2018

Participatory GIS as a Tool for Stakeholder Engagement in Building Resilience to Sea Level Rise: A Demonstration Project

Juita-Elena (Wie) Yusuf
Old Dominion University, jyusuf@odu.edu

Pragati Rawat
Old Dominion University, prawa002@odu.edu

Carol Considine
Old Dominion University, cconsidi@odu.edu

Michelle Covi
Old Dominion University, mcovi@odu.edu

Burton St. John III
Old Dominion University, bsaintjo@odu.edu

See next page for additional authors

Original Publication Citation

Yusuf, J.-E., Rawat, P., Considine, C., Covi, M., St. John, B., Nicula, J. G., & Anuar, K. A. (2018). Participatory GIS as a tool for stakeholder engagement in building resilience to sea level rise: A demonstration project. *Marine Technology Society Journal, 52*(2), 45-55. doi:10.4031/MTSJ.52.2.12

Authors
Juita-Elena (Wie) Yusuf, Pragati Rawat, Carol Considine, Michelle Covi, Burton St. John III, J. Gail Nicula, and Khairul A. Anuar

PAPER

Participatory GIS as a Tool for Stakeholder Engagement in Building Resilience to Sea Level Rise: A Demonstration Project

AUTHORS

Juita-Elena (Wie) Yusuf
Pragati Rawat
Carol Considine
Michelle Covi
Burton St. John III
J. Gail Nicula
Khairul A. Anuar
Old Dominion University
Resilience Collaborative

ABSTRACT

This article describes a participatory geographical information system (PGIS) demonstration project used as part of the stakeholder engagement efforts undertaken by the Citizen Engagement Working Group of the Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project. The PGIS demonstration project was conducted in the Little Creek/Pretty Lake case study area in the Hampton Roads region of southeastern coastal Virginia. PGIS served as a deliberative and participatory mechanism to obtain local knowledge from residents about the location of valued assets within the community and locations challenged by increased flooding and sea level rise. The PGIS application, using the weTable tool, was found to be useful for soliciting and documenting local knowledge, such as by highlighting community assets and identifying community challenges. It was also found to be useful for facilitating community-wide discussion, visualizing the problem, and understanding the severity of sea level rise and flooding. The PGIS demonstration project showed how participatory mapping can directly engage residents in creating sociospatial data, build knowledge, and foster learning and deliberation in a complex issue such as resilience to flooding and sea level rise.

Keywords: Participatory mapping, weTable, Hampton Roads, sea level rise planning, whole-of-community

Introduction

The Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project (the Pilot Project) was a 2-year effort to identify and develop a "whole-of-government" and "whole-of-community" governance structure for holistic sea level rise and resilience planning in the Hampton Roads region of coastal Virginia. The Pilot Project was convened by Old Dominion University and led by a Steering Committee comprising influential leaders at multiple levels of government and from multiple sectors (such as business, nonprofits, and community organizations). The Pilot Project was structured along five working groups: a Legal Working Group, Infrastructure Working Group, Land Use Planning Working Group, Citizen Engagement Working Group, and Public Health Working Group.

This article focuses on the stakeholder engagement efforts of the Pilot Project, undertaken by the Citizen Engagement Working Group, utilizing a participatory geographical information system (PGIS) approach to solicit and codify residents' perspectives on community assets and to help residents assess how these assets and the communities they are embedded in are challenged and impacted by sea level rise and flooding. Regarding the latter, PGIS simultaneously promoted social learning among participating residents by providing an interactive mechanism for collaborative, joint learning about sea level rise and flooding, information exchange, and discussion and analysis of issues associated with building resilience.

Governments, businesses, and residents must work together to build resilience to sea level rise in a collaborative approach that spans multiple sectors and jurisdictional boundaries (Adger et al., 2005). Understanding the actual capacity of communities, businesses, and public institutions to respond and adapt to issues like sea level rise is critical (Moser, 2010), and a multisectoral approach is necessary for responding to sea level rise in an integrated way and for pursuing innovative solutions to more effectively adapt to sea level rise.

Such a multisectoral approach is consistent with the whole-of-community framework that underpins the Pilot Project. This approach emphasizes the involvement of a wide range of stakeholders beyond those in the governmental sector, such as those associated with businesses, nonprofit or nongovernmental organizations, academic institutions, faith-based institutions, communities, families, and individuals. Stakeholder engagement is crucial given a whole-of-community framework, and for the Pilot Project there was an explicit need to engage members of the community in a discussion of flooding, sea level rise, adaptation, and resilience.

The Pilot Project Phase 1 Report explicitly noted that "both community education and input are vital components of resiliency in Hampton Roads" (Steinhilber et al., 2015, p. 9). In the same vein, the Citizen Engagement Working Group highlighted the need to identify or develop strategies for effective two-way engagement with residents on the issue of resilience to flooding and sea level rise (Steinhilber et al., 2015). This emphasis on community engagement was not unique to the work of the Citizen Engagement Work Group, as the Infrastructure Working Group also emphasized in its findings "the importance of community planning and managing the perception of the community" (Steinhilber et al., 2016, p. 31).

Citizen Engagement, Participatory Mapping, and PGIS

There has been increasing emphasis on incorporating citizen engagement into governing (United Nations, 2014). For example, the United Nations Framework Convention on Climate Change (United Nations, 1992) called on countries to implement educational and public awareness programs, provide the public with access to information, and seek public participation in addressing climate change and its effects.

Environmental issues such as those related to climate change and sea level rise, however, are often considered too difficult to be understood by the average community member (Crow & Stevens, 2012; Fischer, 2000) and thought to be best left in the hands of experts and scientists (Rowe & Frewer, 2000). Nevertheless, there is also broad support for the need to improve public understanding of complex environmental issues such as sea level rise (Bord et al., 2000; Brown & Donovan, 2014; Crow & Stevens, 2012; Dickinson et al., 2012; Nisbet, 2009; Whitmarsh et al., 2013). Such public understanding, in turn, is an important precursor for public participation in environmental decision-making. Different engagement approaches have been suggested and used for various environmental issues. Participatory mapping is one category of techniques that has risen in popularity over the last three decades. GIS technologies have been widely used to support participatory mapping applications in environmental issues (Al-Kodmany, 2002; González et al., 2008; Jordan & Shrestha, 2000; Kingston et al., 2000) such as through PGIS. These concepts will be discussed next.

Participatory Mapping

Participatory mapping is defined as any process where individuals, especially local participants, share in the creation of spatial data such as a map (Goodchild, 2007). According to Levine and Feinholz (2015), participatory mapping has played a key role in obtaining critical sociospatial data that are relevant to ecosystem-based planning and management. As such, it is an important tool for helping to situate local observations in the wider geographic context, exploring the human dimensions of coastal management, and examining local participants' perspectives and priorities (Joyce & Canessa, 2009).

For environmental management and monitoring issues, local users can be the best sources of detailed information that is generally lacking in traditional monitoring data (Levine & Feinholz, 2015). Participatory mapping puts human experiences into a spatial context and is a process-driven, vibrant, and vital way of knowing that fosters deliberation on complex issues (Tschakert et al., 2016). The mapping process is considered more important than the resulting map itself because it provides an opportunity for participants to meet and engage with each other in new ways, learn from each other, and share concerns held by different stakeholders (Levine & Feinholz, 2015).

Participatory mapping has been used in monitoring, reporting, and verifying environmental policies and problems, including applications in the areas of environmental degradation (Agyemang et al., 2007; Chagumaira et al., 2016), marine and coastal ecosystem management (Andrade & Szlafsztein, 2015; Frazier et al., 2010), marine spatial planning (Stelzenmüller et al., 2013), disaster management (Gaillard & Pangilinan, 2010; Kaul & Thornton, 2014; Levine & Feinholz, 2015; Villagra et al., 2014), and sustainable management of natural resources (Lubis & Langston, 2015).

The benefits of using participatory mapping for building resilience include introducing new and varied perspectives, creating usable information, promoting active learning, and surfacing unexamined assumptions. By having stakeholders collectively define the problem and identify possible solutions and strategies, it also allows for the coproduction of practice- and policy-relevant knowledge that is grounded in stakeholder values and the local context, enabling the design of adaptation processes with context-specific information (Fazey et al., 2010; Few et al., 2007; Preston et al., 2011). This is particularly relevant when the problem and solutions span multiple jurisdictions and affect various agencies, organizations, and communities.

PGIS

Technological advancements have made GIS increasingly accessible to ordinary citizens (Ganapati, 2011). Because of decreasing computing costs, low-cost GPS technology, and open data access over the Internet, GIS has become more widely used in community initiatives. The integration of GIS technology and community initiatives has led to PGIS that uses geospatial information as a vehicle for interaction, discussion, and analysis in support of advocacy and decision-making (Corbett et al., 2006).

PGIS developed out of participatory approaches that combined a range of geospatial information management tools and methods to represent participants' spatial knowledge, either virtual or physical, using two- or three-dimensional maps. These maps are used as interactive mechanisms for spatial learning, information exchange, discussion and analysis, and ultimately decision-making and advocacy (Rambaldi et al., 2006). Through PGIS, mapping exercises are carried out with local stakeholders to document local spatial knowledge (Baldwin et al., 2013). The mapping exercise can be carried out with individuals or small groups using semistructured or nonstructured interviews (see, e.g., Asare-Kyei et al., 2015; Baldwin et al., 2013; Pozzebon et al., 2015), during formal or informal meetings or focus groups (see, e.g., Bracken et al., 2016; Cinderby et al., 2008), using brainstorming sessions (see, e.g., McBride et al., 2017), or even by recording oral history (see, e.g., Cullen, 2015).

Often the first round of the PGIS mapping exercise is used to create a base map and later iterations of mapping exercises are used to add details such as identifying the distribution of resources and areas of interest or threat (Baldwin et al., 2013; Cullen, 2015). In other examples, the first mapping cycle can be aimed at identifying the preexisting concerns or historical occurrence of events such as floods, and the second iteration at identifying where solutions must be implemented (Bracken et al., 2016). The initial base maps can also be created in advance of the PGIS mapping exercise using existing aerial and spatial data and then further refined using local input (Sletto et al., 2010).

Some PGIS applications use validation exercises with the wider community to refine and finalize the map (Bracken et al., 2016; Cinderby et al., 2008; Sletto et al., 2010). This stage of PGIS may address issues such as relevant geospatial data types (e.g., ArcGIS, Google Earth) or visualization techniques such as color intensity; supplementary products (e.g., atlases/maps, reports, DVDs) and means of accessing resulting data (Baldwin et al., 2013; Cinderby et al., 2008). The final stage involves use of the PGIS products for evaluation and assessments, including to assess coastal vulnerability, identify areas of concern for planning or environmental protection, and obtain stakeholders' evaluation about the PGIS process and products (Baldwin et al., 2013; Cinderby et al., 2008; Cullen, 2015; Jordan & Shrestha, 2000).

PGIS has been used globally, in locales ranging from the Caribbean Islands (Baldwin et al., 2013; Baldwin & Oxenford, 2014; Sletto et al., 2010) to Africa (Asare-Kyei et al., 2015), to the United Kingdom (Bracken et al., 2016; Cinderby et al., 2008), and to the United States (Brehme et al., 2015; McBride et al., 2017). For example, PGIS has been applied to address issues such as effective transboundary marine resource governance (Baldwin et al., 2013), mapping marine habitats (Baldwin & Oxenford, 2014), validating community level flood hazard maps (Asare-Kyei et al., 2015), and coastal planning (Brehme et al., 2015). Across different applications, PGIS has been found to be effective at coproducing knowledge by eliciting high-quality local experiential information compatible with experts' knowledge and for generating spatial products that are understood by locals, while simultaneously promoting learning and capacity building to access and use information produced by a variety of users and decision makers (Torres et al., 2014; Baldwin & Oxenford, 2014; Bracken et al., 2016; Cinderby et al., 2008; Cullen, 2015; McBride et al., 2017; Rambaldi et al., 2006; Young & Gilmore, 2013).

The Pilot Project Citizen Engagement Working Group

The Pilot Project Citizen Engagement Working Group had several objectives, one of which was to develop engagement and communications strategies that enhanced the capacity of Hampton Roads communities to (a) plan for flooding emergencies, (b) prepare for sea level rise contingencies, and (c) strengthen social capital and resilience (Steinhilber et al., 2016). To incorporate a whole-of-community framework into the Pilot Project, the Citizen Engagement Working Group focused its efforts on engaging local residents in addressing issues of sea level rise, adaptation, and resilience.

Adapting to and building resilience for sea level rise requires stakeholder engagement processes that help communities reduce their risks by identifying threats to not only human life and personal property but also to the social fabric of the community. Understanding how residents perceive threats and prioritize their concerns so that communities can respond appropriately is an important part of building resilience. The Pilot Project Citizen Engagement Working Group was driven by the understanding that (a) involving citizens and other stakeholders would improve the quality of information, expand the range of adaptation and resilience solutions, and enhance public support for potential solutions and (b) doing so simultaneously improves the community's capacity to adapt and be resilient, as social learning changes the way residents understand and engage with their environment.

Case Study Area and Demonstration Project

The Citizen Engagement Working Group utilized the Little Creek/Pretty Lake area of Norfolk and Virginia Beach as a case study area to conduct a demonstration project using PGIS as a stakeholder engagement tool for incorporating local knowledge into an assessment of risks from flooding and sea level rise. The Little Creek/Pretty Lake case study area was selected because its ecological boundaries extend across two municipalities (the cities of Norfolk and Virginia Beach) and a federal military installation (Joint Expeditionary Base Little Creek–Fort Story).

The City of Norfolk has two watersheds that drain into the Little Creek/Pretty Lake case study area. The Lake Whitehurst watershed drains approximately 4.5 square miles of area and contains one of Norfolk's 11 fresh water reservoirs and the Pretty Lake watershed drains approximately 4 square miles of area. On the Virginia Beach side, the Little Creek watershed, which contains Lake Lawson and Lake Smith, drains approximately 8.1 square miles of area into the case study area. The Joint Expeditionary Base Little Creek–Fort Story is located near the center of the Pretty Lake/Little Creek case study area and adjacent to the inlet of the system to the Chesapeake Bay, covering approximately 3.3 square miles.

PGIS Demonstration Project

The Citizen Engagement Working Group utilized the Action-Oriented Stakeholder Engagement for a Resilient Tomorrow (ASERT) framework, which was developed by Old Dominion University researchers as an approach to facilitate the engagement of stakeholders from across multiple sectors in building resilience (Considine et al., 2017). The ASERT framework emphasizes the presentation of relevant and accessible information, coupled with the use of two-way communication and deliberative and participatory mechanisms. The deliberative and participatory components of the ASERT framework build on the Structured Public Involvement approach that has been applied in high-conflict decision-making contexts such as environmental and transportation planning (Bailey et al., 2002, 2007, 2011).

The ASERT framework was operationalized through a demonstration project in the Little Creek/Pretty Lake case study area. The demonstration project used PGIS as a deliberative and participatory mechanism to obtain local knowledge from residents about the location of valued assets within the community and locations challenged by increased flooding and sea level rise. The purpose of PGIS was to solicit and codify residents' perspectives on community assets and to help residents assess how these assets and the communities they are embedded in are challenged and impacted by sea level rise and flooding. Information collected through PGIS could be used to inform decision-making by providing context-specific local knowledge. However, for the demonstration project, the goal was to apply PGIS as an engagement and data collection tool and to assess the usefulness of the tool. The sociospatial data collected through the PGIS exercise was shared with local decision makers, but the PGIS exercise was not embedded in any formal decision-making process.

For the PGIS application, the demonstration project team used the weTable tool (Messmore, 2013; Mikulencak & Jacob, 2011) for (a) identification of community assets and challenges and (b) visualization of the flooding impacts of sea level rise. The weTable served as the platform to present maps and geospatial data representing the physical features of the community and the impacts of coastal inundation due to sea level rise and/or storm surge. The geospatial data highlighted the impacts of flooding, such as on critical infrastructure and personal safety, and provided the starting point for residents to identify vulnerabilities to sea level rise and flooding. As shown in Figure 1, the weTable uses Nintendo Wii technology to create an interactive tabletop that allows participants to simultaneously visualize sea level rise scenarios while collaboratively exploring and identifying assets and vulnerabilities. A laptop computer with GIS software is connected to a projector and Nintendo Wii remote. The computer screen showing the GIS software is projected onto a tabletop surface. Participants interact with GIS map using a light pen connected via Bluetooth to the laptop via the Nintendo Wii remote.

A key function of the weTable exercise is to focus participants' attention to sea level rise and coastal flooding by using maps to visually convey the extent of the impacts. Such visualization promotes individual and group understanding because it provides shared references and objects to talk and think about and use as a basis for coordinating actions and perspectives, moving from individual perceptions to a shared perception (Aggett & McColl, 2006; MacEachren & Brewer, 2004). Participants used the weTable to interact with maps to analyze risks and vulnerabilities; for example, indicating specific areas that might be at risk or showing how some areas may be more vulnerable than others (Lieske et al., 2015). The weTable also allows for social learning among participants, which was an important contribution of PGIS, as social learning offers a process through which individuals can learn from one another in ways that can benefit the wider community (Bandura, 1971; Reed et al., 2010). Social learning promotes self-reflection within the community and attitudinal change, which is key for building community resilience to increasing flooding due to sea level rise (Medema et al., 2014).

The demonstration project research team used the Google Earth application to present spatial data and maps to weTable participants. During the weTable exercise, participants interacted with maps of the Little Creek/Pretty Lake area. They also used flood maps associated with the scenario identified by the demonstration project research team involving 1.5 feet of sea level rise combined with a 100-year storm surge scenario. Community data from participants were collected electronically via Google Earth map layers.

Participants were asked to respond to two primary questions. First, they used a base map for the Little Creek/Pretty Lake case study area and were asked to identify assets in the community, such as schools, roads, and parks. Follow-up prompts asked them to consider: (a) Why are these assets particularly useful? (b) Which assets should be prioritized and why? Figure 2 shows the Google Earth map that includes some community assets identified by weTable participants.

Participants then used a map overlay of flooding projections under the scenario of 1.5 feet of sea level rise and a 100-year storm surge. Figure 3 shows the Google Earth map with this flood layer. Participants were posed a second question: With this map as an aide, tell us what kinds of challenges you see. Two follow-up prompts were also offered to participants: (a) Tell us more about the specific challenges in the areas you have

FIGURE 1

weTable set-up.

FIGURE 2

Google Earth map showing community assets.

FIGURE 3

Google Earth map showing the sea level rise and flood scenario.

identified, and (b) What areas would be more challenged than others and why?

Results of the weTable Exercise

Over a period of 3 months in spring 2016, 43 residents of the case study area participated in three exercises utilizing the weTable component of the PGIS demonstration project. The research team solicited participants for the PGIS demonstration project by sending invitation e-mails to neighborhood associations and civic leagues. Flyers were also posted in area businesses, community centers, senior centers, and public libraries. Residents self-selected to participate in the demonstration project and received $20 gift cards for attending the 90-min sessions.

Participants came from a wide range of backgrounds and experience with flooding and adaptation. For example, almost half of participants (47%) indicated being engaged in their neighborhoods or communities at high or extremely high levels. About equal percentages of participants were neutral in their engagement (26%) or had low or extremely low levels of engagement (28%). Their perceived vulnerability to flooding also varied. More than half (59%) perceived their personal vulnerability at high or extremely high levels, while a remaining 26% were neutral and 15% perceived low or extremely low vulnerability. Subsequent discussion with participants also indicated that there was diversity in their experiences with adaptation and mitigation activities.

Through the weTable exercises, participants identified key community assets such as parks and recreational centers, churches and faith-based facilities, restaurants and grocery stores, and transportation infrastructure. weTable participants also identified community assets related to health, such as clinics, medical and dental centers, and pharmacies, in addition to public safety services such as fire stations. Several elementary, middle, and high schools were also identified during the PGIS exercise as being important assets in the community. In addition to these assets, weTable participants also pinpointed several challenges in the community such as flooded bridges and roads, sewage backups, flooded homes, and isolation of community assets due to lack of access during flooding situations.

An important aspect of the weTable as a PGIS tool is its ability to surface collective local knowledge and to engage local participants in better understanding the impacts of sea level rise and flooding. As part of the demonstration project, the research team

TABLE 1

Mean scores and standard deviations for participants' responses to questions regarding weTable usefulness.

	Mean	Std. Dev.
Visualizing the problem of sea level rise	4.6	0.7
Highlighting community assets	4.4	0.9
Identifying community challenges associated with sea level rise and flooding	4.3	0.7
Understanding severity of sea level rise and flooding	4.5	0.8
Facilitating community-wide discussion about sea level rise and flooding	4.6	0.9

Note. Response scale 1-Not at all useful, 2-Slightly useful, 3-Somewhat useful, 4-Moderately useful, 5-Extremely useful.

collected data from participants about the usefulness of the weTable exercise. At the conclusion of the weTable session, participants were asked to respond to the following evaluation questions, providing answers using a scale from 1 to 5, with 1 being *not at all useful* and 5 being *extremely useful*:

- How useful was the weTable for visualizing the problem of sea level rise?
- How useful was the weTable for highlighting community assets?
- How useful was the weTable for identifying community challenges associated with sea level rise and flooding?
- How useful was the weTable for understanding the severity of the problem of sea level rise and flooding?

Results of participants' evaluations are summarized in Table 1. This table shows the mean ratings for each question on the 5-point scale (1 = *Not at all useful,* 2 = *Slightly useful,* 3 = *Somewhat useful,* 4 = *Moderately useful,* and 5 = *Extremely useful*). Overall, participants found the weTable exercise between moderately and extremely useful. They gave the highest ratings (mean ratings greater than 4.5) to weTable usefulness for facilitating community-wide discussion, for visualizing the problem, and for understanding severity of sea level rise and flooding. Interestingly, the primary utility of PGIS in terms of soliciting and documenting local knowledge, such as by highlighting community assets and identifying community challenges, was rated slightly lower (mean ratings of 4.4 and 4.3, respectively). This is consistent with the literature on participatory mapping that points to the mapping process being more important than resulting map, as the former provides the mechanism for participants to interact while

FIGURE 4

Challenges entry form on the web-based community map.

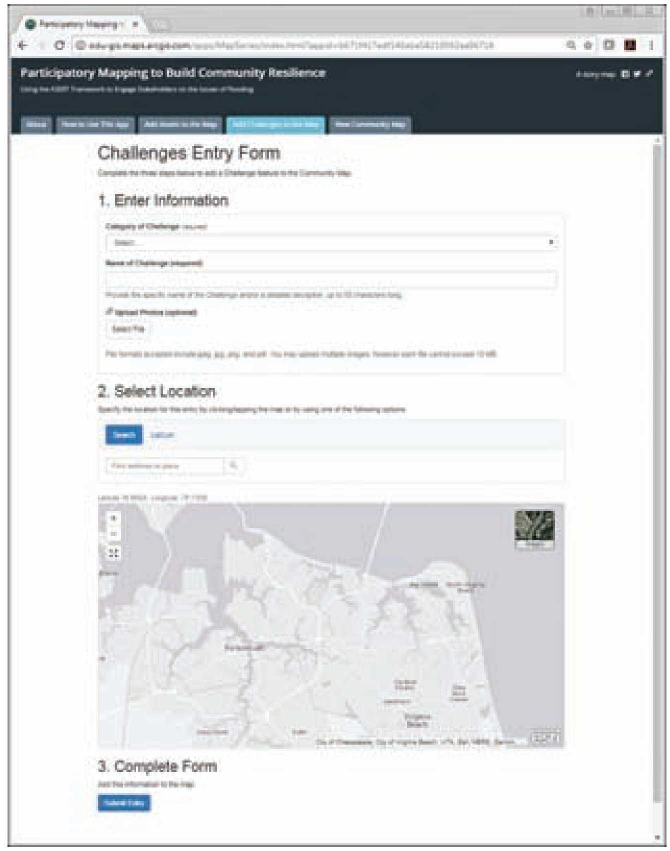
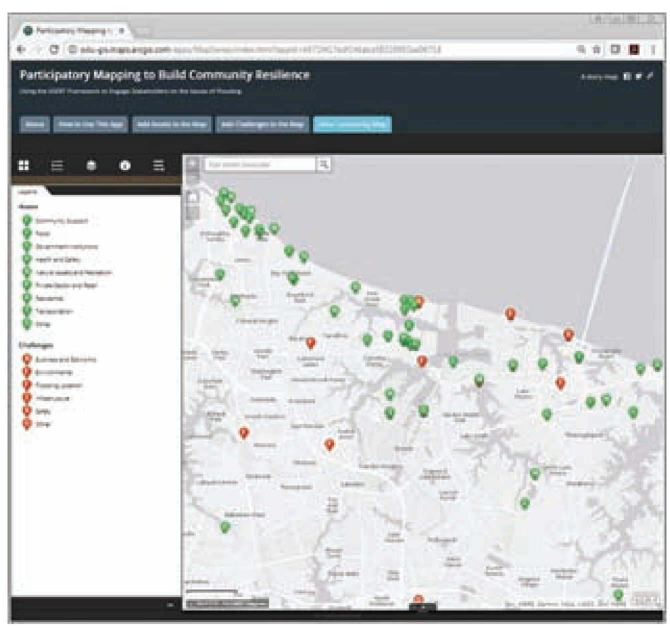


FIGURE 5

Community map displaying assets and challenges.



learning from each other and refining their knowledge and opinions about resilience.

Combined, the results of the weTable exercise in terms of collection of local data and participants' perceptions of weTable usefulness point to a successful PGIS demonstration project. The PGIS demonstration project showed how participatory mapping can, by directly engaging residents in creating sociospatial data, be a process-driven and vital way of building knowledge and fostering learning and deliberation in a complex issue such as resilience.

Taking the PGIS Demonstration Project to the Next Level

The Pilot Project concluded in July 2016, but the work started by the Citizen Engagement Working Group has continued and the PGIS demonstration project has been extended. In summer 2017, the PGIS demonstration project was taken to the next level with the development of a web-based community mapping application that can be deployed over a wider geographic area. This web-based PGIS application builds on the weTable exercise and provides local residents the opportunity to identify and input assets and challenges in their community. For example, as shown in Figure 4, the community map offers a web-based form for local residents to enter a community challenge by selecting a type of challenge (such as flooding location, infrastructure, business and economic, etc.), naming the challenge, and specifying it on the map. Users also have the option of uploading photos associated with the community challenge.

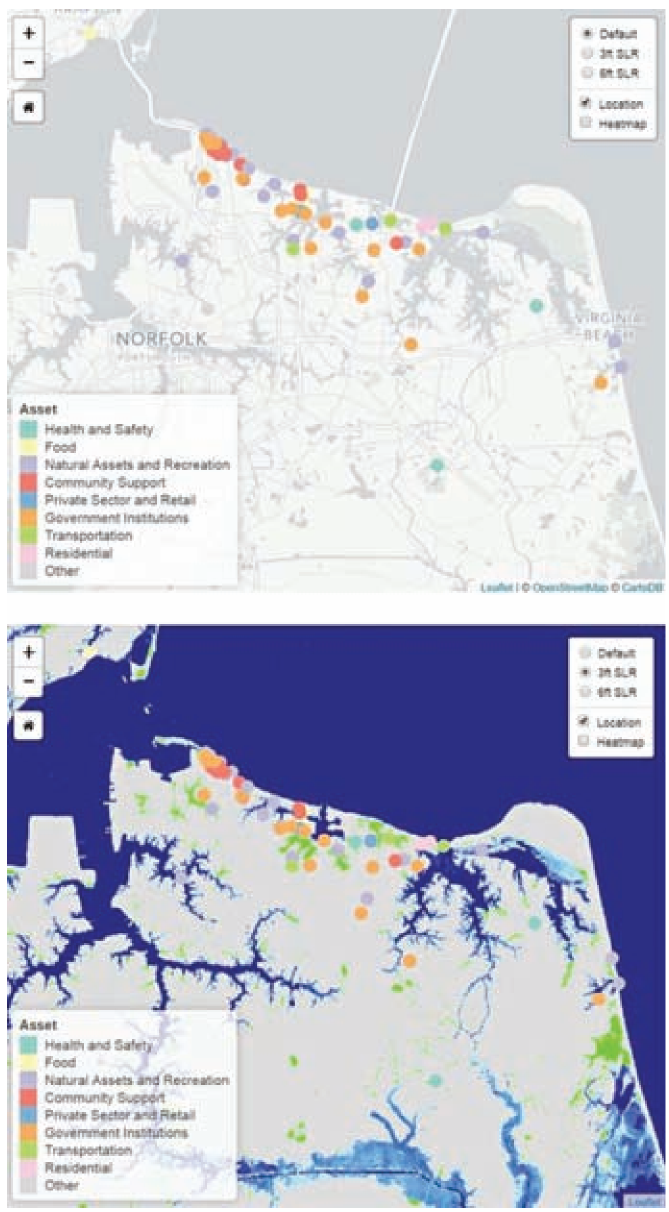
The web-based community map also supports the PGIS goals of codifying, documenting, and disseminating local knowledge about flooding and sea level rise. Users of the community map can, as shown in Figure 5, view the community assets and challenges that have been identified and added by other local stakeholders. Furthermore, the data collected through this PGIS approach can be analyzed in more detail and then disseminated to a wide range of stakeholders to support discussion, deliberation, and decision-making (see Figure 6 for a sample analyses).

Acknowledgments

The authors would like to thank Professor Tom Allen and Nicole Knudson of the Old Dominion

FIGURE 6

Sample analyses of data collected through the PGIS application.



University geography program for their support of the web-based community map component of the PGIS project.

Corresponding Author:

Juita-Elena (Wie) Yusuf
School of Public Service,
Old Dominion University
2097 Constant Hall
Norfolk, VA 23529
Email: jyusuf@odu.edu

References

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., & Rockström, J. 2005. Social-ecological resilience to coastal disasters. Science. 309(5737):1036-9. https://doi.org/10.1126/science.1112122.

Aggett, G., & McColl, C. 2006. Evaluating decision support systems for PPGIS applications. Cartogr Geogr Inf Sc. 33(1):77-92. https://doi.org/10.1559/152304006777323163.

Agyemang, I., McDonald, A., & Carver, S. 2007. Application of the DPSIR framework to environmental degradation assessment in northern Ghana. Nat Resour Forum. 31(3):212-25. https://doi.org/10.1111/j.1477-8947.2007.00152.x.

Al-Kodmany, K. 2002. GIS and the artist: Shaping the image of a neighborhood through participatory environmental design. In Craig, W.J., Harris, T.M., & Weiner, D. (Eds.), Community Participation and Geographic Information Systems (pp. 320-9). New York: Taylor & Francis. https://doi.org/10.1201/9780203469484.ch24.

Andrade, M., & Szlafsztein, C. 2015. Community participation in flood mapping in the Amazon through interdisciplinary methods. Nat Hazards. 78:1491-500. https://doi.org/10.1007/s11069-015-1782-y.

Asare-Kyei, D., Forkuor, G., & Venus, V. 2015. Modeling flood hazard zones at the sub-district level with the rational model integrated with GIS and remote sensing approaches. Water. 7(7):3531-64. https://doi.org/10.3390/w7073531.

Bailey, K., Blandford, B., Grossardt, T., & Ripy, J. 2011. Planning, technology, and legitimacy: Structured public involvement in integrated transportation and land-use planning in the United States. Environ Plann B. 38(3):447-67. https://doi.org/10.1068/b35128.

Bailey, K., Brumm, J., & Grossardt, T. 2002. Integrating visualization into structured public involvement: Case study of highway improvement in central Kentucky. Transp Res Record. 1817:50-7. https://doi.org/10.3141/1817-07.

Bailey, K., Grossardt, T., Ripy, J., Toole, L., Williams, J., & Dietrick, J. 2007. Structured public involvement in context-sensitive large bridge design using casewise visual evaluation: Case study of Section 2 of Ohio river bridges project. Transp Res Record. 2028:19-27. https://doi.org/10.3141/2028-03.

Baldwin, K., Mahon, R., & McConney, P. 2013. Participatory GIS for strengthening transboundary marine governance in SIDS. Nat Resour Forum. 37:257-68. https://doi.org/10.1111/1477-8947.12029.

Baldwin, K., & Oxenford, H.A. 2014. A participatory approach to marine habitat mapping in the Grenadine Island. Coast Manage. 42(1):36-28. https://doi.org/10.1080/08920753.2013.863725.

Bandura, A. 1971. Social Learning Theory. New York: General Learning Corporation.

Bord, R.J., O'Connor, R.E., & Fisher, A. 2000. In what sense does the public need to understand global climate change? Public Underst Sci. 9(3):205-18. https://doi.org/10.1088/0963-6625/9/3/301.

Bracken, L.J., Oughton, E.A., Donaldson, A., Cook, B., Forrester, J., Spray, C., … Bissett, N. 2016. Flood risk management, an approach to managing cross-border hazards. Nat Hazards. 82:s217-40. https://doi.org/10.1007/s11069-016-2284-2.

Brehme, C.E., McCarron, P., & Tetreault, H. 2015. A dasymetric map of Maine lobster trap distribution using local knowledge. Prof Geogr. 67(1):98-109. https://doi.org/10.1080/00330124.2014.883956.

Brown, G., & Donovan, S. 2014. Measuring change in place values for enviornmental and natural resource planning using public participation GIS (PPGIS): Results and challenges for longitudinal research. Soc Nat Resour. 27:36-54. https://doi.org/10.1080/08941920.2013.840023.

Chagumaira, C., Rurinda, J., Nezomba, H., Mtambanengwe, F., & Mapfumo, P. 2016. Use patterns of natural resources supporting livelihoods of smallholder communities and implications for climate change adaptation in Zimbabwe. Environ Develop Sustain. 18(1):237-55. https://doi.org/10.1007/s10668-015-9637-y.

Cinderby, S., Snell, C., & Forrester, J. 2008. Participatory GIS and its application in governance: the example of air quality and the implications for noise pollution. Local Environ. 13(4):309-20. https://doi.org/10.1080/13549830701803265.

Considine, C., Covi, M., & Yusuf, J.-E.W. 2017. Mechanisms for cross-scaling, flexibility and social learning in building resilience to sea level rise: Case study of Hampton Roads, Virginia. Am J Clim Change. 6(2):385-402. https://doi.org/10.4236/ajcc.2017.62020.

Corbett, J., Rambaldi, G., Kyem, P., Weiner, D., Olson, R., Muchemi, J., … Chambers, R. 2006. Overview: Mapping for Change—The Emergence of a New Practice. Participatory Learning and Action. 54:13-19.

Crow, D.A., & Stevens, J.R. 2012. Citizen engagement in local environmental policy: Information, mobilization, and media. In Yang, K., & Schachter, H. (Eds.), The state of citizen participation in America (pp. 131-62). Raleigh, NC: Information Age Publishing.

Cullen, A. 2015. Making sense of claims across institutional divides: Critical PGIS and mapping customary land in Timor-Leste. Aust Geogr. 46(4):473-90. https://doi.org/10.1080/00049182.2015.1080344.

Dickinson, J., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., … Purcell, K. 2012.

The current state of citizen science as a tool for ecological research and public engagement. Front Ecol Environ. 10(6):291-7. https://doi.org/10.1890/110236.

Fazey, I., Gamarra, J.G., Fischer, J., Reed, M.S., Stringer, L.C., & Christie, M. 2010. Adaptation strategies for reducing vulnerability to future environmental change. Front Ecol Environ. 8(8):414-22. https://doi.org/10.1890/080215.

Few, R., Brown, K., & Tompkins, E.L. 2007. Public participation and climate change adaptation: avoiding the illusion of inclusion. Clim Policy. 7(1):46-59. https://doi.org/10.1080/14693062.2007.9685637.

Fischer, F. 2000. Citizens, Experts, and the Environment: The Politics of Local Knowledge. Durham, NC: Duke University Press. https://doi.org/10.1215/9780822380283.

Frazier, T.G., Wood, N., & Yarnal, B. 2010. Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida. Appl Geogr. 30(4):506-17. https://doi.org/10.1016/j.apgeog.2010.05.007.

Gaillard, J., & Pangilinan, M. 2010. Participatory mapping for raising disaster risk awareness among the youth. J Conting Crisis Man. 18(3):175-9. https://doi.org/10.1111/j.1468-5973.2010.00614.x.

Ganapati, S. 2011. Uses of public participation geographic information systems applications in e-government. Public Admin Rev. 71(3):425-34. https://doi.org/10.1111/j.1540-6210.2011.02226.x.

González, A., Gilmer, A., Foley, R., Sweeney, J., & Fry, J. 2008. Technology-aided participative methods in environmental assessment: An international perspective. Comput Environ Urban Syst. 32(4):303-16. https://doi.org/10.1016/j.compenvurbsys.2008.02.001.

Goodchild, M.F. 2007. Citizens as sensors: the world of volunteered geography. GeoJournal. 69:211-21. https://doi.org/10.1007/s10708-007-9111-y.

Jordan, G., & Shrestha, B. 2000. A participatory GIS for community forestry user groups in Nepal. Putting people before the technology. PLA Notes-International Institute for Environment and Development. 39:14-8.

Joyce, A., & Canessa, R. 2009. Spatial and temporal changes in access rights to shellfish resources in British Columbia. Coast Manage. 37(6):585-616. https://doi.org/10.1080/08920750903097517.

Kaul, V., & Thornton, T. F. 2014. Resilience and adaptation to extremes in a changing Himalayan environment. Reg Environ Change. 14(2):683-98. https://doi.org/10.1007/s10113-013-0526-3.

Kingston, R., Carver, S., Evans, A., & Turton, I. 2000. Web-based public participation geographical information systems: an aid to local environmental decision-making. Comput Environ Urban Syst. 24(2):109-25. https://doi.org/10.1016/S0198-9715(99)00049-6.

Levine, A.S., & Feinholz, C.L. 2015. Participatory GIS to inform coral reef ecosystem management: Mapping human coastal and ocean usies in Hawaii. Appl Geogr. 59:60-69. https://doi.org/10.1016/j.apgeog.2014.12.004.

Lieske, S.N., Martin, K., Grant, B., & Baldwin, C. 2015. Visualization methods for linking scientific and local knowledge of climate change impacts. In Geertman, S., Ferreira, J., Goodspeed, R., & Stillwell, J. (Eds.), Planning Support Systems and Smart Cities (pp. 373-89). Switzerland: Springer. https://doi.org/10.1007/978-3-319-18368-8_20.

Lubis, M.I., & Langston, J.D. 2015. Understanding landscape change using participatory mapping and geographic information systems: case study in North Sulawesi, Indonesia. Procedia Environ Sci. 24:206-14. https://doi.org/10.1016/j.proenv.2015.03.027.

MacEachren, A.M., & Brewer, I. 2004. Developing a conceptual framework for visually-enabled geocollaboration. Int J Geogr Inf Sci. 18(1):1-34. https://doi.org/10.1080/13658810310001596094.

McBride, B.B., Sanchez-Trigueros, F., Carver, S.J., Watson, A.E., Stumpff, L.M., Matt, R., … Borrie, W.T. 2017. Participatory geographic information systems as an organizational platform for the integration of traditional and scientific knowledge in contemporary fire and fuels management. J Forest. 115(1):43-50. https://doi.org/10.5849/jof.14-147.

Medema, W., Wals, A., & Adamowski, J. 2014. Multi-loop social learning for sustainable land and water governance: Towards a research agenda on the potential of virtual learning platforms. NJAS-Wagen J Life Sc. 69:23-38. https://doi.org/10.1016/j.njas.2014.03.003.

Messmore, T. 2013, February 20. Gathering around the weTable. Ocean Atmos Res. Available at: http://research.noaa.gov/InDepth/Features/CurrentFeature/TabId/728/ArtMID/1884/ArticleID/10032/Gathering-around-the-weTable.aspx. (accessed July 23, 2017).

Mikulencak, S., & Jacob, J. 2011. The weTable: A Tool for Participatory GIS–Setup and Configuration for Tabletop Planning at Public Workshops. TAMU-SG-11-108. Available at: http://tcwp.tamu.edu/files/2012/06/TheweTablefactsheet-1011.pdf. (accessed July 23, 2017).

Moser, S.C. 2010. Now more than ever: the need for more societally relevant research on vulnerability and adaptation to climate change. Appl Geogr. 30(4):464-74. https://doi.org/10.1016/j.apgeog.2009.09.003.

Nisbet, M.C. 2009. Communicating climate change: Why frames matter for public engagement. Environment: Science and Policy for Sustainable Development. 51(2):12-23. https://doi.org/10.3200/envt.51.2.12-23.

Pozzebon, M., Tello Rozas, S., & Delgado, N.A. 2015. Use and consequences of participatory GIS in a Mexican municipality: Applying a multilevel framework. RAE-Rev Admin Empres. 55(3):290-303. https://doi.org/10.1590/S0034-759020150305.

Preston, B.L., Yuen, E.J., & Westaway, R.M. 2011. Putting vulnerability to climate change on the map: A review of approaches, benefits, and risks. Sustain Sci. 6(2):177-202. https://doi.org/10.1007/s11625-011-0129-1.

Rambaldi, G., Kyem, P.A.K., McCall, M., & Weiner, D. 2006. Participatory spatial information management and communication in developing countries. EJISDC. 25(1):1-9. https://doi.org/10.1002/j.1681-4835.2006.tb00162.x.

Reed, M., Evely, A.C., Cundill, G., Fazey, I. R.A., Glass, J., Laing, A., … Raymond, C. 2010. What is social learning? Ecol Soc. 15(4):r1. https://doi.org/10.5751/ES-03564-1504r01.

Rowe, G., & Frewer, L.J. 2000. Public participation methods: a framework for evaluation. Sci Technol Hum Val. 5(1):3-29. https://doi.org/10.1177/016224390002500101.

Sletto, B., Muñoz, S., Strange, S.M., Donoso, R.E., & Thomen, M. 2010. El Rincón de los Olvidados: Participatory GIS, experiential learning and critical pedagogy in Santo Domingo, Dominican Republic. J Lat Am Geogr. 9(3):111-35. https://doi.org/10.1353/lag.2010.0022.

Steinhilber, E.E., Boswell, M., Considine, C., & Mast, L. 2016. Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project. (2016). Phase 2 Report: Recommendations, Accomplishments and Lessons Learned. Available at: https://digitalcommons.odu.edu/hripp_reports/2/. (accessed August 3, 2017).

Steinhilber, E.E., Whitelaw, J., & Considine, C. 2015. Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project. Phase 1 Report: Accomplishments and Lessons Learned. Available at: https://digitalcommons.odu.edu/hripp_reports/1/. (accessed August 3, 2017).

Stelzenmüller, V., Lee, J., South, A., Foden, J., & Rogers, S.I. 2013. Practical tools to support marine spatial planning: A review and some prototype tools. Mar Policy. 38:214-27. https://doi.org/10.1016/j.marpol.2012.05.038.

Torres, A.B., Acuña, L.A.S., & Vergara, J.M.C. 2014. Integrating CBM into land-use based mitigation actions implemented by local communities. Forests. 5:3295-326. https://doi.org/10.3390/f5123295.

Tschakert, P., Ricciardi, V., Smithwick, E., Machado, M., Ferring, D., Hausermann, H., … Bug, L. 2016. Situated knowledge of pathogenic landscapes in Ghana: Understanding the emergence of Buruli ulcer through qualitative analysis. Soc Sci Med. 150:160-71. https://doi.org/10.1016/j.socscimed.2015.12.005.

United Nations. 1992. United Nations Framework Convention on Climate Change. Available at: https://unfccc.int/resource/docs/convkp/conveng.pdf. (accessed May 10, 2017).

United Nations. 2014. United Nations E-Government Survey 2014: E-Government for the Future We Want. Available at: https://publicadministration.un.org/egovkb/Portals/egovkb/Documents/un/2014-Survey/E-Gov_Complete_Survey-2014.pdf. (accessed May 10, 2017).

Villagra, P., Rojas, C., Ohno, R., Xue, M., & Gómez, K. 2014. A GIS-base exploration of the relationships between open space systems and urban form for the adaptive capacity of cities after an earthquake: the cases of two Chilean cities. Appl Geogr. 48:64-78. https://doi.org/10.1016/j.apgeog.2014.01.010.

Whitmarsh, L., O'Neill, S., & Lorenzoni, I. 2013. Public engagement with climate change: what do we know, and where do we go from here? Int J MCP. 9(1):2-23. https://doi.org/10.1386/macp.9.1.7_1.

Young, J. C., & Gilmore, M. P. 2013. The spatial politics of affect and emotion in participatory GIS. Ann Assoc Am Geogr. 103(4):808-23. https://doi.org/10.1080/00045608.2012.707596.