Land cover change in agricultural landscapes of the Rio Añasco watershed following Hurricanes Irma and María

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USDA United States Department of Agriculture
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Abstract

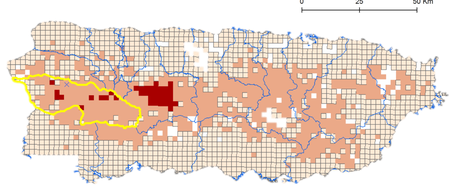
Tropical agricultural landscapes are highly susceptible to damage from extreme climatic events. Despite their large areas and importance to local economies, long-term impacts of hurricanes, droughts, and extreme rainfall events in these landscapes remain understudied. Climate models predict an increase in the intensity of hurricanes in the U.S. Caribbean, where frequent exposure to extreme events, small geographic and economic scales, rapid urban expansion, and a shortage of labor place agricultural systems at especially high risk. In Puerto Rico, the passage of Hurricanes Irma and María in September 2017 caused widespread destruction across the island and resulted in an 80% loss in crops yields. While crops will eventually recover, the loss of topsoils and terrain represent severe and long-lasting impacts to farm landscapes, yet receive less attention.

In this study, we analyze land-cover change in a highly impacted watershed in western Puerto Rico and characterize the amount of bare earth exposed following the hurricanes. We discuss the implications of increased erosion at farm and watershed scales and propose next steps to begin mitigating damages and preparing for a more climatically variable future.

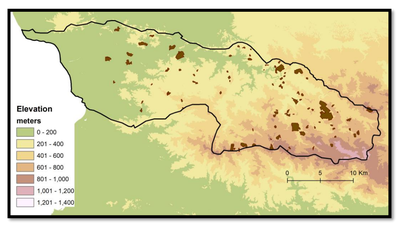
Introduction

- Regional climate models predict an increase this century in the intensity of tropical storms and hurricanes in Latin America and the Caribbean (Hayhoe 2013).
- Stronger hurricanes and extreme rainfall events are likely to cause significant damage to the agricultural sector in the form of crop losses, loss of topsoils, and damage to farm infrastructure. Resulting threats to agricultural productivity and ecosystem services are especially problematic in the Caribbean Region, where food security and economic vulnerability to extreme climatic events are widespread issues (Gould et. al 2015).
- In September 2017, Category 5 Hurricane Irma (9/6/17, sustained winds of ~300 km/h) passed within 80 km of Puerto Rico's northern coast, primarily affecting the northeast. A few weeks later Category 4 Hurricane María (9/20/17, sustained winds of ~250 km/h) crossed the island from southeast to northwest, causing widespread and catastrophic destruction.
- Hurricane impacts to agricultural landscapes in Puerto Rico have received little attention, despite having long-term effects on productivity. Understanding the loss of farm soils to landslides, flooding, and erosion following hurricanes and extreme rainfall events is essential to mitigation and future agricultural planning.
- We address this gap by analyzing the changes in land cover in a highly affected watershed important to food production in Puerto Rico, with a focus on changes in the area and spatial distribution of soils exposed to erosive forces. This information is important for watershed-level erosion estimates and developing best-practices for farms recovering from major soil degradation.

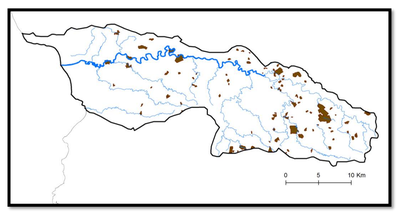
Methods



USGS mapping of concentration of landslides caused by Hurricane María



Plantain farms in a lowland (R) and a mountainous (L) regions



STUDY SITE: Río Grande de Añasco Watershed

- Predominant land covers: agriculture and forests
- Elevation: sea level to > 1,000 meters above sea level (m.a.s.l.)
- Topography: flat coastal lowlands to steep, rugged uplands where slopes commonly reach 70-100%.
- Hydrology: Main river (Río Grande de Añasco), 13 main tributaries, many perennial (lowlands) and intermittent (uplands) streams. Río Grande de Añasco begins (1204 m.a.s.l. to sea level, 74 km long) drains ~ 50,000 hectares before discharging into Mayaguez Bay
- Main economic activity is agriculture, with key crops including coffee, plantain, citrus, and fruits (Duque et al 2016)
- Second highest density of landslides in Puerto Rico after the hurricanes

LAND COVER CHANGE ANALYSIS

1. We classified land cover in agricultural areas of the Río Grande de Añasco Watershed through on-screen digitizing of high-resolution aerial photographs taken before (January 2017) and after (September 2017) Hurricanes Irma and María.
2. We analyzed land cover change on 129 farms actively participating in USDA programs in 2016. Farm boundaries were provided by the United States Department of Agriculture Farm Service Agency (Common Land Units).
3. We developed a land cover transition matrix to compare land cover classes before and after the hurricanes. This was used to calculate changes in the extent and spatial distribution of bare earth (exposed soil or rock with <10% vegetative cover).

Examples of digitized bare areas after Hurricanes Irma and María

Results

Farm level change: Pre Hurricanes
- 25 of 129 farms evaluated contained bare areas
- Total area in bare earth: 36535.44 m^2
- Mean (average), standard deviation: 1461 m^2 , 2226.70

Farm level change: Post Hurricanes
- 93 of 129 farms evaluated contained bare areas
- Total area in bare: 1237747. 62 m^2
- Mean, standard deviation: 13309 m^2, 44032.46

Polygon level: Pre Hurricanes
- Total of 41 bare polygons
- Mean polygon area: 891.1083364 m^2, standard deviation: 1235 m^2
- Max polygon area: 7087.02 m^2

Polygon level: Post Hurricanes
- Total of 328 bare polygons
- Mean 3773.62 m^2 (676 standard deviation)
- Max area: 165870.931 m^2

Matrix of change in land cover (hectares)

	No change/other damages	Water/ wetland	Bare earth	Clouds	Total
Forest	695.72	0.57	16.89	169.79	882.97
Woodland/ shrubland	36.01	0.00	16.55	1.76	54.32
Water/wetland	3.69	1.38	4.64	4.01	13.72
Bare earth	2.34	0.08	1.20	0.03	3.65
Developed	18.20	0.01	1.92	1.94	22.07
Pasture/grassland	29.86	0.18	15.40	1.18	46.62
Agriculture	382.58	0.55	64.05	164.58	611.75
Other	4.33	1.81	3.11	3.26	12.51
Total	1172.73	4.58	123.77	346.54	1647.62

Summary: Results indicate a major transition from vegetative cover to bare soils in agricultural areas of the Río Grande de Añasco Watershed, with the greatest loss occurring in actively cultivated areas.

- The number of farms with bare areas occurred following Hurricanes Irma and María increased three-fold.
- The number of bare-earth polygons increased eight-fold, from 41 to 328.
- The mean area of bare earth per farm increased from 0.1 ha to 1.3 ha (0.37 to 3.78 cuerdas), and the area of bare earth across farms increased from 3.65 ha to 123.77 ha after the storms.
- Out of the total bare area post-hurricanes, 51.7% (64.05 ha) were previously under cultivation, compared with 13.6% (16.89 ha) in forest, 13.4% (16.55 ha) in woodland or shrubland, and 12.4% (15.4 ha) in pasture or grassland.
- 10.5% (64.05 ha) of cultivated areas in our sample of farms transitioned to bare earth after the storms.

Before

After

Ecological and Economic Implications

- Areas of bare earth are subject to soil erosion and degradation, leading to sediment and nutrient pollution in streams and rivers and threatening the storage capacity of reservoirs. On farms, landslides and erosion result in the loss of nutrient-rich topsoil, and may reduce long-term productivity despite the return of vegetative cover.
- The agriculture to bare earth transition included plantain, banana, coffee, and citrus crops. These crops are widespread in the Rio Grande de Añasco Watershed and an important source of income.
- In Puerto Rico the plantain/banana industry suffered losses of over $90 million as a result of Hurricanes Irma and María. Coffee ($18.3 million) and oranges crops ($6.3 million) also suffered major losses. The agricultural sector as a whole in suffered losses of over $231 million (PR Department of Agriculture 2018).
- Short-term crop losses and long-term soil degradation following the hurricanes threaten food security and agricultural livelihoods in Puerto Rico, an island that already imports 80% of its food. Impacts are likely similar for the larger Caribbean region, where agricultural sectors are likewise vulnerable to economic fluctuations and extreme events (Gould et. al 2015).

Next Step: APEX – A Watershed & Land Management Simulation Model

- Quantifying and characterizing areas of exposed earth after the hurricanes is important not only for documenting land cover change and agricultural damage, but also to guide best practices for soil conservation in post-María agricultural recovery.
- Information gained from this study can be used to help (1) evaluate the contribution of agricultural landscapes to watershed-level erosion and sedimentation during extreme events, and (2) evaluate likely levels of erosion under varying land-use practices
- Our next step will be to model soil and nutrient loss on individual farms under different management scenarios using the Agricultural Policy/ Environmental eXtender model (APEX), which simulates impacts of land management practices on watersheds and heterogeneous farms.
- Quantifying the potential contribution of conservation practices to controlling erosion and sedimentation in a watershed highly susceptible to extreme events, and understanding their costs and benefits, are fundamental to preparing for a more climatically variable future.

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