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Research article

Managing household socio-hydrological risk in Mexico city: A game to communicate and validate computational modeling with stakeholders

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A B S T R A C T

Residents of Mexico City experience major hydrological risks, including flooding events and insufficient potable water access for many households. A participatory modeling project, MEGADAPT, examines hydrological risk as co-constructed by both biophysical and social factors and aims to explore alternative scenarios of governance. Within the model, neighborhoods are represented as agents that take actions to reduce their sensitivity to exposure and risk. These risk management actions (to protect their households against flooding and scarcity) are based upon insights derived from focus group discussions within various neighborhoods. We developed a role-playing game based on the model's rules in order to validate the assumptions we made about residents' decision-making given that we had translated qualitative information from focus group sessions into a quantitative model algorithm. This enables us to qualitatively validate the perspective and experience of residents in an agent-based model mid-way through the modeling process. Within the context of described hydrological events and the causes of these events, residents took on the role of themselves in the game and were asked to make decisions about how to protect their households against scarcity and flooding. After the game, we facilitated a discussion with residents about whether or not the game was realistic and how it could be improved. The game helped to validate our assumptions, validate the model with community members, and reinforced our connection with the community. We then discuss the potential further development of the game as a learning and communication tool.

1. Introduction

1.1. General introduction

In vulnerability analysis, we are increasingly aware of the need to incorporate, or make endogenous, social processes into what have traditionally been biophysical models. This process - deriving reliable sources for social data, validating the data, and ensuring the data is credible and salient for decision makers - presents numerous challenges. However, agent-based models (ABMs) have become important computational tools for this process. They allow researchers to represent social actors in terms of decision algorithms which are then represented through the actions of a variety of agents, as well as their interactions with other agents, within a simulated, complex social and biophysical environment (Railsback and Grimm, 2013). However, this capability is not without drawbacks; it is difficult to validate such complex models, both in terms of assumptions made and outputs obtained (Windrum et al., 2007). The computational algorithms designed to characterize actor decision-making can be conceptualized and represented in computer language, but are difficult to substantiate empirically or statistically validate.

Imagine, for instance, simulating the choice made by residents of a city to either invest resources to reduce their exposure to flood water vs. reduce their risk of water shortage. A possible model for representing the choices might be, for instance, the "bounded rational" model (Schlüter et al., 2017). Using this model, options for adaptation can be represented in terms of economic gains and losses. For the researcher programing this model in the computer, it involves finding the "right way" of representing the interactions between factors such as costs, prices of materials, expected income, weather, risk behavior of the residents, and other behavioral considerations. This implies that the implementation can take different forms and, with it, different parameters and parameter values depending on the theory used (Schlüter et al., 2017). Thus, finding a unique "best" representation of a decision-making process that simulates decisions can be challenging and is sometimes impossible. Therefore, it is important to validate with

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stakeholders the manner in which decision-making has been computationally operationalized in order to satisfy both theory requirements and reality. While new techniques are now available to make inference about uncertain parameters, as well as conduct global and local sensitivity analyses, using increasingly available computer time (Smajgl et al., 2011; Thiele et al., 2014), there is still a pervasive problem of how best to represent and validate complex behavioral choices.

Participatory approaches are now more frequently used for data elicitation, and validation is also increasingly participatory. Participatory modeling (PM) is a transdisciplinary approach to modeling; academics and stakeholders engage with one another to discuss and co-produce the goals, inputs, and components of a model (Basco-Carrera et al., 2017; Voinov and Bousquet, 2010). PM projects engage stakeholders in many ways, including through the above-mentioned formats, in order to provide both quantitative and qualitative data from which to create model inputs and algorithms. Unlike a classic modeling approach that extracts information from stakeholders only at the beginning of the modeling process, PM is an iterative process that requires that stakeholders validate model information and inputs after initial consolidation and processing. The model may be repeatedly modified and agreed upon by all stakeholders, therefore increasing model credibility prior to producing results. PM requires creative and flexible modes of communication for diverse stakeholders with different kinds of expertise and epistemologies as some stakeholders may provide and/or understand qualitative, experiential/perception-based inputs while others provide and/or understand quantitative, 'objective' information (Hall et al., 2014; Voinov et al., 2016). Thus, diverse communication methods are required at the beginning of the process during information elicitation, throughout the process of model building and validation, and at the end of the process when presenting results for the purpose of learning.

One communication method is using serious role-play games (RPG) (Pahl-Wostl and Hare, 2004; Castella et al., 2005; Cleland et al., 2012). RPGs are a group, participatory activity during which players are asked to behave as particular actors in an imagined environment (Barreteau et al., 2003). RPGs have been described as a possible method with which to validate complex models (Smajgl et al., 2011). In this paper, we present our initial reflections from our experience developing and using a RPG as an ABM validation tool with stakeholders in Mexico City in a multi-year, participatory modeling project that investigates how hydrological risk (flooding and scarcity) is co-constructed by both physical and social factors. We sought to address the challenge of qualitative data validation with a tool that could clearly communicate some of the complex model dynamics to stakeholders. Here we pose the following research question: how can role games serve as tools to help make model validation processes accessible to stakeholders that are unfamiliar with computerized, algorithmic modeling environments?

1.2. Project context and background

The modeling project, "The Dynamics of Multi-Scalar Adaptation in Megacities," MEGADAPT,[1] is designed to facilitate participatory modeling in relation to addressing a truly "wicked" sustainability challenge in Mexico City: chronic vulnerability to water scarcity and flooding. Water management and infrastructure challenges have existed for centuries as the city was constructed in a drained lake bed (Ezcurra and Mazari, 1996). Many residents do not have access to potable water nor sewage infrastructure, local freshwater resources are overexploited such that water is pumped in from adjacent hydrological basins, and flooding events have increased over the last decade due to multiple system pressures such as increased urbanized land-cover (Tortajada and Castelan, 2003; Romero Lankao, 2010; Aguilar and Santos, 2011).

The MEGADAPT model simulates the decisions of influential actors in Mexico City associated with water management and water related vulnerability (i.e., water managers and residents) using an ABM, informed by multi-criteria decision analysis, and embedded in a dynamic geospatial information system (Eakin et al., 2017; Baeza et al., in review; Bojórquez-Tapia et al., in review). MEGADAPT involves inputs from a diverse array of biophysical models (incorporating the interaction of urbanization and land change with hydrology, urban infrastructure and climatic patterns), which inform the spatially-explicit decision context for simulated agents in the city – i.e., water managers and residents. The agents are designed to represent real-world decision-makers in Mexico City and their decision criteria and decision options were specified through the use of multi-criteria decision analysis (Eakin et al., 2017; Baeza et al., in review; Bojórquez-Tapia et al., in review).

The current version of the MEGADAPT model includes two types of "agent": one represents the city's water provision authority, which manages the infrastructure to supply water and the sewer system; the other type of "agent" (technically, cellular automata) are vulnerable neighborhoods, or census blocks, that respond to exposure to scarcity and flooding. Leaders of civil society groups were interviewed to provide initial insights into the decision environment for residents affected by scarcity and flooding, and then participatory workshops and focus groups with members of vulnerable neighborhoods provided insights into the impact and responses of residents to extreme events (Eakin et al., 2016). The urban boroughs of Xochimilco, Magdalena Contreras, and Iztapalapa were chosen as case study areas in the city to represent vulnerable residents given that each of these areas suffer from both scarcity and flooding although represent relatively distinct geographic contexts in which these hazards occur (Eakin et al., 2016).

Common household risk management actions were elicited from 12 workshops and focus groups (Eakin et al., 2016). For example, to combat water scarcity, residents primarily invest in water storage containers (purchasing water tanks called *tinacos* and constructing cisterns) and purchase water from alternative sources (private water distributors). For flood events, residents construct barriers in front of their homes and doorways, and raise furniture and valuables off the floor. These individual actions, however, only go so far in avoiding crises. Perhaps unsurprisingly, in the context of considerable distrust between the residents and urban authorities, residents frequently brought up the need to "take to the streets" – protest – to demand attention from the public sector.

The research team represented the narratives of the residents in terms of "mental models": internal representations of external reality that can be instrumental in informing perceptions of risk and responses to hazards (Morgan et al., 2002). For example, most of the residents in flood-affected neighborhoods perceived that the cause of the problem was primarily associated with poor water management and ineffective governance. Similarly, those households suffering from chronic water scarcity often attributed the more critical period of water scarcity to the neglect of public officials. Politics – manipulation of water delivery schedules, or the neglect of infrastructure repairs – were often mentioned by these stakeholders as the underlying cause of any crisis they confronted (Fig. 1A).

From these focus group interviews we felt that there was enough similarity across the experiences of residents in the three urban boroughs (as indicated by similar variables and relationships in their independent mental models), as well as homogeneity in the response strategies (also found in their mental models), to create a "generic" decision model to represent the decision context and strategies of residents in a vulnerable census block (Fig. 1B). To do this, we identified the most common criteria influencing the experience of hazards (flooding and scarcity) and the resulting action response strategies, excluding criteria that were clearly idiosyncratic to a particular place of the individual who had participated in the mental model interview. The research team created this common model using the multi-criteria decision analysis software Super Decisions v. 1.6.0 (https://www.superdecisions.com/) independently of the residents.

[1] See project website: http://megadapt.weebly.com/.