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Identifying erosion hotspots and assessing communities' perspectives on the drivers, underlying causes and impacts of soil erosion in Toledo's Rio Grande Watershed: Belize

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ABSTRACT

Erosion in the Rio Grande watershed of Belize, Central America results in widespread ecological impacts and significant economic costs. In this study, quantitative soil loss analysis and qualitative social surveys were integrated to identify erosion vulnerable areas or hotspots, and to analyze varying perspectives between communities near and far from erosion hotspots regarding the causes of erosion. The results of the quantitative analysis suggest that erosion hotspots are located in the upper-mid reaches of the watershed near the communities of Crique Jute, Naluum Ca, San Pedro Columbia and San Miguel. The Mann–Whitney U test identified significant difference in the ranking of erosion drivers (cattle ranching, logging, and clearing of slopes) between communities. Communities far from erosion hotspots (FEH) ranked cattle ranching and logging higher than communities near erosion hotspots as the main drivers of soil erosion (NEH and FEH, mean = 79.02, 105.92, (U) = 3055, $p < 0.001$ and mean = 84.9, 100.90, (U) = 3560.5 $p < 0.05$) respectively. On the other hand, communities near erosion hotspots (NEH) ranked clearing and planting on slopes higher than communities far from erosion hotspots as the main driver of soil erosion (NEH and FEH, mean = 107.03, 81.86, (U) = 3136.5, $p < 0.001$). The logistic regression model depicted that ethnicity, distance, gender, and employment were significant in explaining the data variability on the perceived implementation of erosion prevention techniques in the watershed (2LL = 208.585, $X^2 = 49$, df = 8, $p < .001$). This research provides significant information on the drivers, underlying causes and erosion vulnerable areas that will aid stakeholders to garner community support, develop and implement sustainable soil management practices. Moreover, the study highlights the need to implement cost-effective soil erosion prevention programs and to assess the loss of soil nutrients and agriculture productivity in the study site.

1. Introduction

Soil erosion is common in much of the world, and is particularly devastating in developing countries that struggle to replace eroded soils and nutrients (Naqvi, Athick, Ganaie, & Siddiqui, 2015). In tropical countries, soil erosion is often associated with agriculture. Erosion reduces soil fertility and causes serious environmental problems, threatening agricultural productivity, and water quality (Ferreira, Panagopoulos, Cakula, Andrade, & Arvela, 2015; Prasannakumar, Vijith, Abinod, & Geetha, 2012; Xu et al., 2015). Loss in economic productivity will result in long mounting long-term costs, both financial and environmental. Like many small developing countries, agriculture is an important part of Belize's economy (13% GDP), provides food security and food price insulation (Barrientos & Soria, 2014). Clearly it is in Belize's

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best short and long-term economic and strategic interest to maintain agricultural productivity; however, little is done to prevent soil erosion and mitigate the flow of agricultural runoff into waterways.

Agricultural runoff often contains sediment, fertilizer and pesticides. While regulations exist to protect 20 m of land along watershed banks, these laws are rarely enforced. Logging and agricultural incursions threaten riparian forests and degrade fresh water quality resulting in increased pollution and sedimentation. Greater downstream sediment deposits decrease flood-plains' capacity to store water and mitigate flooding (Palmer, Schilling, Isenhart, Schultz, & Tomer, 2014). Increased nutrient load from fertilizer runoff disturbs fragile aquatic and marine ecosystems (Yuan, Chu, & Shen, 2015). According to Lapointe et al. (2010), in the Caribbean region, pollution from land-based sources is considered one of the most important threats to the marine environment. Increased algae and turbidity cause rapid decline in coral productivity and growth, and disruptions within the marine food web. Massive coral die-offs are associated with agricultural pollution and degraded fresh water quality (Wu, 2015). The broad impacts of soil erosion extend beyond ecological and environmental degradation. The economic costs include loss in agriculture and fisheries productivity, decreased tourism opportunities, increased cost of water purification and degraded public health. Farmers, manufacturers and the general population depend on fresh water for their production systems. The general population uses fresh water systems for drinking, washing and bathing. Clearly the total ecological, environmental and economic value provided by ecosystems exceeds the short term costs of targeted erosion mitigation enforcement. This study aims to provide information to better understand the spatial and social drivers of erosion, and assist in developing mitigation strategies.

Over the past decades, the Revised Universal Soil Loss Equation (RUSLE) has been widely applied to predict soil losses (Ji, Velleux, Julien, & Hwang, 2014; Tanyaş, Kolat, & Süzen, 2015). The RUSLE provides a convenient tool for soil loss evaluation by considering rainfall, topography, conservation support practice, soil, and vegetation (Zhou, Luukkanen, Tokola, & Nieminen, 2008). Although the RUSLE model can be used to determine the spatial distribution of erosion hotspots, little is known about the perceptions of communities adjacent or far from erosion hotspots. Given the undocumented communities' perception, worldwide acceptance, application and relatively simple parameterization of the RUSLE model, this study employs a mixed method approach, combining spatial analysis and social surveys, to generate spatial, quantitative and qualitative information about erosion. Knowing the socio-economic characteristics that influence the perceived implementation of soil erosion measures, stakeholders will have a better understanding of the land management practices and land use history of communities (Avakoudjo, Kindomihou, & Sinsin, 2011). The perception of these erosion drivers is important because, to garner support and behavior requires an understanding of the target audience's perception and attitudes toward erosion. By introducing this mixed approach, this study seeks to address a specific knowledge gap with the aim to improve stakeholder understanding and engage in more effective dialog toward erosion mitigation.

In the Rio Grande watershed of Belize, steep slopes, high rainfall conditions and unsustainable anthropogenic practices are exacerbating soil erosion. Soil erosion has major economic and environmental implications resulting in declining agricultural productivity and increasing water pollution. Communities depend on the watershed as a source of drinking water, for washing, and for irrigation; particularly in San Pedro Columbia and San Miguel (McLoughlin, 2010). Therefore, degradation of this watershed has major impacts not only on the ecology, economy, food security and public health of the communities living within its boundaries, but also on the coastal zone ecosystems (Chicas & Omine, 2015). Soil erosion can be attributed to deforestation and other land cover conversions. These include farming on marginal lands, farming on steep slopes, fire, growth and expansion of human settlements, invasive species, overgrazing of livestock, logging and surface mining (Meerman & Cherrington, 2005). Very little is known about Rio Grande's spatial distribution of erosion hotspots and communities perception of erosion. Given the widespread ecological and economic impacts of erosion in this watershed, this study aims to identify erosion vulnerable areas (hotspots) and to assess, utilizing statistical analysis, the difference of perspective between communities near (NEH) and far (FEH) from erosion hotspots on the drivers and underlying causes of erosion. Identifying erosion vulnerable areas, drivers, underlying causes and the perception of communities will assist stakeholders to promote community-based problem identification, planning, and implementation of efficient and effective soil erosion conservation measures in watershed systems throughout the world.

1.1. Study area

In 2009, the population in Toledo, the District comprising the study area, was comprised of 5.5% Creole, 3.9% Garifuna, 69.4% Maya, 12.1% Mestizo and 9.1% other (Halcrow Group Limited, 2010). A recent poverty assessment of Belize indicates that Toledo is the poorest district in Belize (Halcrow Group Limited, 2010). The climate of this region is characterized by two seasons; rainy and dry with average annual rainfall of approximately 4,000 mm. Within the study area there are both low-lying and mountainous areas which rise to 1070 m. The headwaters of the Rio Grande watershed emerge in the Maya Mountains and are protected by the Bladen Nature Reserve and the Columbia River Forest Reserve. The lower reaches of the watershed partially flow within the Maya Mountain Marine Corridor, and discharge into the Port Honduras Marine Reserve. The Rio Grande watershed consists of three geomorphological areas: Volcanic material and karstic limestone in the upper reaches; flat alluvial plain in the middle reaches; and limestone in its lower reaches (Chicas & Omine, 2015). The river drops through sinkholes and emerges out of springs as it makes its way through the underground limestone cave systems; meandering through indigenous Mayan communities, and on to coastal Creole communities before discharging into the sea (McLoughlin, 2010). The Milpa slash-and-burn agricultural system is sustained in response to local conditions and provides the Kekchi and Mopan Maya of the region with food and material resources (Emch, Quinn, Peterson, & Alexander, 2005).

Accessibility of the communities in the upper-mid reaches of the watershed is often determined by the weather and road conditions (Fig. 1). Major roads are rarely maintained and impassible during the rainy season. Tracks or footpaths are used by community members to access agricultural fields.