Degradation and vulnerability to climate change in high Andean rangelands

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Abstract

Rangeland degradation is a process associated with loss of ecosystem equilibrium. Therefore, this work seeks to identify the most important factors that cause the degradation process of rangelands, assess the degree of degradation and vulnerability to current climate change of these ecosystems; and determine if there is a relationship between the degree of rangeland degradation and vulnerability to climate change in high Andean rangelands. The study was located in the central highlands of Peru (Ancash, Junín, Pasco, Huancavelica and Lima) and involved the design of a framework to assess rangeland degradation based on field information and Landsat satellite products that was contrasted with socioeconomic, ecological and location variables. The estimation of vulnerability to climate change was assessed with the Analytic hierarchy process (AHP) in a Geographic Information Systems (GIS) platform. The results revealed that around 80% of the rangelands were classified as extreme and serious degraded. Extreme and heavy vulnerability was around 85%. There is positive spatial correlation between degradation and vulnerability to climate change in high Andean rangelands (Pearson = 0.67, Spearman = 0.61).

Introduction

There are approximately 22 million hectares of rangelands in Peru, 15 million of which belong to the Puna region (areas above 3800 m of elevation). Although their value as a forage resource for grazing, and environmental services, more than 60% of these rangelands are in the process of degradation due to the absence of conservation policies, inadequate management and overgrazing (Flores, 1996), which make them more vulnerable to climate change. Most of the studies carried out to date have only evaluated the conditions of degradation and vulnerability of ecosystems, based only on the surface biomass estimated from the Normalized Differential Vegetation Index (NDVI), derived from coarse resolution data (i.e. AVHRR with a spatial resolution of 1.1x1.1 km). These studies do not consider the complex spatial interaction of factors that promote degradation at larger scales. The objectives of the study were to carry out an exploratory analysis of the drivers that determine degradation and vulnerability in andean rangelands and map it at medium scale; additionally explore the relationship that exists between rangeland degradation and vulnerability.

Methods

The study area of 349,777,71 ha was located in rangelands of the Departments of Ancash, Pasco, Junín, Lima and Huancavelica. The data sets include Landsat imagery corresponding to the period of 2011-2014; ASTER GDEM; socioeconomic and biophysical data from public entities; and field data. The Rangeland Degradation Map was built using the analysis of the Vegetation Fractional Cover (VFC) based on the NDVI values, reclassified in ranges according to the scale proposed by Gao et al. (2006), where the lowest FCV is related to extreme degradation in rangeland fields, and the cover near to 100% slight degradation. Field vegetation cover assessment was estimated in quadrants of 1 m by 1 m along linear transects in 32 areas of the 8 study zones and within Landsat pixels in August 2015. The calibration of the vegetation cover data with the VFC obtained from Landsat images was done with different regression models, to extract the best model.

In order to explore the Rangeland degradation factors, a multinomial logistic regression was applied using as predictors Annual rainfall (mm), Average annual temperature (ºC), Weathering, Elevation (m.a.s.l), Slope (°), Distance to Lagoons (m), Distance to rivers (m), VFC, Population density (person/km2), Distance to national and departmental roads (m), Distance to local roads and trails (m), Distance to settlements (m), Animal density (sheep/ha) and protection status (0 : No protection, 1 : Reserved areas).

The evaluation of eco-environmental vulnerability is based on a combination of a fuzzy hierarchical analytical model (FHAM), with Geographic Information Systems (GIS), which is mainly composed of three stages: (i) the selection of indicators and weight, (ii) the collection of data and standardization, and (iii) integrated assessment and cartography. We classified all the indicators in three groups (Exposition, Sensitivity and adaptative capacity). Each indicator is then linked to a raster file composed of 30 x 30 m pixels. Finally, the resulting map is used to highlight spatial differences in the vulnerability index. Exposition indicators were precipitation and temperature, Sensitivity indicators included slope and elevation, and distance to lakes and rivers, while Adaptive Capacity indicators involved human and animal density, distance to towns and roads, and protected areas. Each indicator was then weighted based on expert opinion and the Analytical Hierarchy Process (AHP) method. After the standardization of the variables, the Climate Change Vulnerability Index (CVI) was calculated, using the ArcGIS 10.2 Raster calculator tool, as a support platform for creating and editing a vulnerability map, which thresholds were defined using Jenks natural breaks optimization.

The concordance analyses of Kendall's Tau-b and Kendall's Tau-c and the Spearman correlations and Pearson's R were used to determine the relationship between degradation and vulnerability to climate change maps. A layer of points using the Raster to Point tool of the ArcGIS 10.2 was used to extract degradation and vulnerability values of each pixel, which then were exported to a DBF table and processed with the Analysis > Statistics tool descriptive > Contingency tables > Kendall's Tau-b, Kendall's Tau-c, Spearman's Correlation, Pearson's R, from the statistical package SPSS® V.22.

Results and Discussion

Rangeland degradation

The main factors in order of importance associated with the serious and extreme degradation process were the loss of vegetation fractional cover (VFC) from previous years, increments in the annual average temperature, high animal density, poor protection policies, high population density and low rock weathering index.

Field vegetation cover has a strong linear relationship with Landsat VFC (R^2 =0.868, $p< 0.0001$; bias (%) = -2.035) where *VFC field = 0.8348*VFC Landsat + 12.429*. Based on this model we calculated the spatial distribution of rangeland degradation for the whole study area. The proportion of degraded rangelands between seriously degraded and extremely degraded, was of 84.41% for 2011, 90.68% for 2012, 73.73% for 2013 and 81.74% in 2014. Having Santa Ana district, the most degraded areas in and the less degraded Simon Bolivar district. Multinomial logistic regression analysis shows an 80.20% overall accuracy of being correct in predict the degradation degree with 66.64% Kappa index, explaining relations showed in Table 1.

Table 1. Estimated coefficients and odds ratio from multinomial logistic regression (all coefficients are significant p‹ 0.01).

	LD		**MD**		**SD**		**ED**	
	Coef.	**Odds**	**Coef.**	**Odds**	**Coef.**	**Odds**	**Coef.**	**Odds**
Intersection	23.19		34.01		-3.62		-53.51	
Annual rainfall (mm)	6.40E-04	1.00	1.81E-03	1.00	4.34E-03	1.00	0.01	1.01
Average annual temperature (ºC)	-0.45	0.64	-0.51	0.60	1.08	2.93	2.71	15.08
Weathering	0.03	1.03	3.93E-03	1.00	-0.06	0.94	-0.11	0.89
Elevation (m.a.s.l)	-3.38E-03	1.00	-4.68E-03	1.00	2.75E-03	1.00	0.01	1.01
Slope (°)	-0.02	0.98	-0.01	0.99	2.20E-03	1.00	0.01	1.01
VFC 2011	-5.09	0.01	-9.61	0.00	-16.58	0.00	-26.72	0.00
VFC 2012	-1.93	0.15	-2.99	0.05	-5.31	0.00	-9.07	0.00
VFC 2013	-3.25	0.04	-7.99	0.00	-15.26	0.00	-22.4	0.00
Population density (person/km^2)	0.09	1.10	0.16	1.17	0.25	1.28	0.35	1.42
Distance to Lagoons (m)	-1.70E-04	1.00	0.00	1.00	-2.95E-04	1.00	0.00	1.00
Distance to rivers (m)	-2.01E-04	1.00	-1.76E-04	1.00	1.29E-04	1.00	1.53E-04	1.00
Distance to national roads (m)	1.13E-04	1.00	1.84E-04	1.00	2.64E-04	1.00	3.45E-04	1.00
Distance to local roads and trails (m)	1.09E-04	1.00	2.40E-04	1.00	2.96E-04	1.00	2.81E-04	1.00
Distance to settlements (m)	6.29E-05	1.00	1.26E-04	1.00	1.81E-04	1.00	3.12E-04	1.00
Animal density (sheep/ha)	0.39	1.47	0.88	2.40	1.85	6.38	2.81	16.55
Reserved areas (0: No protection)	0.78	2.19	1.08	2.95	0.78	2.18	1.07	2.92
Reserved areas (1: Protected)	0.49	1.63	1.1	3.00	1.37	3.92	2.19	8.89

Note: ED—Extremely degraded; SD—Seriously degraded; MD—Moderately degraded; LD—Slightly degraded; ND—Not degraded.

Based on the multinomial logistic regression, if annual precipitation and temperature increases, rangelands with serious and extreme degradation will be affected, as heavy rains can contribute to the loss of soil for erosion, leaching and influence soil compaction (Padilla et al. 2009). For rangelands with slight and moderate degradation, a recovery is expected considering that decomposition rates increase rapidly with temperature, if there is enough water (Parton et al. 1993). If weathering increases, rangelands with serious and extreme degradation will recover since this process promote soil formation (Hernández, 1995).

Rangelands with serious and extreme degradation, located in the highest elevations and pronounced slopes, degradation increases, even if human activities are greater in places with lower elevation and slope. (Ostaz et al. 2003; Buol et al. 1989).

If the VFC increases, the degradation decreases, because VFC is highly related with green biomass and productivity (Tucker et al. 1991). In addition, if population and animal density increases, the probability that the rangeland area degraded is major, given that the increase in human populations intensifies the demand on rangeland resources beyond the capacity of the land (Talbot, 1986; Angerer 2012). Rangelands outside protected areas are more likely to be in a state of degradation, consistent with the Public Investment Policy guidelines for Biological Diversity and Ecosystem Services 2015-2021 (DGIP-MEF, 2015).

The shorter distances from a river for rangelands with slight and moderate degradation promote recovery, and for rangelands closest lagoons, has a opposite response, because for areas with diverse topography, cattle overuse flat areas adjacent to lagoons (Pinchak, 1991). If rangelands are distant from settlements they present more degradation, this differs with Liu et al. (2006), who affirms that traffic and the effect of trampling promote degradation, however Rodríguez (2006) affirm that settlement provide more organic material to the soil and improve plant cover. If rangelands are distant from an access road, regardless of the type of road, it will increase degradation. Some studies find that roads do not necessarily lead to the degradation since the impact of roads on rangelands depends on the road type and rangeland type (Zhang et al., 2002).

Rangeland vulnerability to climate change

The main factors in order of importance related with Vulnerability are Sensitivity (0.6902), represented by VFC, high slope, low rock weathering index, followed by Exposition (0.1606), represented to low precipitation, and Adaptative capacity (0.1492), associated with long distance to water sources, high population density, high annual average temperature and high animal density.

Table 2. Hierarchical structure of vulnerability to climate change (Values numbers in parentheses are the weights of each indicator).

Level 1 Aim	Level 2 Criterion	Level 3 sub-criterion
Ecological vulnerability	Exposure (B1, 0.1606)	Mean annual precipitation ((C1), 0.1205)
		Mean annual temperature ((C2), 0.0402)
	Sensitivity (B2, 0.6902)	Elevation ((C3), 0.025)
		Slope ((C4), 0.1883)
		Proximity to lakes ((C5), 0.0545)
		Proximity to rivers ((C6), 0.0537)
		Plant cover fraction ((C7), 0.2400)
		Weathering ((C8), 0.1287)
	Adaptive Capacity (B3, 0.1492)	Population density ((C9), 0.0525)
		Animal density ((C10), 0.0365)
		Proximity to settlements ((C11), 0.0263)
		Proximity to local roads and trails ((C12), 0.017)
		Proximity to national and departmental roads ((C13), 0.0098)
		Reserve areas ((C14), 0.007)

The global vulnerability classification for the period 2011-2014 is mostly medium (52.43%), followed by heavy vulnerability (35.24%), light (9.88%), extreme (1.80%) and potential (0.65%). These results denote an intermediate situation of total vulnerability for the evaluated areas, where the sum of medium and heavy vulnerability is 87.67%.

Joyce et al (2013) mentions that the interaction between exposure to climate change, system sensitivity and available adaptive capacity interact generating multiple states of vulnerability, where in many cases an improvement in adaptive capacity may be sufficient action to sustain the means of subsistence of the system and improve the vulnerability index. Likewise, adaptation implies the adoption of alternative techniques and livelihoods that reorganize the system and the use of ecosystem services (Kates et al., 2012).

The vulnerability analysis by district shows that Canchayllo has the largest areas with medium vulnerability level, likewise no presents the largest areas with slight and potential vulnerability; Santa Ana district has the largest areas with heavy vulnerability. The general trend of vulnerability decreases for all the districts.

Relationship between rangeland degradation and vulnerability

There is a moderate bilateral positive association (Pearson = 0.67, Spearman = 0.61) between degradation and vulnerability. Therefore, rangelands with a higher degree of degradation will be more vulnerable to the effects of climate change.

Conclusions and/or Implications

The largest proportion of the studied rangelands are in extreme and serious degradation state with trend to increase, confirming the fragility of these ecosystems.A multinomial logistic regression model was effective in predicting and identifying the factors related to rangelands degradation. Using field, socioeconomic and remote sensing data, this approach revealed that the most important factors to evaluate rangeland degradation were low vegetation fractional cover (VFC), higher temperature, higher animal density, poor protection policies, higher population density and greater weathering. These partially coincide with the main factors for assessing rangeland vulnerability to climate change, where the largest proportion of rangelands present heavy and medium vulnerability, due to greater exposure, high sensitivity and low adaptive capacity.

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