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Socio-economic and biophysical determinants of land degradation in Vietnam: An integrated causal analysis at the national level

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ABSTRACT

Recognizing the socio-economic and biophysical causes of land degradation at the national level is important for cause-targeted strategies when designing policies for combating land degradation. This study aims to identify the biophysical and socio-economic factors that significantly affect land degradation across Vietnam and to interpret the causalities underlying the effects. The dependent variables considered in the study are spatial, the extent and intensity of degradation in three land-use zones (agriculture, forest and severely degraded abandonment). The hypothesized explanatory variables are common economic and demographic drivers and bio-physical factors such as soil, terrain constraints, and neighborhood land-use structures that are often neglected in many large-scale land degradation assessments. Instead of using a single inferential statistic technique, we used multi-linear regression and binary logistic regression in a complementary manner to increase the detectability and credibility of the degradation cause analyses. The results showed agricultural production growth had strong and consistent effects on land degradation extent and intensity. Population growth, especially in rural areas, had a strong effect on the extent of overall land degradation. The importance of a neighboring forest was revealed for its ability to reduce land degradation intensity in abandoned, unproductive lands. The concrete faceting of the causal analysis for each land-use zone as social–ecological stratum allowed us to combine the defined social–ecological contexts, contemporary theories, and hypotheses in the field to clarify the causal factors of a complex phenomenon like land degradation. The study demonstrates these contemporary inferential statistics can be complementarily used to sufficiently detect and understand land degradation causes at the national level. The results suggest implications for national land management policy: internalizing land degradation costs in the farming system evaluation for payment for ecosystem services policy, restricting forest conversion, and improving extension services and education in agrarian communities.

Introduction

Land degradation is defined as either the persistent reduction of the land's biological and/or economic production capacity (Vogt et al., 2011). Land degradation is caused by both natural and anthropogenic phenomena (Le et al., 2012; Vlek et al., 2008; Vu et al., 2012a) where the former is balanced by natural processes and cannot be interfered with and the latter can be mitigated, even though it is a difficult task (Stocking and Murnaghan, 2001).

The problems of land degradation are most serious in tropical regions, where communities' livelihoods depend on land productivity (e.g., food production and products from forests) and the land and soil resources are exposed to natural constraints (e.g., high annual rainfall and steep terrain conditions). Tropical regions are also home to the poorest communities in the world, where there is a downward spiral between poverty and land degradation: poverty and economic marginalization lead to land degradation, and land degradation leads to further poverty (Scherr, 2000). Vietnam can be seen as a prevailing case of anthropogenic land degradation. Though agriculture remains the most important sector of the Vietnamese economy, agricultural land area per capita is, on average, about 0.11 ha/person (GSO, 2009). Given this high land pressure, land degradation is one of the most striking problems for the nation, as at least 64,000 km^2 of land (19% of the national land mass) experienced persistent declines in biomass productivity over the last 25 years (Vu et al., 2012a). As the land resources in Vietnam are limited and many areas are degraded, one of the top questions for

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national policy-makers is how to use the land in a sustainable manner, especially for the mountainous and hilly areas, where the land potential is high, but the degradation is serious (Siem and Phien, 1999).

Combating land degradation by formulating effective mitigating policies requires the identification of the anthropogenic causes of the phenomenon (Vlek et al., 2008, 2010; von Braun et al., 2012). Although the general categories of land degradation causes have been reviewed (Geist and Lambin, 2004; Nkonya et al., 2011), comprehensive portfolios of the actual causes and the understanding of their causalities are still lacking (von Braun et al., 2012). At global level, the Global Assessment of Human-Induced Soil Degradation (GLASOD) (Oldeman et al., 1991) identified the causes of land degradation based on expert opinions that had less scientific rigor. Furthermore, the GLADSOD results are outdated. Some recent global or continental studies used quantitative analyses, but are still limited to the measurement of the correlations between socio-economic factors to indicators of land degradation (e.g. Bai et al., 2008; Vlek et al., 2008, 2010) that are indeed not an scientific inference of degradation causes. Recently, Nkonya et al. (2011) used inferential statistics (i.e., multiple linear regressions) to analyze the relationship between a range of biophysical and socio-economic factors and vegetation greenness decline throughout in East Asia. However, the authors admitted of that no strong and meaningful causal relationships could be drawn from the regression results due to the absence of a clear land-use context. Barbier (1997) statistically inferred the causes of land degradation in developing countries; however, the study was limited to economic factors. On the national and sub/national scales, a few studies have analyzed the correlation between land degradation and some natural factors and land use management practices, but without appropriate inferential analyses to reason scientifically the cause–effect relationships (Ayoub, 1998). In Vietnam, only a few studies have been conducted to quantify the direct drivers of soil erosion, such as slope, rainfall erosivity, soil erodibility, vegetation cover, and soil conservation measures, which are evident and limited to some specific areas of the country (Ha, 1996; Siem and Phien, 1999). Therefore, a socially-ecologically comprehensive understanding of the land degradation causes at the national level is lacking.

Previous large scale land degradation studies recognized methodological gaps that should be fulfilled in next research. First, to address the high diversity of social–ecological context over the national or international scale, causal analyses of land degradation should be carried out within social–ecological strata (e.g. broad climate and land-use zones) (Vlek et al., 2008, 2010; Sommer et al., 2011). Second, because the relationship between land degradation and its drivers can be non-linear (Reynolds et al., 2011), inferential statistical techniques used for the causal analysis should be capable to capture such non-linearity. Moreover, many precedent studies on causes of land degradation focus more one demographic, policy/institutional and economic factors and ignore important biophysical variables that either directly affects, or constrain the phenomenon, such as soil and terrain constraints, surrounding land cover and land use (see a mini review by von Braun et al., 2012). This limitation calls for the inclusion of more biophysical factors in causal analyses of land degradation.

Following the above-mentioned directions, this paper aims to identify the biophysical and socio-economic factors that affect significantly the land degradation across Vietnam and to interpret the causalities underlying the effects. Based on this, the paper endeavors to demonstrate the methodological innovations through a comprehensive assessment of the land degradation causes at the national level and suggest the implications for national policies intended to combat land degradation.

Materials and methods

Dependent variables and inferential statistical methods

The dependent variables reflect two important dimensions of the land degradation severity: (1) the spatial extent of the land degradation within an administrative unit (district), and (2) the intensity of the land degradation on a location (8 km × 8 km pixel) (Oldeman et al., 1991) (see Table 1). We used the pixel-based data for human-induced land degradation in Vietnam (Vu et al., 2012a,b) to compute these two dependent variables. The data concerned the persistent decline of the biomass productivity of the land over the last 25 years (1982–2006), approximated by the trend of the inter-annual Normalized Differentiate Vegetation Index (NDVI) for every 64 km^2 pixel of the land surface. The confounding effect of rainfall variation on the NDVI trend was corrected. The data were validated by comparing with the spatial pattern of the verified Net Primary Productivity (NPP), calculated using another remote-sensing instrument (at a finer resolution) and climate data (Zhao and Running, 2010, 2011), as well as other reported field studies (see details in Vu et al., 2012a).

Land degradation extent

Land degradation extent was measured by the percentage of degraded area within an administrative unit (variable *DEG_SHARE*) (N = 377 districts). The inferential statistical method applied for this variable was a multiple linear regression analysis.

$$DEG\_SHARE = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \qquad (1)$$

where X_i and β_i ($i = 1, 2, 3, \ldots, n$) are explanatory variables and their weights, respectively. Coefficient α is the intercept.

In addition, we considered the degradation extent on a binary scale (variable *DEG_SHARE_L*): minor spreading rate of degradation if the area percentage of degraded land is less than 20% over 22 years (i.e., <1% annually) (*DEG_SHARE_L* = 0), and there is a significantly spreading rate of degradation otherwise (*DEG_SHARE_L* = 1) (see Table 1). This threshold was adapted from the Global Assessment of Human-Induced Soil Degradation (GLASOD) (Oldeman et al., 1991). The causal effects of explanatory factors on this variable were statistically inferred using binary logistic regression, which has the function of the following form:

$$\ln\left(\frac{p(y=1)}{(1-p(y=1))}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \qquad (2)$$

or:

$$p(y=1) = \frac{e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n)}}{1+e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n)}}$$

where y is *DEG_SHARE_L* and $p(y=1)$ is the probability of *DEG_SHARE_L* = 1.

The consideration of degradation extent in binary units can help us capture some important causal effects that may not be addressed by multiple linear regressions, due to the linearity assumptions of this method. The use of binary logistic regression also allows us to apply more techniques for model performance assessment, thus making the result evaluation more comprehensive.

Land degradation intensity

We also used two variables to represent the intensity of the land degradation: reduction of annual mean NDVI (variable *DEG_INTEN*) and intensity level of degradation (variable *DEG_INTEN_L*). The former variable is measured as the percentage of the mean NDVI in the base year (1982), and the latter variable is captured on a binary scale: minor rate of degradation if the NDVI decline is less than 10% over 25 years (i.e., <0.5% annually) (*DEG_INTEN_L* = 0), and substantial degradation rate otherwise (*DEG_INTEN_L* = 1). This threshold