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# A combined approach to physical vulnerability of large cities exposed to natural hazards - the case study of Arequipa, Peru

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Arequipa, the second largest city in Peru with almost one million inhabitants, is exposed to various natural hazards, such as earthquakes, landslides, flash floods, and volcanic eruptions. This study focuses on the vulnerability and response of housing, infrastructure and lifelines in Arequipa to flash floods and eruption induced hazards, notably lahars from El Misti volcano. We propose a combined approach for assessing physical vulnerability in a large city based on: (1) remote sensing utilizing high-resolution imagery (SPOT5, Google Earth Pro, Bing, Pléïades) to map the distribution and type of land use, properties of city blocks in terms of exposure to the hazard (elevation above river level, distance to channel, impact angle, etc.); (2) in situ survey of buildings and critical infrastructure (e.g., bridges) and strategic resources (e.g., potable water, irrigation, sewage); (3) information gained from interviews with engineers involved in construction works, previous crises (e.g., June 2001 earthquake) and risk mitigation in Arequipa. Remote sensing and mapping at the scale of the city has focused on three pilot areas, along the perennial Rio Chili valley that crosses the city and oasis from north to south, and two of the east-margin tributaries termed Quebrada (ravine): San Lazaro crossing the northern districts and Huarangal crossing the northeastern districts. Sampling of city blocks through these districts provides varying geomorphic, structural, historical, and socio-economic characteristics for each sector. A reconnaissance survey included about 900 edifices located in 40 city blocks across districts of the pilot areas, distinct in age, construction, land use and demographics. A building acts as a structural system and its strength and resistance to flashfloods and lahars therefore highly depends on the type of construction and the used material. Each building surveyed was assigned to one of eight building categories based on physical criteria (dominant building materials, number of floors, percentage and quality of openings, etc).

Future steps in this study include mapping potential impacts from flash flood and lahars as a function of frequency of occurrence and magnitude. For this purpose, we will regroup the eight building types identified in Arequipa to obtain a reduced number of vulnerability categories. Fragility functions will then be established for each vulnerability category and hazard relating percentage damage to parameters such as flow velocity, depth, and dynamic and hydrostatic pressure. These functions will be applied to flow simulations for each of the three river channels considered with the final goal to determine potential losses, identify areas of particularly high risk and to prepare plans for evacuation, relocation and rehabilitation. In the long term, this investigation aims to contribute towards a multi-hazard risk analysis including earthquake- and other volcanic hazards, e.g. ashfall and pyroclastic flows, all by considering the cascading effects of a hazard chain. We also plan to address the consequences of failure of two artificial lake dams located 40 and 70 km north of the city. A lake breakout flood or lahar would propagate beyond the city and would call for an immediate response including contingency plans and evacuation practices.