Road erosion in dry and wet tropical settings of the Northeastern Caribbean

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Abstract

Unpaved roads are ubiquitous features of anthropogenic landscapes that facilitate the use and extraction of coveted resources. Until recently, unpaved roads had been overlooked as significant drivers of erosion and sediment yields in the Northeastern Caribbean. This paper summarizes findings of two decades of work documenting the role human disturbance on surface erosion and sediment yields. Project objectives have been to: (1) quantify the role of roads on surface erosion and watershed sediment yields; (2) identify controlling factors; (3) evaluate the effectiveness of mitigating measures; and (4) assess road hydrological and sediment connectivity. In the small, dry-tropical coastal watersheds of the U.S. Virgin Islands and Puerto Rico, land use change is driven by low-density urban development associated to tourism. In this setting, ephemeral streams deliver runoff to coral-bearing waters only ~4–5 times every year. However, unpaved roads covering only ~0.1–3% of the land surface can increase runoff delivery up to ~40 times per year. In this setting, road erosion may be up to four orders of magnitude above background and they contribute 80–99% of sediment yields. Mitigation strategies have included road drainage improvements, road paving, and sediment detention ponds. In the sun-grown coffee growing region of the wet tropical highlands of Puerto Rico, roads are a key source of the sediment affecting downstream water resources. A high erosion potential exists due to its steep relief, copious rainfall (1.6-2.1 m y^{-1}), and considerable soil exposure. Here, watershed-scale sediment yields are 3–30 Mg ha^{-1} y^{-1}, yet surface erosion rates under its natural forested cover are only ~0.25 Mg ha^{-1} y^{-1}. Unpaved road erosion on these settings is 14–780 times faster than on forested hillslopes. Gravel reduces road erosion rates by 66 – 90%, but the effect seems to fade after one to two years. Cultivated lands contribute 5–63% of farm-scale surface erosion, and roads are responsible for the remainder—even though they cover 8–15% of the total farm area. In the 45-km^2 Lucchetti Watershed, surface erosion from coffee farms equals 1–18% of its long-term sediment yield. The residual sediment is believed to originate from sources being quantified presently; these include road cutslopes, gullies, and landslides.

Poster #227

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Background

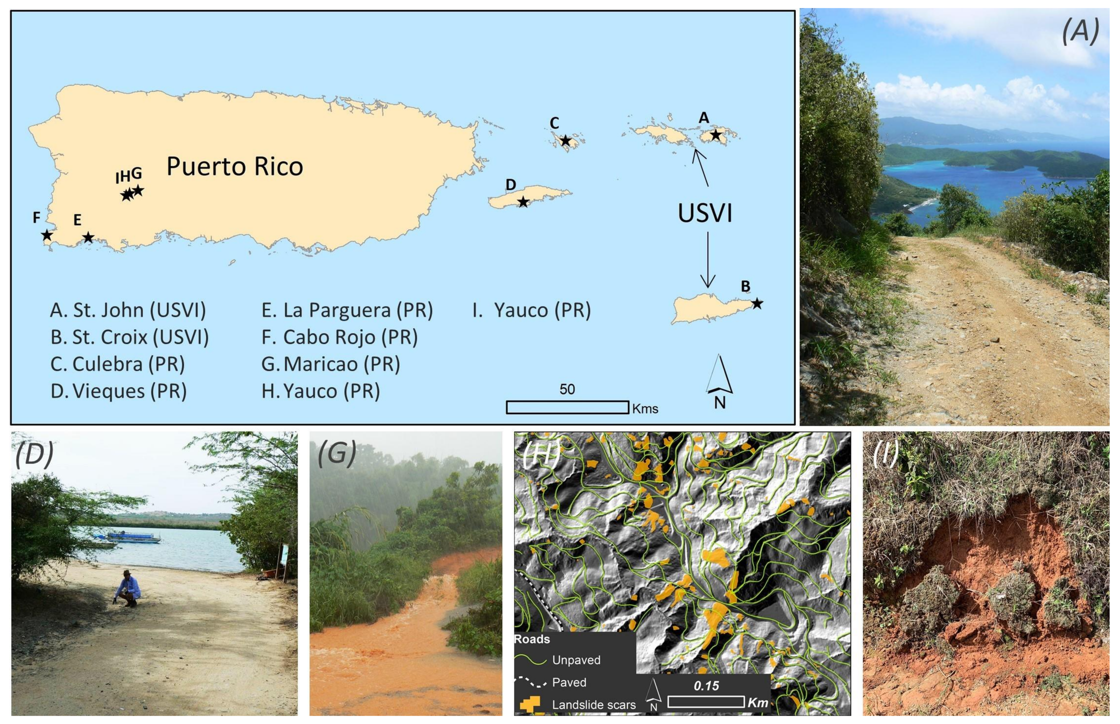
Erosion is a key concern in the Caribbean in part because sediments can reduce water reservoir capacity and may affect marine habitats such as coral reefs. Research conducted since the 1990s has shown that incorporating roads into sediment budget analyses is essential in understanding sediment dynamics in the region.

Research Questions

- What are the *hydrologic impacts* of roads across various scales?
- What are the impacts of roads on *surface erosion* and *shallow landsliding*?

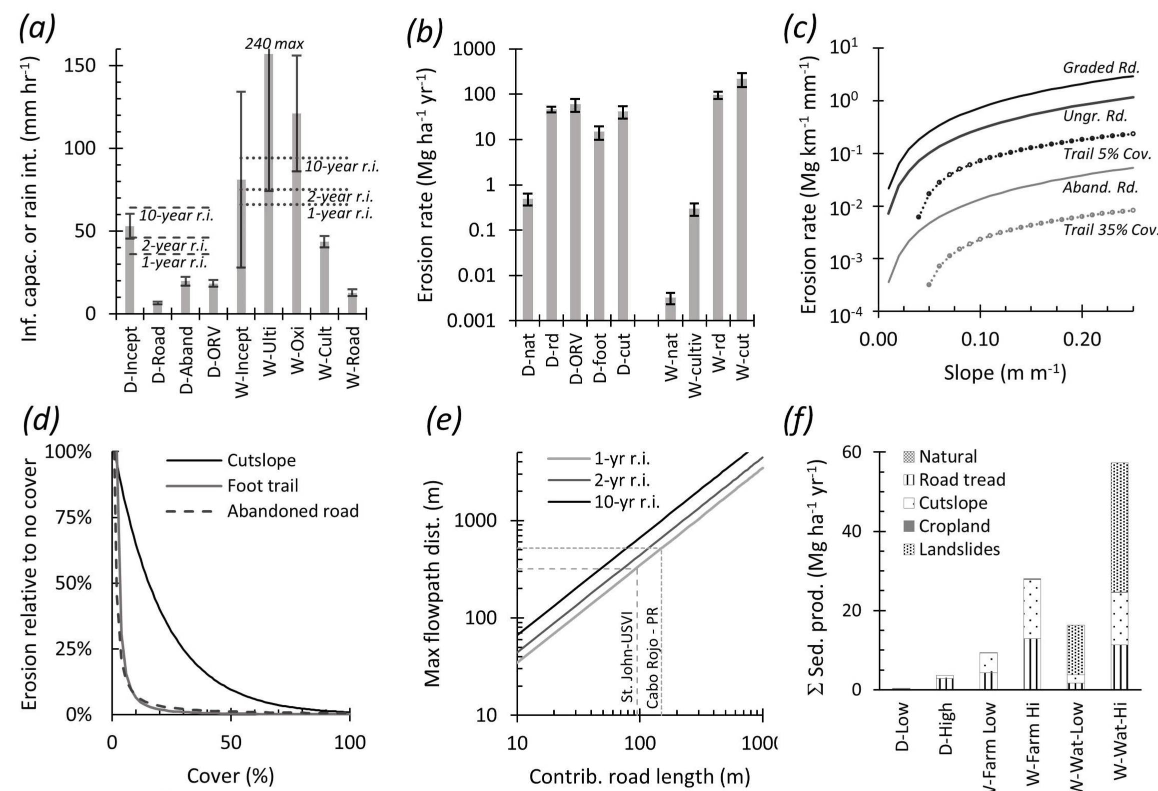
Methods and Materials

- **Hydro**: Guelph, runoff plots, portable flumes, unit hydrog. & kinematic wave modeling, crest gages, stream discharge
- **Erosion**: runoff plots, sediment traps, graph theory GIS modeling
- **Landslides**: aerial photos, lidar dem, frequency ratios

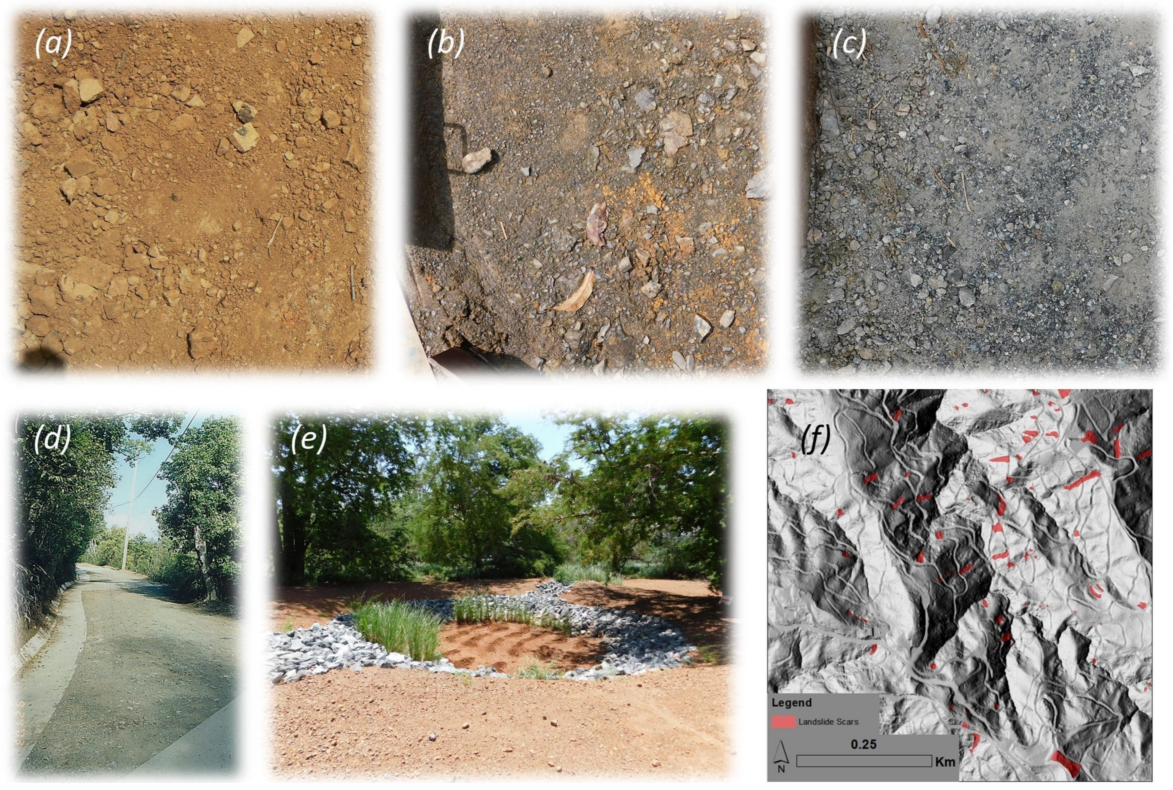


Study sites. *(A1 & 2) Coral Bay, STJ-USVI; (B) East End, STX-USVI; (C) Culebra-PR; (D) Mosquito Bay, Vieques-PR; (E) La Parguera-PR; (F) Cabo Rojo-PR; (G) Maricao-PR; (H) Hda S. Carlos, Yauco-PR; (I1 & 2) Hda Candelaria, Yauco-PR.*

Methods: *(A & B) Sed. traps; (C) Runoff plot; (D) Guelph; (E) Rain simulations; (F) Det. pond survey; (G) GIS mapping; (H) Flumes; (I) Landslide mapping & repeated lidar digital elevation model analyses*



Results: *(a) Avg inf. dry (D) & wet (W) settings. (b) Erosion various surfaces. (c) Erosion vs. slope (d) Erosion relative to 0% cover vs. veg. cover. (e) Max flow dist. below road drain (f) Road- and non-road-related sources at the farm and watershed scales.*



Discussion. *Surface texture of unsurfaced (a) and gravel-covered (b-c) roadways in coffee farms in PR. (d) Road drainage improvements at Maho Road in St. John included insloping and the construction of a cemented inside ditch and cross-drains. (e) Sediment detention pond used to reduce connectivity (Cabo Rojo-PR). (f) Preliminary mapping of landslides in the Yahuecas Watershed in PR showing their close proximity to unmapped farm roads.*

Results

- **Hydro**: Rain threshold for HOF ~2-6 mm; infiltration capacity ~10-40% undisturbed
- **Erosion**: f(slope$^{1.5}$, road drainage pattern, grading frequency, traffic/usage, rain, vegetation cover, practices); Σerosion watershed = f(rd density)
- **Landslides**: ~ ¾ of mobilized sediments within 5 m of roads; frequency ratios > 1

Future work

- **Hydro**: connectivity, surface and subsurface stormflow interception
- **Erosion**: empirical evidence of road to stream & coast sediment connectivity; effectiveness of management practices;
- **Landslides:** improved and management-relevant understanding of road impacts on slope stability

Conclusions

- **Hydro**: HOF *contributing areas*
- **Erosion**: 10^1 – 10^4 faster than undisturbed; >90% farm and watershed sediments
- **Landslides**: proximity to roads and slope (30-60°) are key factors

Key References

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