Arizona Resilience Assessment

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Table of Contents

Pandemic Recovery & Resiliency Plan 3
The Federal Emergency Management Agency (FEMA) Community Resilience Indicator (CRI) Analysis 4

Methods 5

Indicators Included in the Az CRI 6
Map of Arizona's Population by Census Tract 8

Results 12

Az CRI Indicators Pearson Correlation Matrix 12
Spatial Auto-correlation analysis 15

Future Development 15

Recommendations 17

Resilience Equation 18

References 21

Appendix A: Maps of the Arizona Community Resilience Indicators 23

Acronyms 37

Resilience has received considerable attention as a guiding construct for individuals and communities to demonstrate a valuable ability to overcome adversity in the face of unwanted events. The construct of resilience has been adopted by professionals in public health, emergency management, and academia to promote community-level actions to overcome events with negative consequences as a collective social action in an effort to return to a state of normalcy, safety, and well-being. The use of the word “resilience” now goes beyond "response" to a pandemic or any other kind of threat, by understanding holistically how we can transform our society when facing unprecedented threats. The Arizona Department of Health Services (ADHS) has identified “Pandemic Recovery and Resiliency” (PR&R) as one of the Priorities in the 2021-2025 Arizona Health Improvement Plan (AzHIP).

Pandemic Recovery & Resiliency Plan

Peter Drucker famously stated[1] “What gets measured gets improved.” As such, the Arizona State University (ASU) Knowledge Exchange for Resilience (KER), the Knowledge Enterprise (KE), and the ASU Data Science and Analytics Alliance (DSAA) have initiated a program to measure the resilience of communities and individuals within Arizona. This assessment will consist of a baseline Arizona Community Resilience Indicators (Az CRI) Assessment that is based on the current national standards and guidance from the Federal Emergency Management Agency (FEMA) Community Resilience Indicators (CRI) program[2]. The Az CRI Assessment will apply an Arizona-specific lens to the FEMA CRI assessment methodology including local knowledge and experiences.

The Az CRI is a foundational component of the 2021-2025 AzHIP and PR&R Priority area. It will serve as a data-informed platform to promote a shared understanding of federal programs that use resilience as a barometer of local programs. Health officials in Arizona will be able to evaluate state-level performance against national benchmarks, and simultaneously advance efforts to differentiate Arizona’s unique communities, cultures, and resources. Utilizing the Az CRI, ASU will outline recommendations to increase Arizona’s resilience and improve future pandemic recovery efforts.

Subsequently, the AzHIP, PR&R Assessments Team will continue to advance this initiative to implement an Arizona Resilience Assessment (Az RA) program that is tailored to the specific nuances of health resilience in Arizona that often deviate from national trends. For example, hurricanes and earthquakes in Arizona are less frequent

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[1] Peter Drucker is a widely cited management consultant. https://www.google.com/url?q=https://link.springer.com/chapter/10.1057/9781137375469_7%23citeas&sa=D&source=docs&ust=1674758815460128&usg=AOvVaw1l4zTIHrDKMuvUHs4o4lcl

[2]https://www.fema.gov/sites/default/files/documents/fema_2022-community-resilience-indicator-analysis.pdf

than heat waves and flash floods, both locally and regionally. Pandemics, climate change, and other global events continue to remain concerning, even with highly resilient communities, although the impacts will differ from state to state. It is imperative that Arizona take steps to promote resilience against the greatest risks and threats to our state, and use our unique cultural heritage to include all communities.

Our intent is to provide an evidence-based, data-informed assessment methodology that offers a stable foundation to improve health outcomes for all Arizonans. This assessment can be used to inform future ADHS investments in programs towards quantifiable improvements in resilience and health while including our diverse populations equitably.

The Federal Emergency Management Agency (FEMA) Community Resilience Indicator (CRI) Analysis

The first step in conducting this resilience assessment, appropriate to inform and assess the AzHIP initiative, was a review of extant academic literature and similar assessments. We reviewed over 20 assessments for their definition of resilience, analytic framework, and metrics to identify appropriate representations for resilience (specifically health resilience) in Arizona. We wanted to balance competing priorities for (i) a resilience assessment tool appropriate for public health and associated stakeholder groups, (ii) consistency with similar assessments in emergency management and public health, and (iii) robust scientific definitions, validity, and repeatability.

The FEMA Community Resilience Indicator Analysis met all three criteria and was selected as a baseline instrument for current and future work. First, it has been under development for several years by scientists at Argonne National Laboratory (Argonne) with support from the US Government and has been broadly socialized within public health and emergency management communities at state and local levels. It also includes data from tribal nations, when available, through the US Census and other sources. Second, as part of the FEMA-supported initiative, Argonne conducted an exhaustive review of individual indicators used in prior assessments to harmonize them into a single framework resulting in 22 indicators used commonly among 14 different methodologies. Thirdly, the FEMA CRI conducted a thorough review of academic resilience studies including geographic scale, statistical binning, and rationale for inclusion. The FEMA CRI provided a well-documented, repeatable assessment framework to serve as the basis of the Az CRI.

FEMA (2017) defines resilience as “the capacity of individuals, communities, businesses, institutions, and governments to adapt to changing conditions and to prepare for, withstand, and rapidly recover from disruptions to everyday life, such as hazard events" (p.1). The 2022 FEMA CRI Analysis proposes indicators of community resilience at various geospatial levels and provides the Az CRI with a baseline resilience assessment that is consistent with national programs (Federal Emergency Management Agency, 2022). FEMA also provides an online mapping tool, the Resilience Analysis and Planning Tool[3] (RAPT) that allows users to conduct online mapping of indicators at the county and census tract level.

Local knowledge is always required to appropriately inform risk-based management approaches to environmental, political, technological, and sociological stressors[4]. In part, this is because local priorities are informed by local knowledge of places including infrastructure (both community and physical), local governance, socio-economic conditions, and recent events. Although the FEMA Community Resilience Indicator Analysis is a valuable tool used to understand differences between communities' resilience to shock, it does not predict how communities will recover from specific hazards or adapt to changing conditions.

Arizona-specific indicators will be required to capture the unique sociocultural and geopolitical features of Arizona's resilience posture. An investigation of Arizona's resilience, using similar methodologies and data sources as the FEMA CRI Analysis (the Az CRI), is outlined in this document as a baseline to begin a robust, ongoing effort (the Az RA) with the PR&R Priority Area of the AzHIP.

Methods

Review and selection of indicators: We conducted a review of recent resilience literature and assessments to inform our approach and choice of indicators for an Arizona-specific resilience assessment. We selected the FEMA CRI as the baseline due to its widespread use in federal and state, local, territorial, and tribal (SLTT) settings. The FEMA CRI also contains a thorough literature review of published, peer-reviewed research from 2003-2021 and a review of indicators used in 5 or more of 14 related studies. We chose to begin by replicating, as closely as possible, the FEMA methodology at the census tract level (rather than the county level due to the large size and heterogeneity of Arizona's counties). We also chose to rebuild the Az CRI in a newly created geographic information system (GIS) to explore additional indicators, refresh data in the future, and conduct statistical analysis not possible in the FEMA RAPT system.

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[3] https://www.fema.gov/emergency-managers/practitioners/resilience-analysis-and-planning-tool
[4] https://www.sciencedirect.com/science/article/pii/S2212096314000254

Of the 22 indicators the FEMA CRI includes, 15 are retained for the Az CRI. These include percent of households with limited English proficiency, median household income (USD/year), medical professional capacity, percent houses that are mobile homes, percentage of the population below the federal poverty line, percent of adults without a high school diploma or GED, percent of households without a vehicle, percent of owner-occupied households, the percent population age 65 and older, percent population with a disability, percent households with a single-parent, percent of the labor force that is unemployed, percent of unemployed women labor force and the GINI Index of income distribution, and percent population without health insurance. Data for the other nine indicators were available only at the county level, but not at the census tract level.

Data collection: All data were collected from the US Census American Community Survey[5] (ACS). See Table 1 for a summary of the indicators used in the Az CRI. We anticipate this list will evolve over time.

Table 1

Indicators Included in the Az CRI

Indicator
% of unemployed women in labor force
GINI Index of income distribution
% of households with limited English
Median household income (USD/year)
Medical Professional Capacity
% Housing that are mobile homes
% of population below federal poverty line
% of adults without a high school diploma or GED
% Households without a vehicle
% Households that are owner-occupied
% Population age 65 and older
% Population with a disability

[5] http://census.data.gov

% Households with a single-parent
% Population of the labor force that are unemployed
% Population uninsured

ACS data were manipulated by standard data science routines to extract, transform, and load (ETL) records into formats convenient for curation, analysis, and mapping. We used Microsoft Excel and custom scripts to select the specific FEMA CRI indicators and transform them into a single flat file. Tract-level data was imported into a postgres[6] database with PostGIS[7], a spatial database extender, on an ASU-hosted virtual machine. Tract geographies were obtained from the US Census tiger-line files program and joined with ACS datasets using SQL. Data verification and management are handled using pgAdmin4[8]. Maps were created for each of the 13 census-tract level indicators using qGIS[9]. All applications except for Microsoft Excel are open-source. No PII was collected or used.

Mapping and visualization: In the FEMA Community Resilience Indicator Analysis: 2022 Update[10], authors from Argonne state "Because there is no validated method for weighting resilience indicators [into an index], the research team did not weight individual indicators in developing the FEMA CRI." In general, there are no validated methods for weighting any type of indicators into a single, numeric index unless they are explicitly created/selected to have such a meaning. The ACS was created to provide broad demographic and economic characteristics across the US, not to assess community-level outcomes from hazardous events! In non-technical terms, this means that a single, numeric index will be a unitless, dimensionless metric without definition (except the weighted sum of other indicators). The one use they have is the comparative evaluation of multiple criteria simultaneously. (In this case, the definition of the index is the same as the formula for the index). We do not compute an index as part of the Az CRI Assessment for this reason. Instead, we favor a detailed visual inspection of each of the map indicator layers to discern patterns and observations that are necessary to interpret the data holistically.

After the careful examination of collected data in a mapping software, the best binning method was applied that provided the clearest and easy-to-grasp visualization of the geographic distribution of data ranges specific to Arizona. Each variable was binned

[6] https://www.postgresql.org
[7] https://postgis.net
[8] https://www.pgadmin.org
[9] https://www.qgis.org/en/site/
[10]https://www.fema.gov/sites/default/files/documents/fema_community-resilience-indicator-analysis_2022.pdf

into four bins using the Natural Jenks classification method followed by slight rounding up or down of values for each color band to maximize the variance between bins and improve map readability.

Figure 1

Map of Arizona's Population by Census Tract

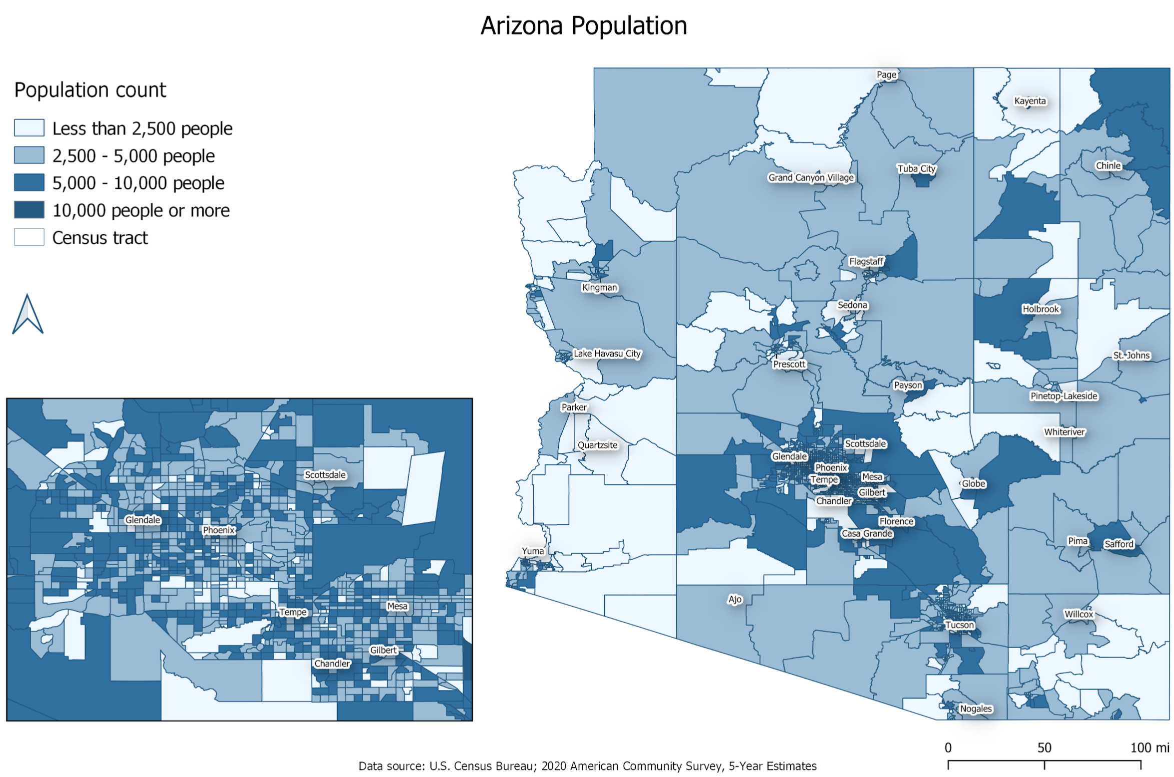

Figure 1 shows Arizona's population by census tract. Census tracts are defined by the Census Bureau as relatively permanent statistical subdivisions with a population size generally (but not necessarily) between 1,200 and 8,000 people, with an optimum size of 4,000 people.[11] Visual inspection of the map leads to many observations that are useful, but not holistic. For example: small tracts in central Maricopa county with greater than 10,000 people are the highest-density urban areas in the state. Large tracts with less than 2,500 people are low-density, and likely rural areas. However, it is not easy to compare tracts between 2,500 and 10,000 people in tracts that are varied in size. Nonetheless, the Phoenix metropolitan area, Tucson, and Flagstaff all appear as heavily populated areas. Yuma, Navajo Nation, and outlying cities also appear as

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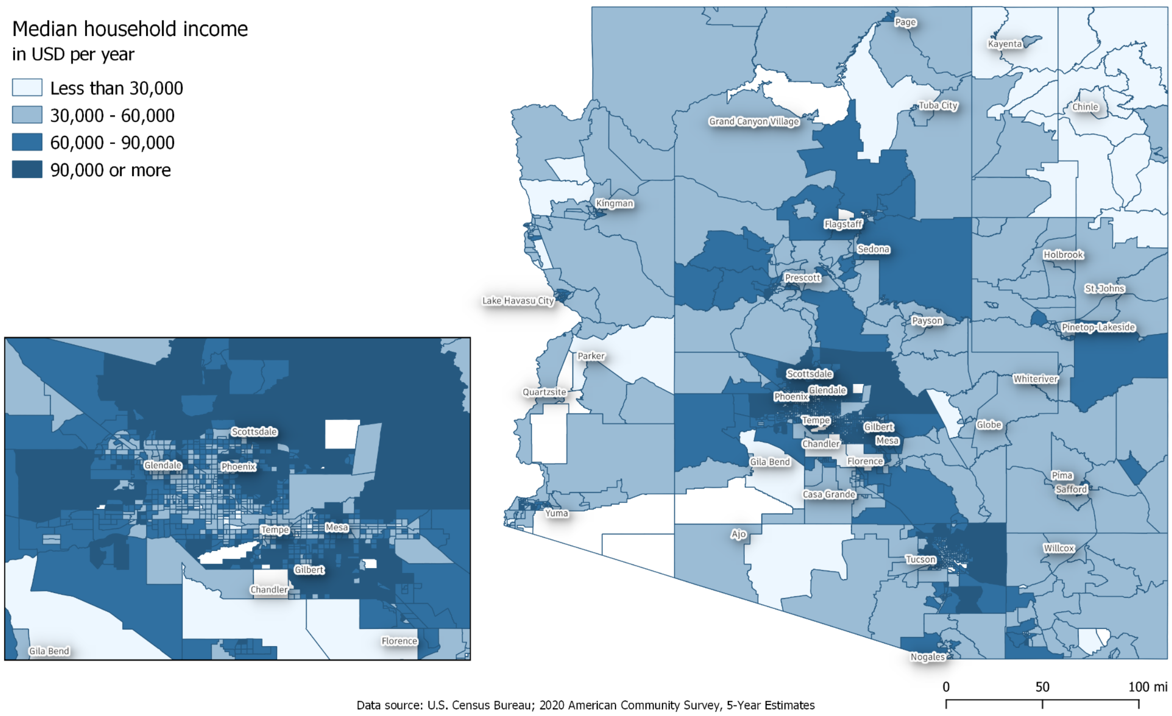
[11] https://www.census.gov/programs-surveys/geography/about/glossary.html#par_textimage_13

population centers. Census tract population is used as the denominator for many of the ACS indicators, so it is important to include a map for visual pattern recognition and understanding.

In contrast, income - or more precisely median household income (fig. 2) - has a different spatial distribution that is important to include. Arizona has a highly heterogeneous income distribution. Higher-income households tend to cluster around urban centers, but there are many high-density population centers with low income. There are also many high-income areas in rural areas. Local knowledge and deeper investigation into the correlates of geographic data are necessary to derive meaning from these maps. Social determinants of health researchers have amassed significant data that income and, more broadly, socioeconomic status, are highly determinative of health outcomes, but other correlates including employment status, race, ethnicity, and access to resources are significant - especially when programs and services are in need for tailored populations.

Figure 2

Map of Arizona Median Household Income Distribution by Census Tract



Appendix A has a complete catalog of the Az CRI indicators. Visual analysis is an important and useful tool to search for trends and overlapping patterns that lend to narrative form and local knowledge to understand nuanced interpretations of how resilient and connected communities can be.

Statistical techniques are also available to identify visual patterns methodically or to identify patterns that are not readily apparent. Indicator matrix correlation is used in the Az CRI (see following section) to measure the statistical similarity between the two metrics. For example, census tracts with a high percentage of people below the poverty level are highly correlated with census tracts that have a high percentage of people without a high school or degree or equivalent. While neither of these indicators alone indicate higher or lower resilience to a hazard event, using correlation analysis to identify the characteristics of unique communities improves our ability to find solutions to increase resilience.

Correlation Analysis: A correlation analysis is conducted to measure the strength and direction of the indicators utilized in the Az CRI. Pearson's Correlation is used as the statistical method for this correlation analysis[12]. The correlation coefficient ranges from a value of -1 to +1. A correlation coefficient of -1 represents a strong negative correlation, zero represents no correlation, and +1 represents a strong positive correlation. RStudio is used to conduct the Pearson correlation analysis, produce a correlation matrix, and present correlation coefficients in table format. The correlation matrix and table can be found in the Results section.

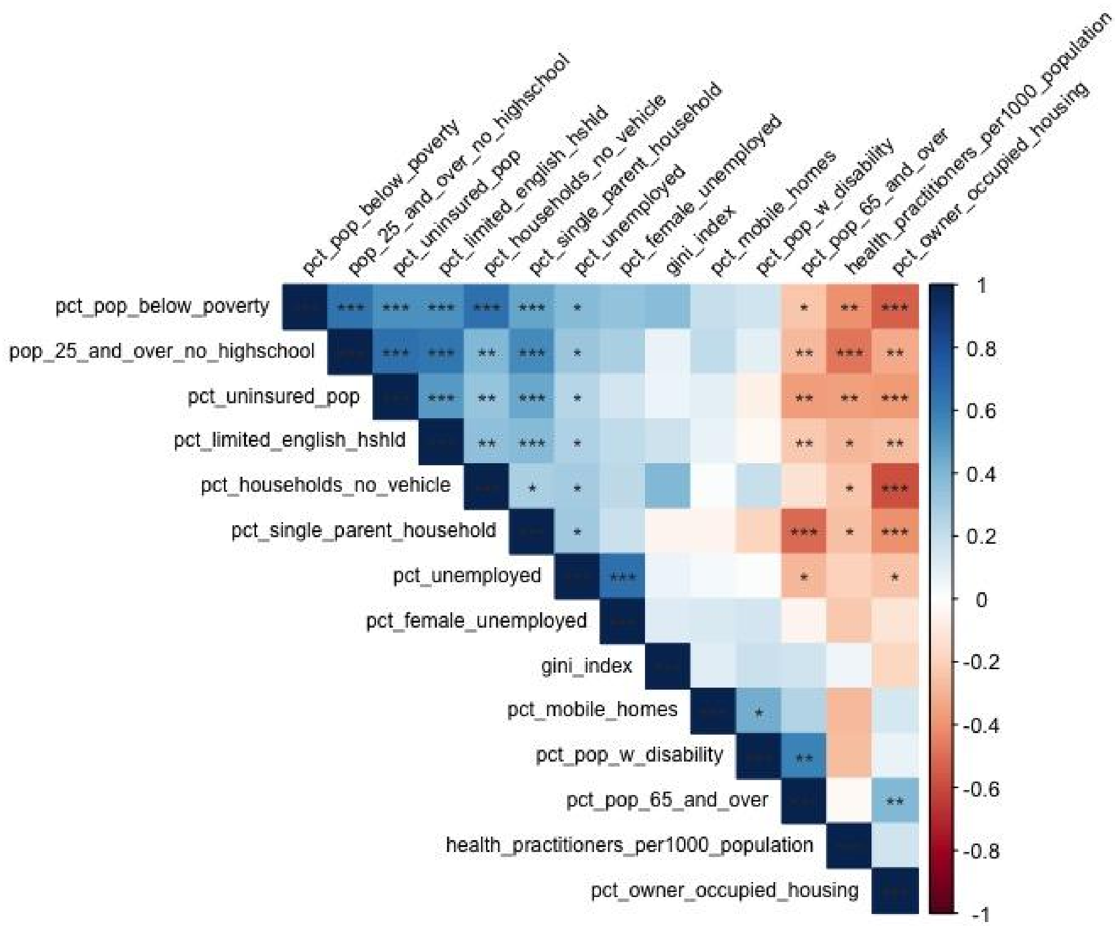
[12] https://doi.org/10.1016/B978-0-12-803781-2.00004-7

Results

The correlation analysis matrix visualizes the significance and direction of indicator pair relationships. Both the matrix (fig. 1) and table (table 2) identify significant statistical relationships with asterisks: '***' denotes significance at the 0.001 confidence level (p<0.001), '**' denotes significance at the 0.01 confidence level (p<0.01), and '*' denotes significance at the 0.05 confidence level (p<0.05). The absence of an asterisk indicates no statistically significant correlation. The matrix (fig 1.) contains a bar at the right which indicates the color that corresponds to a correlation ranging from -1 (red), 0 (white), and +1 (blue). A significant negative coefficient indicates that the relationship is negative: as one indicator value increases, the second indicator value decreases. In contrast, a significant positive coefficient indicates that the relationship is positive: as one indicator value increases, the second indicator value also increases.

Figure 3

Az CRI Indicators Pearson Correlation Matrix



Note. *p < .05. **p < .01. ***p < .001*. No asterisk indicates no significance.

Table 2

Az CRI Indicator Correlation Coefficients and Significance

	pct_pop_65_and_over	pct_pop_w_disability	pct_limited_english_hshld	pop_25_and_over_no_highschool	pct_households_no_vehicle	pct_single_parent_household	pct_mobile_homes	pct_owner_occupied_housing	health_practitioners_per1000_population	pct_uninsured_pop	pct_unemployed	gini_index	pct_female_unemployed	pct_pop_below_poverty
pct_pop_65_and_over	1***	0.58**	-0.23**	-0.27**	-0.13	-0.51 ***	0.26	0.39**	-0.03	-0.36**	-0.29**	0.16	-0.04	-0.24
pct_pop_w_disability		1***	-0.02	0.09	0.19	-0.19	0.43*	0.08	-0.26	-0.06	0.02	0.18	0.16	0.16
pct_limited_english_hshld			1***	0.64***	0.35**	0.39 ***	0.07	-0.27**	-0.29*	0.51***	0.27*	0.18	0.22	0.53***
pop_25_and_over_no_highschool				1***	0.4**	0.55 ***	0.22	-0.33**	-0.47***	0.66***	0.32*	0.08	0.28	0.64***
pct_households_no_vehicle					1***	0.27*	0.02	-0.58***	-0.23*	0.33**	0.29*	0.4	0.22	0.66***
pct_single_parent_household						1***	-0.04	-0.41***	-0.25*	0.46***	0.31*	-0.05	0.19	0.47***
pct_mobile_homes							1***	0.14	-0.27	0.1	0.04	0.1	0.13	0.2

pct_owner_occupied_housing								1***	0.16	-0.38***	-0.24*	-0.18	-0.11	-0.53***
health_practitioners_per1000_population									1***	-0.35**	-0.2	0.06	-0.23	-0.41**
pct_uninsured_pop										1***	0.25*	0.07	0.16	0.53***
pct_unemployed											1***	0.07	0.65***	0.38*
Gini_index												1***	0.11	0.37
pct_female_unemployed													1***	0.35
pct_pop_below_poverty														1***

Note. *p < .05. **p < .01. ***p < .001*. No asterisk indicates no significance.

Spatial Auto-correlation analysis

Spatial auto-correlation analysis is a statistical technique to identify regions/areas that have similar socio-demographic characteristics. Geographic boundaries are often arbitrary, or designed to delineate a natural feature or civic infrastructure. Rarely do the spatial units of a particular variable correspond to the same spatial units about where decisions are made with respect to changing a factor represented by that variable, especially since most are in census tract units that are not congruent with decision-making jurisdictions. While spatial auto-correlation is not part of the Az CRI, it would be useful to include in future assessments. See the section below on Future Development.

Future Development

When using any index or set of indicators, there are several limitations and caveats to keep in mind. First, caution must be taken with respect to selection bias. The choice of indicators included in the index can introduce bias if certain important aspects of the issue being measured are not represented. In this Arizona CRI, we mitigated the selection bias by beginning with a thorough assessment of a set of methodologies and indicators that are already proven in national use by various federal government agencies. The process for selection included ample discussion by experts in resilience, public health, data science, and geospatial statistics. The interpretation must only then be limited to the variables included in the analysis. In the Az CRI this means that this does not include many other factors that might be important to the fine-grained analysis of resilience to a particular threat or shock, which is not incorporated into this general selection of variables. In the conduct of this assessment, our team identified additional important indicators which could be incorporated into future iterations of the development of an index that is specific to serving the State of Arizona.

Secondly, indexes are often compiled by applying weights and normalization. The way in which indicators are weighted and normalized can have a significant impact on the final index, and can introduce bias if certain indicators are given more weight than others. We mitigated this limitation by following the standard of the chosen reference index, whereby FEMA acknowledges that there is as yet no validated methodology for a single indicator. This means that the index for a particular spatial area is only relative to other areas, and not set against a specific national standard. For the main index, FEMA instead opts to produce it as a single number measuring the average of counts of standard deviations from the national mean for each indicator. For Arizona, we proposed that this be changed to “the state mean” so that it is adapted to Arizona, and relative to the local context. Interpretations should consider that no specific threshold or flag for risk have been identified.

Third, data quality and availability are important caveats. The data used to calculate each indicator can vary in terms of comprehensiveness or quality, depending on what location it is taken to represent. This can introduce complexity, missing data, and ultimately uncertainty into the index. Our assessment mitigates this challenge by relying on universally accepted ACS data wherever possible. Similarly, certain indicators used in the index may not be relevant or meaningful in certain contexts, may not indicate the same problem in different locations, or the index may not be directly comparable across different regions or time periods. This caveat is inherent to indices in general, where they simplify complex phenomena, leading inevitably to a loss of information, which ultimately requires experience and qualitative contextual understanding to correctly interpret the underlying drivers of the results. The availability of data over time is one aspect of this quality limitation. Variables provide a single snapshot of a community. Multiple events and duration of events may further impact a community’s resilience over time.

The resulting index is only as relevant as the underlying datasets and the date on which the index was compiled. Further, the relevancy dates of the underlying datasets could be a limitation. For example, data from the ACS at the census tract level is only available as 5-year averages from the most recent survey release - currently 2016-2020. As such, socio-demographic changes resulting from the pandemic will not be fully realized for several years.

Mapping resilience is important because it provides a visual representation of potential risks, helps to identify vulnerable populations, strengthens community networks, improves emergency response, and supports ongoing monitoring and evaluation. When mapping these indicators, however, it is important to be aware of the limitations and caveats associated with spatial statistics. This includes properly interpreting the scale of the data. For example, statistics at a small scale, such as at the neighborhood level, might not be representative of the larger area, such as the city or region, and vice versa.

Furthermore, while utilizing a number or set of variables, it is important to consider how those variables may be statistically correlated to properly interpret results. Spatial statistics as well must be interpreted in addition to assessing the spatial autocorrelation of multiple variables in an index.

Spatial autocorrelation refers to the phenomenon where the similarity of values for a variable of interest (such as an indicator) is greater for nearby locations than for distant locations. This means that the value of a variable at a location is likely to be similar to the values of that variable at nearby locations. Statistical correlation and spatial autocorrelation are similar in that they both measure the relationship between two or more variables. However statistical correlation is typically used to measure the relationship between two variables, whereas spatial autocorrelation is used to measure the relationship between the values of a single variable at different locations. This is important for any index that is relative. Whereas statistical correlation measures the linear relationship between two variables, spatial autocorrelation measures the similarity of values between locations. Statistical correlation is typically used at the individual or aggregate level, whereas spatial autocorrelation is used at an aggregate, usually regional level.

Spatial autocorrelation can be measured using a statistic called the Moran's I. This statistic takes values between -1 and 1, with positive values indicating positive spatial autocorrelation (similar values tend to be found near each other) and negative values indicating negative spatial autocorrelation (dissimilar values tend to be found near each other). When mapping indicators for comparative purposes, then, it is thus important to consider spatial autocorrelation because it can affect the interpretation of the map. For example, if an indicator is positively spatially autocorrelated, this means that high values tend to cluster together, which may indicate the presence of a particular underlying cause or pattern. On the other hand, if an indicator is negatively spatially autocorrelated, this means that high and low values tend to be interspersed, which may indicate the absence of a particular underlying cause or pattern.

Ultimately, the choices made by the assessment team were driven to mitigate such limitations, and align specifically with the needs and ongoing engagement of the large stakeholder community already involved with the production of an Arizona-specific social vulnerability index.

Recommendations

As a result of conducting a baseline assessment of resilience, our team of experts and scientists recommends an ongoing, in-depth resilience assessment program that goes beyond this baseline assessment, in order to transform systems that can improve community resilience. This initiative is being proposed as the Az RA. As part of the broader program, we will continue to make use of the FEMA/Az CRI to benchmark across other states and stay current with their methodology.

A more robust and holistic methodology is necessary to manage risk and improve resiliency for two primary reasons:

1. Resilience is a dynamic and complex construct. It has a temporal component that transcends preparedness, mitigation, response, and recovery. It is event/hazard specific, yet is important across a broad range of scenarios. It is a function of other nuanced constructs including vulnerability, exposure, adaptive capacity, and social cohesion. The Resilience Equation (fig. 4) is a mathematical representation of this phenomenon.
2. The impacts of hazards that can be mitigated by resilient communities do not appear at the same spatial resolution as geographic boundaries or government decision-making.

There is a well-understood inconsistency between the spatial unit of analysis at which data is collected and the geographic jurisdiction at which decisions are made. Furthermore, the spatial scale at which impacts are felt often appear at the household or community scale, which align with neither. This problem creates difficulties in linking data to decisions because decision-makers must make choices based on incomplete or inaccurate information about the effects of their actions (Solís et al. 2016).

For resilience, which links vulnerability, exposure, capacity, and cohesion in an understanding of how a community faces a threat, this is even more imperative. As Meerow et al. conclude (2016), "resilience is inevitably a contested process in which diverse stakeholders are involved and their motivations, power dynamics, and trade-offs play out across spatial and temporal scales. Therefore, resilience for whom, what, when, where, and why needs to be carefully considered."

Figure 4

Resilience Equation

$$\textbf{Risk (Shock)} = \frac{\textbf{(Exposure x Vulnerability)}}{\textbf{(Adaptive Capacity x Social Cohesion)}}$$

Note: Resilience as a function of time, is the process of reducing the risk of a shock.

We believe that this Az CRI Assessment can be improved in several ways, transitioning ultimately to the Az RA program. First, the current FEMA CRI needs to be interpreted through a more nuanced lens that includes local knowledge. This can only be achieved by including diverse community members who have that local knowledge. Second, resilience and vulnerability are statistically related, but not the obverse of one another (Cutter et al. 2014).The equation of resilience (fig. 4) structures additional concepts which need to be assessed in relation to the variables of the Az CRI in order to better capture the asset-based dynamic of resilience, moving into a greater resolution of resilience.

The resilience equation (fig. 2) represents a mathematical function of building resilience to a particular shock or threat through a time-dependent process. In Arizona we often think of this shock as the multiplier threats that rising temperatures or heat presents, not only to the experiences of thermal change, but also to our water systems, our jobs, and our daily life in Arizona. The equation is composed of four main components: Risk (to experiencing a particular shock or threat), Exposure, Vulnerability, Adaptive Capacity, and Social Cohesion.

- **Risk** (of Shock): This term represents the likelihood and potential impact of a particular shock, long-term stress, or threat happening to a community or system. This can include natural disasters, economic crises, or political instability, among others. In measuring resilience, it is important to have a clear idea of which shocks and stresses are the subjects of the metric in order to best understand specific resilience.
- **Exposure:** This term represents the degree to which a community or system is exposed to a particular shock or threat. This can include factors such as location, infrastructure, and resources. It is again important to define the particular shock and then determine what is the specific exposure to that shock or stress. For example, some people are more or less exposed to heat in Arizona. People who work outdoors, or people with AC are more exposed to heat.
- **Vulnerability:** This term represents the susceptibility of a community or system to persistent conditions that are disadvantageous. Vulnerability is generally thought of as a pre-existing state that will lead an individual or population sub-group to have worse outcomes under similar circumstances to an individual or sub-population that is less vulnerable. This can include factors such as poverty, inequality, and weak governance. Vulnerability is inversely or negatively related to resilience, however, resilience is a more dynamic construct that is both situation-dependent and time-dependent, and includes assets that offset or mitigate vulnerabilities. There are measures that attempt to capture social vulnerability independently of specific hazards or events, such as the CDC Social Vulnerability Index[13]. The resilience equation is a useful tool to understand the relationship and ordinality among these constructs.
- **Adaptive Capacity:** This term represents the ability of a community or system to prepare for, withstand, and recover from a particular shock or threat. This can

[13] https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

include factors such as early warning systems, emergency management plans, and community mobilization. It is an asset-based component of an improved assessment of resilience.
- **Social Cohesion:** This term represents the degree of social connectedness and trust within a community or system. This can include factors such as community participation, social networks, and trust in institutions. These factors can improve resilience.

The resilience equation is based on many decades of scientific literature in the fields of risk and disaster management. It states that the risk of a shock or threat is the product of exposure and vulnerability, mitigated by adaptive capacity and social cohesion. This means that the risk of a shock or threat is lower when a community or system has high adaptive capacity and social cohesion, and reduced when there is lower exposure and vulnerability, which can be accomplished by mitigation actions.

We recommend that future iterations of the Az RA take better account across all of these concepts. In particular, we need greater attention to defining the Arizona-specific shocks or threats that the resilience index should target. We also need additional data on actual exposure to perceived prioritized threats/shocks. We need to base some specific additional variables on asset-based metrics to represent adaptive capacity (e.g. pandemic resilience related to hospital capacity and numbers of beds); and on the more qualitative and contextual connections which are challenging to measure, but can be captured in indices and variables that seek to assess social cohesion.

To that effect, there remain several ongoing local and national-level assessments, largely under development in academic organizations focusing on threat and hazard reduction, risk-management, health equity, resilience, and preparedness science. This includes the following sources: the CDC Social Vulnerability Index (Centers for Disease Control and Prevention), Baseline Resilience Indicators for Communities (University of South Carolina Hazards & Vulnerability Research Institute), Community Resilience Estimates (US Census), and the National Risk Index (FEMA). The Az RA program should enable communities and government organizations to include resiliency as a guiding construct in the ongoing execution of the AzHIP, the Arizona Health Assessment, and future health-related programs within the state.

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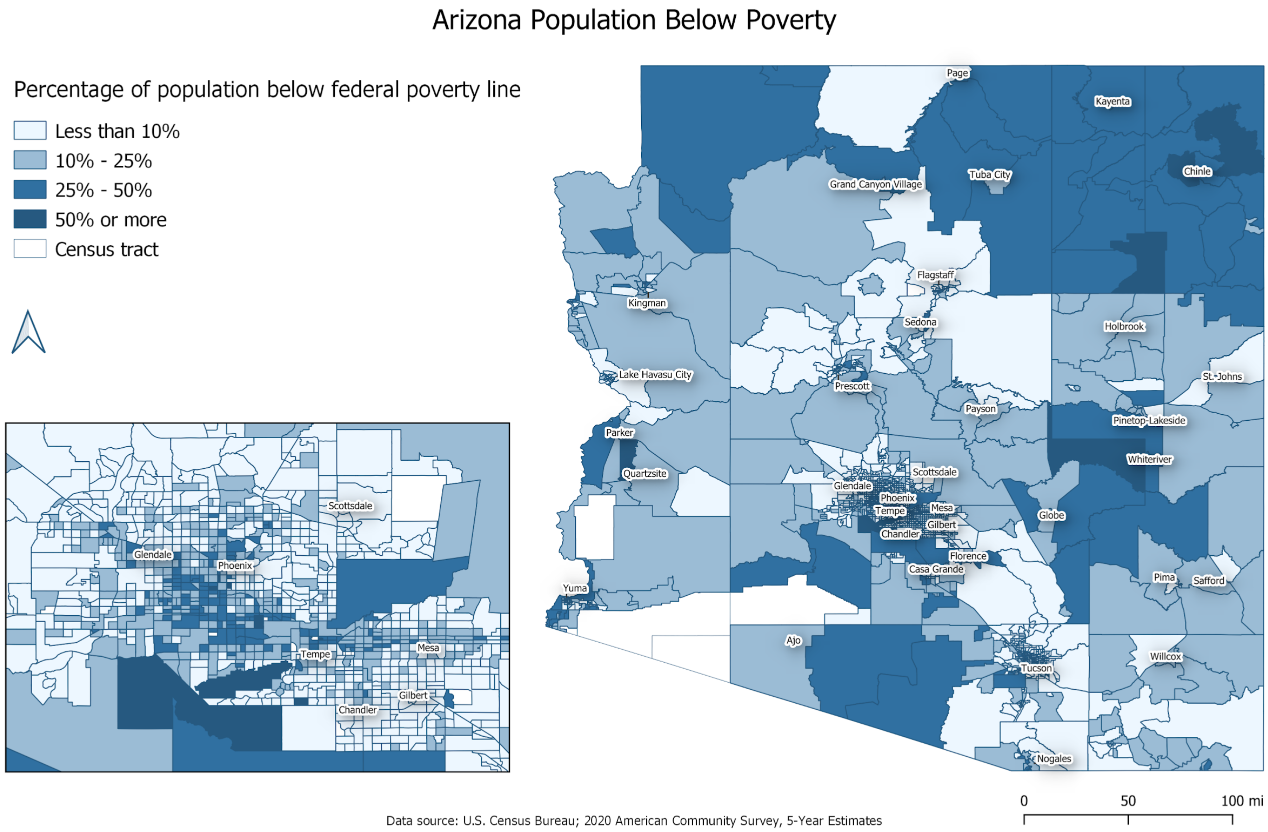
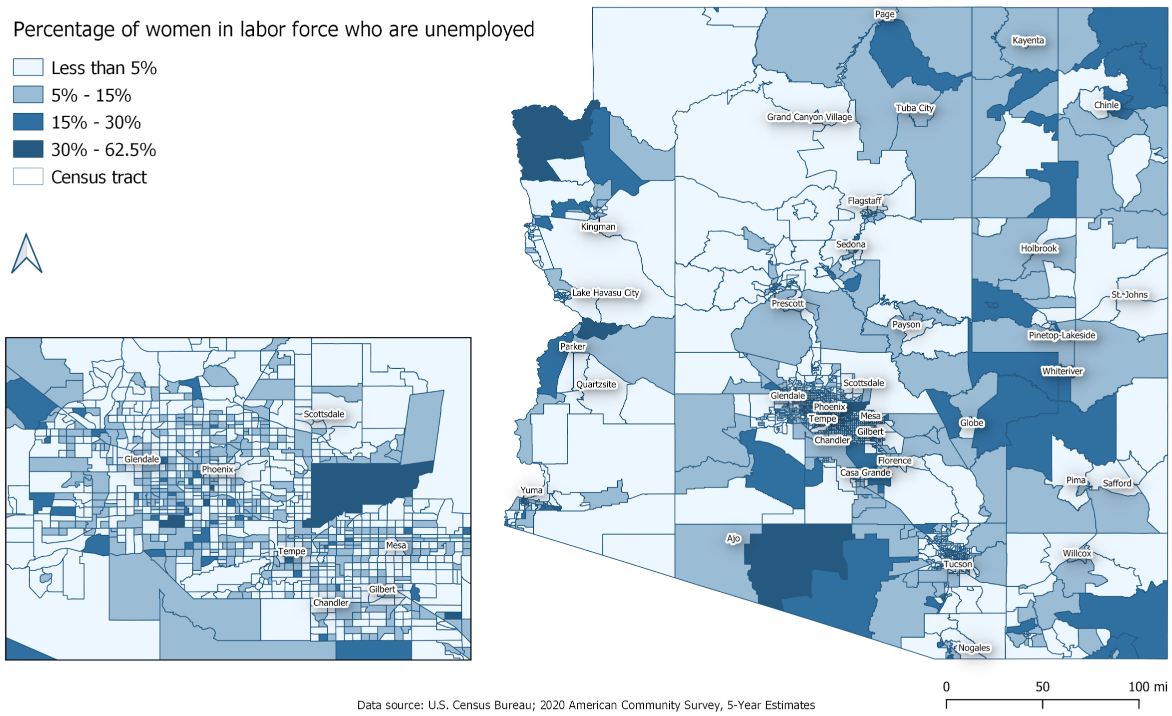
Appendix A: Maps of the Arizona Community Resilience Indicators



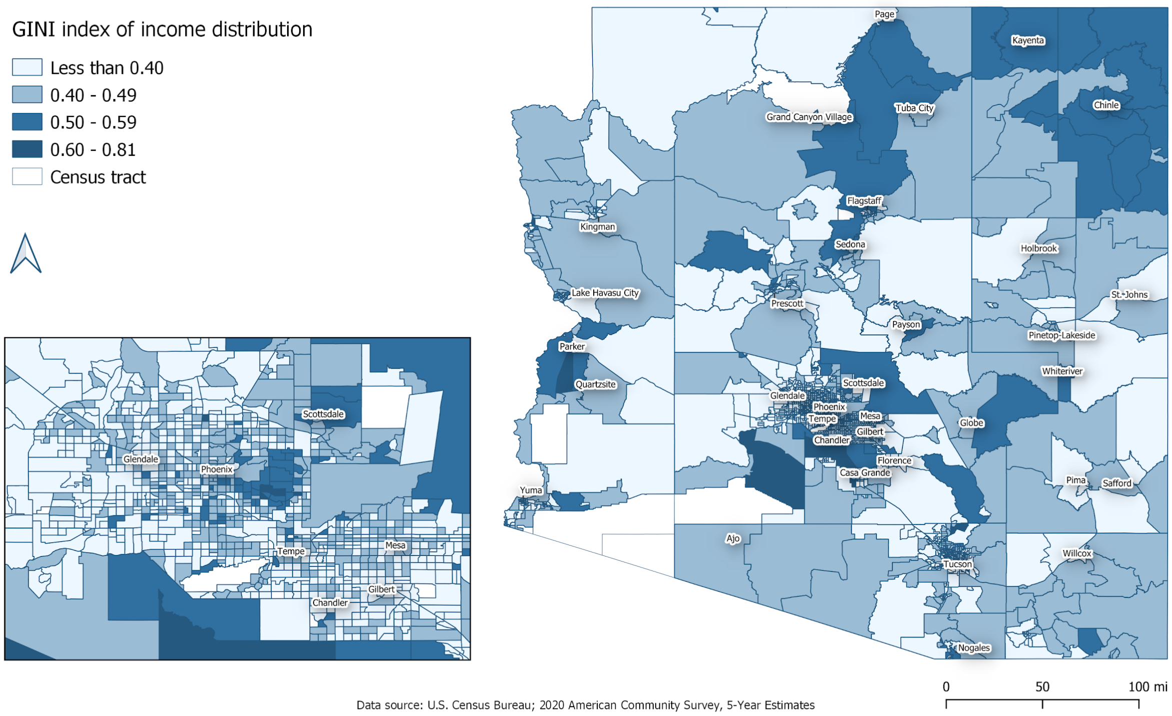
Across Arizona, we see a high concentration of poverty in particular rural and Tribal areas as well as in certain urban neighborhoods, with racial/ethnic minority populations being disproportionately affected. Additionally, poverty can be intergenerational, perpetuated by a lack of resources and opportunities for those living in poverty to escape their situation. Arizona as a whole experiences a higher poverty rate than the national average.

Arizona Unemployed Women



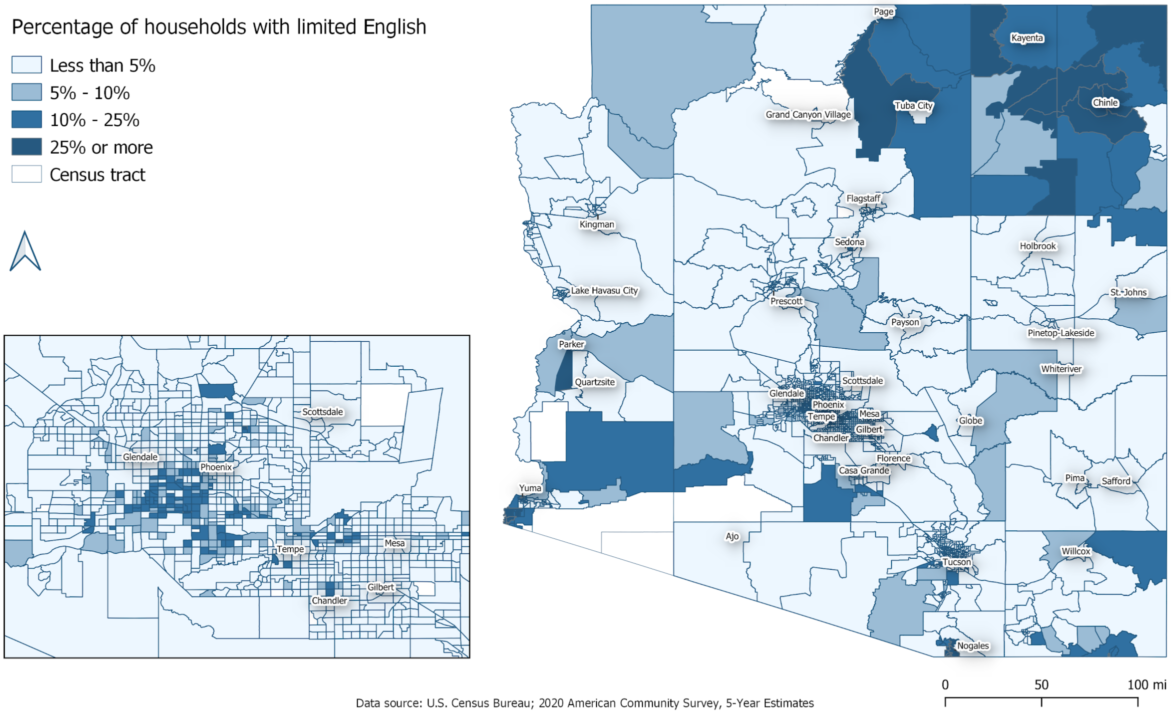
Women face unique challenges in the labor market and are more likely to experience unemployment compared to men. Some factors that contribute to higher unemployment rates among women include a lack of access to affordable child care, gender pay disparities, and job segregation, where women are concentrated in low-wage, unstable jobs. It is also worth noting that the COVID-19 pandemic has had a disproportionate impact on women's employment, with many losing jobs in industries such as hospitality, retail, and education.

Arizona Income Inequality Index

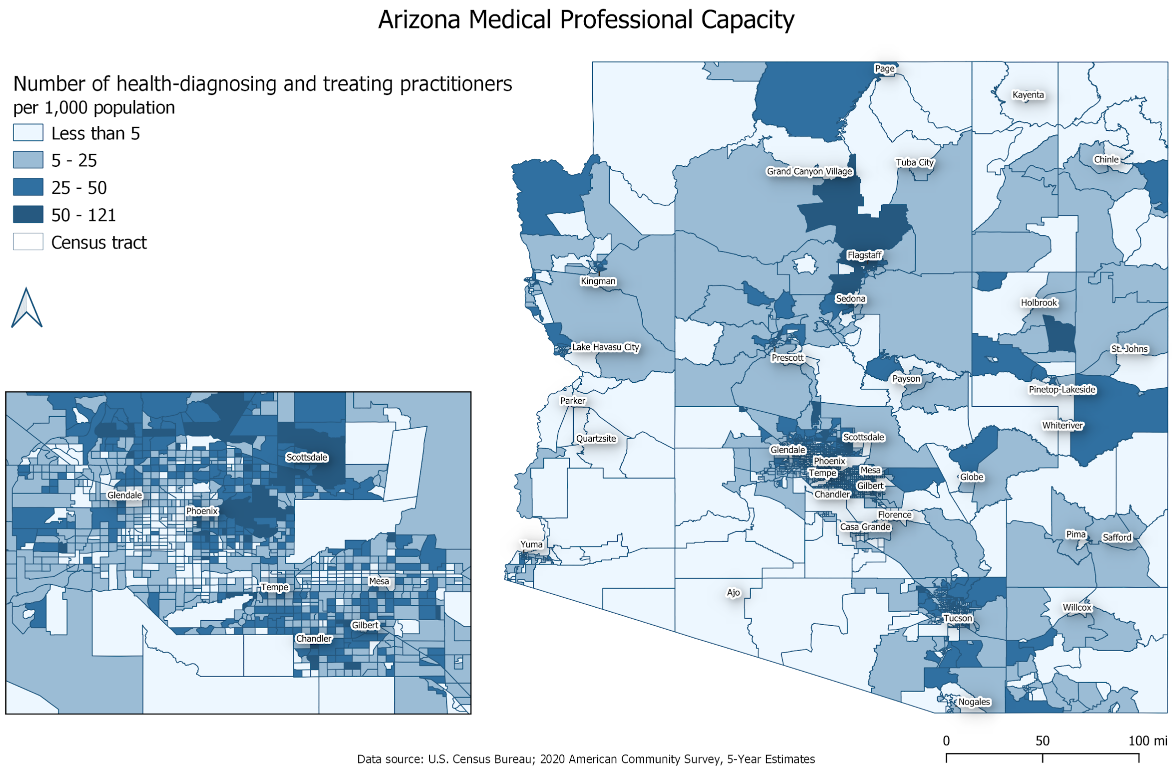


Income itself is an outcome of many complex factors, including variables such as educational attainment, employment opportunities, access to resources, and broader economic and political structures. These factors, in turn, interact to shape individual and community-level outcomes visible in these spatial patterns that reveal inequalities across the state of Arizona. The Gini index summarizes the distribution of income across the population. An index of 0 indicates income equality across a population. An index value of 1 indicates that there is great disparity of income across the population. Arizona has regions where income is relatively evenly distributed and other areas with wider income disparity.

Arizona Households With Limited English Proficiency

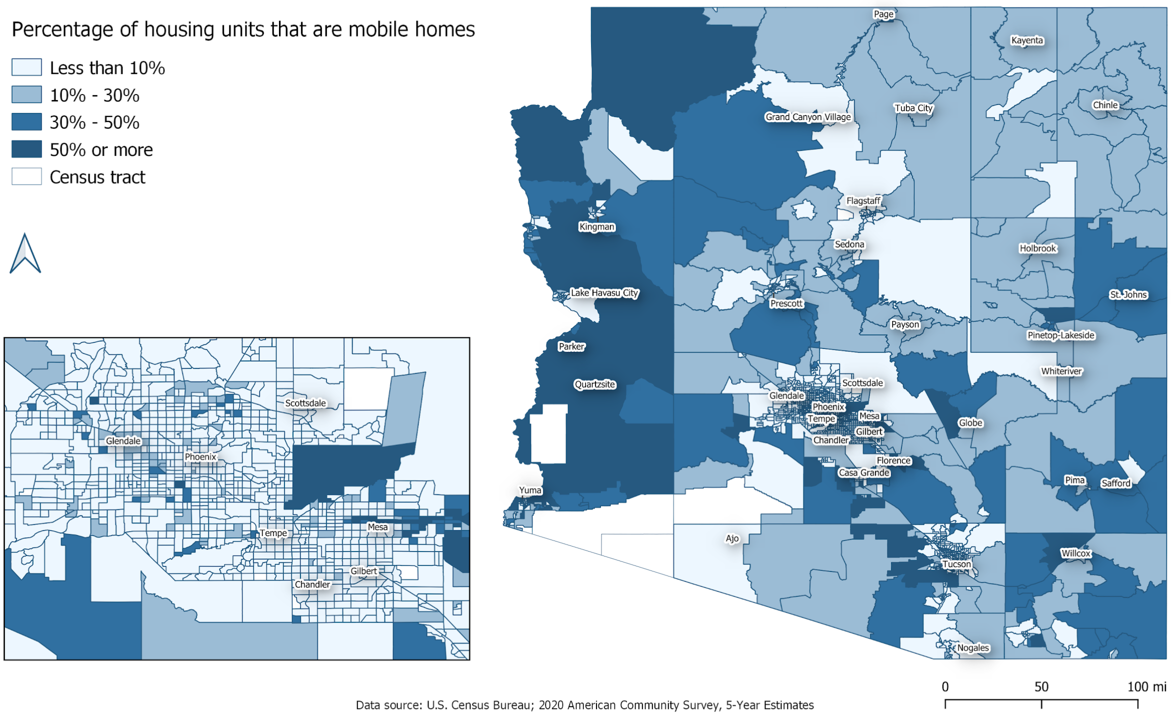


Limited English proficiency can create barriers to prevention, mitigation, and response to risks, making it difficult for individuals to effectively communicate their needs, understand important information, and navigate complex systems and services. These patterns in Arizona strongly reflect places where immigrant populations reside.

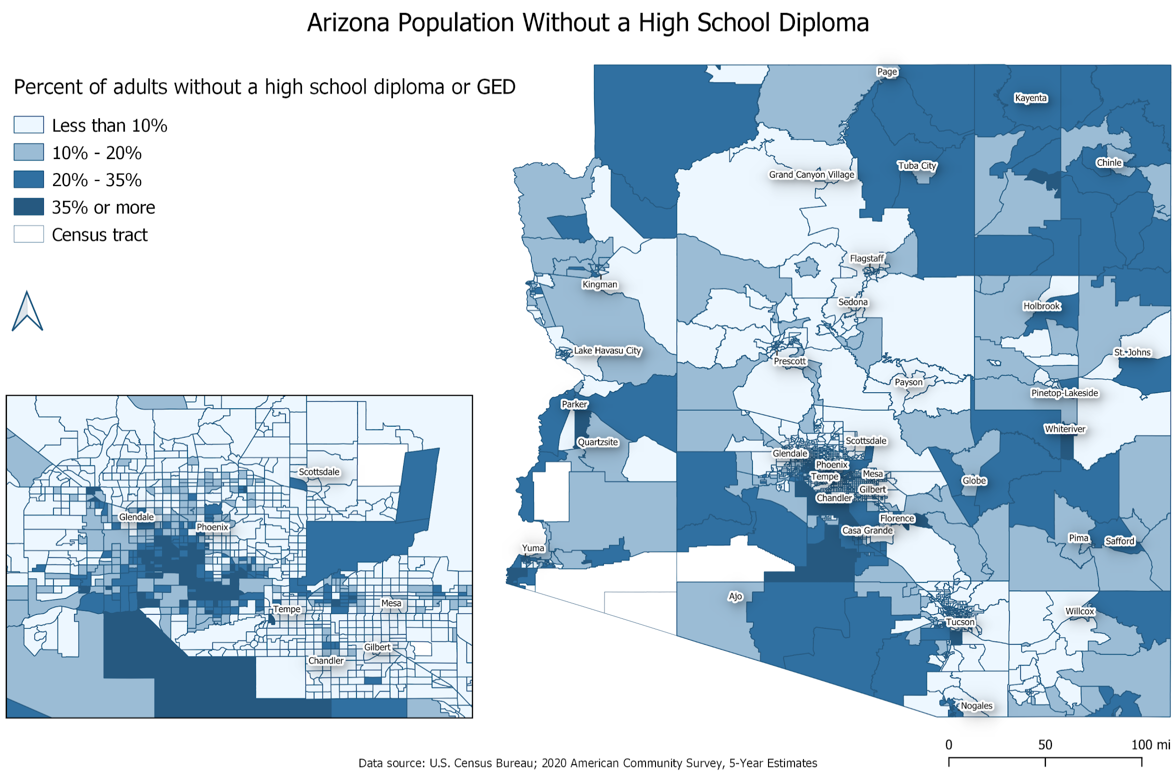


For community health, it is important to map where the capacity of medical professionals is strong. The pattern in this map appears dominant in locations where there are fewer instances of vulnerability factors shown in other maps in this appendix.

Arizona Mobile Homes

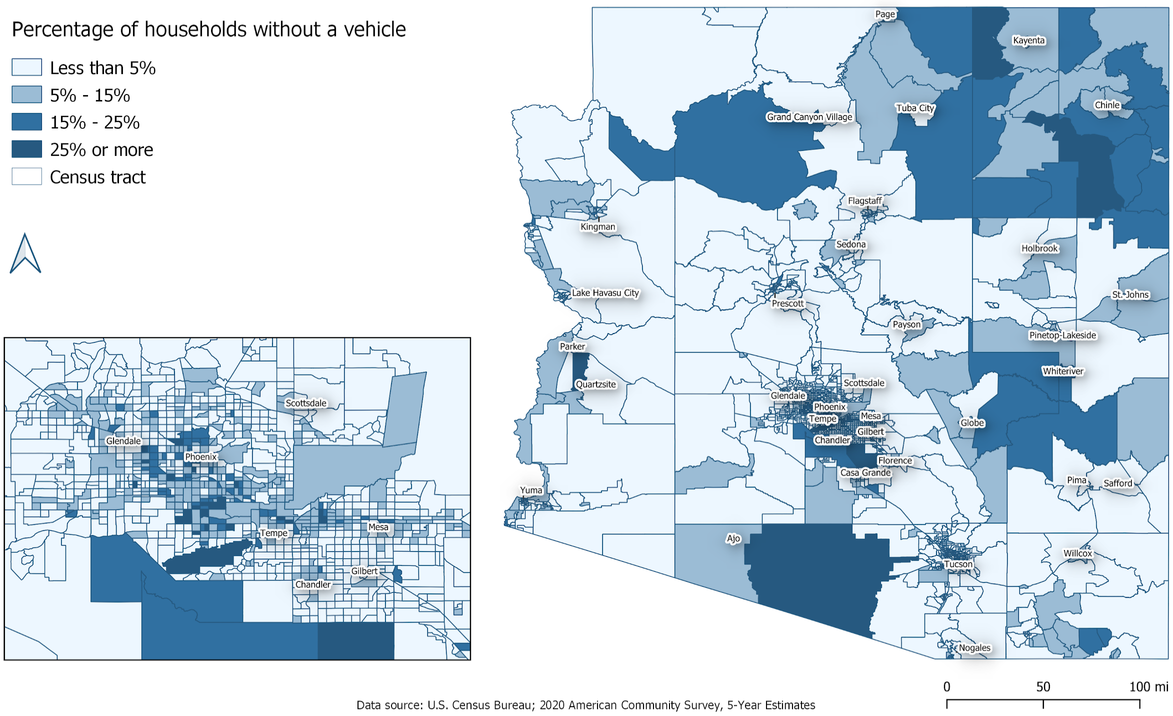


Mobile and manufactured housing represents an affordable option for many lower to middle income households, but can expose residents to greater risks related to heat, in particular. KER research underscores the disproportionate occurrences of heat-related deaths compared to residents in other types of housing.

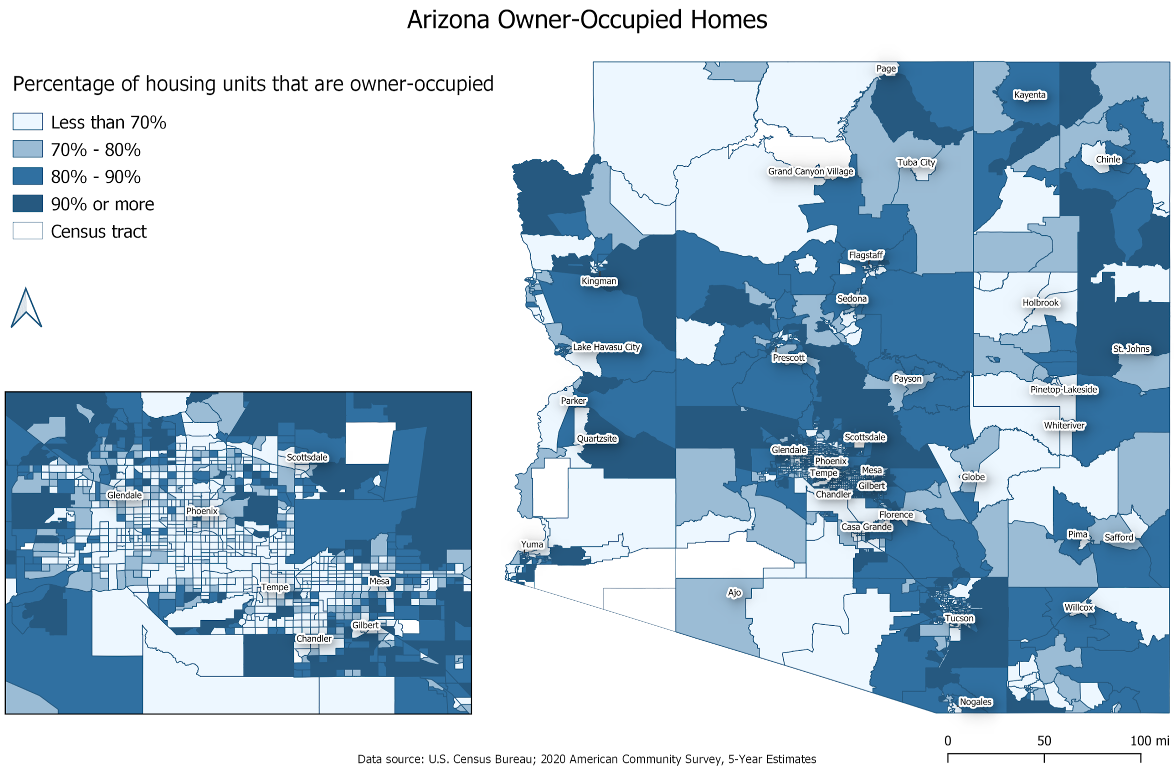


A high school education can have a significant impact on individuals and communities, reducing vulnerability and promoting greater well-being and prosperity. Lack of a secondary school diploma can exacerbate other vulnerabilities. This indicator is strongly correlated with limited english proficiency, poverty, and single-parent households.

Arizona Households Without a Vehicle

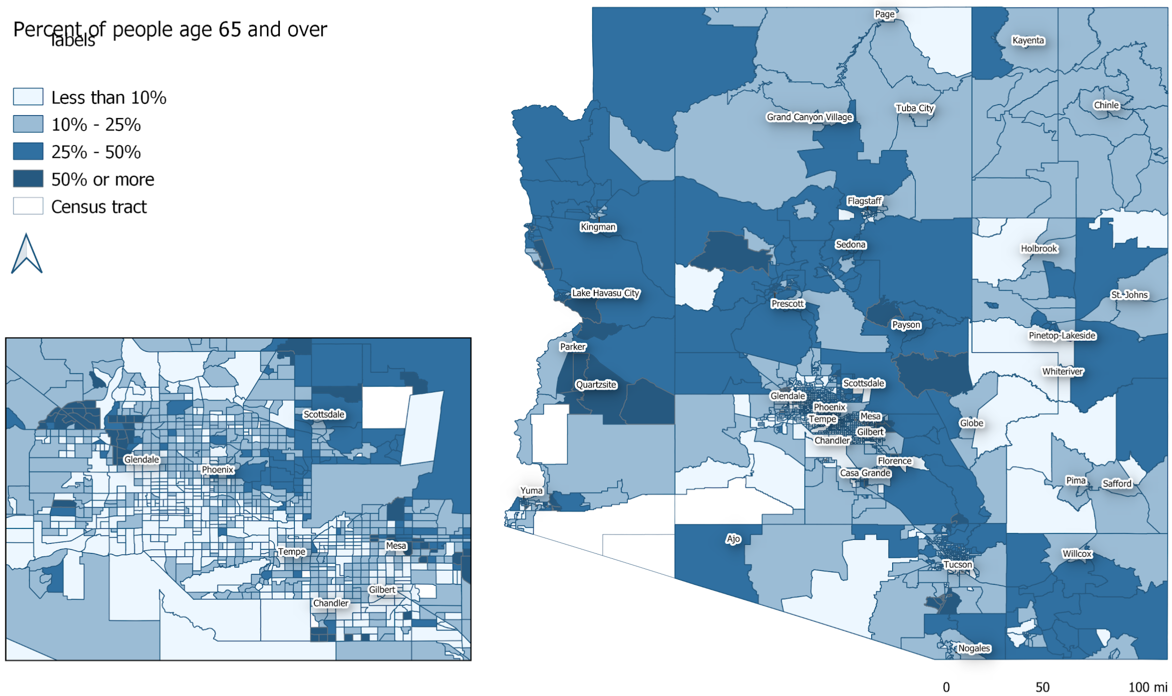


In many of the areas of Arizona where the data shows households have no vehicle, there may not be adequate public transportation to make up for transit options. This lack of mobility can hamper community resilience particularly when responses to shocks require movement out of harm's way.



The pattern of owner-occupied homes in Arizona favors many rural and suburban areas. Owner-occupied housing can be a sign of stability and investment in a community, but also indicate disadvantages due to the burden of mortgages and maintenance costs.

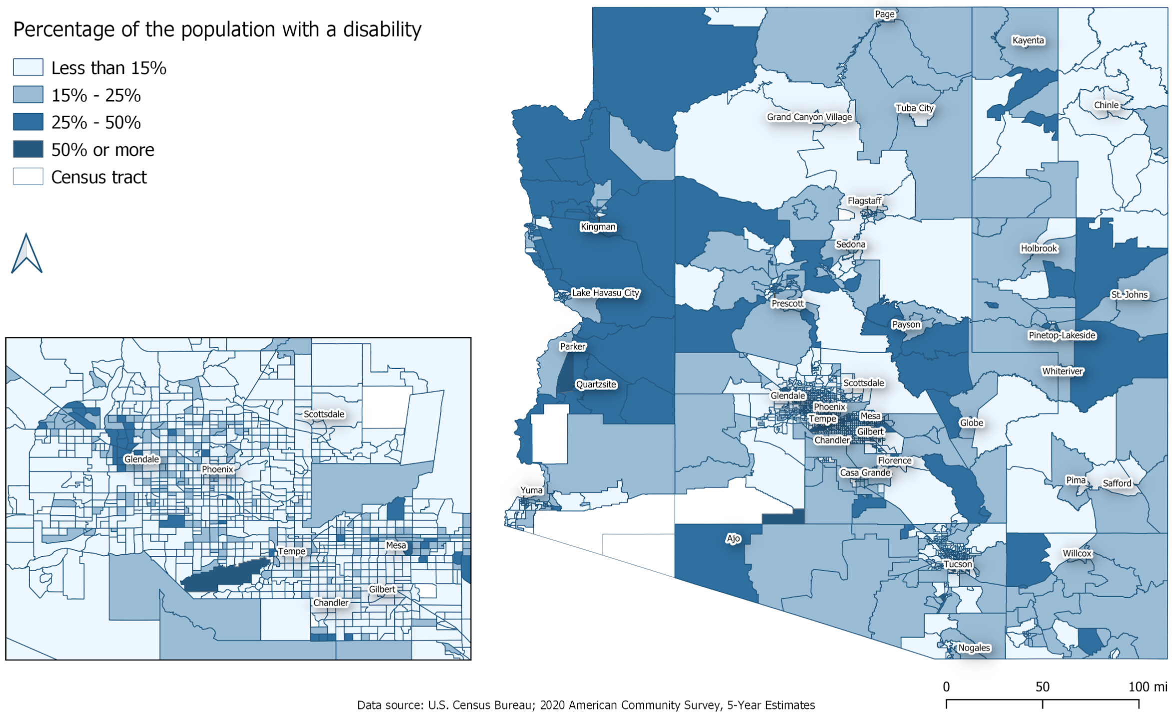
Arizona Population 65 and Older



Data source: U.S. Census Bureau; 2020 American Community Survey, 5-Year Estimates

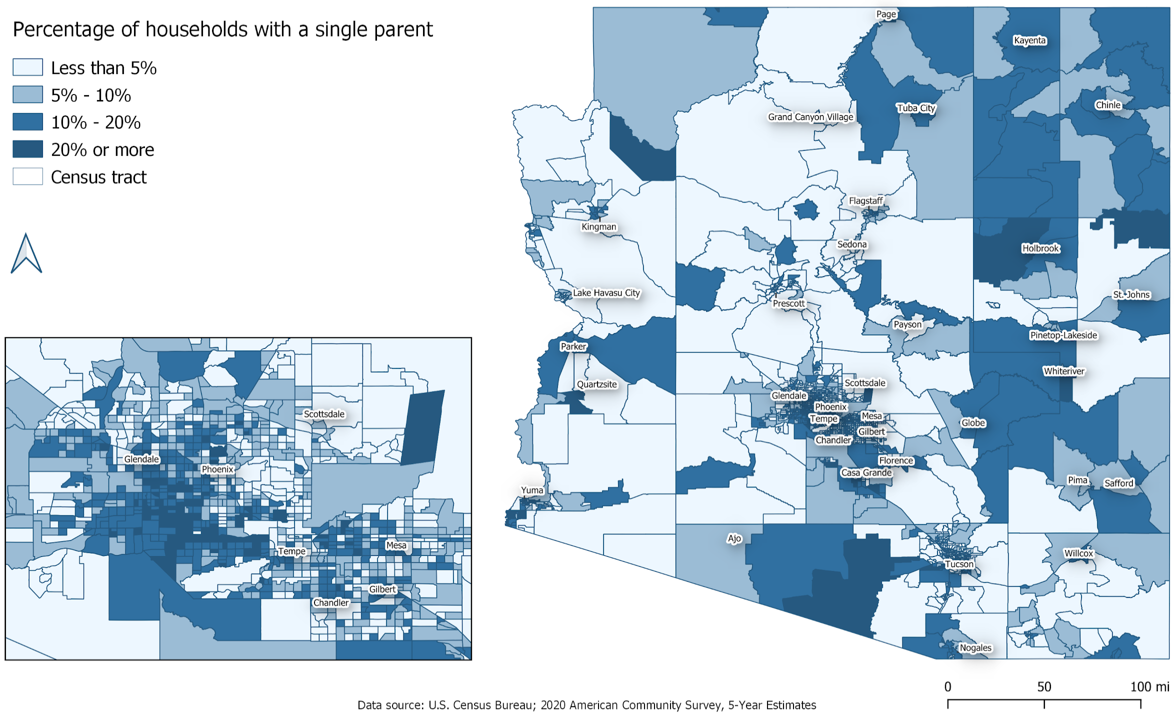
Older adults tend to have greater health risks in general, but age might also present negative associated factors such as fixed income, or declining social cohesion. However, depending on the location, some communities with significant concentrations of adults over 65, like retirement havens, could offer greater community resilience where social cohesion may be strong. Careful interpretation and context should be considered.

Arizona Population With Disability



Arizonans with a disability may be more vulnerable for many reasons, including lack of mobility or independence, making it harder to cope with or respond to shocks. Health equity is an important goal for communities to support individuals with disabilities by providing accessible services, promoting inclusivity, and reducing barriers to essential services. Western Arizona is home to a significant proportion of the population with a disability. Disabled persons tend to be older and are more likely to live in mobile homes.

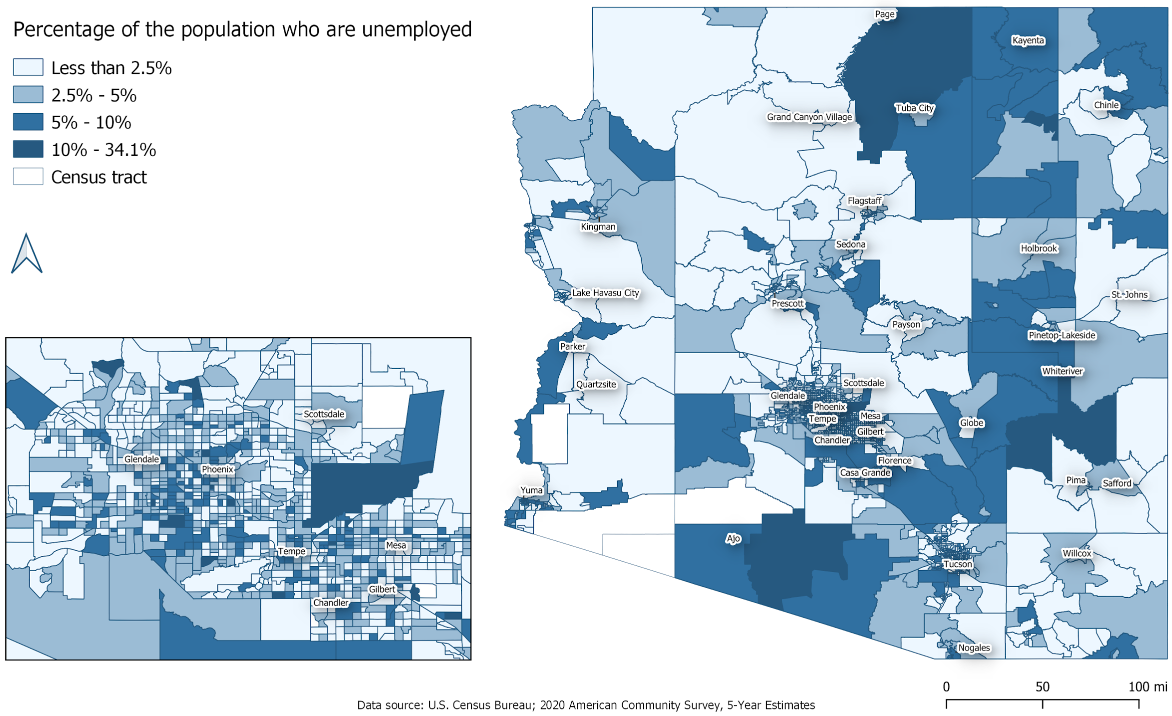
Arizona Single-Parent Households



Data source: U.S. Census Bureau; 2020 American Community Survey, 5-Year Estimates

Single parents are usually more vulnerable than two-parent households due to the lack of financial and social resources, overwhelming responsibilities and fewer opportunities for crisis recovery. In Arizona, most single-parent households are seen in communities with higher percentages of racial and ethnic minorities.

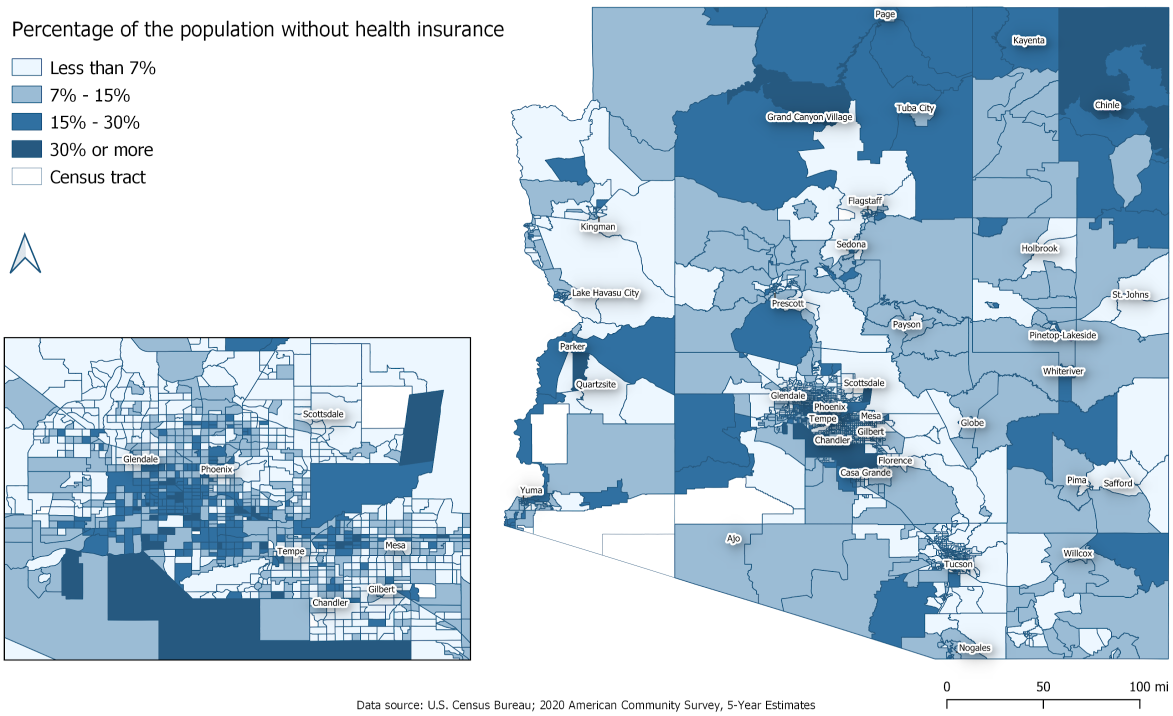
Arizona Unemployed Population



Data source: U.S. Census Bureau; 2020 American Community Survey, 5-Year Estimates

People without stable employment typically lack financial resources necessary for crisis mitigation and recovery. Additionally, low employment is associated with lack of health coverage and life insurance.

Arizona Population Without Health Insurance



Access to healthcare is an important measure of community resilience. Populations that cannot freely and easily access health services are more vulnerable to both mental and physical illnesses and have a harder time recovering from crises. Arizona's Native American communities and communities with higher percentages of ethnic and racial minorities are showing a larger portion of uncovered individuals.

Acronyms

ACS	American Community Survey
ADHS	Arizona Department of Health Services
ASU	Arizona State University
Az CRI	Arizona Community Resilience Indicators
AzHIP	Arizona Health Improvement Plan
Az RA	Arizona Resilience Assessment
BRIC	Baseline Resilience Indicators for Communities
CDC	Centers for Disease Control and Prevention
CRI	Community Resilience Indicators
FEMA	Federal Emergency Management Agency
KE	Knowledge Enterprise
KER	Knowledge Exchange for Resilience
NAPSG	National Alliance for Public Safety GIS
PR&R	Pandemic Recovery & Resiliency
SVI	Social Vulnerability Index

Knowledge Exchange for Resilience

Arizona State University