A New Approach for Land Degradation and Desertification Assessment Using Geospatial Techniques

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ABSTRACT

Land degradation reduces production of biomass and vegetation cover in every land uses. The lack of specific data related to degradation is a severe limitation for its monitoring. Assessment of current state of land degradation or desertification is very difficult because this phenomena includes several complex processes. For that reason, there is no common agreement has been achieved among the scientific community for its assessment. This study was carried out as an attempt to develop a new approach for land degradation assessment based on its current state by modifying of FAO[1]/UNEP[2] index and normalized difference vegetation index (NDVI) index in Khuzestan province, placed in the southwestern part of Iran. The proposed evaluation method is easy to understand the degree of destruction due to low cost and save time. Results showed that based on percent of hazard classes in current condition of land degradation, the most widespread and minimum area of hazard classes are moderate (38.6%) and no hazard (0.65%) classes, respectively. While results in the desert area of study area showed that severe class is much widespread than other hazard classes, showing environmentally bad situation in the study area. Statistical results indicated that degradation is highest in desert and then rangeland compared to dry cultivation and forest. Also statistical test showed average of degradation amount in the arid region is higher than other climates. It is hoped that this attempt using geospatial techniques will

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be found applicable for other regions of the world and better planning and management of lands, too.

Keyword: Land Degradation, Desertification, FAO/UNEP, GIS, Khuzestan

1. Introduction

Land degradation is a severe environmental problem confronting the world today (Taddese, 2001). It has detrimental impacts on agricultural productivity and on ecological function that ultimately affect human sustenance and quality of life (Taddese, 2001; Zehtabian and Jafari, 2002; Eliasson et al. 2003; Masoudi, 2010; Jing-hu and Tian-yu, 2010; Barzani and Khairulmaini, 2013; Masoudi, 2014; Masoudi and Amiri, 2015). Nearly 25% of the global biomass was degraded (Manh Quyet, 2014). Because of environmental factors tasking during multi-scales in time and space, comprehending the land degradation needs a multi-scale approach (Manh Quyet, 2014; Masoudi, 2014; Masoudi and Amiri, 2015). This approach is important in relation to land management goals. A few studies were investigated land degradation with a multi-scale approach (e.g. Masoudi, 2014; Masoudi and Amiri, 2015; Masoudi and Jokar, 2017).

Land degradation resulting from different parameters, including climate changes and human activities in arid, semi-arid and dry sub-humid regions (UNEP, 1992). Land degradation is still a global issue (UNCED, 1992; UNEP, 2007). In the 1990s, the main goal of land degradation was on soil degradation assessment. The Global Assessment of Human-induced Soil Degradation (GLASOD) (Oldeman et al., 1991) was the first global evaluation of soil degradation. It is still main global source of soil degradation data (FAO, 2000). The soil degradation map was provided based on expert judgment of a few hundred scientists in 21 regions in the world (global scale 1:10 million; GLASOD project by Oldeman et al., 1991). Based on mentioned cases, it is not easy task to evaluate land degradation, and different methods should be investigated (Lal et al., 1997). The information produced by estimating the vulnerability to desertification and erosion (Eswaran and Reich, 1998) give a different picture than those based on estimating the present (actual) state of land degradation (Oldeman, 1994). For example, the data based on risk assessment show that most regions of the world, affected by different severity classes of water and wind erosion, are 5-6 time more about those estimates done on the basis of assessment of present status.

Three aspects in land degradation assessment can be evaluated (FAO/UNEP, 1984) namely: 1) current status; 2) rate or trend; and 3) risk or vulnerability of hazard. The different models were designed to evaluate these aspects. The FAO/UNEP (1984) introduced a model which evaluates the main parameters affecting desertification processes.

The MEDALUS[3] model showed regions that are environmentally sensitive areas (ESA) to the desertification (Kosmas et al., 1999). In this method, four main quality layers including soil, climate, vegetation, and management are evaluated. Some other important models are GLASOD[4] (Oldeman et al., 1991) and ASSOD[5] (Van Lynden and Oldeman, 1997) and recently LADA[6] (FAO, 2002; Ponce Hernandez and Koohafkan, 2004).

Project of LADA has been set up by FAO, UNEP-GEF and various other partners to assess Land Degradation in Dryland Areas (LADA).

Geographic Information System (GIS) in conjunction with remote sensing and photogrammetry are also suitable instruments in order to estimate the environmental hazards. The GIS is used to analyze satellite images, aerial photos and field survey data. It is also used to determine new hazard through overlaying of hazard data sets. Studies also have shown that GIS and RS can investigate temporal variations in desertification and land degradation, analyze changes between land cover features and to develop base-line desertification maps and also monitor desertification (Congalton, 1996; Lu et al. 2004; Rangzan et al. 2008; Higginbottom and Symeonakis, 2014; Miehe et al. 2014; Pinzon and Tucker, 2014). In these studies, Remote Sensing (RS) uses satellite images or aerial photos to produce trend maps showing changes in land condition through time. Remote Sensing always includes linkages with ground observations.

Vegetation-based models have been currently applied in global, continental, and national evaluations of land degradation (Eklundh and Olsson, 2003; Julien et al. 2006; Duanyang et al. 2009; Pinzon and Tucker, 2014; Seboka, 2016). Researchers often apply the NDVI[7] index as a remotely sensed signal to analyze changes of vegetation. Vlek et al. (2008, 2010) investigated long-term NDVI trends in relation to the inter-annual dynamics of rainfall and atmospheric fertilization in order to determine the extent to which humans affect the NPP (net primary

[3] Mediterranean Desertification and Land Use
[4] Global Assessment of Soil Degradation
[5] Assessment of the Status of Human-induced Soil Degradation in South and Southeast Asia
[6] Land Degradation Assessment in Drylands
[7] Normalized Difference Vegetation Index

productivity). Lanorte et al. (2014) used NDVI time series to monitor vegetation recovery after disturbance by fire at two test sites in Spain and Greece.

Remote sensing is also being used in the vulnerability analysis (Oldeman et al., 1991; Van Lynden and Oldeman, 1997; Sepehr et al. 2007; Bai et al., 2008; Masoudi and Zakeri Nejad, 2010; Hein et al. 2011; D'Odorico et al. 2013; Masoudi, 2014; Masoudi and Amiri, 2015), focusing on spatialized models for assessment of desertification or land degradation.

One can retrieve information at various spatial and temporal scales and in addition, models can be modified, re-calibrated with update data on the actual status of the environment (De Jong, 1994; Boer, 1999).

Among three aspects of degradation, more emphasis is on current status of degradation. Also this issue is observed in some important desertification models like FAO/UNEP (1984), GLASSOD (Oldeman et al., 1991) and ASSOD (Van Lynden and Oldeman, 1997). Therefore the main aim of this paper is to develop a new technique in order to evaluate the current state of land degradation in south western part of Iran using satellite images and GIS.

2. Material and Methods

(i) Study area

Khuzestan province (Figure1) is placed in the south western part of Iran, with area of 63633 km^2. This province is located between the latitudes of 29°59′ and 33°01′ N and the longitudes of 46°48′ and 50°30′ E. The estimated population in the study area is 4710509 in the year 2016 (Population and housing statistics of Khuzestan, 2016). Ahvaz city is the capital of Khuzestan province. The climate of the study area varies from arid to humid. The northern parts of the province experience cold weather, whereas the southern parts experience tropical weather (Zarasvandi et al. 2011). Most parts of the province are arid and average of precipitation is 266 mm per year, but mean annual rainfall reach to 950 mm in the north eastern parts (Masoudi and Elhaeesahar, 2016). The main period of precipitation is during the winter. Temperature in most parts reaches above 50°C during summer. Topographic elevations in the province vary between 0 and 3740 m. Geomorphologically, Khuzestan province is located in a basin occupied by Cenozoic-quaternary alluvial sediments mostly derived from the chemical and mechanical erosion of the Zagros Mountains (Zarasvandi et al. 2011).

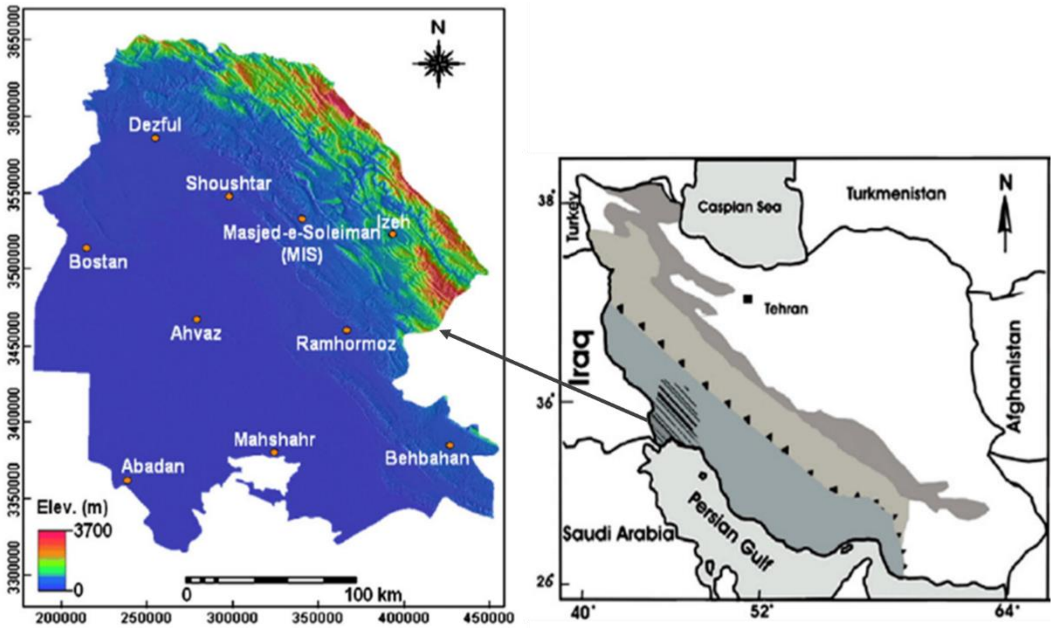

Figure1. Location of the study area in Iran

(ii) Data and methodology

The difference between actual or current production (in physical or monetary terms) and the maximum attainable (potential) production is often used for a suitability assessment for a crop (FAO/UNEP, 1984). On the other hand, this indicator may be used to assess state of land deterioration in terms of plant losses (Narain, 1977; Ballayan, 2000). Compared to the other methods of assessment of current state of degradation, this indicator seems to be more significant, as plant loss is affected not only by erosion, but also by land deterioration (all environmental influences, for that matter). To show the current state of land degradation, this indicator have been used by several models like Narain assessment (Narain, 1977), FAO/UNEP model of desertification (FAO/UNEP, 1984), LADA (FAO, 2002; Ponce Hernandez and Koohafkan, 2004) and models of GLASSOD (Oldeman et al., 1991) and ASSOD (Van Lynden and Oldeman, 1997).

Evaluation of present status of land degradation in FAO/UNEP model and models of GLASSOD and ASSOD is emphasized to the equation1:

$$\text{Equation (1)} \qquad \text{Degradation} = \frac{\text{Current Production}}{\text{Potential Production}}$$

Evaluation of current production by field sampling of vegetation cover is not suitable for regional scale. On the other hand, potential production is almost calculated by ecological condition like average of rainfall and soil limitations by general models that doesn't have good accuracy in regional scale (FAO/UNEP, 1984). For both of them we need a lot of data to assess degradation in regional studies that makes assessment with difficulties in some parts (Oldeman et al., 1991; Van Lynden and Oldeman, 1997).

Based on the GLADA[8] approach current productivity on the regional studies and bigger areas can be estimated by general equations using NDVI indicator, but there is a concern in their overall application in regional studies. Therefore, this proposed theory helps us finding potential production with taking into consideration of the non-degraded situation for each land-use in only that area.

Because of the above problems, in this study, instead of estimating potential production and current production we use only the values of NDVI. NDVI is calculated from equation2:

$$\text{Equation (2)} \qquad NDVI = \frac{NIR - RED}{NIR + RED}$$

This study uses NDVI data (from MODIS satellite images) produced by the Modeling and Mapping images at 500m spatial resolution. Vegetation images relating to two years of 2011 and 2013 that there was normal rainfall during these years were extracted from the USGS site. Then geometric position was corrected by Geo-reference (Figure 2).

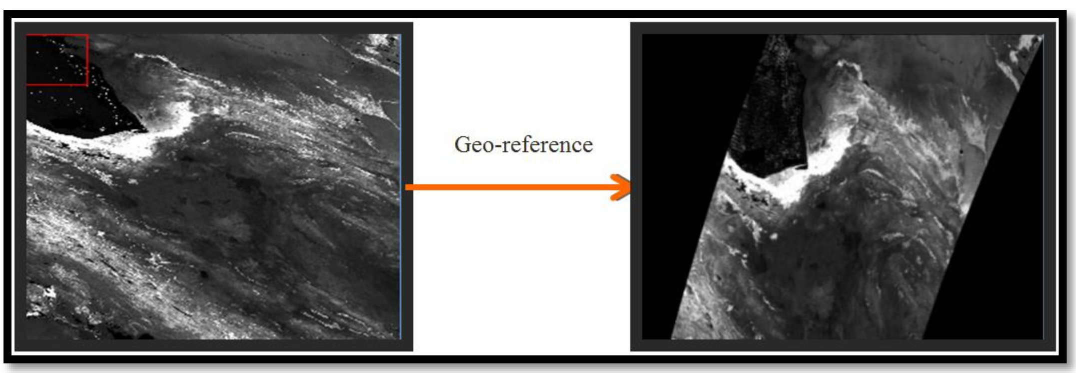

Figure 2. Correction of geometric position by Geo-reference

In the current work three images belong to months of March, April and May that represent the highest production for natural resources area during every year in the study area were chosen. Then one image was extracted using selection of maximum NDVI among them (three images) for

[8] Global Land Degradation Assessment

each pixel in ENVI 4.7 software that maximum NDVI represents the highest production in mentioned three months or whole year for each point of study area (Figure 3).

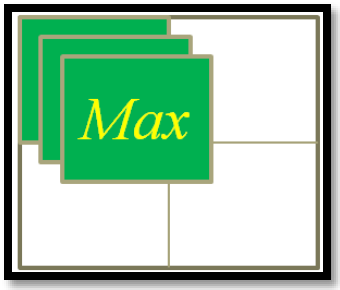

Figure 3. Preparation of new image from between three months for selection of highest NDVI or production during a year

In order to reduce fluctuations between 2011 and 2013 (from drought, pests, etc.) an average from images of two years including maximum NDVI for each pixel were obtained to show an average of highest production for each point using equation3:

Equation (3) $$\text{Average of NDVI Max} = \frac{\text{NDVI Max}_{in\ 2011} + \text{NDVI Max}_{in\ 2013}}{2}$$

Average of maximum NDVI is an indicator to show current production in the study area. In order to find potential of production based on production in the non-degraded situation, study area was divided to several land units. Land units are prepared according to overlaying of three maps of precipitation, land use and land form (divided to two parts of plains and highlands). Land units were coded in two steps by the equation4 (Makhdoum, 2001):

Equation (4) $$E = J \times (I-1) + J_i$$

E: Unit code, J: Number of classes for underlying map, I: Code of class for overlying map, J_i: Code of class for underlying map

In the next step standard deviation, average and maximum amount for NDVI values of each land unit were calculated to help us find Potential of NDVI for each land unit as an indicator to show potential of production in the study area for each land unit. To find potential of production in each land unit in a region we can consider the production in environmental conservation region with none or very low anthropogenic activities for the same land unit or minor ecosystem. But finding conservational condition for all land units in regional and higher scales is very difficult. Therefore this technique is helpful for finding potential of production in each land unit or minor ecosystem in a region. Equation 5 is used for this case:

Equation (5) $$\text{POTENTIAL NDVI in each land unit} = ((\text{AVERAGE} + \text{SD}) + \text{MAX})/2$$

This amount shows a high value for NDVI in each land unit as an indicator of higher production in the non- degradation situations. Therefore current state of land degradation was calculated for each pixel using equation6 that is equaled to index of FAO/UNEP:

Equation (6) $$\text{Current State of Degradation} = \frac{\text{Current Production}}{\text{Potential Production}} \approx \frac{\text{NDVI}_{\text{Max}}}{\text{NDVI}_{\text{Potential}}}$$

Then Current state of land degradation is classified based on the FAO/UNEP classification (Table 1).

Table 1: FAO/UNEP Classification for Current State of Degradation (based on Percent of Current production to potential production)

Degree of Degradation	None	Slight	Moderate	Severe	Very Severe
Percent of Current production to potential production	>100	80-100	40-80	20-40	< 20

Testing method: In order to evaluate accuracy of proposed model quantitatively, the prepared map was compared to ground reality. The ground reality map was prepared based on the highest hazard class of current degradation among water and wind erosion, soil salinity and vegetation cover. Therefore information of 402 points scattered systematic randomly in Gharehagahj Basin, in southern Iran were used.

3. Results and Discussion

Most studies conducted by like Feiznia et al. (2001) and on global scale such as USLE model for water erosion or Metternicht and Zinck (1997) for soil salinity have done base on the calculation of present status of degradation.

The different type degradation maps like soil salinization and wind erosion alone based on the present status of degradation are difficult to evaluate regions under hazard of land degradation or desertification. It requires knowing weight of effect all degradation types on the region that makes assessment with difficulties.

This kind of classification evolving a new technique using potential of production taking into consideration regional condition instead of using different models that are not useful for everywhere is the first effort for identifying regions under severity classes of current state of degradation.

The main types of land degradation in the province studied are: water and wind erosion, soil salinization, lowering of ground water table and vegetation degradation. The hazard map of province is one example of this kind of methodology for assessing current state of land degradation (Fig. 4). Figures 4 and 5 showed that about 30% land in the province is under severe and very severe state of land degradation. Such areas are observed much more in plain areas compared to the highlands. The main types of land degradation in the plains are soil salinity and wind erosion. While in the highlands, moderate class is more extensive with occurrence of water erosion in sloppy lands. Also among the severity classes, regions under moderate hazard have a greater extension (38.6% of the study area) while regions under no hazard show the least (0.65% of the study area).

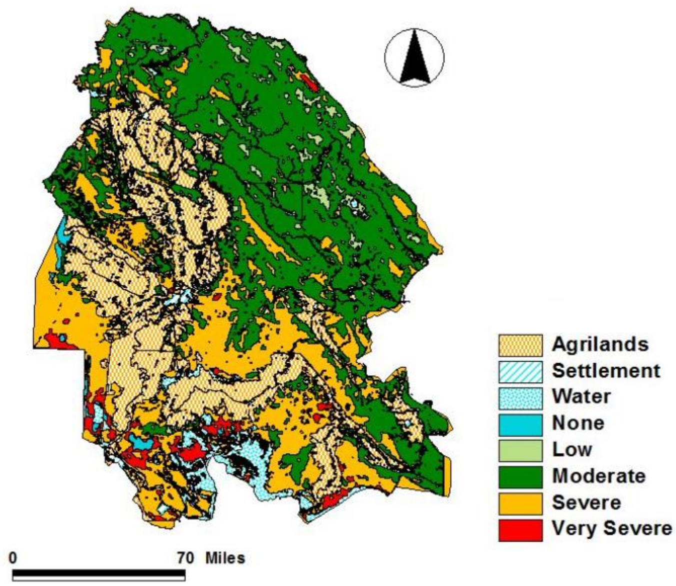

Figure 4. Current state map of land degradation in the study area

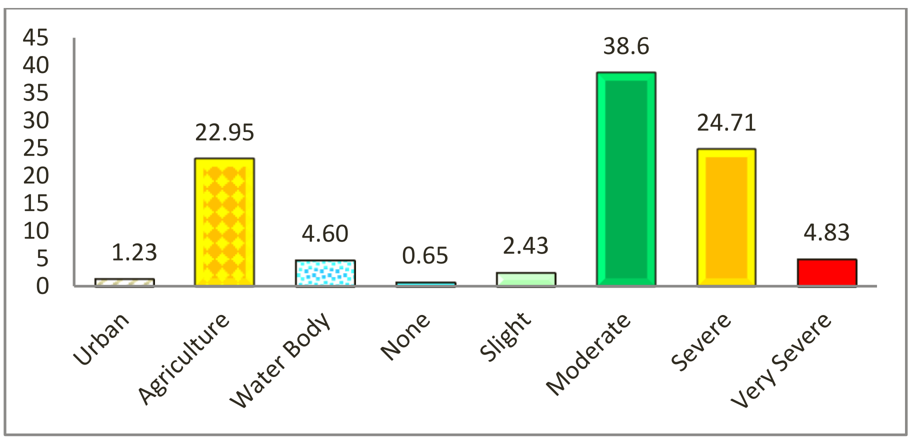

Figure 5. Percent land under different severity classes of land degradation in the study area

Also results of test between two maps of current model and maps prepared by taking into consideration ground reality of degradation show significant relationship at the 0.01 level (R=0.264). This result indicates the current method is useful theory for finding degree of land degradation or desertification.

To qualify the severity classes of desertification map, first desert land was determined based on new definition derived by desertification definition by UN (UNEP, 1992). Actually there is controversy between experts of natural resource offices of Iran for separation of desert land from poor rangeland. Based on their new recommendation and desertification definition by UN, in this assessment "desert" is defined as "plains that include two conditions, first with climate of arid or semi-arid or dry sub-humid, second with vegetation cover of less 5%". Therefore mountainous areas and regions with other climates don't have desertification but have land degradation.

A comparison between map of land degradation and different land uses in study area including forest, rangeland, dry cultivation and desert areas (like bare land, saline lands and sand dunes) shows that a greater proportion of desert lands is under 'severe state' of degradation while for other mentioned land uses the most widespread class is moderate hazard (Fig. 8). Also Table of analysis of variance (Table 2) shows that between severities of land degradation in 1738 points scattered systematic randomly and different ecosystem types in the study area there is a highly significant relationship. Also Duncan test shows average of degradation amount in the desert area is significantly higher than other land uses while in the forest areas show the least degradation (Figure 9). Results of this statistical test confirm results of percent land under different severity classes in the figure 8. This result implies the obvious that sever degradation is being occurred in the desert areas of study area. But in some reports like ASSOD assessment for Asian countries (FAO, 1994), it is mentioned that in desert area degradation is low and stable condition is observed. This severe degradation may be is related to different causes of degradation that are affecting the region and it is concluded that the desert are younger than other deserts like Lut desert in Iran.

Table 2. Tables of analysis of variance between degradation severity and different ecosystem types.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	109.729	3	36.576	85.126**	.000
Within Groups	745.482	1735	.430		
Total	855.211	1738			

Also Table of analysis of variance (Table 3) shows that between severities of degradation in 1812 points scattered systematic randomly and different climate types in the study area there is a highly significant relationship. Also Duncan test shows average of degradation amount in the arid region is higher than other climates (Figure 10). This results confirm those results derived with other studies mentioned higher degradation in arid zones compared to humid zones in Iran and other Asian countries (FAO, 1994; Masoudi et al., 2006; Masoudi et al., 2007; Masoudi, 2014; Masoudi and Amiri, 2015; Masoudi and Jokar, 2017). In case Figures 9 & 10 some researches (FAO, 1994; Van Lynden and Oldeman, 1997; Salehi, 2017) have shown that land degradation in regions with arid climate is higher than humid areas. Also Salehi (2017) showed that land degradation in desert and rangeland ecosystems is higher than forest and rain-fed ecosystems.

Table 3. Tables of analysis of variance between degradation severity and different climate types.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	205.373	5	41.075	99.657**	.000
Within Groups	744.770	1807	.412		
Total	950.142	1812			

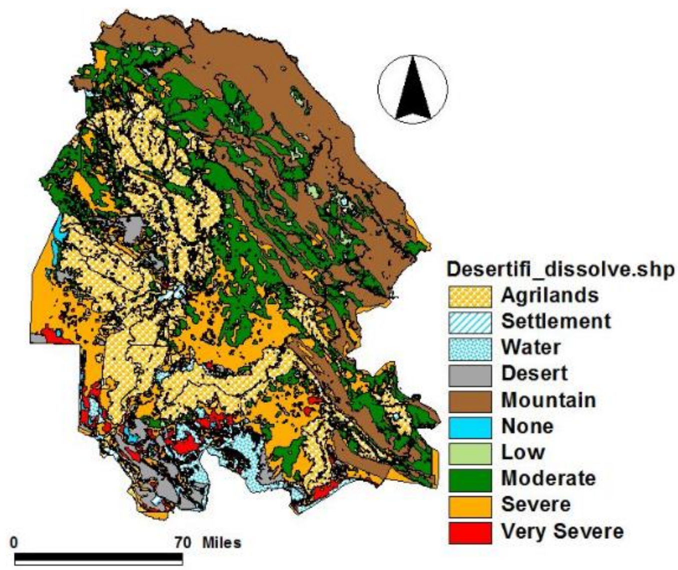

Figure 6. Current state map of desertification in the study area.

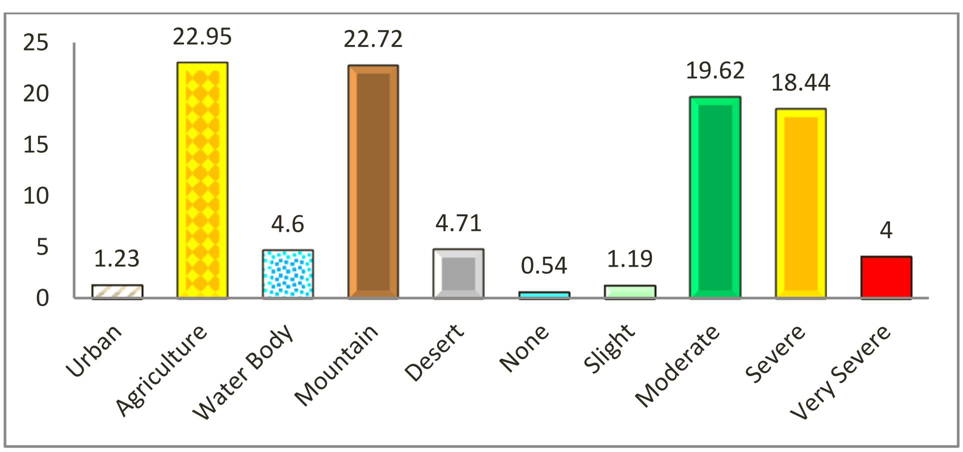

Figure 7. Percent land under different severity classes of desertification in the study area.

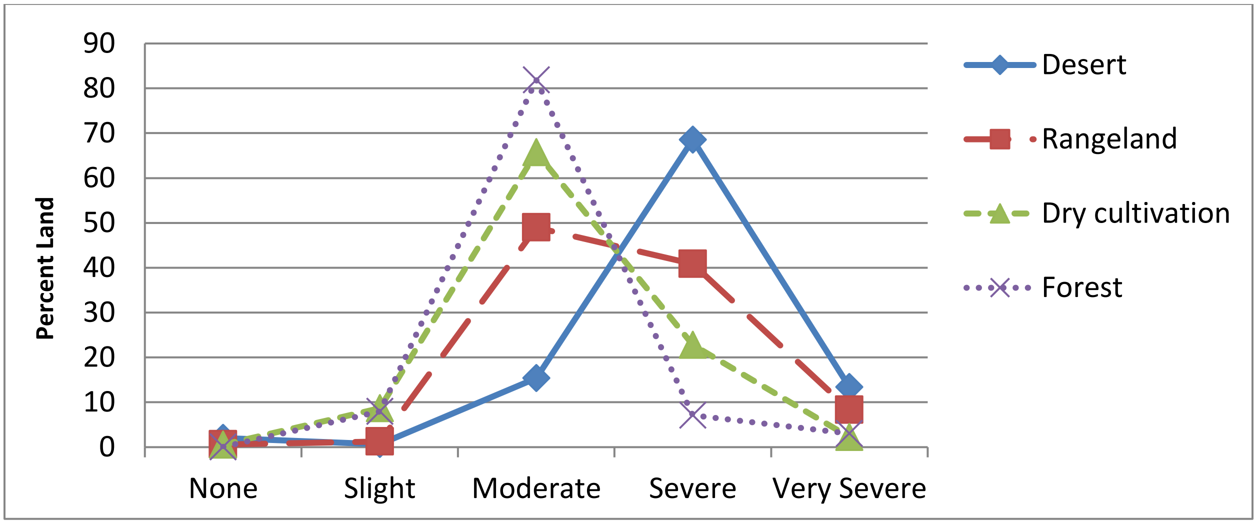

Figure 8. Percent land under different severity classes of degradation in the land uses.

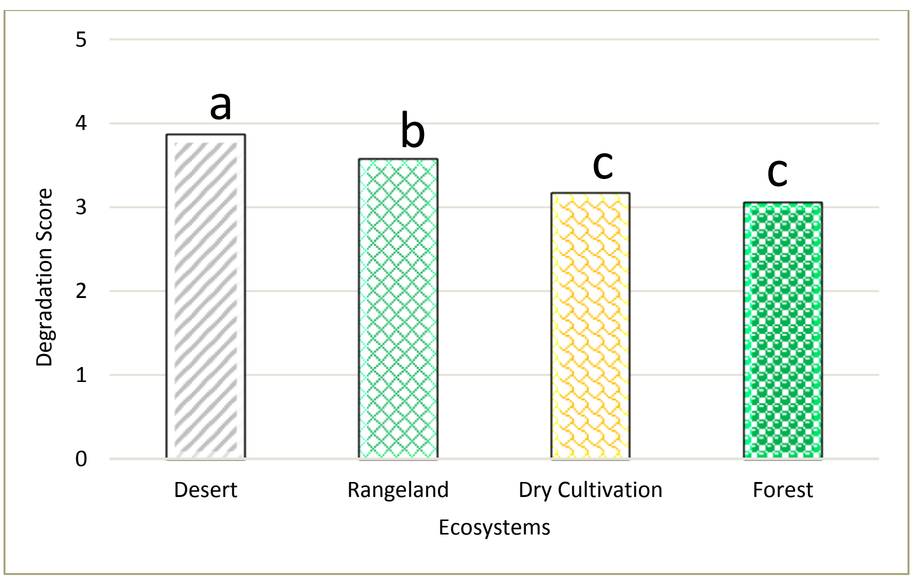

Figure 9. Average of degradation amount in the different ecosystem types using Duncan test.

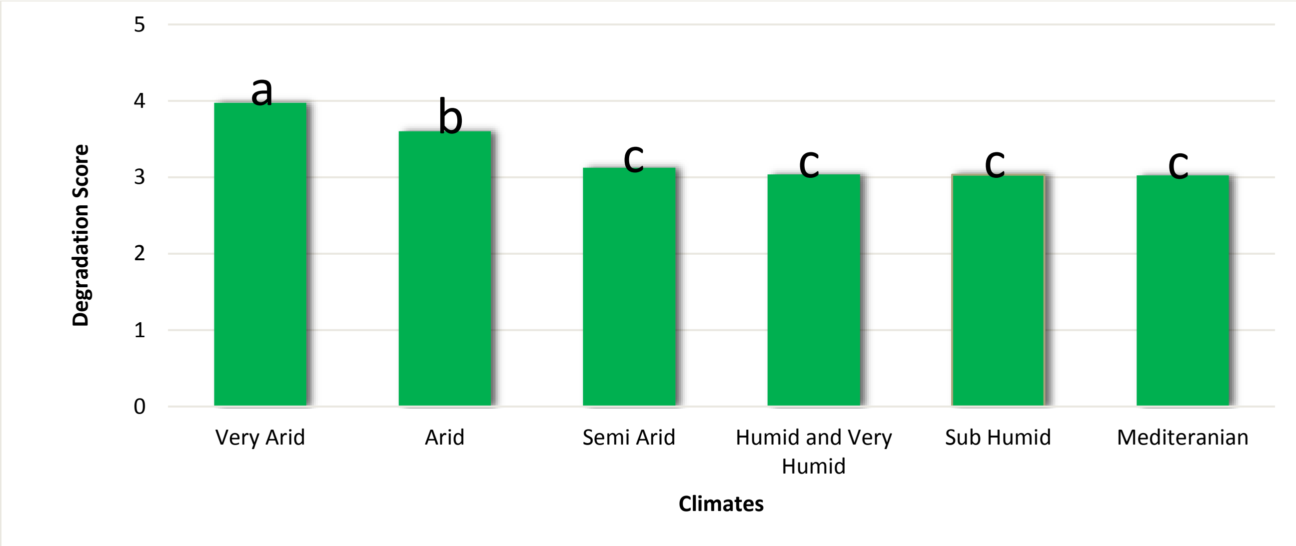

Figure 10. Average of degradation amount in the different climate types using Duncan test.

Conclusion

The desertification map (Fig. 6) is the same as land degradation map but with this difference that desert lands and mountainous areas are defined on it. Once again from this map the areas under severity classes were identified. From the Figures 6 and 7, it is concluded that in the province regions under both severe and very severe (22.4%) classes are more widespread compared to regions under other severity classes showing environmentally bad situation in desertification in the study area. Result of test between two maps prepared by current model and ground reality of degradation confirms that this new approach based on using FAO-UNEP view and NDVI index is good technique for assessment current state of land degradation.

Results show degradation is highest in desert and then rangeland, dry cultivation and forest, respectively. On the hand, results of current study show that degradation is higher in arid regions compared to other climate types, confirming many results in this subject. Also, such areas will be the area needing immediate attention for remedial measures for reclamation and conservation for each type of degradation like those measures mentioned by Masoudi, 2014; Masoudi and Amiri, 2015; Masoudi and Jokar, 2017.

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