Towards a Geospatial Household Natural Hazard Resilience Model in Rwanda

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***Abstract*— Household resilience to natural hazards is a critical issue facing society with the advent of climate change. In this work, we developed one of the first household natural hazard resilience geospatial models for Rwanda designed to understand household resilience at detailed spatial resolutions. We evaluated indicators within the model through empirical field work using an easy to deploy survey on Android tablets. To the best of our knowledge, the work presented here is innovative as it some of the first work to use geospatial technology-based surveys to conduct household-level natural disaster resilience surveys in Rwanda. Select results presented in this paper indicated that household vulnerabilities and subsequent resilience generally matched with existing district-level risk mapping of Rwanda. However, our work went beyond existing risk mapping to understand individual household perceptions of resilience. Respondents generally reported a mix of positive and negative drivers of household resilience. Security vis-à-vis natural disasters and economic situation was perceived as very insecure, healthcare and education were very secure, and utilities, food and water, and housing were generally perceived as insecure but not as insecure as economic situation and security to future disasters. There is much more that can be understood in terms of household resilience as it relates to many factors of household resiliency in our model including physical vulnerabilities, financial capacity, information access, technological capacity, and most importantly, resilience perceptions.**

Keywords—resilience, households, geospatial, Rwanda

I. Introduction

In this work, we present preliminary results on developing and evaluating one of the first geospatial model of household natural hazard resilience and select results of using the model to understand household natural hazard resilience in Rwanda at the sector-level based on empirical field data collected using geospatial technology. To the best of our knowledge, the work presented here is innovative as it some of the first work to use geospatial technology-based surveys to conduct household-level natural disaster resilience surveys in Rwanda and can guide other researchers interested in using geospatial technology for household disaster resilience and humanitarian purposes.

Worldwide, natural hazards such as earthquakes, floods, and landslides continue to be a threat to vulnerable populations. These issues are further compounded by the effects of climate change. Subsequently, there has been increased attention on developing resilience to natural hazards as evidenced in efforts such as the Sendai framework [1]. In particular, there has been an emphasis on how to model, measure, and index community and individual households resilience to natural hazards for policy and decision making (c.f. [2]) Geospatial technology key is to developing insight into resilience [3]. Rwanda is a developing country with a geopolitical history, physical geography, and hazard profile that make for a unique case study to understand household natural hazard resilience with geospatial technology.

A. Case Study: Rwanda

Rwanda is a small, low-income, landlocked country in East Africa. Particularly frequent disasters that occur in Rwanda include landslides due to mountainous terrain and floods. Household resiliency against natural hazards is a key issue for sustainable development in Rwanda - in particular for poverty reduction and economic development [4].

This work was supported by a grant from. the US National Science Foundation (NSF OISE-1854247).

II. A Geospatial Household Natural Hazard Resilience Model for Rwanda

Geospatial models, in the context of this work, are the idea of how real-world entities can be represented in a data structure such that the entity can then be quantified and visualized [5]. Risk modeling in general for Rwanda has primarily been focused at the province level [6]. Although an important and useful starting point for understanding resiliency, province-level mapping is simply too spatially coarse to provide insight into nuances that may occur in resiliency at household scales. Thus, a key contribution of the work we present here is filling gaps in understanding how natural hazard resiliency is manifested at the household scale. Fig. 1 is a graphical outline of a model of household natural hazard resilience for Rwanda that we developed for this work.

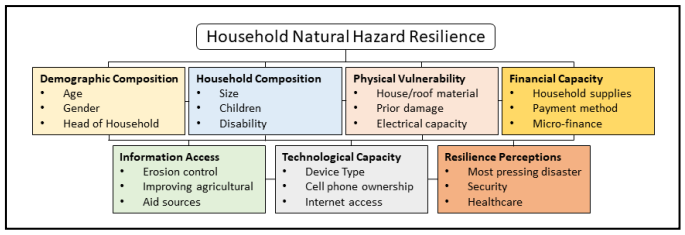

Fig. 1. Household Natural Hazard Resilience Model for Rwanda.

Demographic composition, household composition, information access, and technological capacity categories within the household natural hazard resilience model for Rwanda were derived from a variety of sources including natural hazard resilience indicators used in a variety of specific contexts (c.f. [2]). Rwanda-specific items, most notably physical vulnerabilities, were also based on existing models but adjusted for the Rwandan context given the prevalence of earthquakes, landslides, and floods in Rwanda. Financial capacity drew upon household indicators often used in developing country contexts such as access to banking systems and savings and were adjusted for the Rwandan context [7]. Perception of resilience by heads of household were also included to gauge how households personally view their overall resilience. Perception of risk included categories such as access to medical care and education [8] . Personal security refers to expectations an individual household has about impacts of future natural disasters [9] .

A. Evaluation – Technology and Field Research Context

The household natural hazard resilience model was used as the basis for developing a field survey to collect complex empirical data on household resiliencies in Rwanda. The survey questionnaire was developed using the XLSForm standard via Survey123 technology from Esri. The survey was loaded onto Android tablet computers which proved to be a very effective low-cost, no-to-low internet bandwidth option for collecting data on household resiliency in rural areas of Rwanda. Survey responses were collected via a mix in which native Kinyarwanda speakers would ask questions of respondents and a US-based researcher would record responses into the survey form (Fig 2).

52 survey questionnaires total were collected from all five of Rwanda's provinces in summer of 2022. Specific survey locations were selected based on areas of Rwanda with varying hazard profiles such as areas more prone to landscapes versus floods. In terms of societal and ethical implications of the technology used, all responses were anonymous. We made a point of including native Kinyarwanda speakers to collect survey responses to ensure understanding of Rwandan societal resilience was properly captured. By using the XLSFrom

Fig. 2. Field research context.

standard, our survey questionnaire is available for both open source (i.e., ODK Collect) or commercial survey tools for follow-up use and expansion.

III. Results

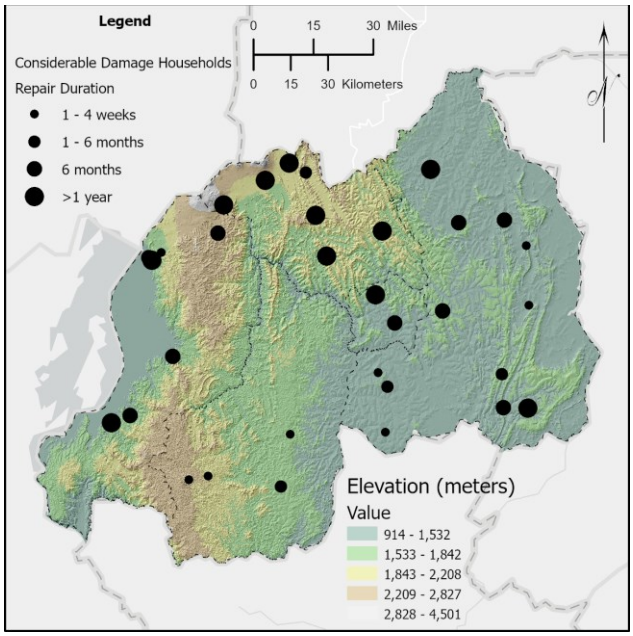

Fig. 3. Considerale household damage and repair duration.

It is beyond the scope of this paper to present all of the results that were collected. Thus, we present some select results that demonstrate the utility of the model and technology used for

characterizing household resilience and providence guidance for follow-up work.

A. Physical Vulnerability - Household Damage and Repair

As seen in Fig. 3, there a general regional pattern of households with considerable damage and time to repair in areas of high

slope and poverty when comparing our field research to the Rwandan National Risk Atlas (discussed further in section IV). 94% of the household survey reported some type of damage to their house due to natural disasters. 56% of the households indicated that damage occurs annually. 55% of respondents indicated that when damage did occur, it was considered 'considerable damage' in which over 30% of the household was damaged. Of these respondents, it is notable that household repair took mostly one week to six months although several respondents indicated that repairs took anywhere from six months to over a year and in some cases, houses were never repaired.

Fig. 4 graphically outlines all of the responses to the vulnerability perceptions questions.

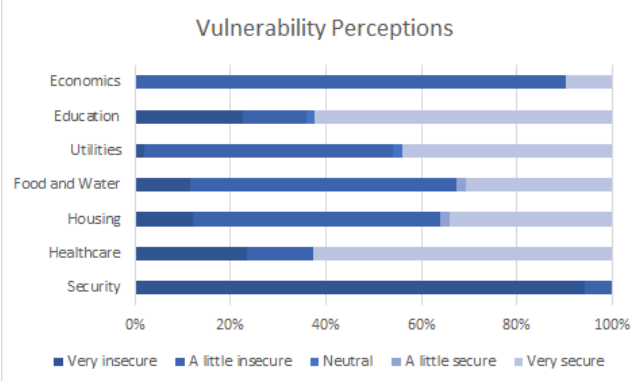

Fig. 4. Vulnerability perceptions summary.

Results of the vulnerability perception questions indicate a mix of positive and negative drivers of household resilience. In particular, survey respondents perceived their personal security to future disasters and economic situation of as very insecure. By contrast, education and healthcare were considered to be generally secure. Utilities, food and water, and housing were generally perceived as insecure, but not as strong a negative trend when compared with economic and personal security to future disasters.

IV. Discussion

Household damage and repair duration results from our household surveys generally matched with existing national province-level risk mapping from Rwanda. Figure 5 are slope (left) and poverty level (right) maps from the National Risk Atlas.

Note how areas of high slope are often where there where the highest levels of household damage as shown in Fig 3 – particularly in western and northern Rwanda. The categories of

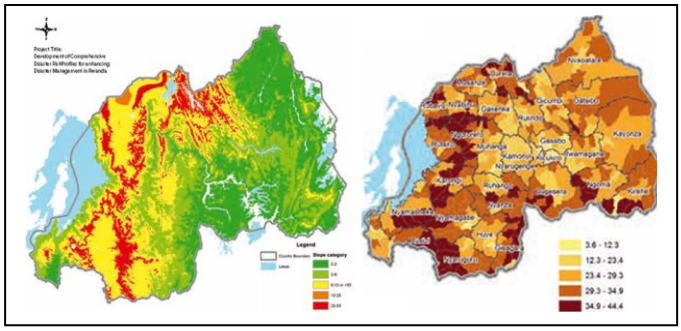

Fig. 5. Slope (left) and 'moderately poor' poverty maps from [6] .

'moderately poor' (one of four poverty categories that include severely poor, moderately poor, slightly poor, and non-poor) also generally corresponded with areas of high household damage and long recovery.

V. Future Work

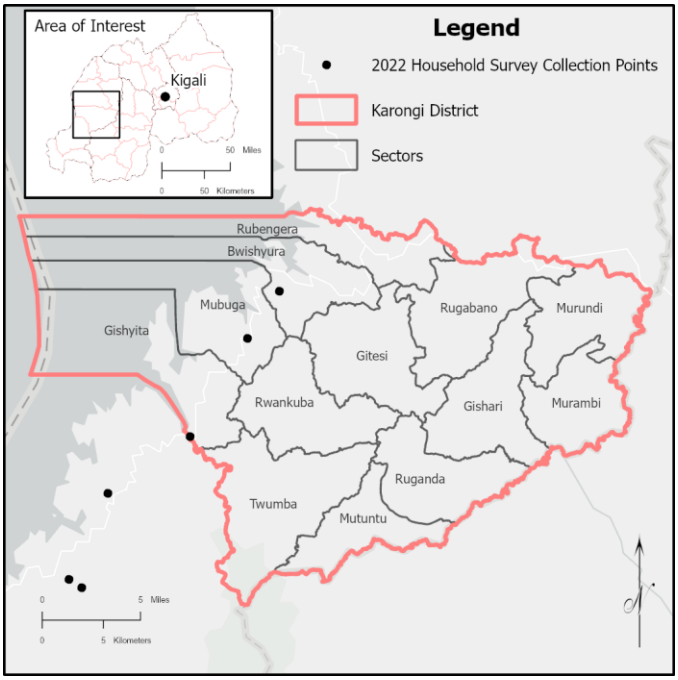

Fig. 6. Followup field researech – sector-level mapping of household resilience .

In the current work, we presented a conceptual model of household resilience and select results derived from indicators in the model derived from a geospatial technology survey. The next step in this work would be to use the model to create a geospatial index of household resilience at the sector level scale. Geospatial indexes are well established for measuring and quantifying household natural hazard resilience (c.f. [10]). Developing a geospatial index of household resilience at the sector level scale would start with a systematic survey of one particular sector to identify subtleties with household resilience that may not be apparent through courser district-level mapping (Fig 6).

For example, at the time of preparing this paper in Spring of 2023, Rwanda was undergoing some of the worst flooding in over a decade [11]. As seen in Fig. 6, which is showing the Karongi district where there was particularly destructive flooding in 2023, our 2022 survey was only able to gather data on two households within this district. Note in Fig 6. how there are numerous sectors within this district that were not surveyed but could provide an opportunity for gathering finer spatial resolution of resilience that could be used to create a geospatial index for decision making when situations like intense flooding in 2023 occur. Additionally, we plan to work with Rwandan officials to develop weights for indicators for developing index scoring methods. We also plan to include household access to information as a category in the model as communication and access to information is critical when disasters occur.

In general, our approach of using easy to use geospatial survey technology can also enable surveys of household resilience to be conducted by Rwandan citizens themselves, in particular as projects for secondary school students to enable citizen science and general use of humanitarian technology for sustainable development and societal resilience.

VI. Summary and Conclusions

Household resilience to natural hazards is a critical issue facing global society with the advent of climate change. In this work, we developed a household natural hazard resilience model for Rwanda and evaluated indicators within the model through empirical field work using an easy to deploy survey on Android tablets. Select results presented in this paper indicated that household vulnerabilities and subsequent resilience generally matched with existing district-level risk mapping of Rwanda. However, our work went beyond existing risk mapping to understand individual household perceptions of resilience.

Respondents generally reported a mix of positive and negative drivers of household resilience. Personal security to future disasters and economic situation were perceived as very insecure, healthcare and education were very secure, and utilities, food and water, and housing were generally perceived as insecure but not as insecure as economic situation and personal security to future disasters. There is much more that can be understood in terms of household resilience as it relates to many factors of household resiliency in our model including physical vulnerabilities, financial capacity, information access, technological capacity, and most importantly, resilience perceptions. Ideally, collection of further empirical data from Rwanda at the sector level will create a more nuanced picture of household resiliency leading to geospatial indexing of household resiliency that can inform decision making and ultimately save lives as directly witnessed in the 2023 floods that occurred in Rwanda.

Acknowledgment

We thank all of the anonymous participants who responded to the survey during our field work.

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