Applied Geography 34 (2012) 559–568

Contents lists available at SciVerse ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

# Spatially and temporally varying associations between temporary outmigration and natural resource availability in resource-dependent rural communities in South Africa: A modeling framework

Stefan Leyk [a,*], Galen J. Maclaurin [a], Lori M. Hunter [b,d], Raphael Nawrotzki [b], Wayne Twine [c], Mark Collinson [d], Barend Erasmus [c]

[a] Department of Geography, University of Colorado, Boulder, CO, USA
[b] Department of Sociology/Institute of Behavioral Science, CU Population Center, University of Colorado, Boulder, CO, USA
[c] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa
[d] MRC/Rural Public Health and Transitions Research Unit (Agincourt), School of Public Health, University of the Witwatersrand, South Africa

*Keywords:*
Migration models
Outmigration-environment associations
Spatial non-stationarity
Scale
Agincourt
Demographic surveillance

ABSTRACT

Migration-environment models tend to be aspatial within chosen study regions, although associations between temporary outmigration and environmental explanatory variables likely vary across the study space. This research extends current approaches by developing migration models considering spatial non-stationarity and temporal variation – through examination of the migration-environment association at nested geographic scales (i.e. whole-population, village, and subvillage) within a specific study site. Demographic survey data from rural South Africa, combined with indicators of natural resource availability from satellite imagery, are employed in a nested modeling approach that brings out distinct patterns of spatial variation in model associations derived at finer geographic scales. Given recent heightened public and policy concern with the human migratory implications of climate change, we argue that consideration of spatial variability adds important nuance to scientific understanding of the migration-environment association.



## Introduction

Fueled by recognition of the world's changing climate (IPCC, 2007, 2012), the past several years have seen burgeoning academic interest in the environmental dimensions of human migration. The connection is logical, particularly in rural regions where daily lives are dependent on proximate natural resources, since environmental change portends dramatic shifts in livelihood options. In the face of livelihood decline, migration can be seen as an adaptive strategy (McLeman & Hunter, 2010) and, therefore, methodological advancements in the study of migration-environment associations are particularly timely.

This paper offers substantial methodological advancement in this context through systematic examination of the robustness of migration-environment associations across different spatial scales (whole-population, village, and subvillage). Since migration-environment associations are expected to vary under different socio-ecological conditions, models not accounting for such variations (i.e. 'global' statistical models) are limited in that they provide only an averaged estimation of this association across a predefined space. How to methodologically assess the robustness of such associations across different scales, and to explore the effects of inherent spatial variation of such associations with statistical rigor, remain open questions. We explore these questions here.

### *Environmental dependence in rural regions*

Recent studies document widespread use of natural resources and natural resource-based products in rural regions across the globe. Millions of households make direct use of wild resources for dietary and other household uses (Crookes, 2003), while some engage in direct trade of collected products such as fruit, mushrooms, worms (e.g. Wynberg et al., 2003). Resource-based craft trades are also common, for example producing and selling twig brooms and reed mats, represent important livelihood strategies in parts of rural South Africa (Botha, Witkowski, & Shackleton, 2004; Gyan & Shackleton, 2005; Shackleton, Campbell, Lotz-Sisitka, & Shackleton, 2008). Although cash returns to resource-based livelihoods are often quite low, many households devote time and

* Corresponding author.
*E-mail address:* stefan.leyk@colorado.edu (S. Leyk).

0143-6228/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apgeog.2012.02.009

energy to these activities to enhance livelihood security and lessen the need to seek demoralizing, insecure casual labor (Shackleton & Shackleton, 2011).

Proximate natural resources also often serve as “safety nets” for vulnerable rural households in less developed settings (Hunter, Twine, & Johnson, 2011; McSweeny, 2004). A recent study in rural South Africa found that, in the wake of a shock such as job loss or mortality, a majority of households increased use of locally-collected resources such as wild foods, fuelwood and medicinal plants (Paumgarten & Shackleton, 2011). In the wake of environmental change, the availability and variability of such natural “safety nets” may shift and households may adapt alternative strategies such as migration.

*Migration as adaptation*

Human migration as an adaptive strategy is certainly nothing new, and historical analogs, such as investigation of migration from the Great Plains’ Dust Bowl, have informed recent understandings of migration potential (McLeman & Smit, 2006). Yet, what *is* new is the sheer number of households potentially impacted by contemporary environmental change, the magnitude of vulnerability due to widespread impoverishment, and the security concerns being articulated by policymakers and the public (Scheffran & Battaglini, 2011). Further, recent methodological advancements have provided the basis for improved scientific examination of the migration-environment association.

Aspatial empirical models have taken two key forms. First, aggregated data (such as information at the state, county or village levels) are used as units of analysis in order to estimate associations between migration rates and relevant socio-economic and environmental characteristics (e.g. Feng, Krueger, & Oppenheimer, 2010; Hunter, 1998, 2000). Within such models, environmental factors are included as general spatially undifferentiated measures. As a logical consequence, spatial dependence and clustering effects are rarely considered, and variation in the migration-environment association within the broader study region is not explored. Second, individual- and household level predictive models of migration have been extended to add environmental measures to the set of typical cross-sectional predictors at the individual-level such as gender, age, and education, or at the household level, such as size and compositional indicators (Findley, 1994; Meze-Hausken, 2000). Within these ‘global’ statistical approaches, factors such as estimated (regional) rainfall or general undifferentiated measures of natural resource availability can represent local or even regional environmental pressures at a particular point in time, or they can be used to analyze change within a recent temporal window (e.g., Gray, 2009; Henry, Schoumaker, & Beauchemin, 2004). As a consequence, results tend to reveal that environmental factors act in concert with other migration pressures and thus differential effects within the study region, net of incorporated controls, cannot be estimated.

*Needs in modeling migration-environment associations*

Within the past several years, models of the migration-environment association in resource-dependent regions have become increasingly sophisticated through the use of, for example, longitudinal and/or multi-level models. These often integrate random effects (e.g., Barbieri & Carr, 2005; Gray, 2011; Henry et al., 2004; Yabiku, Glick, Wentz, Haas, & Zhu, 2009) and have, therefore, advanced inclusion of general spatial effects. However, rarely has spatial variation in the migration-environment association itself nor the role of scale in the modeling approach been the content of substantive query. Exploring spatial variation raises two important connotations of scale. Geographic scale refers to the spatial extent within which the phenomenon or association is being studied (Lam & Quattrochi, 1992), and analysis scale (or resolution) refers to the size of the units at which observations were recorded or aggregated (Montello, 2001). In this study we vary the geographic scale used for modeling (i.e. the population size, or $n$, in the statistical model) while holding the analysis scale (i.e. the household unit) fixed. This approach allows to explore how associations (regression coefficients) change at different spatial extents of analysis (whole-population, village and subvillage). We argue that much can be learned from how migration propensity varies with changing geographic scale of the modeling approach.

Although methods to investigate spatial non-stationarity are routinely employed in the field of geography, migration-environment connections have not been studied in this context. These existing approaches usually rely on local estimations such as varying coefficient models (Cleveland, Grosse, & Shyu, 1991; Hastie & Tibshirani, 1993) or geographically weighted regression (GWR) models (Brunsdon, Fotheringham, & Charlton, 1996; Fotheringham, Brunsdon, & Charlton, 2002) which have significant limitations that result in a lack in robustness for statistical inference (O’Sullivan & Unwin, 2010). For instance, models can suffer from local over-fitting as a result of reduced degrees of freedom and the spatial weighting of observations in each local regression can lead to patterns of induced spatial heterogeneity (Cho, Lambert, & Chen, 2010). Furthermore, the instability of coefficient estimates as a function of bandwidth (Farber & Páez, 2007) and multicollinearity of the local coefficient estimates have been identified as serious hindrances with the GWR method (Griffith, 2008; Wheeler, 2007). For modeling Poisson distributed migration data, local estimation models have not been readily extended into a Generalized Linear Model (GLM) framework. In order to improve our ability to understand existing associations between migration and environmental factors on the household level and thus improve program and policy recommendations, these limitations must be addressed. Particularly, the sensitivity of statistical models to changes in geographic scale and the variation of target associations across space (non-stationarity) have to be evaluated. Identifying subregions experiencing heightened vulnerability to environmental change could greatly enhance targeted interventions.

This research taps into the potential of spatially explicit demographic surveillance data from a remote rural region of South Africa, combined with indicators of both spatial and temporal variation in natural resource availability across the study site. We make use of the Normalized Difference Vegetation Index (NDVI) derived from MODIS remote sensing imagery as an indicator of natural resource availability and variability.

An analytical framework is developed that overcomes the above limitations by using traditional regression approaches on nested geographic scales generated by random simulation (spatial permutation). This allows for:

(i) comparison of models across (nested) geographic scales (i.e., whole-population, village and subvillage scales) in order to systematically examine the sensitivity of the migration-environment association to changing (sub)populations used for modeling;
(ii) investigation of the spatial non-stationarity of migration-environment associations estimated on a set of subpopulations (i.e. villages) at the same geographic scale within the study site. In contrast to common local estimators, each model association is estimated from an entire subpopulation and has sufficient statistical rigor without induced effects of over-fitting or multicollinearity;
(iii) comparison of models for two different points in time (2002 and 2007) in order to estimate the effect of changing environmental conditions on the migration-environment models.