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Land degradation assessment using landscape unit approach and normalized difference vegetation index in Northwest of Tunisia

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Abstract

Land managers and decision makers need sound, evidence-based information about land degradation patterns and about the effectiveness of their management practices. Obtaining such information is particularly difficult in Mediterranean lands, where for long time a combination of anthropogenic pressure, high topographical and climatic variability, and frequent disturbances created a complicated and unstable environment. Likewise, the normalized difference vegetation index (NDVI) has gained particular recognition in the scientific community as proxy of vegetation and degradation – given the importance of the vegetation cover in preventing land degradation in drylands. This study aims at designing a methodology to provide land managers in a representative site in Northwest of Tunisia with spatially explicit, up-to-date information on the state of their land, the pressures driving land degradation, and the effectiveness of their management efforts using remotely sensed NDVI data. To apply the NDVI index in the process of land degradation assessment, the variance of the annual average NDVI was analysed within different landscape units, which they were identified based on land cover, aspect, and slope steepness parameters. After calibrating and validating the land degradation mapping methodology using field observations, the obtained land degradation patterns were related with spatial information about overuse and monoculture, as well as fallow and agroforestry practices. Therefore, the main objective of this study is to create land degradation maps that show the state of semi-natural dry ecosystems and highlight man - made land degradation, then to assess the relation between patterns shown by the degradation map and the main pressure drivers affecting the study site. More specifically, three hypotheses derived from information provided by experts and stakeholders has to be proven: (1) Ecosystems are more sensitive to pressure in steep and south-facing terrain than in flat and north-facing areas. (2) Inappropriate management mainly the monoculture not led only to a physical soil deterioration but also the decline of soil fertility, particularly if they occur repeatedly in continuous way, especially in hilly south terrains, which are more exposed to solar radiation and erosion by wind and rain. (3) Third, we aimed to obtain evidence of the impact of specific land management practices that had been identified as promising.

1. Introduction

Land degradation and desertification are considered relevant processes in Mediterranean arid and semi-arid ecosystems (Geeson et al. 2003; Hill et al., 2005). Mapping the impact of human activities in natural and semi-natural environments is crucial for tackling land degradation and desertification processes (Schwilk et al. 2009).

The Normalized Difference Vegetation Index (NDVI) is widely used to estimate the vegetation density and cover. However, the reflectance of vegetation and thus the NDVI values are influenced by several factors such as type of cover, type of land use and seasonality.

In this paper, we propose a simple method to analyze the variance of NDVI signal considering the main factors that shape the vegetation. This variance analysis enables us to detect and categorize degradation in a much more precise way than simple NDVI analysis. The methodology comprises identifying homogeneous landscape areas in terms of aspect, slope, and land use and disturbance regime (if relevant). Secondly, the NDVI is calculated from corrected Landsat images and the vegetation potential for each landscape is determined based on the percentile (highest 10% value). Thirdly, the difference between the NDVI value of each pixel and the potential is used to establish degradation categories. Through this methodology, we are able to identify realistic objectives for restoration, allowing a targeted choice of management options for specific degraded areas. For example, afforestation would only be done in areas that show potential for Agroforestry. Moreover, we can measure the effectiveness of management practices in terms of vegetation growth across different landscapes and conditions.

More specifically, three hypotheses derived from information provided by experts and stakeholders were tested:

(1) Ecosystems are more sensitive to pressure in steep and south-facing terrain than in flat and north-facing areas.

(2) Present-day inappropriate management remains a relevant driver of degradation in steep south terrains.

(3). Third, we aimed to obtain evidence of the impact of specific land management practices that had been identified as promising.

2. Materials and Method

2.1. Study site

We selected Wadi Beja watershed in Northwest of Tunisia, as a representative site that comprise a variety of conserved and degraded areas, it has a long history of field crops land use, and face the risk of monoculture of field crops under inappropriate land management practices. This agro-ecological zone covers an area of about 33766 ha. The watershed is drained by a series of wadis, mainly Wadi Beja (Hidrotehnika-Hidroenergetika 2011).

Most soils are threatened by water erosion, which is provoked by the land topography, 64 % of soils with a high to steep slope and 36 % of soil with a moderate slope (AVFA 2016).

The lithology of the basin consists mainly of limestone, marl, clay and gypsum (AVFA 2016). Rainfall, characterized by its irregularity, varies from 200 mm to 800 mm, depending on the year. The rainfall season is from winter and autumn, and the period of early spring (AVFA 2016). The maximum temperatures are recorded at the end of July, when they range between 38°C and 44°C. Minimum temperatures are recorded at the end of December, when they are between 6°C and 8°C (AVFA 2016). 4 different land use classes were defined; field crops (75%), grazing lands (10%), forest (5%), permanent crops (7%) and urban area (3%) which was excluded from the study. Agriculture is the main economic activity and it depends primarily on rainfed production systems dominated by cereal crops and small ruminant livestock (Jendoubi et al. 2015).

2.2. Materials

To create land degradation maps we relied on land cover maps derived from DTM and NDVI vegetation index from Landsat 8 satellite scenes. The Landsat scenes were selected among all those available in the green season (out of harvesting) for the year 2015, considering only those with less than 20 % of cloud cover overall and without clouds on the study site area.

Many Landsat and sentinel images downloaded from 2013 until 2016 and assessed in order to check the calendar of the fallow, so we ensure to not to be confused to consider the no vegetation (fallow) as very degraded lands.

Detailed information about the data used is presented in table 1.

Table 1. Input data for the creation of land degradation maps.

Input data	Wadi Beja watershed
Digital Elevation Model	Date : 2009 Type: Lidar DTM (airborn) Resolution: 1m resolution Provider: Istituto Geográfico Nacional
Landsat scenes	Path: 192 Row: 034 Dates: 28-Dec-14, 15-Jan-14, 6-Feb-15, 18-Mar-15, 03-Apr-15, 5-May-15, 6-June-15

Table 2. Detailed description of visual indicators used for calibration of degradation maps

Indicators	Weight	Very degraded (1)	Degraded (2)	Semi degraded (3)	Healthy (4)	Vegetation potential (5)
Soil fertility (% OC); according to HCN analysis results	3	0 - 2 %	2 – 4 %	4 - 6 %	6 %	>6 %
Loss of topsoil ; according to the soil map	1	Very high	High	Moderate	low	Insignificant
Erosion; according to the scoring notation system	2	Very high	High	Moderate	low	Insignificant
Physical soil deterioration (Structure of soil); Compaction	2	Very high	High	Moderate	low	Insignificant

In the soil, organic matter is crucial since it holds a key position with regard to soil functions (e.g. moisture storage capacity, nutrient cycle). Soil organic matter (OM) is also strongly interlinked with various soil degradation processes. On the one hand, OM influences the dynamics of these processes as a crucial force within the soil (e.g. by determining soil aggregate stability, which again is crucial for soil crusting, compaction and sheet erosion), and on the other hand, it is affected by degradation processes (Heger et al. 2018). The impact on OM content be either direct, through loss of topsoil enriched with organic matter as a result of erosion, or indirect, through reduced vegetation growth and subsequently reduced amounts of biomass available for decomposition and transformation into soil organic matter (Blaikie 1985; Borelli et al 2016).OM content may be conserved by adapted land management, especially by erosion control, and enriched through agronomic and vegetative measures involving cover of the soil (e.g. no removal of crop residues or through permanent vegetative cover) (Lal 2015; Cerdà et al. 2016; Muñoz-Rojas et al. 2015).For this purpose, 165 soil samples are collected from the field and processed by a combustible CNS analyser, in order to identify the percentage of organic matter.

For the same selected points, a simple template of erosion scoring was carried out. The erosion assessment is based on a visual observation that aim to identify the type, the state, the density, the stabilization and the trend of the assessed erosion. Then a classification of erosion was carried out.

Some others soil physical parameters were extracted from the available data, such soil map and, soil profiles and visual observations. The assessment was based on a predefined set of indicators of soil conditions, along with position, topography and land cover information, which they are in direct interaction with the state of the vegetation and seems explicable for the land degradation state.

Field data and observations of degradation, measured through visual indicator were collected to be used to calibrate the degradation maps.

The land use information served additionally for the validation of the land degradation maps (table 2).

165 field observation points were collected in Wadi Beja Watershed (October 2015). To validate and analyze the results of the degradation maps. All the field data and observations were clustered into categories from the very degraded (1) until vegetation potential (5).

A weight factor was established according to the expert judgment in order to recognize the importance of the different indicators.

Furthermore, several informal interviews and exchanges were organized with land managers, local administrators and land users to obtain information and discuss the information provided by the degradation maps.

2.3. Methods

For producing the degradation maps data, the following methodology was proposed:

The landscape units for the analysis of the NDVI variance are based on land use, slope and aspect categories. As the field crops class represents 75 % from the study area, this study focuses more in this famous land use in order to assess land degradation through different conditions. Aspect and slope features were derived from Lidar DTM, aligned and resampled to 30 m. Slope categorization was based on the FAO guidelines for soil description (Barham et al. 1997). The soil was grouped in five slope categories. Aspect/Orientation was categorized in 2 classes of 180 degrees (north and south). Both aspect classifications were tested as input of the NDVI variance analysis. Details about slope and aspect categories are presented in Table 3.

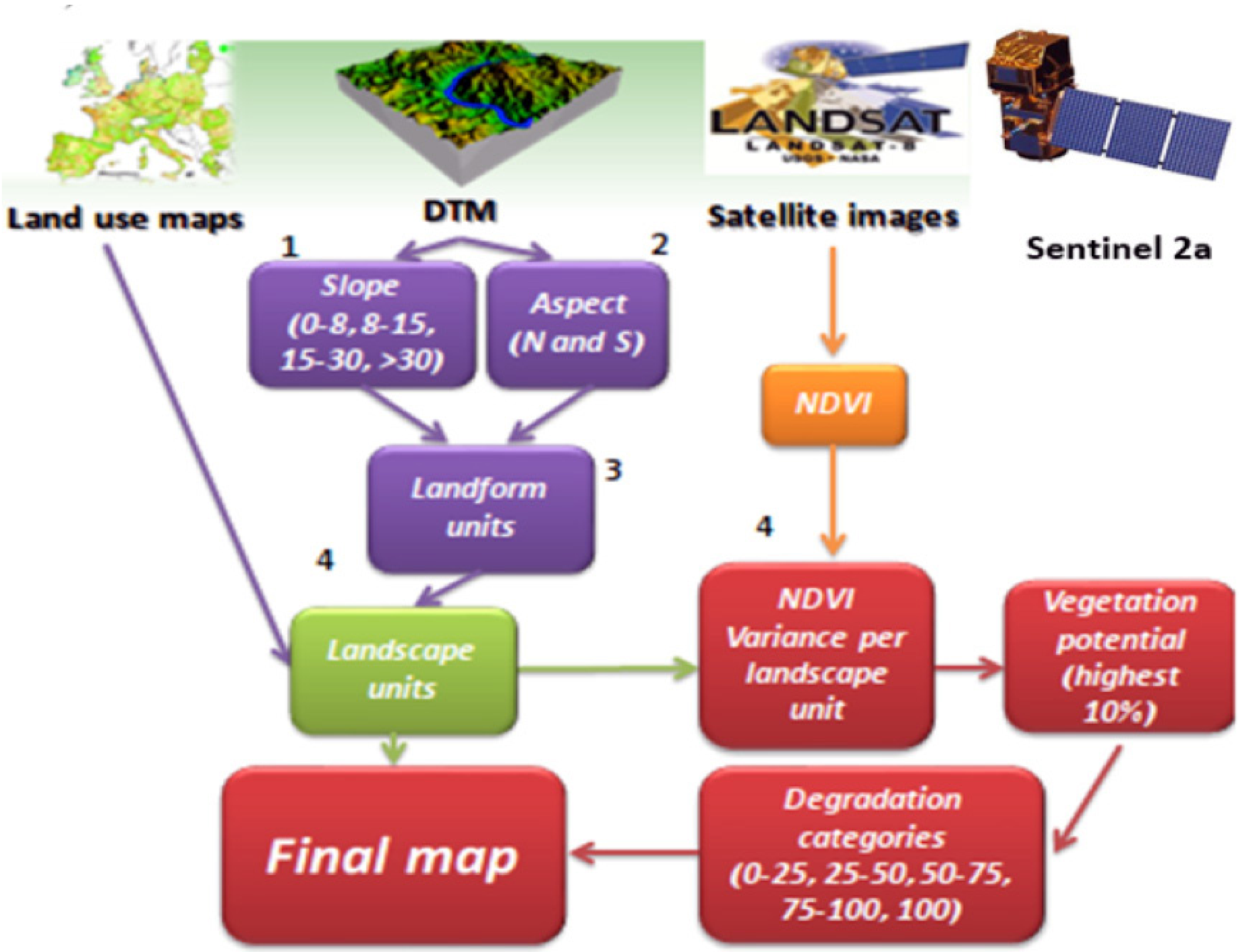

Figure 1. The overall methodology

Table 3. Aspect and slope categories

Slope		Aspect classification	
Code	Breaks (in %)	Code	Breaks (in azimuth degrees)
1	0 to 2 (Flat)	1	0 to 90, 270 to 360 (North)
2	2 to 8 (Moderate)	2	90 to 270 (South)
3	8 to 16 (Sloping)		
4	16 to 30 (Steep)		
5	30 to 100 (Very Steep)		

Land use maps were elaborated from corrected Landsat 8 Surface Reflectance data and Sentinel. Categories have been defined by merging expert's knowledge on the different land uses and the data available in the study site.

2.3.1. Calculating Vegetation Potential

It's important to assess across landscapes in order to allow more precise identification of land management objectives and restoration options (Bautista et al. 2009).The landscape unit (LSU) map is obtained by intercepting the raster holding land cover classification values with those holding slope and aspect values, followed by a generalization using a window of 3×3 pixels and the mode value, so that the minimum size of each polygon would be of 9 pixels (8,100 m²).

Secondly, each pixel is classified on a scale of 1 to 5 indicating the degradation level: 1 is the "very degraded" and 5 is "potential", where "potential" indicates the best situation existing at present for each LSU. We do so by comparing its average NDVI value index value with the distribution of values in the homogeneous landscape unit area, see figure 1.

In the majority of studies that investigate NDVI, in relation to degradation by evaluating degradation in time, rather than in space, the mean value or mean trend is often considered as reference to identify the positive and negative anomalies. In terms of NDVI signal, that can highlight the degradation or conservation areas (Yengoh et al. 2014) and (Higginbottom and Symeonakis 2014). Moreover, this is the threshold setting often used "instinctively" by land managers, who are able to identify what is degraded based on the average situation they have experienced. To follow this logic, we have adapted the threshold setting used by Ivits et al (2013), using the mean as breakpoint between healthy and degraded areas, and the standard deviation to identify the area of exception deviation from the mean, here classified as “potential” (highest NDVI values) and “very degraded” (lowest NDVI values). Once the Vegetation Potential (VP) is identified for each landscape unit the pixels in the unit are standardized accordingly on a scale 0-100, where 0 is the minimum value of the NDVI for that category and 100 is the VP. For interpretation and display, five categories are defined: Very degraded, Degraded, Semi-degraded, Healthy and Vegetation Potential.

The process of land degradation can be described as a decline of Net Primary Productivity or a loss of fertility (Bai et al. 2008). We classified the pixels based on the difference from the areas identified as best, i.e., the areas with the highest value of NDVI. At the resolution of Landsat 8 images (30×30 m pixel), the actual maximum value of NDVI could be misleading, as it could correspond to a large tree canopy or to another area of very dense vegetation and it shouldn’t be taken as a reference. Thus, we introduced a buffer on the 90th percentile to account for the signal uncertainty and natural variability within the best areas.

Land degradation has to be understood within the local context (Warren, 2002), and is often non-linear (Scheffer et al. 2009). In this method, 90th percentile was set as reference for the potential of vegetation, as shown in table 4.

Once we have the NDVI values per each landscape unit, I calculate the 90th percentile and consider that the Vegetation Potential (VP). The idea behind it is that we cannot consider only the max value, as it represents too little of the study area and might be misleading. The best 10% of the pixel appears to give a better idea of what is the potential of that area. Obviously, the relation between min value, max value and Vegetation Potential is different in each landscape category.

Table 4. LSU map pixel classification according to the threshold setting

Category	Method
	Absolute value with upper buffer
VP	90th percentile of NDVI value within landscape category
Healthy	Between 0.75*VP and VP
Semi degraded	Between 0.5*VP and 0.75*VP
Degraded	Between 0.25*VP and 0.5*VP
Vegetation Potential	Between min value and 0.25*VP

After processing landform units derived from DTM, and masked the field crop LSU attribute from the overall LSU map, a combination between NDVIs maps for each landscape unit was generated, then, a combination between all the NDVI maps categorized values (5 categories) was carried out for all the maps (6 times, mean and max).

2.3.2 Calibration

The output maps of land cover classification, aspect classification and obtained threshold setting for classifying degradation categories were calibrated with different parameters and land degradation threshold settings obtained from the field observations.

The degradation values of the pixel corresponding to each NDVI Mean and Max classification values are related with the scale and centered value of all field indicators observations. Correlation between all the categories will be assessed in order to deduce map fitness that represent the final degradation maps.

To gain further information about the impact of pressure drivers (anthropogenic, climatic and topographic) on the study site we have analyzed the correlation between pressure and degradation by aspect and slope classes in the study site. Our hypothesis was that steeper slopes and south and west exposed areas would be more sensitive to pressure, as this factors increase soil erosion and runoff (slope) and mean temperature and evapotranspiration (aspect), thereby reducing availability of water and nutrients for the plants.

3. Results and discussion

3.1 Results

Unsupervised classification was processed for the corrected Landsat 8 image of June 2015 in order to define the major land use classes. The accuracy assessment was identified according to the field data, which is 83%.

At total of 4 major land use classes were found; field crops (75%), grazing lands (10%), forest (5%), permanent crops (7%) and urban area (3%) (figure 2). Moreover, as we can see that 75 % of the area is covered by field crops, so we decided to focus in this LSU and to extract it from the overall land use map, for further assessment. Most of the forest in the study site are closed and used by military activities, so there is no authorization for access.

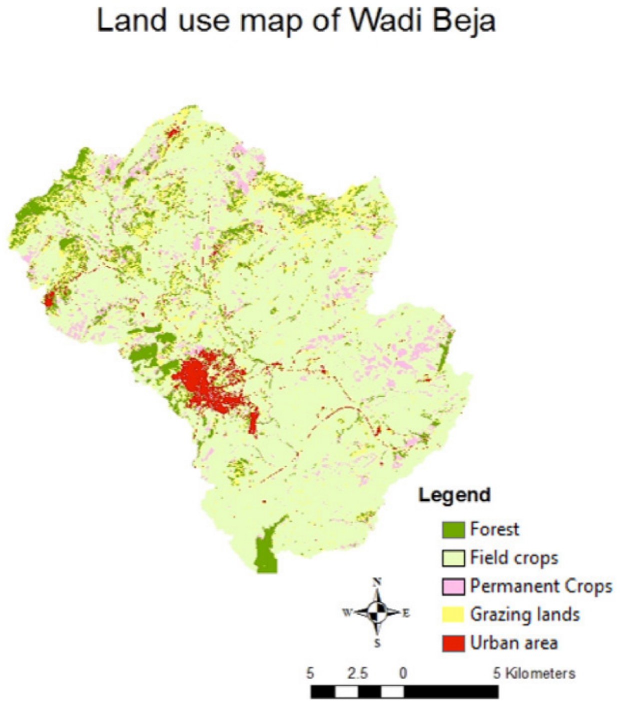

Figure 2. Land use map of Wadi Beja watershed

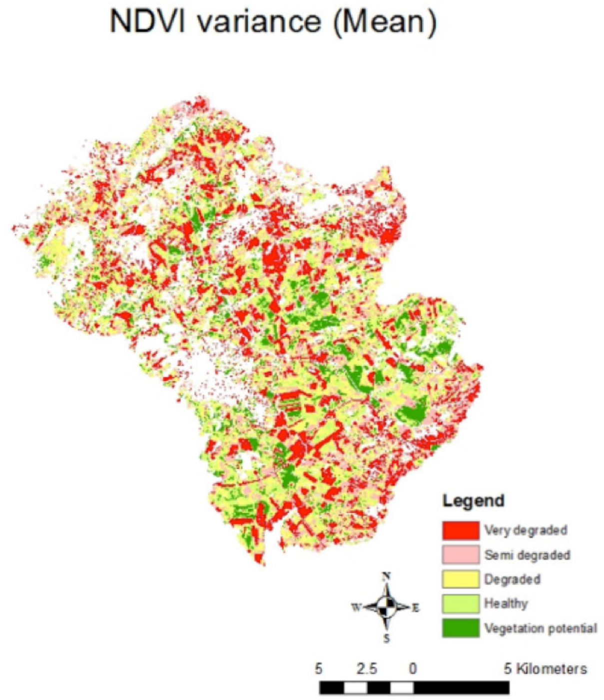

Figure 4. Degradation map based on the mean NDVI values

The degradation maps resulting from the NDVI variance analysis are the combinations of all the NDVI maps for each landform unit map.

After checking the maps fitness of all the categorized NDVI values with the categories of field observation and assessment data, the best correlation was observed the values extracted from the mean NDVI map (see figure 3).

There is a linear relationship between the degradation classifications derived from the mean NDVI variance and the mean values per class of the selected indicators. 77 % of correlation was accepted to consider that the mean NDVI variance can be considered as a degradation map based on NDVI variance across different landscapes. From this result, we can consider the "very degraded and degraded" categories as the hotspots, and the "healthy" category as the bright spots.

We describe the most relevant pattern in the degradation map, based on the information we have collected through other assessment data, stakeholder interactions and field visits.

We have identified the hot spots (degraded) and the bright spots (healthy) based on our hypothesis and used NDVI as a proxy indicator for land degradation, as suggested by literature and by available data and field observations. We displayed the NDVI variance in

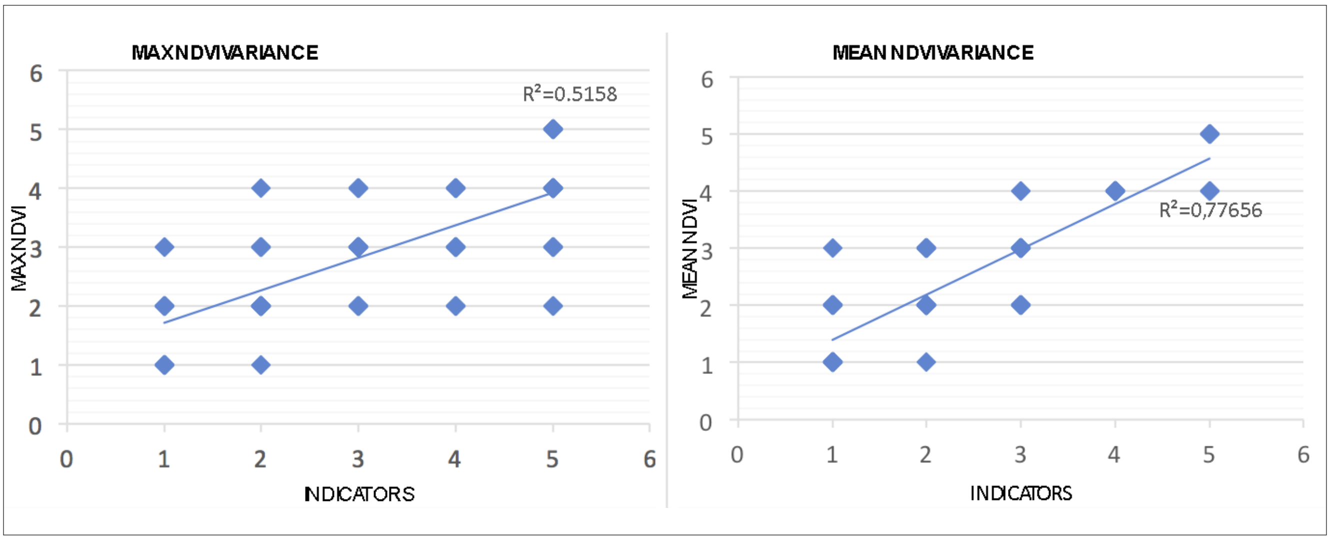

Figure 3. Histograms of the correlation between Maximum and Mean NDVI values with the categories of indicators based on field and observations data.

South and North in flat slopes and the South and North steep slopes as well, to detect the distribution of the different categories. Accordingly, the distribution of the following NDVI values is indicated from relevant histograms, see figure 5, 6, 7 and 8.

The figures 5, 6, 7 and 8, show the NDVI variance in the different slope and aspects positions, which we can get a first impression if we would like to focus for example on the very degraded areas that the reddish areas are more appearing in the South steep map compared to the remaining ones and appearing less in the North flat map. Therefore, we can say that the hypothesis on the role of the aspect first appears to be generally valid in the study site: i.e. “South” LSUs exhibit a higher distribution NDVI in the very degraded category than “North” ones. With regard to steepness, the same trend appear to the slopes, which we can observe more very degraded areas in the steep slopes terrain. Almost 25 % of the South steep slope is categorized as very degraded areas beside just 13 % classified as healthy in the same landform unit. 15 % of the North steep slopes are classified as very degraded beside 19 % of healthy areas. For the north flat face, 20 % of the area is classified as healthy beside 14 % of very degraded areas.

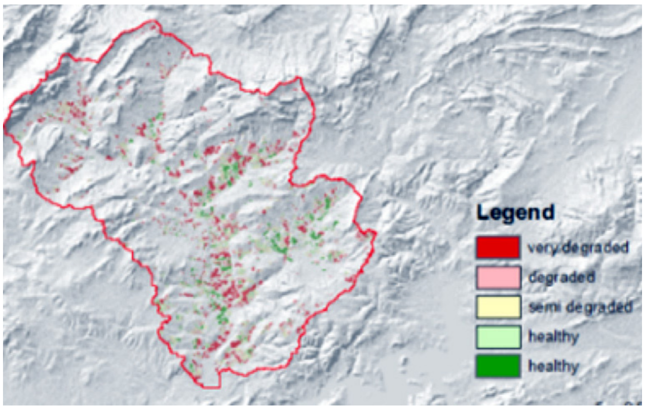

Figure 5. NDVI variance in South flat slope

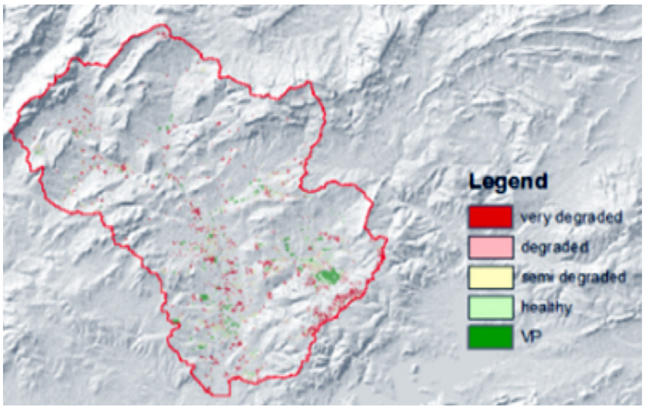

Figure 6. NDVI variance in North flat slope

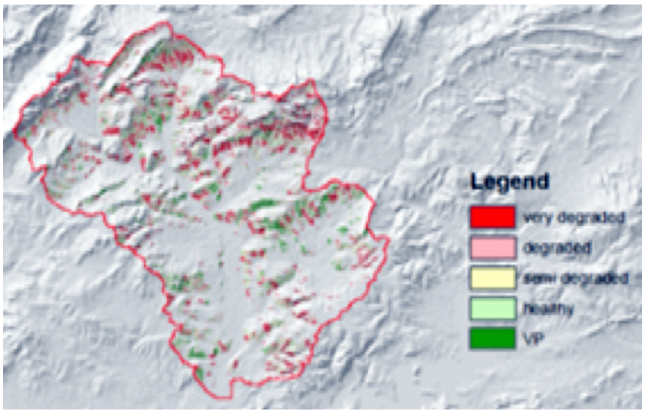

Figure 7. NDVI variance in South steep slope

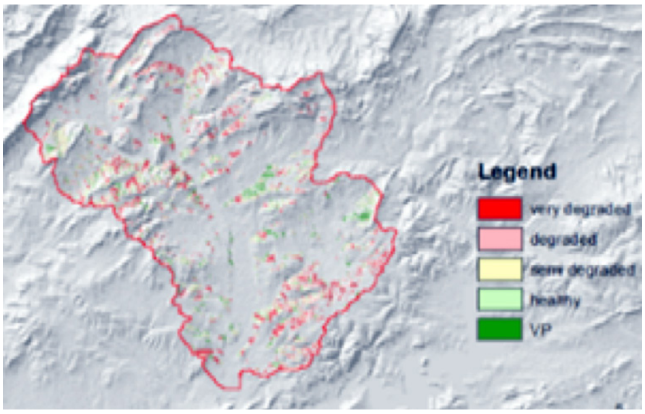

Figure 8. NDVI variance in North steep slope

3.2. Discussions

In order to ensure the identification of hot spots of land degradation and bright spots of land conservation, the hot/bright spot map developed for this study constitutes a simple approach that allows the soil erosion information to be linked with vegetation quality indicators in a flexible manner, since it may be used at various spatial resolutions and either for raster derived data (as in this study) or for field data. However, there are also limitations in the explanatory power of the hot/bright spot classification, which need to be addressed before wider application of the hot/bright spot map is possible:

Not only inappropriate land management lead to “hot spots of soil degradation”. As an example of an area showed, stony soils in mountainous regions with presumably inherently low soil organic carbon SOC content may also be classified as hot spots. Thus, in areas, where also non-loessial soils are present the classification using the hot/bright spot map will likely lead to spurious results.

A spatially explicit soil type classification is needed, in order to incorporate effects, which must be attributed to a specific soil type.

The assumption with regard to loess soils being generally homogeneous (if not affected by degradation) requires analysis that is more detailed / validation. Analysis that is more detailed is needed with regard to sites with inherently low SOC. Especially, the relationship between soil texture and SOC needs to be analyzed in more detail.

A spatially explicit geology assessment is needed, in order to incorporate the geologic aspect, which must be attributed to a specific soil type.

We tested the assumption that present day monoculture was still an important factor in the development of the vegetation and the degradation of study site. This factor was accelerated and recognized by the land management, which inappropriate tillage in steep slopes terrain was the main factor, and of course water erosion and runoff. However, some area appears like patches of less vegetation caused from overuse and tillage in the slope direction.

In this study case, where erosion consists of three phases (uprooting, transport and sedimentation), soil degradation only involves the destabilization of soil structure and macro porosity on the soil.

The degradation of the soil in the present context resulted essentially from three processes:

- The mineralization of organic matter in the soil, which is more active as the climate is hot and humid;

- Mineral export by crops, which will lead to a decrease in the activities of micro- fauna and fauna, responsible for the macro-porosity of the soil and the diffusion of air and water in the soil;

- The skeletonization or enrichment of surface horizons in sand and gravel by selective erosion of fine particles, organic matter and nutrients, following the rainfall. Raindrops fall down to the soil, break up the aggregates, and tear off particles that will form around decking and sedimentation crusts that are favorable to runoff.

Regarding land management, overuse and field crops monoculture appears to explain land degradation to a relevant degree for north-facing LSUs, while all other LSUs exhibit low NDVI values. This might be because low water availability and poor soil fertility generally limit vegetation growth across all south-, east-, or west-facing areas in the site, resulting in a low vegetation cover (and low NDVI values) regardless of the land use intensity.

Healthy land is primarily located in three areas in the northeast and north-west and center of the study site. Among the highlighted areas, good land management on fairly flat slopes was followed through some conservation agriculture attempts. Accordingly, they are less affected by land use and they have been heavily maintained by other conservation measures.

The result regarding aspects and slopes, appear suitable to the hypothesis, it could be related to the fact that the south and western exposed LSUs appear more sensitive to runoff and water erosion and further pressure than others. Land degradation is more accelerated in these fragile environments mainly by inappropriate tillage.

Looking at practices to combat desertification, our results stress the perils of widespread conservation efforts. Their success rate is low and depends highly on factors beyond human control, such as slope steepness and aspect, as stressed by other researchers (Príncipe et al. 2014).

This can be explained by the higher solar radiation and mean temperatures that are reached during the afternoon affecting evapotranspiration; moreover, humidity is often brought in this area by eastern winds, and deposits in eastern exposed LSUs more than western exposed.

Our assessment of land degradation was based on two major steps: (1) identifying LSUs based on land use system, aspect, and slope; and (2) classifying degradation based on the variance of NDVI value within each LSU according to a specific threshold setting.

By looking at LSUs we aimed to identify the differences in vegetation development that occur in the areas, in order to highlight man-made degradation and other unknown factors that might influence vegetation greenness and maintenance. While is it difficult to say whether the identified degradation patterns are entirely related to anthropogenic pressure, the correlation values between degradation and pressure drivers are a good indication that the maps indeed describe well the processes occurring in the study site.

We interpret the fact that explanation for the NDVI variance in field crops land use system were obtained when differentiating between different slope and aspect classes as a confirmation that the resulting degradation patterns indeed highlight man made degradation and even out differences resulting from aspect and slope.

The second step in degradation mapping focused on translating variance in NDVI values into the appropriate degradation class. Similar studies have showed similar results (Eckert et al. 2015, Liniger et al. 2016). There is no agreement among scientists on how to measure or classify land degradation. Most recent methodologies revolve around the use of a set of indicators that vary depending on the specific environment considered, and analysis of the causes and impacts of one or more pressure drivers. This multifaceted approach is difficult to translate into a logic using a single variable such as NDVI value.

The specific threshold setting was chosen by correlating the degradation classification with the values obtained through field observation. This calibration yielded different results for the study site: Threshold setting based on the 90th percentile, performed good correlation for this site. The mean NDVI values for the green season generate the fittest map for land degradation according to the field data.

In the study site, the values of the pixels with the lowest vegetation cover are much more spread out (expressed in the longer tail of the distribution). In addition to the steep slope position, this may be related to the climatic conditions, which are much drier. Soil characteristics may have an influence as well: In some area, the study case the soil is very shallow, with frequent rocks at the surface. By contrast, in some other areas, soil, is characterized by deep calcific soils that are highly prone to erosion. In this case, we have to consider that the lowest NDVI values are probably related to rock outcrops that were recognized as heavily degraded land by the NDVI methodology, while this does not occur in some others areas, where low NDVI values actually correspond to degraded land also according to field observations.

However, the methods selected do take into account the different shapes of the distributions, and are thereby applicable on different landscape types within the same agro-ecological zone such as in the study of (Liniger et al. 2016).

4. Conclusion

The maps obtained by analyzing NDVI variance provided important spatial information on degradation patterns and conserved areas in a simplified form that made it easy to explain to land managers and local stakeholders. The map scale was appropriate for investigating land management in the study sites. Using the information provided by stakeholders, were able to identify and explain the overall pattern shown by the map, and to relate this, at least partly, to the monoculture risk and water erosion occurrence in the site.

The threshold methodology enabled us to adequately capture current land degradation, or at least those aspects of degradation that translate into reduced vegetation greenness.

Some limits of the methodology emerged when the maps were analyzed in detail. For one thing, local microclimatic, topographic (altitude), or soil conditions influence the location of areas classified as potential. However, even if these local factors are not related man-made pressure or land management, highlighting them was still important for understanding degradation processes and provided important information to consider when planning land management interventions. Second, some degradation processes do not translate into a decrease of greenness and can therefore not be detected by means of the NDVI. This was particularly relevant for example where the main long term impact of – changes in the type of vegetation (e.g. from trees to shrubs) or in the species composition – went undetected in our study. Third, the relation between NDVI and land degradation depends on local soil and climatic characteristics (e.g. 10% of each LSU is considered as heavily). However, it is possible to try different threshold settings within the same methodology, it is possible maybe to apply the same methodology and obtain comparable outputs for ecosystems situated in different agro-ecological zones. Besides these intrinsic limitations of the threshold methodology adopted, the low quality of available land cover maps and of spatial information about land management remains a source of uncertainty in the results, and required extra efforts to improve the input data using threshold methodologies (supervised classification, long-term time series analysis, Sentinels 2a images, and phenology analysis).

The resulting land degradation maps proved to be useful exploratory tools for gaining insights into the state of field crops ecosystems in the study site, which is the strategic and main land use system of the region. This study aims to investigate how monoculture and inappropriate tillage influence land degradation, and to obtain evidence of the impact of land management practices. The maps also enabled us to analyze how different landscapes react to pressure and land management, and we can conclude that slope steepness increases sensitivity of the land to erosion.,

Concerning our analysis of the study site, it appears that monoculture land use is a highly significant driver of degradation, particularly in south – western steep slopes terrains, whereas its impact of erosion is more relevant in the long term. Moreover, there is a significant relationship between topography and land management practices: on steep, south-facing slopes, the role of erosion is far more important than in flat areas. Looking at land management practices, it appears that successful management in term of restoration is very demanding to achieve, especially on steep, south facing slopes. Nonetheless, it appears to have a beneficial effect, expressed in increased greenness.

Using landscape units to translate NDVI values to land degradation proved a successful way of highlighting the effect of land management and anthropogenic pressure. Further integration of measured data based on soil or vegetation parameters, as well as expert knowledge about the conditions of different LSUs could allow us to define a universally valid way to translate NDVI values to land degradation, applicable to all ecosystems and agro-climatic zones. Provided that land use maps and reference points are available, the methodology could easily be implemented in other dry ecosystems to generate information on degradation patterns and assess the impact of land management practices. Furthermore, the methodology could be used for resilience studies and to monitor vegetation recovery after a disturbance across different landscapes and under different management strategies.

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