BUILDING COMMUNITY RESILIENCE THROUGH GEOSPATIAL INFORMATION DASHBOARDS

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Commission IV, WG IV/9

KEY WORDS: Resilience, Dashboards, Decision support systems, Big data, Community resilience.

ABSTRACT:

This article discusses a dashboard toolkit designed at the Knowledge Exchange for Resilience at the Arizona State University to integrate and analyze multi-agency data offering many ways of visualizing big data representable, contextualizable, and intelligible to a non-expert target audience. We outline a community-driven approach to identify pressing resiliency issues and deploy dashboard tools on targeted areas for significant community benefit. Our research builds on the offerings of data science to aid community-focused decision support systems to enable evidence-based and real-time decision-making. We hypothesize that building community resilience in response to emerging challenges requires a combination of timely data at the local scale and easy-to-use decision support tools. This research particularly focuses on augmenting the capacity of communities through dashboard technologies to comprehend rapidly evolving issues and address them in a timely and efficient manner. Our work contributes to a rapidly growing research domain around geospatial data visualization technologies that are increasingly playing a vital role in the shaping of government policies, including resiliency planning and disaster response. This study argues that dashboards that are action-oriented, easy-to-use, and locally embedded within the community have much more potential to be used as a decision-support system. The findings indicate that community-based knowledge networks catalyzed and influenced by modern technologies might provide a model to negotiate the gaps between ecosystem-based and social-science-focused conceptualization of community resilience.

1. INTRODUCTION

The concept of resilience is captivating governments, researchers, and the public more generally amidst growing concerns about climate change, natural disasters, and the widespread disruptions inflicted by the COVID-19 pandemic. The current challenges raise the question: how resilient our communities are to shocks and what can be done when existing social and policy adaptations are insufficient to deal with new kinds of global change? A range of literature exists on the resilience of ecosystems with their roots in the biophysical sciences (Chapin et al. 2009, Davidson 2010). The other set of resilience studies predominantly offers a social science perspective focusing on psychology and individual behavior (Norris et al. 2008, Brown and Westaway 2011), and a host of factors that allow communities to deal with adversity. The conceptual development of community-level resilience is relatively new and there is a need for productive common ground between these diverging strands of literature.
This study emphasizes the role of social learning (Wilson 2012) in converging and transforming individual and collective behavior and the existing human-ecological system ''to create untried beginnings from which to evolve a new way of living.'' Our hypothesis is that disasters may provide windows of opportunity to transform these systems and build new narratives that the enhancement of community-based knowledge networks will provide pathways to a stronger and more effective model of community resilience. Our research particularly focuses on augmenting the technological capacity of communities to comprehend rapidly evolving issues and address them in a timely and efficient manner.

Our research builds on the offerings of the ongoing revolution in data and analytics to aid community-focused decision support systems to enable evidence-based and real-time decision-making. This work is grounded in the fact that building community resilience in response to emerging challenges requires a combination of timely data at the local scale and easy-to-use decision support tools (Batty 2015). With the advancements in technology, organizations today are generating near-real-time feeds of data at a very high volume, velocity, veracity, and variety—technically referred to as 'big data' (Praharaj 2020). We examine, how digital data can be collected, processed, and disseminated through 'public dashboards' during the event of a disaster to enable local communities to gain critical knowledge, decipher complex evolving issues, and prepare responses to or avert the crisis.

Dashboards are software tools that allow data visualization through maps, graphs, diagrams, and indicators to present the most critical information needed to achieve one or more objectives, consolidated and arranged on a single screen or a webpage (Few, 2006; Rojas et al., 2020). Dashboards are dynamic visualizations because they are programmed to update as new data are released (Batty, 2015), helping the users track and compare over time and space to support real-time decision making. The COVID-19 pandemic triggered a deluge of data dashboards that visualize cases of infection and fatalities over time and space. These dashboards emphasize the importance of real-time data and the effectiveness of geospatial technologies in understanding and tackling disasters. However, with all the COVID-19 data, graphs, and maps available to the decision-makers, the pandemic response has been chaotic, inconsistent, and in places disastrous, implying that the mass visualization from authorities does not necessarily lead to better community outcomes (Budd, 2020). For reasons, researchers highlight the complexity of navigating visualization and widgets in the elitist government-provided dashboards and the lack of user focus and

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engagement with such tools (Mattern, 2015). Some indicate dashboards as a general instrument to convey a range of information (e.g., London City Dashboard) rather than a tool that focuses on a single aspect leading to tangible solutions. Emerging literature also suggests dashboards often fail to engage with local issues as they provide high-level executive data (Pettit et al. 2017), which does not allow communities to examine granular level issues, often termed the "scale problem".

This article sheds light on a dashboard toolkit designed at the ASU Knowledge Exchange for Resilience to integrate and analyze multi-agency data offering many ways of visualizing a variety of data representable, contextualizable, and intelligible to a non-expert target audience. Drawing on the lessons learned from the critical literature, we outline a community-driven approach to identify pressing resiliency issues and deploy our dashboard tool on targeted areas for maximum community benefit. For example, we deployed the Arizona Economic Resilience dashboard (Praharaj et al. 2020a) during the COVID-19 pandemic providing daily and weekly updated data and visualization to help communities understand and respond to the disruptions caused in the economic processes and household living conditions in the counties, cities, and neighborhoods of Arizona. Using the same toolkit, we built the Mobility Disruptions Tracking Dashboard (Praharaj et al. 2020b) providing communities unique insights into how the people were moving differently in the wake of the pandemic, due to stay-at-home policies, work stoppages, and social distancing observances. Such dashboards are useful in influencing human behavior and adjusting government policies, all of which lead to community resilience. Recently, we unveiled a Poverty tracking data Dashboard (Praharaj et al. 2021) developed in collaboration with a community-based organization. The tool delving into neighborhood-level data highlights the communities at risk from a future economic collapse. In the following sections, we outline the methodology of such dashboard development, some snapshots of these mission-critical dashboards, and we share key lessons for dashboard designers for building effective data-driven decision-support systems.

2. METHODS AND APPROACH

Building on various approaches discussed in dashboard literature (Batty, 2015; McArdle and Kitchin, 2016; Pettit et al., 2017), we first identify appropriate indicators and datasets for developing our dashboards. We conceptualize our dashboards around a vital issue facing the local community that can provide critical data and visualization to help communities understand and respond to the disruptions caused in the social and economic processes and household characteristics in the counties, and metropolitan statistical areas (MSA's), and cities. Knowing from previous dashboard studies (Praharaj, 2020) that higher-level aggregated data is less compelling and actionable, our goal was to provide granular data to assist local stakeholders in identifying key issues and solutions. As Pettit (2017) argues, integrating micro-level real-time data can assist executives and citizens in responding to disruptions in a timely and efficient manner. Addressing the gaps identified from previous dashboard literature, we provide time-series information and data segregation options to allow users to drill into and explore the history of data metrics, a feature that McArdle and Kitchin (2016) found missing in most of the at-a-glance dashboards. Our dashboarding approach provides a multiple-view scrolling webpage dashboard allowing more space to describe the contextual information behind the data and we offer layouts to order visualizations in clearly defined sections that improve users' understanding and navigability. We also offer data segregation by population sub-groups (e.g., race, ethnicity, and education) that enlighten users about the unequal effects of disasters and pandemics. To address the known gaps from the dashboard review, we emphasize the socially embedded data indicators that help communities visualize the interaction between economic changes and social and human impacts.

We have developed a four-layer architecture (see Figure 1) seamlessly connected to produce the dashboard visual analytics interface. The first, database layers act as an edge-level device, providing secure data feeds. We access these databases through an open API from the data publishers. We adopt an open-source framework to harvest the data in our cloud data storage platform where all datasets are stored. The datasets are brought into this platform through a web data connector using SQL, forming the second layer of AERD architecture. The data storage hub is built using the GeoNode framework—an open-source and web-based application for developing geospatial information systems and deploying spatial data visualization systems (Open Source Geospatial Foundation, 2020). We integrated the disparate datasets hosted at the cloud data storage platform through layer joining and blending techniques in R to draw correlations and dependencies between indicators to support user-provided data queries and advanced analysis.

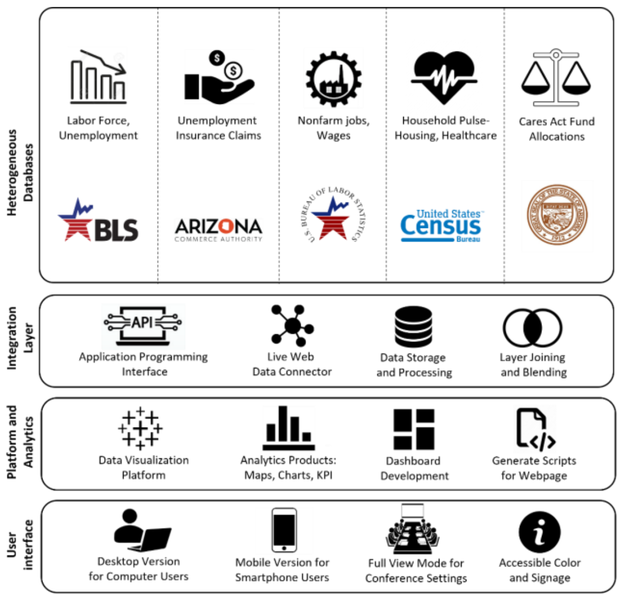

Figure 1. Technical architecture for Dashboard development

The platform and analytics layer provided the base for creating various maps, charts, widgets, and navigation menus assembled into the dashboard (see Figure 2). We publish the dashboards to a server to generate JavaScript codes for deploying the dashboard visualizations to a web page. We embed these codes into the Drupal operating system (a free and open-source web content management framework) to construct the user interface, which is then made public through the website environment at https://resilience.asu.edu/dashboards-and-tools. The user interface (fourth layer) is a scrolling web page, which provides the output view to navigate different metrics and retrieve data and visualization on demand. We have optimized the dashboard for the visualization to automatically adjust on both computer/laptop and mobile devices. The interface simultaneously allows users to enter full-screen view mode for each section and indicators for deeper dives into the data. Keeping the accessibility of the users in mind, we used the Web Design System recommended color scales available at https://designsystem.digital.gov/ and provided info icons showing definitions and explanations of keywords or technical phrases used in the dashboard.

3. RESULTS AND DASHBOARD SNAPSHOTS

We present an overview of the different modules, sections, and infographics of the dashboard tools in Figures 2-4. The dashboards support communities, planners, non-profit responding organizations, and policymakers to explore and query data to formulate questions and examine responses. They can evaluate issues like the monthly change in the unemployment rate in a County, or which sector experienced the most job loss in the last quarter? The graphical user interface adheres to the Model-View-Controller (MVC)—a three-part design pattern (Jing et al., 2019), dependent and connected, that allows the controller to receive handler inputs. It manages and sends a query to the model, which contains the data and the rules for carrying out a specific task. The interface provides users with a set view highlighting the most important trends, and detailed information can be visualized through drill-down buttons, navigation panels, map-based selection and filtering, and timeline sliders placed in strategic locations across the interface. The dashboard tool gives users the capabilities to perform historical data analysis for counties, metropolitan statistical areas, and city levels. The dashboards are hierarchically organized in different modules to enable a connected dashboard environment to be navigated across indicators from summary-to-detail exploration within a single system. The interface ultimately addresses the characteristics of exploratory dashboards (McArdle and Kitchin, 2016).

Figure 3 provides the overview of the "Economic Resilience Dashboard" (Praharaj et al. 2020a), which links the economic trends with demographic information (e.g., race, ethnicity, and education) to examine equity issues around the COVID-19 impact on communities (Praharaj and Han, 2022). The tool integrates dynamic data from diverse sources, including the U.S. Bureau of Labor Statistics, Arizona Commerce Authority, U.S. Census Bureau, Department of Treasury, and Office of the Arizona Governor, to provide a comprehensive analysis of the unfolding economic scenarios and associated social dynamics. The best practice design approach to information dashboard design (Few, 2006) is used to integrate a range of charts, maps, and big number KPI to communicate and visualize the data. Line charts in our dashboard analyze indicators with historical time-series information. Donut charts visually capture proportional data such as the share of unemployment insurance claims by different racial/ethnic groups. The butterfly charts were presented to capture two-dimensional data (sector-wise total nonfarm employment and annual change in jobs generated by these sectors) and bar charts visualize categorical and continuous datasets (e.g., unemployment rate by cities). The dashboard also has KPI text indicators to highlight key facts and outliers, such as which county shows the positive changes in unemployment in the last month or the quarterly change in the wages across regions. We follow the approach of geospatial BI dashboards (Badard and Dubé, 2009) to integrate spatial querying and filtering tools in our dashboard. The map area selection commands enable users to select different geographic units. The dashboard is organized in coherent sections: the first section of the dashboard presents the monthly unemployment rate, the second shows data on weekly unemployment insurance claims, followed by a section highlighting monthly changes in employment by industry, and weekly average hours and wages/earnings of workers on the payroll, with the last two sections exploring the linkage and impact of the COVID-19 pandemic with the socioeconomic profile of communities.

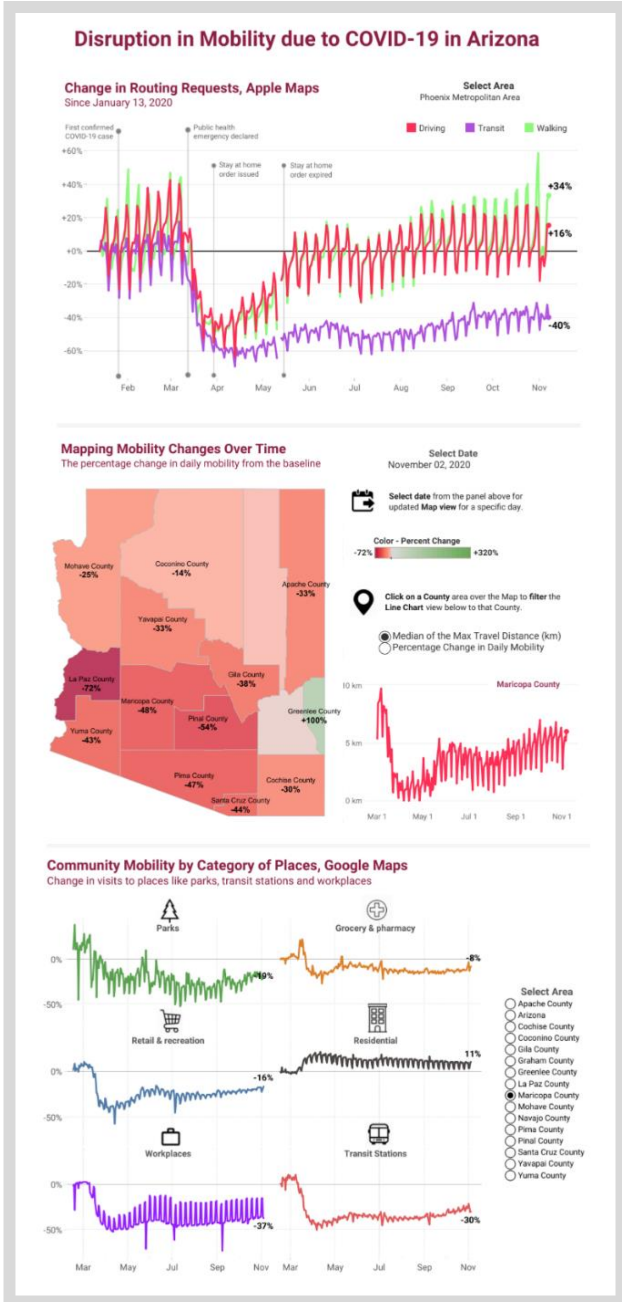

Figure 2. A screenshot of the Mobility Tracking Dashboard.

Figure 2 provides a snapshot of the "Mobility Tracking Dashboard" (Praharaj et al. 2020b), which aims to measure how travel behavior was impacted in the wake of the COPVID-19 pandemic, due to stay-at-home policies, work stoppages, and social distancing observances designed to slow the spread of COVID-19. This dashboard brings together aggregated and anonymized mobility data from discrete sources and visualized those through charts and maps for exploration at different geographies and spatial scales. Following our template, we aligned the dashboard in three sections.

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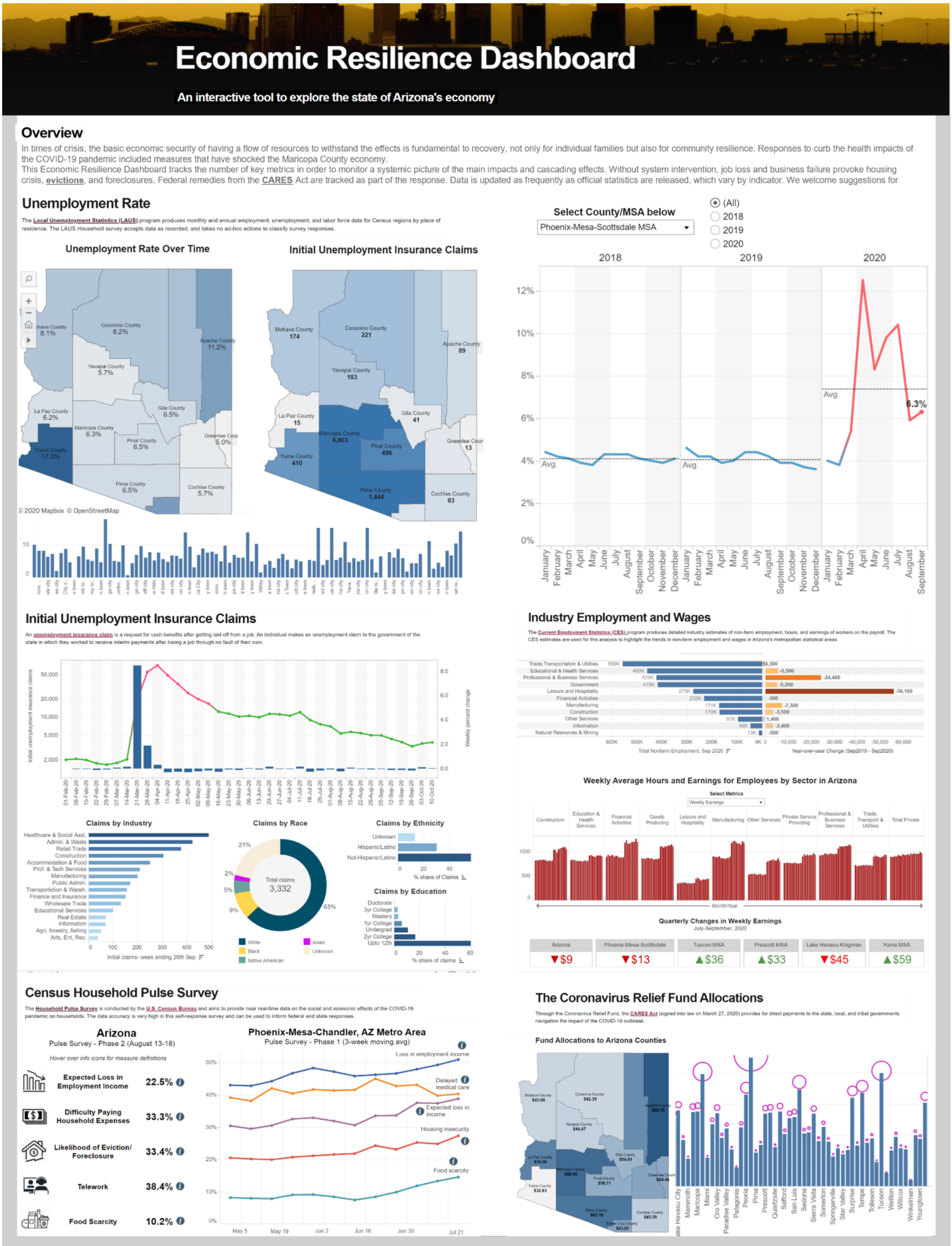

Figure 3. A screenshot of the Economic Resilience Dashboard (Source: https://resilience.asu.edu/economic-resilience-dashboard)

The first section plots mobility trends data from Apple showing a relative volume of directions requests per County and Metropolitan areas in Arizona compared to a baseline volume on January 13th, 2020. The second part of the dashboard provides maps and charts using data released by Descartes Labs, showing the percent change in mobility from a baseline and changes in daily maximum travel distance (km) of a sample population within each County. The last section of the mobility dashboard leverage data from Google Community Mobility Reports showing how visits to (or time spent in) categorized places like parks, workplaces, retail locations, transit stations, and residential areas changed compared to baseline days. These trends in mobility over time and by geography offer insights into how people changed travel behavior due to the pandemic and the impacts of social distancing policies in various jurisdictions and communities.

Figure 4 presents the outline of "HEIGHT Poverty Dashboard" (Praharaj et al. 2021), which explores the gap between household expenses and income in Counties and neighborhood micro areas in Arizona. The dashboard tool measures and visualizes the true costs of living at the county and neighborhood level, highlighting the emerging gap between household income and living costs. The tool builds a living cost budget for various family sizes accounting for the costs of food, housing, health care, childcare, transportation, taxes, and other essential needs. Analyzing those local costs of living with the household's income data, the tool determines how many families are struggling to meet basic living costs. This dashboard emphasizes poverty in families with different

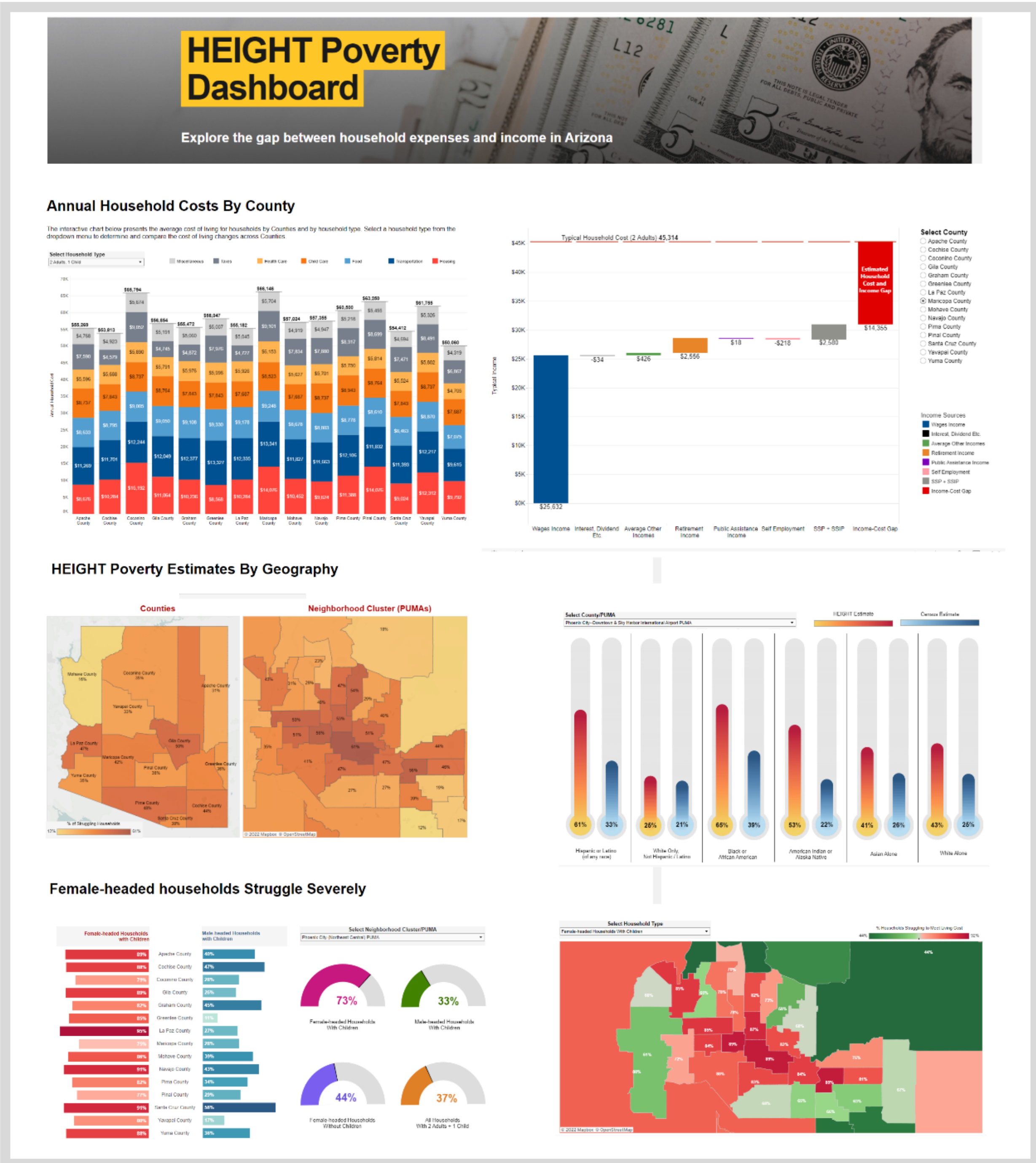

Figure 4. Overview of the HEIGHT Poverty Dashboard (Source: https://resilience.asu.edu/HEIGHT-poverty-dashboard) .

characteristics — whether the household includes children, whether the head of household is male or female, the number of adults in the household, and the ethnicity of householders — to enable communities to design interventions targeted to their specific needs. The interactive chart in the first section of the HEIGHT dashboard presents the average cost of living for households by Counties and neighborhoods across various household types. The following section breaks down the household income by sources and highlights the difference between the typical household cost and families' total income. Next, the dashboard provides maps and charts to illustrate the percentage of households struggling to meet the average living cost to provide a spatial understanding of poverty inequity. The dashboard also offers a novel understanding of the poverty scenario by race and ethnicity by analyzing the annual household costs with the annual income by Race/Ethnicity data provided through the American Community Survey (2014-2019). The final section of the dashboard explores the gender dimension of poverty by focusing on male-headed and female-headed families where no spouse is present. The results highlight that single women-headed families are at severe risk of poverty. The economic distress further increases for women-headed families with the presence of children. Such data dashboards have the potential to act as a decision support system for policymakers and non-profits working to better understand and address poverty at various levels.

4. DISCUSSION AND WAY FORWARD

This research bridges existing knowledge gaps on resilience dashboards in two dimensions. In terms of data provision over existing dashboards, there is a lack of granular information at the local level, missing data by population sub-groups, and severe inadequacy in reporting social and economic indicators (Budd, 2020). From the perspective of user-interface design, previous literature (Fareed et al., 2021; Lan et al., 2021) pointed to the challenges of single-screen dashboard layout adopted by many projects, limited focus on data download and metadata provision, and a general disregard for providing explanatory narratives to describe the background, source, and purpose of the data. Building on these gaps, we illustrate a technical architecture for building community-situated dashboards, implemented through the Economic Resilience Dashboard, Mobility Tracking Dashboard, and HEIGHT Poverty Dashboard. We demonstrated the fit-for-purpose dashboard model (Dong et al., 2020; McArdle and Kitchin, 2016) that provides localized data, drill down-down options, visualization narratives, open access to data, and accessible features on the interface to facilitate two-way information exchange. We emphasized and exhibited the value of linking pandemic-related information with socio-economic data to illustrate how intervention policies affect the spread of disasters and vice versa, a feature generally lacking on the existing COVID-19 dashboards (Fareed et al., 2021; Ivanković et al., 2021). The tools we have discussed and introduced here are synergetic to the broader agenda of 'dashboard governance' (Few, 2006) where data sharing and visualization interface play a vital role in everyday decision-making, acting as a channel of communication between the decision-makers and the community. The application we provide can easily be replicated for other regions across the world, as we consistently use open sources source technologies and data.

These dashboard solutions designed around specific local issues help in shaping conversations and knowledge exchange that are critical for social learning and transforming social-ecological systems as emphasized in our hypothesis. We define these solutions as "Resilience Dashboards" as the data and visualization used by the community support both 'instantaneous resilience' (ability to limit the magnitude of immediate loss during/before an event) and 'dynamic resilience' (policy-induced ability to reconstruct and recover). Our work contributes to a rapidly growing research domain around geospatial data visualization technologies that are increasingly playing a vital role in the shaping of government policies, including resiliency planning and disaster response. Our experience suggests that dashboards that are action-oriented, easy-to-use, and locally embedded within the community have much more potential to be used as a decision-support system. The findings indicate that community-based knowledge networks catalyzed and influenced by modern technologies might provide a model to negotiate the gaps between ecosystem-based and social-science-focused conceptualization of community resilience.

While dashboards are critical for building resilience, we must also be cognizant that data communicated over dashboards are not always neutral and value-free, neither independent of external influence and always treated and engineered before sharing (Batty, 2015; Kitchin et al., 2015; Mattern, 2015). Dashboards hide data as much as they reveal critical information. For example. there is a severe gap in reporting social, behavioral, and economic impacts, and interdependencies with the COVID-19 dashboards (Lan et al., 2021). We argue that without estimating and sharing data about meaningful population subgroups, communities are at risk of not being educated about these issues. A reversal of these trends from politically correct data reporting policies to user-need-driven information-sharing mechanisms is essential. The provision of segregated local data and data breakdown options over public dashboards offer novel opportunities for exploring interrelations between public health, social, and economic trends (e.g., economy and unemployment, behavioral responses to government policies, and equitable recovery). These findings together suggest a clear pathway forward for researchers, policymakers, and community organizations to incorporate more action-oriented data and easy-to-use interfaces as they refine existing and develop new information systems and data analytics dashboards. Such projects may generate an exciting collection of informed community development strategies on a systematic comparative basis.

ACKNOWLEDGEMENT

This study reports dashboard activities that are developed at the ASU Knowledge Exchange for Resilience (KER), which is supported by Virginia G. Piper Charitable Trust. Piper Trust supports organizations that enrich health, well-being, and opportunity for the people of Maricopa County, Arizona.

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