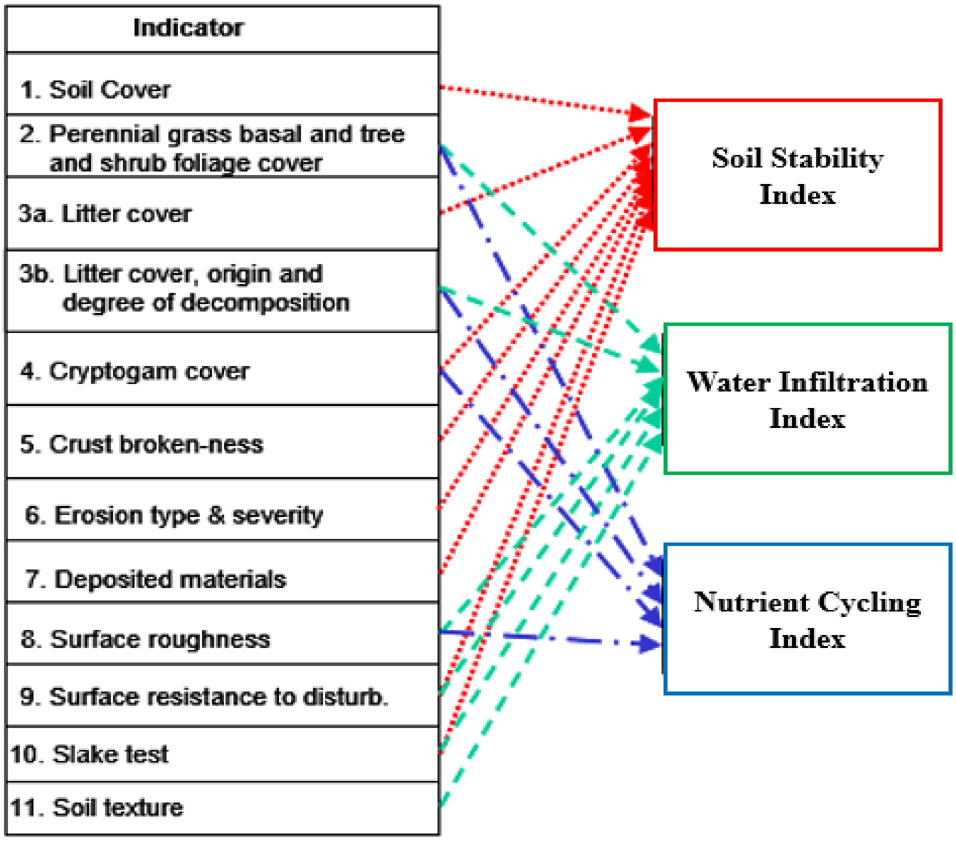


**Fig. 4.** The Field Indices That Lead to Emergent Indices (Tongway, 2010)

## Sampling Design and Statistical Analysis

Five samples were collected at each monitoring site (1 sample per line): each sample exhibits the mean of 20 replications. For the field samples data collection, a 1m$^2$ quadrate was used along the line transect with a distance of 5m between each of the two samples (20 quadrate per line). The LFA-SSA-data-entry spreadsheet (Tongway and Ludwig, 2011) was implemented to calculate LFA-SSC indices. SPSS software version 20 was employed for all statistical analysis (SPSS Inc., Chicago, IL, USA). Across all statistical testing, significant differences were regarded as probability values of less than 5%. We hypothesized a positive significant difference in the LFA indices between the fenced rangelands, and those open for grazing, as well as between 2006 and 2014. A non-parametric statistical hypothesis test (Wilcoxon signed-rank test) was conducted in order to examine this hypothesis by comparing the Medians of LFA indices (Woolson, 2008). It has been chosed to employ this test instead of a t test after checking the normality of data.

## Results

### Perennial Species Richness Index

33 and 29 perennial plant species in the three exclosures were identified in the first and second surveys, respectively. The entirety of the recorded species is related to 14 families (Appendices 2 and 3). Amid the exclosures of MZ and OG, the Perennial Species Richness Index (PSR) was noted to be higher (32 and 27 respectively). Meanwhile, in the rangelands of TT and AJ the PSR was noted to be significantly lower (14 and 1 respectively). No changes in perennial plant species richness were observed amid the study areas, with the exception of the Thahar Altair area (Table 3).

**Table 3.** Perennial Plant Species Richness inside the Exclosures

| Study Area | Species Richness Index | |
|---|---|---|
| | 2006 | 2014 |
| Maduar Zetun | 32 | 32 |
| Omguzlan | 27 | 27 |
| Thahar Altair | 14 | 10 |

The outcome indicates a decline in the number of perennial plant species in the fenced rangeland of Thahar Altair where four species had already disappeared. All the lost species were planted and exported from Australia including *Atriplex rosea*, *Atriplex vesicaria*, *Eucalyptus sp*., and *Acacia cyanophylla* (Table 4). This negative change is due to very low rainfall, as well as the high mortality rates of the planted shrubs (Fig. 5).

**Fig. 5.** High Mortality rate of Planted Shrubs

**Table 4.** Perennial Plant Species inside the Exclosure of Thahar Altair Location

| No. | Species | Family |
|---|---|---|
| 1 | *Anabasis articulata* | Chenopodiaceae |
| 2 | *Atriplex halimus* | Chenopodiaceae |
| 3 | *Atriplex rosea* * | Chenopodiaceae |
| 4 | *Atriplex vesicaria* * | Chenopodiaceae |
| 5 | *Hamada scoparia* | Chenopodiaceae |
| 6 | *Salsola tetrandra* | Chenopodiaceae |
| 7 | *Suaeda pruinosa* | Chenopodiaceae |
| 8 | *Eucalyptus sp* * | Myrtaceae |
| 9 | *Atractylis serratuloides* | Asteraceae |
| 10 | *Pituranthos tortuosus* | Apiaceae |
| 11 | *Acacia cyanophylla* * | Mimosaceae |
| 12 | *Peganum harmala* | Zygophyllaceae |
| 13 | *Polygonum equisetiformis* | Polygonaceae |
| 14 | *Asparagus stipularis* | Liliaceae |

*=Missed species

These results indicate that protecting the native vegetation is an effective strategy for the improvement and rehabilitation of rangeland conditions compared with planting foreign species. Consequently, our results assert that the process of restoring semi-arid steppes via plantation of woody shrubs does not require a prior phase for the reconstruction of ecosystem functions. Our results indicate that the potential for improving ecosystem functions and fostering succession, which is using these species, seems to be limited in arid rangelands. Furthermore, our findings are in line with related studies conducted in North Africa (Derbel *et al.*, 2009; Mahmoud *et al.*, 2008; Zucca *et al.*, 2013). Qualities of plant biodiversity have been termed as an imperative determiner of dry area ecosystem operations (Maestre *et al.*, 2012), and are equally linked to the inception of desertification procedures in such localities (Jauffret *et al.*, 2003; Lezama *et al.*, 2014; Zatout, 2014). The finding has emphasized that plant species richness is one of the important indices of rangeland environment health. Furthermore, current results tend to demonstrate that grazed sites basically have a low number of perennial plant species when compared to those protected by fencing.

## Soil Surface Assessment (Grazing vs. Fenced Areas)

A high distribution was observed in soil stability inside all the fenced rangelands where the values of above 39.6% and below 64.1% of the threshold were recorded. In terms of higher indices, slightly lower Soil Stability Index (SSI) values were recorded in the open areas for grazing, while fenced areas recorded slightly higher values. In general, the changes were positive and significant except in the TT area. It should be noted that some physical soil properties in the study areas positively affect soil stability; even the ones with very low vegetation cover. The soil mechanical structure is the most effective property where the silt was found to be very high in most soils of the study area, reaching 40% in some monitoring sites (Table 5).

Compared to the grazing areas, the soil in the fenced areas is stable, this is manifested in plant produce and behavior such as litter fall and infiltration of water (Ludwig *et al.*, 2005; Tongway and Ludwig, 2007). This ranking also exemplifies the high heterogeneity in plots, where each monitoring site has LFA values that are both high and low. The low Infiltration indices imply that most of the quadrats have a tendency to discard excess rainwater instead of infiltrating it with the soil.

Data from the LFA-SSA results, as well as the field data of LFA produced a very low mean in Nutrient Cycling Index (NCI), both inside and outside all the protected areas. Also, a very high variation in the NCI value was noted amidst all study areas. The results showed that NCI positively affects protection efforts in all locations, however, this index increased insignificantly in the TT area. According to most of the other LFA-SSA indices, negative changes were found to occur inside the TT area plantation, so the rise in NCI may be a result of the high rate of mortality of the planted shrubs, which increased NCI indirectly by increasing the litter cover on the soil surface. This is also known as short-term positive changing.

Slight high variations were observed between the fenced areas and those open for grazing, in terms of Soil Surface Condition Index (SSCI). Overall, SSCI had increased significantly in all the exclosures. This may be attributed to TPA, which also increased significantly in the fenced areas of MZ and OG. For TT, the reason may be due to the mechanical structure of the soil where the high percentages of silt had a positive effect on SSI.

**Table 5.** Means of Some Soil Physical Properties in the Study Areas (Mahmoud *et al.*, 2008)

| Site | Code | Soil Humidity% | Mechanical analysis% | | | Organic matter % | |
|---|---|---|---|---|---|---|---|
| | | | Clay | Silt | Sand | Patch | Inter patch |
| Madur Zetun | MZ | 4.74 | 44.31 | 40.05 | 15.18 | 4.40 | 2.47 |
| Omguzlan | OG | 2.62 | 36.27 | 34.31 | 29.12 | 3.84 | 3.05 |
| Thahar Altair | TT | 2.11 | 33.25 | 36.7 | 27.91 | 3.99 | 2.52 |
| Ajramiah | AJ | 2.17 | 27.68 | 29.5 | 41.15 | 3.51 | 2.72 |

## Landscape heterogeneity (Patch and Interpatch structure)

The results showed a high significant increase in Total Patch Area (TPA) inside the Maduar Zetun exclosure area. Also,a positive changing in the same index is noted in the protected rangelands of the Omguzlan area. On the other hand, there was a decrease in the Total Patch Area in the closed rangelands of the Thahar Altair location. The Total Patch Area reflects the variations in closed rangeland conditions as well as open rangelands for grazing (Table 6). Furthermore, the indicator showed the outcomes of inappropriate management practices. TPA is strongly related to average rainfall; the Maduar Zetun area had the highest significant differences between TPA in the open rangelands and exclosures ($p<0.01$), followed by the Omguzlan and Thahar Altair areas ($p<0.01$ and $p< 0.07$ in that order).

**Table 6.** The Descriptive Statistics Results of Total Patch Area (TPA) inside and outside the exclosures

| Study Area | Total Patch Area | N | Mean ± SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Maduar Zetun | Open rangeland | 30 | 1.91 ± 2.16 | 0.50 | 13.00 |
| | Fenced rangeland | 30 | 10.64 ± 2.42 | 7.50 | 14.60 |
| Omguzlan | Open rangeland | 20 | 1.96 ±2.90 | 0.10 | 7.00 |
| | Fenced rangeland | 30 | 7.15 ±3.74 | 3.50 | 18.10 |
| Thahar Altair | Open rangeland | 10 | 1.13 ±1.19 | 0.00 | 2.40 |
| | Fenced rangeland | 10 | 0.66 ±0.64 | 0.00 | 2.20 |

The number of Patches/10 m had increased inside all the exclosures, except for the TT area, where an insignificant decrease in the number of patches was observed. A significant point concerning the number of patches is that an increase in the intensity of grazing has led to an increase in the quantity of invasive species. The insignificant decline may be due to the rainfall factor where the rainfall is very low in the southern regions. As we mentioned earlier, this negative change may be due to very low rainfall and high mortality rates of te planted shrubs; also, weak management may have caused low restoration rates, especially in the OG and TT areas where grazing animals were observed inside the exclosures.

The presence of a large number of grazing animals was cited as a major cause of the reduced size of patches in the Omguzlan area. As the intensity of livestock grazing in the grazing areas increased, the distance from one patch to another was also increased. This may be attributed to the removal of palatable patches because of grazing (Wang and Batkhishig, 2014; Zatout, 2014). It was also noted that heavy grazing negatively affected most variables in the open rangelands (the variables recorded an average decline of 50%). In some variables, heavy grazing also changed the manner in which individual shrubs impacted their sub-canopy surroundings. As a result, heavy grazing also negatively affected the positive effects of individual shrubs mentioned above, because heavy grazing increases shrub cover.

## Soil Surface Assessment (2006 vs. 2014)

The results demonstrate that the landscape function analysis index of soil stability increased inside all the exclosures. In the protected area of MZ, OG, and TT, the stability index increased significantly by 10.3%, 2.1%, and 4.2%, respectively. However, the index values are still very low and below the medium scale. The increase in stability index may be attributed to a very significant change in the patch area. In all of the study areas, the patch area changed significantly, but the change is still small and a long time might be needed to obtain a value equivalent to a good soil surface condition. The MZ area had stability indices that were different from others locations, in a manner that was statistically very high, significant with high variation (42.2– 64.1).

For the current research study area, the bio-crust cover (cryptogam cover) is relatively low (less than 1% in all study locations), since establishment of bio-crust communities is not effected by strong winds and the sandy texture of the soil, this resembles conclusions from factors such as creation of desert pavements, which are widespread in the study locality 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 the soil may have helped reduce the effects of erosion factors. Therefore, locations with diverse vegetation cover can attain identical stability index values; in some situations existing desert pavements can provide stability, while other cases rely on vegetation covers.

MZ area had the highest value of Water Infiltration Index (WII), whilst TT had the lowest value. WII was generally lower and reduced in the fenced rangeland of the TT area, which has a very low average rainfall, and with the lowest amounts of cover, species richness, and functionality, in accordance with the assertions of LFA indices. High variations were observed between the WII in the study areas (20- 46), and this enabled us to explain the subtle, and noteworthy variations between the different plant communities, soil, and averages of precipitation.

The results show that the highest Nutrient Cycling Index (NCI) was obtained in the protected area of Maduar Zetun, and this index increased significantly by 4.8%. On the other hand, the results indicated that NCI in the exclosures of Omguzlan and Thahar Altair have been decreasing throughout 8 years by 8.5% and 6.6%, respectively. The cause of this decline may be due to the fact (Rezaei *et al.*, 2006) that most of the selected sites in these regions tend to lead to the southern direction. Notably, the slope tops yield medium and high NCI whilst lower slope levels predominantly have low NCI with no vegetation. The values of NCI for all the study areas represent the harsh climate conditions of these locations, as NCI is seem to decrease in the southern study areas where negative values numbered more than the positive ones. Also, positive and negative effects of cattle-grazing patterns on NCI can be seen. The positive effect is observed as a result of adding organic matter to the soil, and the negative effect indirectly arises with the decrease in or removal of vegetation cover, the result of which will be a decline in nutrient cycling. However, without grazing management and control, the negative effects of overgrazing will immediately overpower the positive effects, and this phenomenon could be observed in many of the monitoring sites in the open grazing areas.

The Soil Surface Condition Index (SSCI) reflects overall soil surface health. The SSCI values are mostly very low; the soil surface assessment attributes of all study areas are the mean of Soil Surface Condition indices (SSI, WII, and NCI). These soil surface assessment attributes are used to determine whether or not there are variations in the exclosures after 8 years of protection. The highest total soil surface functionality (SSCI) was observed in the MZ area while the second and third highest SSCI mean were observed in the OG and TT areas. The protected area of Maduar Zetun had a positive significant difference between 2006 and 2014, and its value exceeded the values of other study areas that showed insignificant negative changes (Fig. 6).

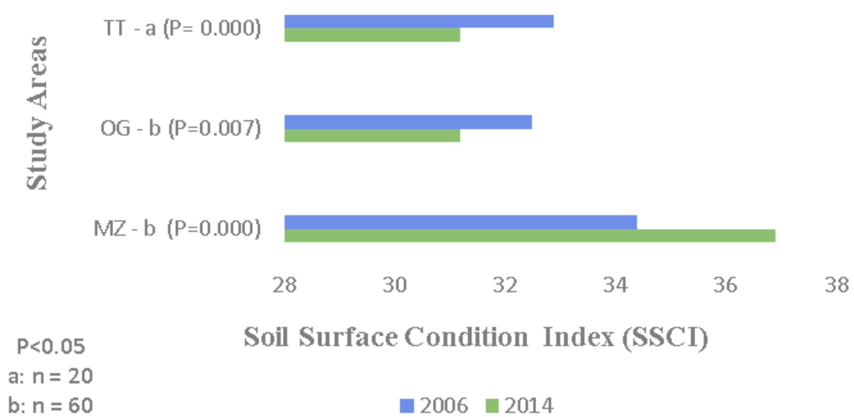


**Fig. 6.** Comparison between the Means of SSCI in the Fenced Areas

## Landscape Heterogeneity

The values of Total Patch Area increased from 2006 to 2014 in the high and medium rainfall locations (Table 7). However, this index value declined in the lower rainfall rangeland (TT area). This could be attributed to the presence of more patches, different patch dimensions, as well as more litter within the MZ and OG areas compared to the other locations.

**Table 7.** Wilcoxon Signed-Rank Test Results of TPA inside the Exclosures

| TPA - 2014 VS 2006 | | N | Mean Rank | Sum of Ranks | Sig. p<0.05 |
|---|---|---|---|---|---|
| MZ Area | Negative Ranks | 0[a] | 0.00 | 0.00 | 0.002 |
| | Positive Ranks | 30[b] | 15.50 | 465.00 | |
| | Ties | 0[c] | | | |
| | Total | 30 | | | |
| | Negative Ranks | 0[a] | 0.00 | 0.00 | 0.007 |
| OG Area | Positive Ranks | 29[b] | 15.00 | 435.00 | |
| | Ties | 1[c] | | | |
| | Total | 30 | | | |
| | Negative Ranks | 4[a] | 3.50 | 14.00 | 0.473 |
| TT Area | Positive Ranks | 2[b] | 3.50 | 7.00 | |
| | Ties | 4[c] | | | |
| | Total | 10 | | | |

a. TPA - 2014 < TPA - 2006
b. TPA - 2014 > TPA - 2006
c. TPA - 2014 = TPA - 2006

The mean of number of patches is very low in all exclosures, and the TT area, which is the location with the lowest rainfall, had no positively ranked patches. The number of patches was also noted to vary as locations varied. For example, in 2014, the average number of patches was almost twice that of 2006 in the MZ area, while no significant difference was observed between the averages in the OG area in that same time period. On the other hand, a significant decrease was noted in the exclosure of the TT area. These scenarios give us a clear indicator about the impact of rainfall on the re-vegetation process in the study area.

Inside the three exclosures, the general mean of Landscape Organization Index was 0.058. There was a significant difference in the mean, as it increased by 42.8% in 2014. The Landscape Organization Index is made up of all the differences that were noted in all areas. The improvement of Landscape heterogeneity inside the exclosures of Maduar Zetun and Omguzlan may be attributed to low grazing intensity (Fig. 7). Notably, the introduction of an enclosure in TT did not really impact the Total Patch Area possibly because of very low amounts of rainfall in that area, as well as the high mortality rates of the planted shrubs. The increase in Total Patch Area in the fenced areas of MZ and OG may be attributed to the number of patches and low grazing intensity. As livestock grazing intensity increases, the size of the patch decreases.

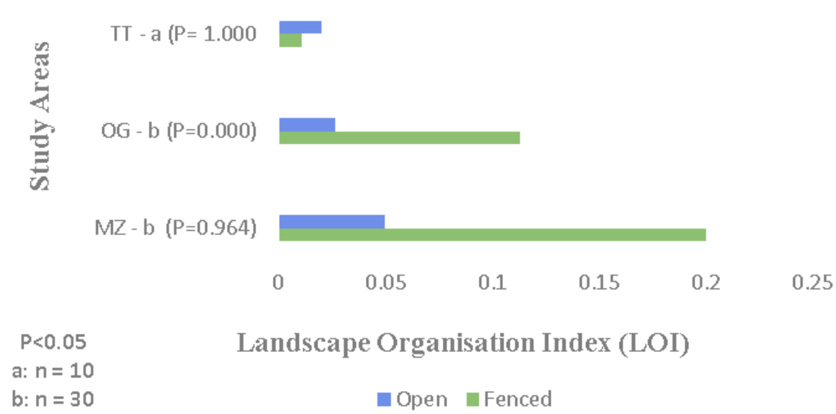


**Fig. 7.** Comparison of LOI between Grazing and Fenced Areas

## Discussion

The examination of ecosystem landscape health over the period of responding to environmental management as well as regulatory drivers plays an important role in helping land managers who include individuals and governments, particularly if the monitoring output is directly relevant for making management decisions. The main aim of monitoring entails searching for evidence that relates to landscape decline or rehabilitation. Additionally, monitoring may provide invaluable data for daily property management.

Results obtained from the study offer insightful data on factors, which hamper the rehabilitation of degraded arid and semi-arid rangelands in the study area. Additionally, the results may be applied when guiding land managers as well as restoration practitioners to take part in the rehabilitation process. Additional experiments with a larger portion of regions that have been sampled for long durations may be required for broadening the understanding pertaining to the relative significance of ecosystem factors against abiotic attributes in the initial phases of rehabilitation. This is crucial when testing existing conceptual models and when advancing the ecological development of effective models for restoring degraded ecosystems. The hypothesis of our study was that the ecosystem structural features as well as soil-surface conditions in grazing and fenced areas are key factors that impinge on site-to-site variations in LFA-SSC indices in the study area. This hypothesis is further substantiated by our results.

This current study is a confirmation of errors in the management of these natural pastures as shown in the exclosures of the OG and TT areas, especially the inability to protect them from overgrazing and from adverse human activities. The increasing vegetation cover is not up to expectations because of poor management such as overgrazing when plant growth is not adequate. On the other hand, landscapes that contain a low functional status have a tendency of losing or leaking available soil resource materials, failing to capture enough incidental rainfall, and the inability to capture other replacement materials.

A large number of grazing animals also damage the rangelands to a great extent due to overgrazing, crushing of vegetation, and their impact, leading to a decrease in vegetation cover. According to Snyman and Du Preez (2005), the trend reversals in LFA indices can be attributed to the variations in biodiversity. Ludwig *et al.* (2004) substantiated their claim based on Australian conditions where low LFA indices corresponded with low biodiversity, and high LFA indices corresponded with high biodiversity. This might be attributable to the different levels of disturbance in the sites of these different types of vegetation where there is a high disturbance. On the other hand, this might also be a sign of a decrease in resilience due to high levels of disturbances from different types of grazing systems with high biodiversity (Lezama *et al.*, 2014). However, since there is no sufficient data regarding this issue, it is difficult to further explain. Consequently, it is still not clear whether it is the physiognomic effects or biodiversity effects that affect the LFA results, or a combination of the two. The most noticeable attribute is that the difference in the values of LFA indices is less in the open rangelands, especially in the northern regions of the study area.

## Conclusion

In conclusion, uncontrolled grazing is the primary cause of desertification, as demonstrated by decreased growth of shrubs, and the reduction in the restoration rate in the open rangelands. This tends to advance the concept that the pressure reduction on rangelands may be the solution to the ending of the degradation processes. This has made it essential to adopt all-inclusive programs that will assist in the preservation of natural resources for the future. Finally, estimates reveal that a period of 10 years meant to protect the vegetation from grazing may be required in the higher rainfall location at the north. Regions that experience low rainfall, which are situated in the south, prior to the recovery of vegetation, as well as the condition of the soil surface at the time of grazing, require a period of over 10 years. Additionally, animal grazing must be controlled in order to facilitate the conservation and rehabilitation of natural resources amid these rangelands. Harmful human activities have to be minimized, and vegetation ought to be protected from grazing by creating a demarcation zone.

An important aspect of this research is the modular structure which allows additional particular research objectives, consistent with the overall objective. This would be achieved by the installation of additional monitoring sites in selected exclosures providing an opportunity to promote the application of range science in the Al-Jabal Al-Akhdar.

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