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Dr. Salisbury Borders…

Quantifying Soil Loss in the Hispaniola Borderland

Introduction

Resource management is a highly contested topic, as various methodologies have been employed by governments, corporations, and interest groups across the globe. Contemporary debates regarding resource management primarily focus on two linked issues: the role of government and problem recognition. This paper will explain the two different resource management strategies and delve into the problem recognition process. Ultimately, this paper will examine the Haitian-Dominican borderland to address both of these issues and demonstrate the need for an integrated, sustainable, interventionist approach in the management of borderland resources.

Resource Management

As the world continues developing into an ever more complex, interconnected, and interdependent system, the need for effective resource management becomes an urgent priority. Global pressures, such as climate change (IPCC, 2013), economic globalization and mobilization (Kelly, 2013), and population growth (Ezeh et al., 2012) threaten basic livelihoods. Local pressures defined by each spaces' physical and human geographic situation add an additional layer of complexity. As global and local pressures mount and interact, spatial and environmental resources will likely face unprecedented stress with potentially disastrous consequences (Malthus, 2013; Lambin & Meyfroidt, 2011). The need for strategic and sustainable planning is paramount, as intensified resource scarcity would likely result in economic insecurity, environmental instability, civil unrest, and institutional failure (Linnér, 2003; Brander & Taylor, 1998; Diamond, 2006).

Effectively managing resources minimizes internal and external costs and maximizes benefits. Efficient environmental/spatial resource management is achieved through an integrative approach, conducting multi-scalar and multi-disciplinary analyses to determine the most efficient plan of action given the decision-makers priorities (Mitchell, 2005). Integrative resource management is a derivative of systems thinking, a well established methodology of understanding the inputs, outputs, responses, relationships within a system (Senge, 1990). The success of effective, integrated resource management has been limited in scope, however, as governments and institutions often lack appropriate legislative frameworks, communication pathways, and intra- and inter-governmental solution networks (Bolleyer, 2009; Atkinson, 2001).

The need for institutional cooperation is greatest in situations involving multiple governmental constituencies, such as borderland regions. The abutment of two (or more) differing governmental schema, cultural norms, and/or economic realities increases the potential for environmental mismanagement (Stratford & Davidson, 2002). Intra-national borderlands face less serious threats to environmental mismanagement stemming from a lack of institutional communication because hierarchical channels for issue rectification generally exist (i.e. judicial, legislative, executive). The environmental continuity of many borderland regions further complicates the situation, often discouraging the creation of an environmental resource plan. Lockwood et al. (2010) has introduced a legislative model to guide borderland management, but the recency of the model has been a hindrance to its application. Lockwood outlines an institutional framework that relies cooperative-management and top-down regulation.

Lockwood's model is grounded in the well-established literature of cooperative game theory (Parrachino et al., 2006), yet, the need for legislation remains a debated topic. Hardin's classic piece, "Tragedy of the Commons" (1968), laid the foundation for environmental policy and theory. Hardin (1968) contends common (shared) resources will be overexploited by its users given that the users are all motivated by self interest. Hardin (1968) concludes that strategic planning must be employed to sustainably manage the exploitation of the commons.

More contemporarily, however, the tragedy of the commons has come under scrutiny. Ostrom et al. (1999) provide numerous examples in which the tragedy of the commons was avoided through local control of the resources. Ostrom et al. contend that so long as local peoples are controlling their resource base, the resources will be effectively managed, avoiding an environmental collapse. Ostrom's maintains that a collective self-interest exists in a system occupied by local people, creating informal regulation networks. This collective interest, Ostrom argues, prevents collapse or an overexploitation of resources.

Ostrom's revisitation of Hardin's classic article challenged the norms of how scholars conceptualize the tragedy of the commons.

The Hardin-Ostrom debate is a modification of the long-standing dialogue regarding the responsibilities and limitations of governments. The free-market approach, endorsed by Ostrom, while theoretically sound, falters when applied in reality. Markets fail to incorporate all costs, leaving environmental, social, cultural costs as unaccounted externalities (Aidt, 1998; Bremmer, 2010). Thus, Ostrom's analysis fundamentally rests upon a legislative (top-down) approach to achieve sustainable management through the modification of market pricing mechanisms.

Further, assuming market failures have been addressed, the universal utility of this argument is unclear. In Ostrom's analysis, the study groups were part of a single social group with complete sovereignty of their collective resources. Her analysis, while exposing holes in Hardin's work, did not change the underlying concept of Hardin's thesis. Additionally, the complexity and fluidity characterizing contemporary landscapes challenges the notion of one entity maintaining sovereign control of their "own" resources. The borderland is one such example of a heterogeneous, fluid, and interconnected space. Thus, without formal legislation and a detailed resource management scheme, the system would likely fail.

Problem Recognition

Acknowledging a problem is one of the largest obstacles for institutions in policy formation. Problem recognition is predicated upon condition recognition. A condition is the status of a system, while a problem is a condition that requires resolving (Kingdon & Thurder, 1984). The transition of a condition into a problem first requires that a condition be explicitly stated. Without conditional data, institutions lack the ability to create meaningful, thoughtful policy.

The importance of data in the policy process cannot be underestimated. Data informs effective policy and allows for the condition of a system to be monitored. Data-gaps require institutions to extrapolate from preexisting data, bringing uncertainty into the the policy process. Data availability is complicated in borderland regions, where informational diffusion may be impeded due to spatial, geopolitical, economic, linguistic, or cultural barriers.

Borderland-Watersheds

This paper explores borderland-watersheds. Watersheds are the functional units of water system management and are easily delineated (Valenski et al, 2014). The clear demarcation of a borderland region facilitates an easier and more reproducible study methodology.

Borderland-watersheds are contentious areas, as each entity within the catchment area affects all other entities within that watershed. Proper watershed maintenance is crucial for longstanding economic, cultural and ecological vitality. Land use, pollution, ground water withdrawals, agriculture, tillage techniques, and land development all affect landscape hydrology and ecology (Wheater & Evans, 2009; Wang, 2001; Xiaoming, 2009). Gaining an understanding of the spatial patterns and consequences of these activities is fundamental to the creation of a sustainable resource management system.

The application of a sustainable resource management system at the watershed level is instrumental in maintaining and conserving hydrologic, ecologic, and economic resources. Adopting an integrated, cooperative, and adaptive approach has reaped positive benefits in the sustainable management of watersheds historically and contemporarily (Pahl-Wostl, 2007; Biswas, 2004). Watersheds are complex systems strongly affected by changing land use, natural phenomena, and immediate physical geography (Tong & Chen, 2002). Thus, in order to create an effective framework for the maintenance of a watershed, an interdisciplinary, multi-scalar approach must be employed using the highest quality data available (Schmoldt & Rauscher, 2011). However, many borderland regions with shared-watersheds lack sufficient data to begin formulating an effective resource management plan.

The Haiti-Dominican Borderland

This study examines the shared watershed-borderland of Haiti and the Dominican Republic (Dominica) on the island of Hispaniola (~75,000km^2) in the Caribbean Sea to identify erosional and depositional differences within the borderland region. The Hispaniola borderland has a relatively homogeneous environmental landscape, sharing a common geology, lithology, and elevation-mosaic. Additionally, Hispaniola has a relatively constant climate with relatively small gradients in precipitation and temperature caused by local rain shadow effects. Both nations have significant coastal areas, river delta wetlands, and a mountainous inland region.

Hispaniola is limited in resource exploitation potential due to its finite spatial extent. Limits of both space and resources exert an intense pressure on island systems, which have acted as large obstacles in development (Brander & Taylor, 1998; Diamond, 2006). Conserving island resources is crucial, as friction of distance, transferability, technological limitations, and geopolitics prevent the realization of complete economic connectivity.

The differences between Haiti and Dominica are largely economic, political, and cultural (Bryan, 2004). The two nations have complex histories marred by conflict, poverty, environmental disaster, and failed cooperation dating back to their initial colonial inception (Diamond & Robinson, 2010). Recently, the economic gap has become increasingly pronounced, as the Dominican Republic has experienced sustained growth while Haiti's economy has repeatedly stalled (Frankema & Masé, 2014). In 1960, Haiti and the Dominican Republic had equal per capita GDPs, but, by 2005, Haiti's per capita GDP had halved and the Dominican Republic's had tripled (Jaramillo & Sancak, 2009).

The economic disparity between Haiti and the Dominican Republic has resulted from differing economic approaches and institutional capabilities. The Dominican government has committed itself to an economic model based on tourism: capitalizing on the nation's unique geography, facilitating the development of tourism infrastructure, and partitioning its natural resources to best fit the nation's economic niche (Crawford, 2006). While the Dominican Republic has successfully developed and implemented their economic model, Haiti has failed in controlling its economic system (O'Connor et al., 2014). Haiti's economic development has been limited due to a combination of state failure in maximizing the nation's resources, developing adequate infrastructure, and providing its population with basic human services (Silva, 2011). Internal state failures have been intensified by environmental disasters beyond the nation's control (earthquakes, hurricanes, tropical storms, etc). Haiti's vulnerability and instability was dramatically exposed by the earthquake that shook Haiti in 2010, killing over 300,000 and crippling the nation's fragile economy.

The Dominican Republic's successful economic development further intensified the relative poverty in Haiti through economic exclusion. As a result, Haiti has struggled to compete in Dominican markets and faced internal struggles to provide adequate livelihoods for its people (Frankema & Masé, 2014; Silva, 2011). The underlying economic gap between the nations has fueled issues of migration (Ferguson, 2003), violent conflict (Martinez, 2003), racism (Kushner, 2012), and classism (Guilamo, 2013). The multitude of challenges presently facing Haiti have synergistically initiated a downward spiraling of conditions within the nation (Winters & Derrell, 2010).

In addition to the economic inequality on Hispaniola, the differences in political stability and cultures between the nations further complicates the relationship between Haiti and Dominica (Baldacchino & Milne, 2006). Haiti has a long standing history of governmental corruption (Saye, 2010; Annis & Ives, 2011), while Dominica has maintained general and relative stability. The differences in institutional capacities to control and provide for its people has led Haitians to migration, illegal trafficking, and distrust of the government (Winters & Derrell, 2010).

Haiti and the Dominican Republic have strong national identifies, reinforced by local geographies, cultures, languages, politics, and economies (Hernández & Stevens-Acvedo, 2011; Lundy, 2011). Strong national identities maintained within the Haitian and Dominican states often conflict with borderland realties, disconnecting policy from people. The geographically explicit border culture is characterized by sexual fluidity, economic interaction, and a willingness to cooperate between Haitians and Dominicans (Taylor, 2014; James, 2013). Thus, the border-core tension is not well understood by national institutions and results in inappropriate border strategies, often targeted at securitization and policing (Kusher, 2012; Petrozziello & Wooding, 2013) and failing to capitalize on the existing economic and social capital of the borderland (Fumagalli, 2013).

The border-core tensions go largely unnoticed as a result of problem prioritization on Hispaniola. The acute, immediate problems facing Haiti have dominated the political agenda and academic literature. Consequently, the chronic problems facing Haiti remained unresolved in an effort to bring immediate, temporary benefits. Paradoxically, the billions of dollars funneled into Haiti during recovery efforts following the 2010 earthquake have not addressed the structural problems concerning Haiti and their institutions (Buss, 2013). Only recently has the chronic environmental degradation occurring on Hispaniola been examined with the help of spatial analysis and geospatial activities.

Currently the island is experiencing intense ecological instability due to poor planning, reckless land management, and efforts to achieve short term economic gains (Alscher, 2011). Specifically, Haiti is currently undergoing vast desertification due to intense deforestation and subsequent tilling of land (Williams, 2011). This stringent imposition necessitates the cooperative management of the island's increasingly scarce resources and the efficient land use planning to maximize the economic gains and minimize the ecological costs (Brandimarte et al, 2009).

An important component in creating efficient networks of cooperation and policy is having access to objective data. Recently, geospatial analyses have revealed differences in NDVI (Normalized Difference Vegetation Index) between the countries and exposed the rapidly transforming Haitian landscape, while the Dominican Republic has experienced more modest changes in its land cover (Hernandez-Leal et al., 2006; Wilson et al., 2001). Rapid deforestation and land transformation projects on the Haitian side of the borderland could potentially be affecting the Dominican Republic borderland through runoff, erosional losses, hydrologic stress, decreased landscape connectivity, and pollution. The effects of this rapidly transforming landscape have gone largely unstudied on Hispaniola and their effects on the ecology, lithology, and hydrology of the island are unknown (Lugo et al., 2012). Additionally, the economic losses of this transformation have also gone unexamined, creating an environment devoid of certainty.

The lack of substantive research exploring the effects of rapid land use change in the borderland region between Haiti and the Dominican Republic has imposed a major obstacle towards intra- and inter-governmental cooperation. Thus, the need to examine the effects of borderland transformation is paramount to solidifying the island's shared future.

The transformation of the borderland region and its effect on surface water is especially important. As global climate change (IPCC, 2013) and local pressures continue to exert increasing stress onto the island, it is critical to maintain the borderland's ecological integrity. If the borderland is ecologically compromised, the likelihood for illegal migration, crime, and conflict greatly increases as individuals are now unable to provide for themselves. Additionally, the “blame” for this collapse will likely pose the question of “Who is responsible?” This burden will likely fall disproportionately on one of the countries and the mitigation/restoration process will likely be riddled with complications.

The role of erosion is particularly important to study as it can be related to a number of ecological complications: soil loss, landslides, sedimentation, eutrophication, heavy metal transport, and nutrient loss. As the borderland is a shared watershed for much of its duration, the erosional effects land use transformation poses dangerous consequences for both ecological stability and human settlement. Deforestation has been linked to increases in erosional losses and the destabilization of soil profiles (Meyfroidt & Lambin, 2011). Additionally, the loss of top soils has been shown to lead to the massive loss of nutrients, creating dead desert zones (Lal, 1989). This trend has already been described in Haiti, but not yet studied empirically. The transport of these particles into water bodies has been shown to be equally dangerous. Sedimentation of streams, rivers, and lakes has from erosional deposits has been shown to disrupt biogeochemical equilibrium (Quinton et al., 2010), decrease flow rates and cause hypoxic conditions (Blanco-Canqui & Lal, 2010), and decreases overall water quality and biodiversity (Khadam & Kaluarachchi, 2006).

Through geospatial analyses, this study will quantify erosional losses for the borderland region and present conclusions concerning the lithological stability of the Hispaniola borderland. The access to information in the decision making process is paramount and this study aims to fill that void. Through the expansion of accurate, objective data made available to these nations, the potential for inter-governmental cooperation greatly increases.

Theoretical Perspective

This paper utilizes a positivist approach, premised upon the assumption that each assertion and statement can be scientifically verified and/or logically proven (Sheppard, 2001). Positivism requires a repeatable methodology and controlled experimentation/analysis to reveal objective truths.. Using GIS-driven analyses, the objective condition of the Hispaniola borderland can be deduced without observer-biases.

A GIS allows users to conduct automated geospatial analyses. GIS studies have revolutionized how humans study, understand, and analyze the spatial and temporal characteristics of areas, historically and contemporarily informing academics, policy makers, and the general public through a positivist approach (Sui, 1994). The debates about the biased nature of GIS studies has largely been dismissed in mathematical, topological, and landscape metric studies as derived results are the product of strictly empirical methodologies (Schuurman, 2000). Consequently, GIS-driven studies have become a cornerstone component of both human and physical geography (Lake, 1993; Joerin & Musy, 2000). A GIS-driven research approach with an underlying positivist foundation reveals objective spatio-temporal conditions defined by inputs, analysis, and scale.

The subsequent interpretation of the objective findings also follow an objective, positivist approach seeking to understand and explain the current hydrologic situation of the Hispaniola borderland region. However, these analyses are much more vulnerable to Western, post-positivist critiques as the explanations will be framed from an outsider's mentality. Nonetheless, the positivist theory of moving towards an objective truth are preserved in this study, although implicit bias is inevitably a characteristic of the subjective analysis of the objective findings output from the computer driven GIS analyses.

Methodology

This study examines shared hydrology of the Hispaniola borderland of Haiti and the Dominican Republic. More specifically, this study quantifies the erosional and surface flow differences in the shared watershed borderland of the two countries through a set of GIS-driven analyses. The first step in the process was delineating a specific borderland region. The Hispaniola borderland is defined in this study as the area containing all of the watersheds that transect the Haiti-Dominica border.

The erosional and runoff potential for the borderland landscape are determined using the Revised Universal Soil Loss Equation (RULSE). The RULSE is an updated and improved version of the longstanding Universal Soil Loss Equation and has been successfully incorporated into GIS studies (Chen et al., 2011; Prasannakumar et al., 2011).

The RULSE is defined as:

$$A = R \ x \ K \ x \ LS \ x \ C \ x \ P$$

Where A is the calculated spatial average of soil loss over a specified time frame, R is the the rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover and management factor, C is the cover and management factor, and P is the conservation support-practices factor.

The R factor quantifies the effect of rainfall and the run-off rate associated with the precipitation events. Precipitation data were taken from Mitchell & Jones' (2005) high resolution, long-term climate grid. The R factor was determined using the equation developed by Wischmeier (1978) and improved by Arnoldus et al. (1980):

$$R = \sum_{i=1}{}^{12} = 1.735 \times 10(1.5\log 10(Piz/P) - 0.08188)$$

where R is the rainfall erosivity factor (MJ mm ha−1 h−1 year−1), P i is the monthly precipitation (mm), and P is the annual rainfall (mm).

The K factor represents the susceptibility of a surface or soil to erosion, as measured under a standard condition. The K factor is an intrinsic characteristic of soil types, so values do not change with changing situations (Fu et al., 2006). Stone and Hillborn (2000) proposed a successful classification of K factor values by soil type, shown below in Table I. Soil data for Haiti and Dominica was taken from the United Nation's Food and Agriculture Organization's Harmonized World Soil Database (2012).

Textural class	*K* factor
Loamy sand	0.04
Sandy loam	0.13
Loamy fine sand	0.11
Coarse sandy loam	0.07
Clay	0.22
Clay loam	0.30
Sandy clay loam	0.20
Silt clay	0.26
Silt loam	0.38
Very fine sand	0.43
Loamy very fine sand	0.39

Table I. The K-factor values of the traditional soil types

The *LS* factor is the combined effect of both the slope length factor (*L*) and the slope steepness factor (*S*). These topographical data were taken from the Digital Terrain Elevation Dataset at a 30x30 meter resolution (Geocommunity, 2014). The *LS* factor was calculated using GIS extension and the below equation:

$$LS = (\text{flow accumulation x cell size}/22 \ : \ 13)^{.04} \text{ x } (\text{sin slope}/0.0896)^{1.3}$$

Where *LS* is the combined slope length and slope steepness factor, flow accumulation represents the total upslope contributing area, cell size is the size of grain/pixel size of the data, and the sin slope is the slope degree value in sin.

The *C* factor refers to the effects of cropping and management practices on a landscape. The most effective technique to gather these data is through the use of satellite imaging to account for high spatial and temporal diversity of land uses (Karydas et al. 2009; Tian et al. 2009). The normalized difference vegetation index (NDVI) was used as an indicator for vegetative land cover and can be modified to determine a *C* factor value. NDVI values were taken from Wilson et al.'s Hispaniola's study of vegetation dynamics (2001). Wilson et al.'s NDVI values were then input into the following equation:

$$C = \exp[-\alpha(\mathrm{NDVI}(\beta - \mathrm{NDVI}))]$$

Where "α and β are unitless parameters that determine the shape of the curve relating to NDVI and the C factor" (Prasannakumar et al., 2011).

Land cover	*P* value
Tree cover: broadleaved, evergreen	1
Tree cover: broadleaved, deciduous, closed	1
Tree cover: needle-leaved, evergreen	1
Tree cover: mixed leaf type	1
Shrub cover: closed-open, evergreen	0.75
Shrub cover: closed-open, deciduous	0.75
Herbaceous cover: closed-open	0.5
Sparse herbaceous	0.4
Regularly flooded shrub	0.4
Cultivated & managed lands	0.25
Water bodies	X
Artificial surfaces	1

Table II. The P-values of Hispaniola's land cover types.

The *P* factor represents the effects of practices that would reduce the amount/rate of water runoff in a given area. The *P* factor was determined by assigning values based on land cover to each cell within the data layer. Cells within the watershed were given values from 0.25 to 1. Areas of forest/natural land cover were given values of 1 and areas of crop land were given values of the minimum value of .25. Land cover data was taken from the most recent Landsat survey classification of Hispaniola from 2000 (MDA Federal, 2000). Table II details the scoring of P values for all of the land cover classifications on Hispaniola. 'Water bodies' were not given a *P* factor value as these areas are considered terminal waterways and are not accounted for in the calculation. Artificial surfaces were also given a score of 1 because the temporal scale of their erosion is not considered in this analysis.

Following the determination of the *R, K, LS, C,* & *P*, the intensity of erosion can be determined for each grid cell within the Hispaniola borderland. The *A* values gathered from this were then compared. These data then underwent statistical T-test analysis to evaluate whether the Haitian and Dominican landscapes have statistically significant differences in erosivity at a macro-level. Following the borderland-region level analysis, the *A* factor values from within each watershed were compared to examine if significant differences existed at an intra-borderland level.

As the final component of the hierarchical statistical approach, the scores were aggregated within each nation's portion of the borderland region and regional watershed. Once aggregated, the *A* factor scores were normalized by areal extent to reveal each nation's contribution to erosional losses within the watershed.

The results of the hierarchical scalar approach employed by this study were then synthesized to glean characteristics regarding the nature of the borderland region and how resources are utilized. The hydrologic conditions of the watershed and the revealed responsibilities of erosivity across the border were then analyzed in the context of economic, political, and governmental perspectives.

Results

The spatial analysis of the Hispaniola borderland showed no significant liable country regarding the shared hydrological borderland. The findings suggest that the hydrological borderland, which was divided into five sub-basins (Figure I), is not being degraded solely and/or predominantly by a single nation. The average annual soil loss in Haiti ranged from 2,445–21,601 tons/acre, while the Dominican Republic ranged from 1,347–21,643 tons/acre (Table III).

Average Soil Loss in the Hispaniola Borderland

Basin	Haiti (tons of soil loss/annual/acre)	Dominican Republic (tons of soil loss/annual/acre)
Basin I	3,746	3,860
Basin II	8,513	7,645
Basin III	6,344	4,216
Basin IV	2,445	1,347
Basin V	21,601	21,643

Table III. The average annual soil loss for Haiti and the Dominican Republic in the Hispaniola borderland.

Figure I. The five-sub basins of the Hispaniola borderland, labeled Basin I-V from North to South.

When weighted according by areal extent, the relationship becomes increasingly complex. In basins II and IV, Haiti is the major contributor of soil losses, while the Dominican Republic is the losing the majority of soil in basins I, III, & V (Table IV). The trans-boundary flows of soil are regional and dependent on the basin of interest with strong inter-basinal variation (Figure II). Interestingly, the convergent basins[1] (Basin I & V), the Dominican Republic is the major contributor of eroded soil.

Area Weighted Soil Loss in the Hispaniola Borderland

Basin	Haiti Average Soil Loss x Area	Dominican Republic Average Soil Loss x Area
Basin I	108,237	362,525,024
Basin II	13,970,437,423	4,861,088,540
Basin III	110,040,751	3,549,425,694
Basin IV	746,013,999	17,675,192
Basin V	853,450,109	1,119,186,583

Table IV. The average annual soil loss for Haiti and the Dominican Republic multiplied by the areal extent of each nation's portion of the sub-basin.

Further analysis of the borderland landscape when compared to the entire country revealed unique borderland land cover differences. The Haiti-Haitian borderland complexes revealed that the borderland region differed minimally from the nation's "core," with noticeable differences existing only in the percentage of tree cover (Figure II).   Oppositely, the Dominican Republic had large fluctuations in its land cover mosaic between the nation's whole and borderland. The Dominican Republic had major changes in its proportion of Tree Cover, Herbaceous Cover, and Managed Land Cover (Figure III).

[1] Convergent basins are sub-basins in which the water flow is convergent from both Haiti and the Dominican Republic.

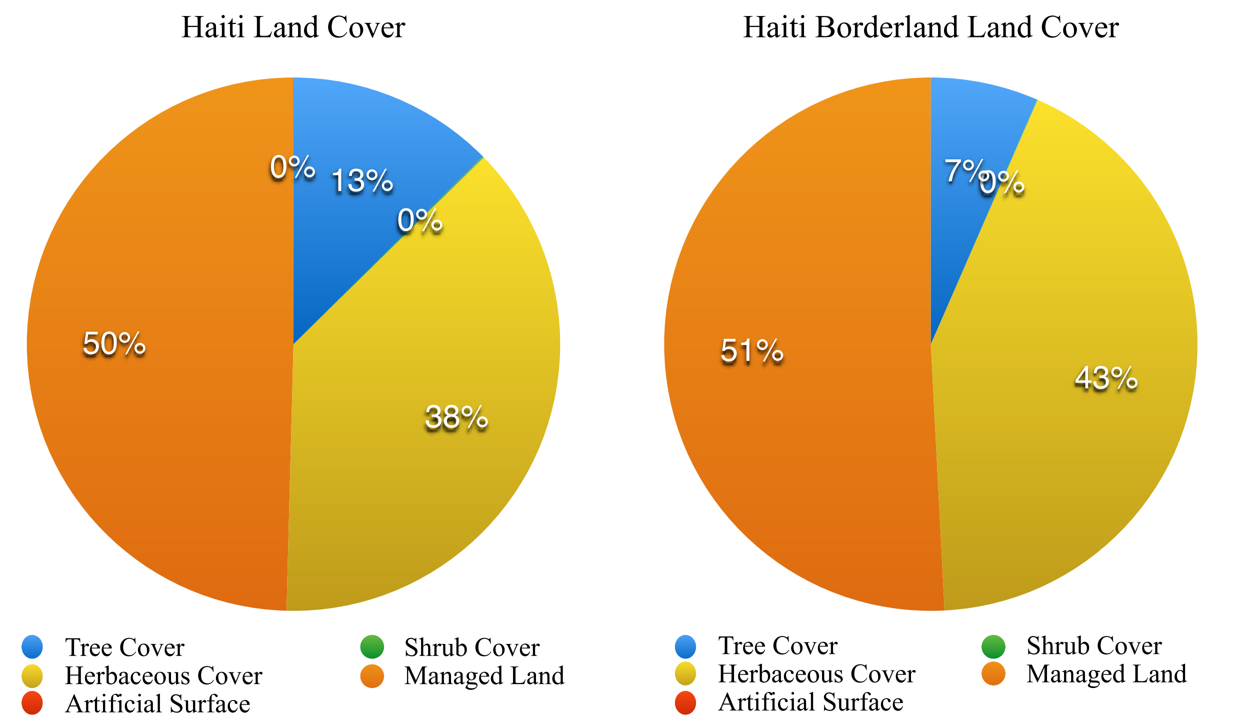

Figure II. The proportion of land covers for the nation of Haiti and the Haitian portion of the Hispaniola borderland region.

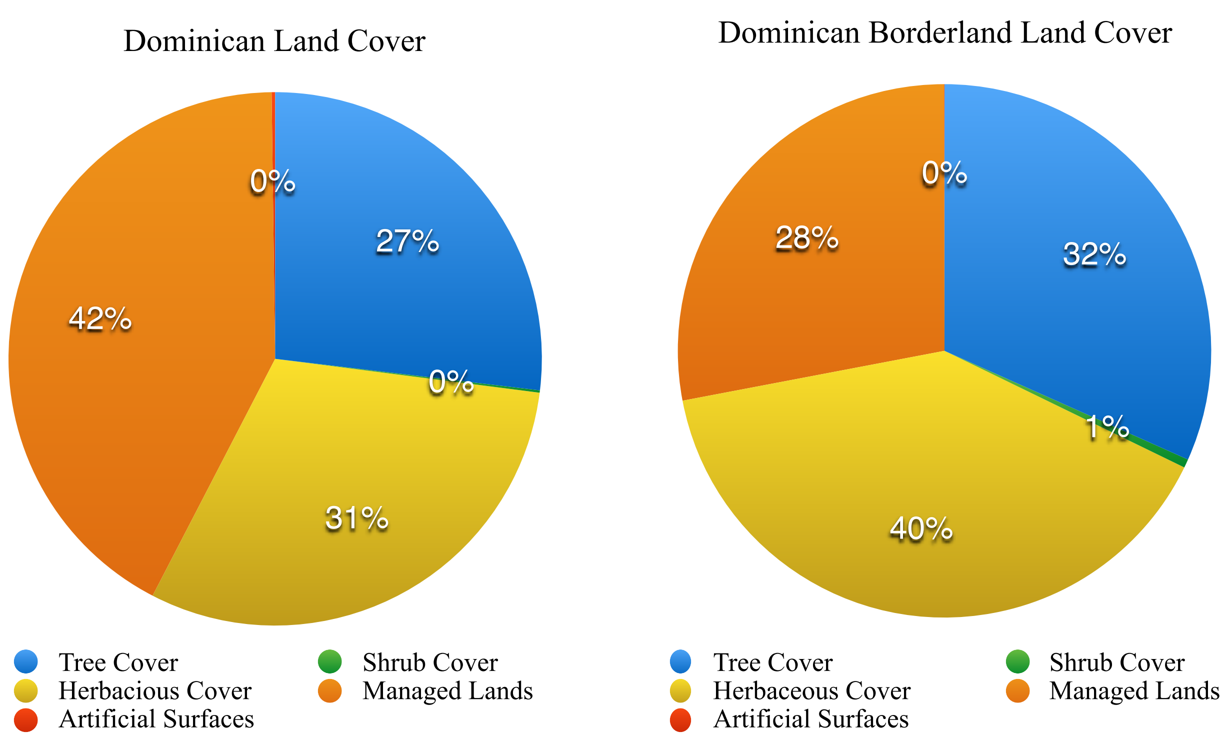

Figure III. The proportion of land covers for the nation of the Dominican Republic and the Dominican portion of the Hispaniola borderland region.

Discussion

The lack of a definitive liable party for erosional soil losses in the Hispaniola borderland is the product of a heterogeneous borderland region, characterized by multi-scalar processes and interactive relationships. Explaining the lack of a single, easily responsible party for erosional losses requires a detailed examination at the factors controlling the erosional potential of the borderland landscape.

Differences in Slope

Slope was one of the most influential characteristics in this study and there was a strong correlation between erosional potentials and steep slopes ($p \leq .05$). The differences in slope in the borderland are, on the whole, minimal, but extant. The mountain ranges that characterize the island's interior are all transnational, as each nation has flatlands and highlands (Figure IV). The resulting landscape is vertically heterogenous and regional slopes (as a function of elevation) are distributed relatively evenly in the borderland. The lowlands that characterize Dominican tourism are predominantly located towards the eastern portion of the country, separated from the mountainous inland region. The extensive highlands that characterize Haiti and largely confined to the western most tail of the island.

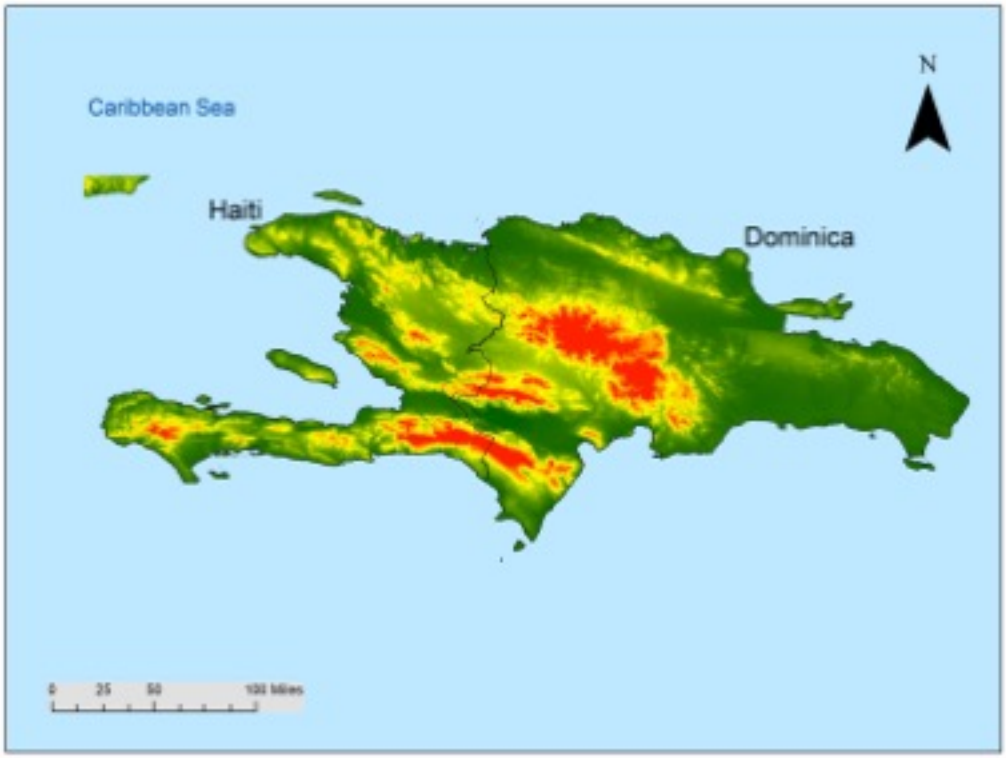

Figure IV. The elevation map of Hispaniola.

Differences in slope and elevation terrain become significant at the most local scale, as steep local slopes create highly erosive surfaces. However, when viewed at the sub-basin or borderland scale, these variations balance become less significant, although the Dominican Republic has a slightly more erosive surface.

Differences in Precipitation

The differences in precipitation in Hispaniola borderland are minimal in terms of biotic requirements as the island's tropical latitude provide the nations' with abundant rainfall (Figure V). However, recent precipitation data reveals that significant variation exists within the borderland. The borderland region receives maximally 2000mm (~80 inches) of rainfall annually and its driest location receiving over 600m (~24 inches) of rainfall. This variation in rainfall was a major factor in determining the erosive losses in the borderland due to its unexpected variation.

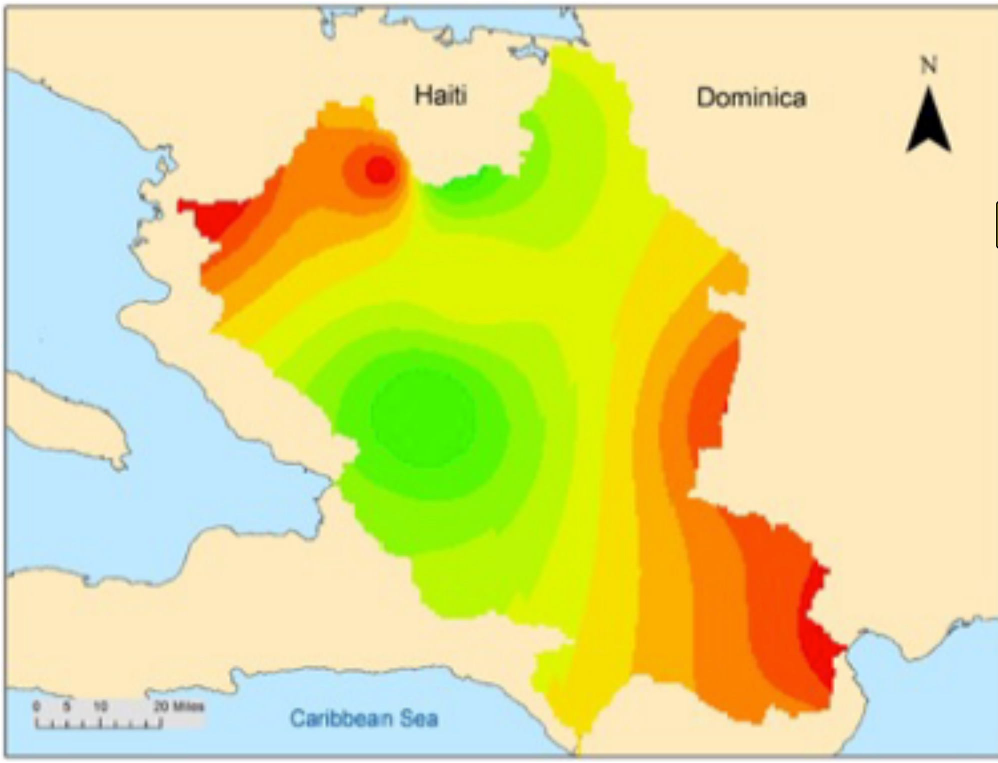

Figure V. An interpolated precipitation map of the Hispaniola borderland region.

Differences in Soil

The island has a relatively homogenous geology as it was born from volcanic activity, meaning it consists predominantly of igneous and metamorphic rocks. Further, the relatively young age of the island arc means that the geologic weathering processes have affected the strata in a relatively constant and homogenous manner. Consequently, the island's geologic and lithologic condition is, at the scale of this analysis, ~~is~~ homogenous.

Differences in Land Cover

Haiti and the Dominican Republic have different land cover mosaics, but the difference in the erosional losses is not reflected by these differences. The Dominican Republic has considerably less managed land and herbaceous cover and almost quadruple the amount of tree cover (Figure VI). Under otherwise constant conditions, this would result in a less erosive surface, however, this is not what is found in this scenario. The differences in elevation, slope, and regional precipitation patterns have, in effect, negated the effect of the land cover.

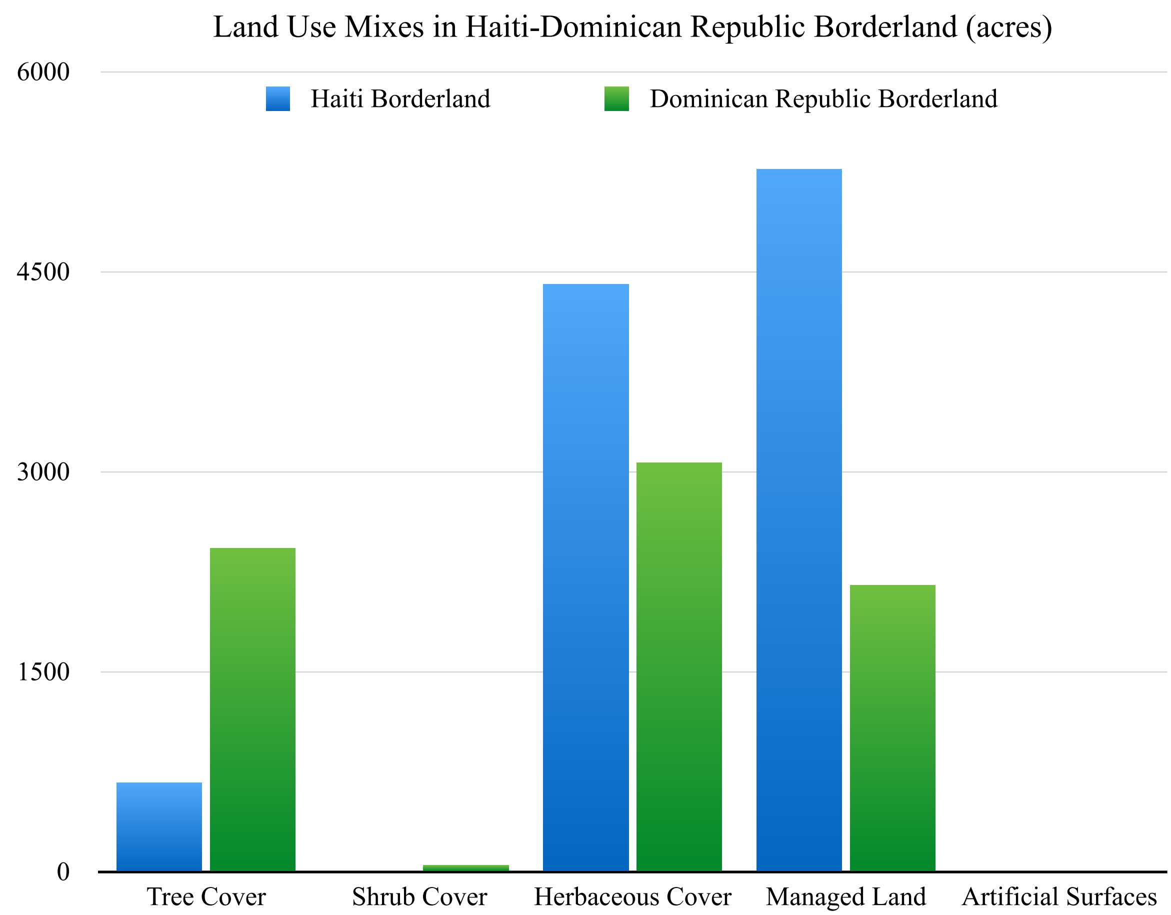

Figure VI. The Land Cover mixes of the Haitian and Dominican borderland region.

Borderland Continuity

The borderland region of Hispaniola is a complex physical landscape, with differing conditions on each side of the border. However, despite these differences, a hydrologic continuity appears to exist in the borderland region. The borderland region, while managed differently between Haiti and the Dominican Republic, is losing over double the global annual average (Montgomery, 2007). The rate of soil loss is a function of Hispaniola's physical situation and the anthropogenic processes transforming the island. Interestingly, the borderland region has a unique set of characteristics that differ considerably from the island's average characteristics (Figure II & III). The differences between the borderland region and the country's whole underscore the long-established theory of borderlands existing as its own region.

The borderland experience is a function of both local and national pressures and processes. The intense transformation of land on both the Haitian and Dominican sides of the border reflect the highly rural lifestyles of the area. Undoubtedly, the land transformation has been more severe on the Haitian side of the border (7% Forested; 51% Managed Lands), but this proportion of land cover is similar to the nation's whole (13% Forested; 48% Forested). The Dominican Republic, however, has considerably different characteristics between the borderland and nation's whole, being composed of 32% Forest and 28% Managed Lands in the borderland 27% Forest & 42% Managed Lands on the country's whole.

The underlying cause for the differences between the Haitian and Dominican borderland experience is a function of geography, national economies, and state failures. National conditions exert tremendous pressure on Haiti and, to a lesser, but substantial degree, the Dominican Republic. While the national pressures exerted on Haiti are largely negative, the Dominican experience is affected (generally) positively from state function. The negative-positive dynamic of national pressures is reflected in each nation's land cover mix.

The spatial configuration and limited extent of each island nation limits the growth and distribution of people and activities. The island (30,000 square miles) has a population of over 20 million, resulting in a population density of over 650 persons/square mile, over five times the global average. The unequal spatial division of the island further intensifies the requirements for land. Haiti, the smaller of the two nations, has a population density of over 780 persons/square mile, while the Dominican Republic has a population density of about 490 persons/square mile.

The need to transform land is a basic human requirement in the current global paradigm. Urban development, agriculture, and resource exploitation are fundamental needs to survive biologically and compete economically. The intense land cover modifications experienced in the Haitian borderland are partially a function of the extension of development into the nation's extremity and the nation's need for immediate benefits. With no alternative, Haiti has been forced to exploit its lands in the most basic ways known, ultimately degrading over 40% of their entire nation (Bai et al., 2008). The Dominican Republic, however, due to its larger areal extent and lower population density, has been able to contain most of its agricultural activities in the nation's lowlands. Nonetheless, the Dominican Republic, too, has suffered considerably, degrading over 35% of their nation's land, but this is predominantly concentrated outside of the borderland region (Bai et al., 2008).

The differing situations caused by the spatial extent of Hispaniola are compounded by differing economic systems and niches. Haiti, the poorest country in the western hemisphere, has failed to compete internationally and develop a strong economic niche (Silva, 2011). Without a strong economic model (or a diversified economic portfolio), Haiti's economy has repeatedly stalled. Haiti's continued economic struggle also has its roots in Haiti's colonial legacy. The rapid decolonization of Haiti (and other colonial states) left areas with variable levels of development, infrastructure, land conditions, and human capital. As a result, the level of colonial investment has been found to be proportional to the quasi-Darwinian economic and political succession of states (Collier, 2009). After Haiti's decolonization, the nation had minimal infrastructure, human capital, or economic momentum, as the nation was viewed as more of plot of land for agriculture rather than a satellite state.

The Dominican Republic, however, has profited considerably due to its economic schema. The Dominican Republic has invested heavily in tourism and tourist infrastructure, tailoring its economic niche to fully (and more sustainably) exploit their resources. The Dominican Republic's economic history has shown a commitment to making economic decisions with long-term foresight implemented, having positive ancillary (if not primary) environmental effects (Silva, 2011). Additionally, the Dominican

Republic's sustained growth has been complimented by the relative poverty of Haiti, which has functionally removed the nation's most likely competitor (Frankema, 2014).

The economic failures and successes of Haiti and the Dominican Republic, respectively, are also connected to potentially the most serious force of land use transformations: state failures. Haiti's continued struggle to create a stable, strong democracy has led to weak policies and failed governance. The continued support of Haitian democracy has struggled, as international relational dynamics have changed with time, and Haiti's dictatorial legacy remains a powerful influence on daily life (Shamsie, 2004). The Haitian state has continued to fail on multiple fronts, which fundamentally root back to the nation's inability to provide for its people. Overpopulation, urban slum development, unemployment, land degradation, under-education, and health hazards continue to hamstring the Haitian nation, even as the population repeatedly calls for reform (Maternowska, 2006).

Haiti's inability to create a legitimate, non-corrupt government have also undermined international aid practices. The Haitian government's inability to utilize incoming funds efficiently has caused a massive rift to form between Haitian expectations and reality (Marroquin Gramajo, 2005). The longstanding reality of Haitian state failure has also hindered their international image, as countries are unwilling to invest in a Haitian future due to their history of corruption, state failure, and oftentimes, bad luck.

The Dominican Republic, however, has made strong advances in strengthening its democratic government, gaining the trust of its people and international players. The ability of the Dominican government to move forward, enact and enforce legislation, and highlight its successes has caused the Dominican and international community to recognize the nation as a stable power (Stoyan et al., 2014). The ability of the Dominican state to control its people has made it a legitimate governing body, a major component of governments that Haiti lacks. The Dominican Republic has, thus, had the ability to create a land management plan, which includes creating reserves, preserving natural lands, and understanding land use changes within the greater context of the entire nation's status (Holmes, 2014).

The reasons for the Haitian-Dominican borderland's differing land covers are manifold, but are not necessarily reflected in the liability of borderland soil loss. However, while no one nation is predominantly responsible for borderland soil loss, trans-boundary flows are significant and the cumulative soil loss is of concern for both Haitians and Dominicans. The interrelationship between Haiti and the Dominican Republic is important in combatting the issue of soil loss, and in order to appropriately deal with the issue, an integrated approach must be undertaken.

Minimizing Soil Loss in the Borderland

Soil loss in the Hispaniola borderland is of serious concern, as the amount of soil lost is more than double the global average annually. Soil, typically not understood as a scarce resource, is crucial to maintaining ecological stability, thriving agriculture, a stable hydrology, and proper nutrient cycling (Coleman & Crossley, 1996). Additionally, the loss of soil has the acute effect of increasing landslide likelihood, which was exposed during the January 2010 earthquake (Figure VII). The deleterious effects of soil loss are numerous and understanding the problem is the first step to properly handling the situation.

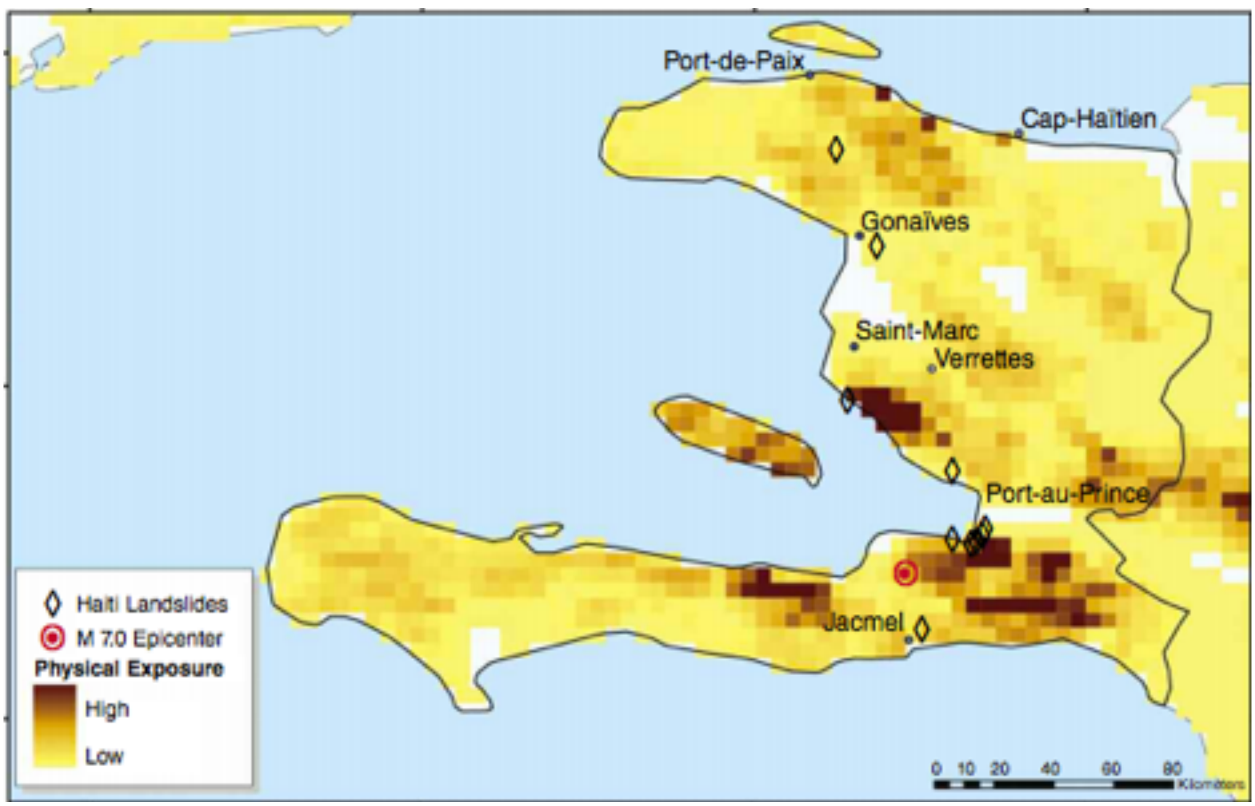

Figure VII. Landslide events caused by the 2010 earthquake in Haiti and areas prone to future landslides (Map taken from NASA's Haiti page)

The scope of this study concentrated on the borderland region, as it is an important area as of cultural diffusion, conflict, and cooperation (Bufon, 1993; Kaplan, 2000). Maintaining the conditional health of the borderland is crucial to maintaining core stability. The borderland happenings can, and for long-term sustainability, should, be relevant to the core's management and legislative framework.

In order to properly and effectively deal with soil loss, an integrated management approach must be employed. Integrative management is a coordinated, cooperative approach that begins with a detailed understanding of the status of a system. Prior to this research, no estimates for the Haitian-Dominican borderland existed and policies (if they were ever to be enacted) would require lengthy analysis or broad-brush estimations. Upon recognizing an issue, the affected parties would weigh the pros and cons of enacting policy. This step would be primarily driven by economic considerations, as Haiti lacks financial backing and the Dominican Republic may not have the capabilities to address this problem without Haiti's commitment. Organizing an integrated management approach requires systematic evaluation to target the root and symptoms of the problem (Senge, 1990).

An integrative management approach would consist of a retroactive plan as well as a proactive plan, lying the foundation for an informationally driven discourse, a range of sustainable agriculture practices, and an educational component. The informationally driven discourse would consist of long-term, cooperative monitoring and data sharing between Haiti and the Dominican Republic. Monitoring soil loss can be costly, but proxies and models exist to estimate soil loss at a cost-effective level. Monitoring precipitation more regularly and at more sites is another way to gain finer resolution estimates for soil erosion. A legitimate monitoring program, however, requires capable governmental faculties, which Haiti has struggled to establish.

Sustainable agriculture techniques are extensive. Techniques such as terracing greatly reduce the soil lost through a series of platforms (Guobin, 1999). Efforts to minimize soil loss can also be achieved by selective cropping, crop rotation, riparian buffers, and water bars (Tilman et al., 2002). The techniques to minimize the problem exist and have been shown to be cost-effective in the long-run, meaning that if non-affected actors were to aid in their development, payback would be likely (Pimentel, 1995).

The final portion of an integrated management approach would be an educational program. Education has the power to expand career opportunities, to make more aware constituents and considerate stewards, and to elevate women from traditional roles. Education would also have ancillary effects throughout the borderland, as poverty, overpopulation, and environmental ignorance strongly affect Haiti and the Dominican Republic.

Conclusion

The Hispaniola borderland is a complex system of interactive forces that shape and transform the landscape. Soil loss has been found to be a major problem in the area with both parties majorly responsible for the losses. Trans-boundary flows create a system of potential conflict, as the effects of different land uses are largely divorced from their actions. To combat this issue, an integrative, cost-effective approach should be employed to best deal with this situation. However, this is unlikely, given the Haitian state's inability to effectively control its population and the set of serious acute problem Haiti faces currently. More research should be done regarding the biotic health of the borderland, as it represents the junction of two potentially conflicting land use plans.

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