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Semi-parametric Geographically Weighted Regression (S-GWR): a Case Study on Invasive Plant Species Distribution in Subtropical Nepal

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Abstract

Geographically weighted regression (GWR) is a spatial statistical methodology to explore the impact of non-stationarity on the interaction between spatially measured dependent and independent variables. In this paper we use a semi-parametric geographically weighted regression (S-GWR) and demonstrate the effectiveness of the method on a case study on socio-ecological factors on forest vulnerability. The case study is based on community forests in and around the buffer zone of Chitwan National Park, Nepal, a biodiversity hotspot that is being rapidly degraded by exotic invasive plant species. This research integrated heterogeneous data sources such as observational ecological surveys, household interviews, and remotely sensed imagery. These data were utilized to extract and represent invasive plant species coverage, human activity intensity, topographical parameters and vegetation greenness indices. Research findings both demonstrate the S-GWR method and offer possible interventions that could slow the catastrophic spread of invasive plant species in Chitwan, Nepal.

1. Introduction

Geographically weighted regression (GWR) is a spatial analysis method that uses the spatial distribution of dependent and independent variables to specify non-stationarity to quantify the drivers of spatially dependent processes. GWR has been widely applied in application domains such as species distribution modeling in ecology and crime analysis in sociology (Foody 2004; Zhang and Song 2013). This paper presents a semi-parametric geographically weighted regression (S-GWR) method to model the factors that influence the spatial distribution of invasive plants in Nepal. We chose to use a semi-parametric model to include both parametric and non-parametric variables in the model specification. The S-GWR is implemented in a case study on the relationship between socio-ecological factors and invasive plant species in Chitwan, Nepal.

Invasive plant species are considered as a serious global environmental threat to ecosystem structure and function by creating disturbances in ecosystems, reducing native species diversity and abundance, limiting human usage of ecosystems and triggering environmental changes. It is an emergent research topic to prevent invasive plant species spread and alleviate their influences in forest ecosystems. The case study aims to quantify the relationships between invasive plant species coverage and socio-ecological factors in community forests (CFs) in Chitwan, Nepal. We demonstrate the use of S-GWR to understand the spatial nonstationarity in invasive species distribution modeling (iSDM). With the social factors, the modeling results enable us to better understand how invasive species are influenced by human activities in the CFs, and how to balance the human activities and CF ecosystems by appropriate forest management.

2. Case study in Chitwan, Nepal

In forest ecosystems, community forest (CF) management has been recognized over the past three decades as a successful method for improving forest conservation methods (Klooster and Masera 2000). In Chitwan, Nepal, CFs were established with the intent of allowing citizens to manage forest resources while reducing negative impacts on the surrounding National Park. Even though the CF ecosystem has been extremely successful in the buffer zone of Chitwan National Park since the 1990s, by 2005 exotic plant invasion broke the current ecological equilibrium. Among all the invasive plant species found in Chitwan, *Mikania micrantha*, or "Mile-a-Minute weed", is considered the most harmful invasive species to ecosystem processes and requires an immediate forest management intervention in Nepal (Rai and Scarborough 2015). *M. micrantha* has the potential to catastrophically disrupt this urbanizing socio-ecological ecosystem in inequitable ways depending on CF vulnerability. Thus, the relationships between *M. micrantha* coverage, forest biophysical characteristics and human activities must be studied to design an effective intervention for the exotic plant invasion in the CF ecosystems at Chitwan, Nepal.

2.1 Study area

The study area focuses on the 12 continuous southern riverine CFs in western Chitwan district, which are in or nearby the buffer zone between the cultivated Chitwan valley and the Chitwan National Park at Nepal (see Figure 1).

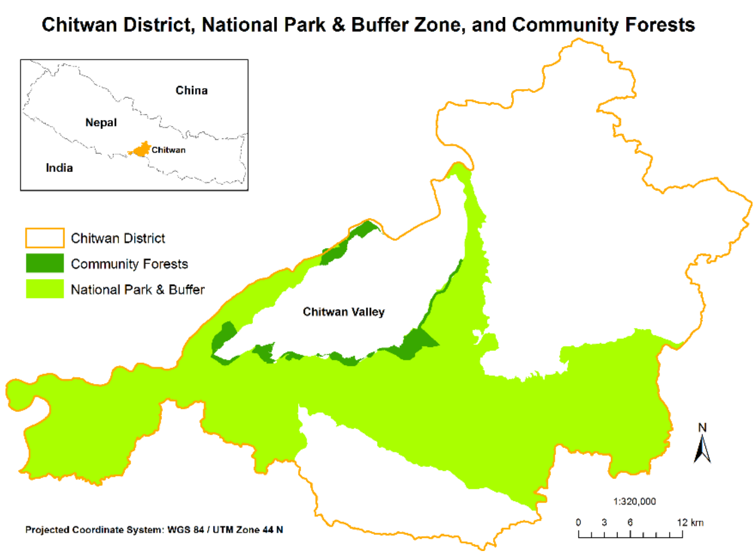

Figure 1. Study area in community forests at Chitwan National Park, Nepal.

2.2 Data sources

This research integrates numerous heterogeneous data sources such as observational ecological survey, household social survey, and remotely sensed imagery to understand the drivers of the *M. micrantha* invasion in this region. Invasive plant species and environmental surveys were conducted from 2013-2015 in the CFs. From the environmental survey, *M. micrantha* coverage, canopy coverage, fire evidence and dominant vegetation type were observed and recorded. A household social survey collected information on household resource use activity information in the CFs, including the intensity of collecting firewood, fodder, thatch, and medicinal plants. A set of enhanced vegetation index (EVI) images were derived from Landsat imagery from 1988 to 2015 to represent the time series forest greenness conditions. Topographical parameters such as elevation and distance to river were extracted from ASTER DEM and Landsat image.

3. Semi-parametric geographically weighted regression

GWR captures locally varying processes to better understand the drivers of the spatial distribution of the dependent variable. The S-GWR, in contrast, has both geographically varying coefficients and fixed coefficients in the same model (Fotheringham *et al.* 2002; Nakaya *et al.* 2009). This enables S-GWR to model spatial stationarity and spatial nonstationarity in the same framework.

The S-GWR model can be presented as equation (1):

$$y_i = \sum_{j=1}^{k} \alpha_j x_{ij} + \sum_{l=k+1}^{p} \beta_l(u_i, v_i) x_{il} + \varepsilon_i \quad (1)$$

where (u_i, v_i) are coordinate locations for each location i, α_j denotes the global parameter estimates of fixed independent variables, and $\beta_l(u_i, v_i)$ denotes the local parameter estimates on each location i in space.

4. Results and discussion

GWR 4.09 software was used for the S-GWR analysis. The results of S-GWR are shown in Table 1. The S-GWR model contains 1 global variable and 5 local variables. Fire evidence has a negative relationship with *M. micrantha* coverage, which tells us fire is a method to temporarily remove the invasive plants. In the local parameter estimates, recent EVI values (average EVI from 2010-11) all have the positive relationship with *M. micrantha* coverage, which indicates that *M. micrantha* increases the forest greenness. The estimates of canopy coverage are all positive, but the parameter estimates vary across different CFs. Both positive and negative coefficients coexist for the past EVI parameter (average EVI from 1988-89), which represents the local properties for each CF. Although the household resource collection activities (firewood, fodder and thatch) positively influence the *M. micrantha* coverage in the ordinary least squares (OLS) regression analysis results, this variable is not statistically significant in the S-GWR results. This finding shows the weak influences from human activities comparing to biophysical factors. The S-GWR model recognizes an extreme local pattern through the small optimal bandwidth found by S-GWR.

Table 1. S-GWR model results.

Global coefficients					
Variable	Estimate		Standard error		*t*-value
Fire evidence	-6.106		2.615		-2.335
Local coefficients					
Parameter	Minimum	Lower quartile	Mean	Upper quartile	Maximum
Intercept	-62.269	-9.836	12.148	24.641	192.111

Canopy	0.027	0.088	0.144	0.180	0.391
Past EVI	-67.162	-24.450	-8.120	5.085	72.560
Recent EVI	5.583	36.658	58.209	78.728	130.590
Elevation	-1.433	-0.233	-0.156	-0.023	0.536

Mean adjusted R^2 = 0.404; Global AICc = 9325.022; S-GWR AICc = 9248.952; Optimal bandwidth size = 52.

5. Conclusions

This research applies S-GWR to capture the spatial stationarity and nonstationarity to model the factors that influence the spread of invasive plants. By using S-GWR method, spatial stationarity and nonstationarity effects are all incorporated into the same framework and a better model fit is achieved with higher R-squared and lower AICc. Human resource collection activities only exhibit statistically significant influence to *M. micrantha* coverage in OLS model rather than S-GWR model. A further examination needs to be conducted to better understand how human activities influence the spread of *M. micrantha* in Chitwan area.

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