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Integrating resident digital sketch maps with expert knowledge to assess spatial knowledge of flood risk: A case study of participatory mapping in Newport Beach, California

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ABSTRACT

Public participation geographic information systems (PPGIS) have been increasingly used to assess resident spatial knowledge of environmental hazards and to validate and supplement expert estimates of hazardous areas with local knowledge, but few studies have demonstrated methods for directly comparing local and expert knowledge of the spatial distribution of hazards. This study collected PPGIS digital sketch maps of flood-prone areas from 166 residents living adjacent to the Newport Bay Estuary in Southern California to examine variations in spatial knowledge of flood risk. First, we assessed agreement among participants and found that residents of areas with a higher percentage of homeowner, older, and higher income residents had greater agreement regarding areas at risk of flooding. Second, we introduced composite indices to assess the agreement between participant sketches of flood-prone areas with modeled estimates of the distribution of flood hazards, and found that the level of agreement between local and expert knowledge varied by the scale of analysis and by personal and contextual factors. Respondents with higher educational attainment, household income, and homeownership were associated with greater agreement between resident sketch maps and expert estimates of hazardous areas. Results inform spatial aspects of flood risk planning and communication by demonstrating how digital sketch maps can be used to identify potential shortcomings of expert hazard models, as well as hazardous areas where resident risk perception may be weak.

1. Introduction

Sketch maps have been increasingly used in conjunction with digital mapping tools in environmental hazard research to characterize spatial awareness of environmental risk and to validate and supplement expert estimates of hazardous areas with local knowledge (O'Neill, Brennan, Brereton, & Shahumyan, 2015). This approach builds on the cognitive mapping research by geographers, urban designers, and environmental psychologists which used sketches or maps to provide important insights regarding how individuals perceive and orient themselves to their environment, and how such spatial perceptions are influenced by age, gender, economic class, familiarity, and physical and social aspects of the environment assessed (Appleyard, 1981; Golledge, 2008; Kitchin, 1994; Lynch, 1960). Sketch maps have also been used to help delineate neighborhood boundaries and perceptions of place (Coulton, Korbin, Chan, & Su, 2001; Haney & Knowles, 1978), assess spatial aspects of crime perception and fear (Curtis et al., 2014), and understand variations in spatial knowledge by travel mode (Mondschein, Blumenberg, & Taylor, 2010).

Although early studies required participants to sketch maps of their perceptions in a free-form fashion using a blank sheet of paper or on a hardcopy base map, in recent years sketch maps have been integrated with and analyzed using Geographic Information Systems (GIS). Researchers often digitize participant hardcopy sketch

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maps into GIS or have participants draw sketches and/or record spatial data directly into GIS using web-based tools which enable interactive and dynamic mapping (Brown & Kyttä, 2014; Cadag & Gaillard, 2012; Curtis, 2012). This shift has given rise to the field of public participation GIS (PPGIS), which engages non-experts using mapping technologies to identify spatial aspects of social and ecological problems (Brown & Kyttä, 2014; Elwood, 2006). PPGIS has been used as a decision support tool in the fields of agricultural systems (Debolini, Marraccini, Rizzo, Galli, & Bonari, 2013), coastal ecosystem management (Levine & Feinholz, 2014), and urban forest and greenspace management (Hawthorne et al., 2015).

A few environmental hazard studies have used participatory data collection integrating paper sketch maps and/or PPGIS to characterize spatial awareness of environmental risk, and to integrate local and non-expert knowledge into decision-making processes. Assessing resident spatial awareness and knowledge of hazards and hazardous areas is particularly important because it could improve our understanding of individual actions and decisions prior to and during a disaster event, inform public debate about flood risk management, help identify areas where public perceptions or science-based assessments might be weak, and contribute to research on how risk perception might affect variables such as mental heath or policy support (Blum, Silver, & Poulin, 2014). Moreover, given the prohibitive cost associated with hiring professional engineers to develop products such as fine resolution flood models, alternative tools such as PPGIS can be used to create cost effective preliminary flood hazard assessments that can be widely disseminated. Sketch maps and/or PPGIS have been used to collect information on spatial awareness of natural hazards including riverine flooding (Brilly & Polic, 2005; Hung & Chen, 2013) and volcanic hazards (Gaillard, 2008; Leone & Lesales, 2009). These studies compared spatial knowledge and risk perception across different respondents to support planning and decision-making, but they did not quantify the level of spatial agreement between sketch maps and official warnings systems or scientific forecasts.

A handful of studies has compared non-expert spatial environmental knowledge collected through sketch maps and/or PPGIS with knowledge from official hazard designations or historic impact zones to support decision-making. In the area of conservation planning, Brown (2012) found an error rate of only about 6% when comparing participant PPGIS locations of native vegetation to official land cover data (Brown, 2012), and Brown, Weber, and De Bie (2015) found that over 70% of PPGIS points identified as having biological/conservation value were aligned with modeled areas of high conservation importance (Brown et al., 2015). In the area of spatial awareness of flood risk, Ruin, Gaillard, and Lutoff (2007) asked 200 participants in Southern France to draw sketch maps of roads prone to flooding, and subsequently compared respondents' drawings with official sources. They found that motorists who traveled on short daily itineraries in close proximity to their residences had high flood risk perception (Ruin et al., 2007). Pagneux, Gísladóttir, and Jónsdóttir (2011) compared sketch maps of areas perceived to be at risk of flooding from 90 residents in Iceland with areas impacted by historic flood events, and found that spatial knowledge of the boundaries of previous inundations was very poor (Pagneux et al., 2011). O'Neill et al. (2015) collected sketch maps of areas vulnerable to inundation during a severe flood event from 305 participants in Ireland, and found significant deviations between the participant risk perceptions and the extent of a historic major flood (O'Neill et al., 2015).

Our research investigates the application of digital sketch maps of flood-prone areas collected from 166 residents living adjacent to the Newport Bay Estuary in Southern California as a potential decision support tool given increasing flood hazard in coastal areas due to climate extremes, extensive urban development, and sea level rise (Burby, 2002). This study has two objectives: (1) to assess the level of agreement among participants with regards to their perceptions of areas vulnerable to flooding, and (2) to assess the level of agreement between participant sketches of flood-prone areas with modeled estimates of the distribution of flood hazards. It contributes to the geography and environmental hazard literatures, as well as advances disaster response planning. First, given the limitations of flood hazard models (Gallien, Sanders, & Flick, 2014; Thompson & Frazier, 2014), it demonstrates how local knowledge of hazards could help validate and inform expert models by identifying potential model shortcomings and hazardous areas that may have been overlooked by the models. Second, it demonstrates how digital sketch maps can be used to identify hazardous areas where resident risk perception may be weak, and to inform spatial aspects of flood risk planning and communication.

2. Methods

2.1. Study area

This study focused on the highly urbanized low-lying coastal lowlands of the Newport Bay Estuary within the City of Newport Beach, California (Fig. 1) and is part of the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project to promote resilience to coastal flooding in Southern California. The city encompasses Newport Harbor, which includes the constructed islands of Lido Isle and Balboa Island, and the urban coastal lowlands of Balboa Peninsula. Large portions of the city are below extreme high tide levels, and one study estimates that four decades of sea level rise could transform the present 100 year flood event along this coast into an annual occurrence (Gallien et al., 2014; Tebaldi, Strauss, & Zervas, 2012).

2.2. Modeled estimates of the distribution of flood hazards

Our analysis incorporates two modeled estimates of the distribution of flood hazard in the study area: (1) 2009 areas predicted by FEMA (Federal Emergency Management Agency) to flood from an event with a 1% annual chance (100 year flood), and (2) 2014 areas predicted by our street-level FloodRISE model to flood from an event with a 1% annual chance (100 year flood). The FEMA flood hazard mapping approach for the Newport Beach site involved one-dimensional hydrologic analysis of ocean water levels considering storm surge, waves, and wave runup followed by mapping still water flood elevations along the coastline and urbanized embayment by applying an equilibrium mapping approach (Gallien, Schubert, & Sanders, 2011; National Research Council, 2009). FEMA flood hazard maps are used by lenders during real estate transactions, federal and state agencies, and the National Flood Insurance Program to determine whether a property is inside a Special Flood Hazard Area.

The FloodRISE model is a two-dimensional hydraulic model that was developed at the University of California, Irvine, and has been used in this project for flood hazard mapping in Newport Beach, California. The model relies on an unstructured grid of triangles, which can be locally refined for accurate topographic representation of the site's terrain and infrastructure geometries, such as streets and flood defenses. The model is also able to account for a wide range of flow regimes resulting from abrupt changes in topography like those caused by flood walls. The model has been previously validated for the modeling of storm tides and wave overtopping in Newport Beach (Gallien et al., 2014, 2011).

Results of our quantitative comparison of resident digital sketch