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Defining and analyzing health system resilience in rural jurisdictions

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Abstract
Rural areas face well known and distinctive health care challenges that can limit their resilience in the face of health emergencies such as the COVID-19 pandemic. These include problems of sparsity and consequent limited health care provisioning; poverty, inequalities, and distinctive economic structures that limit access to health care; and underlying population health risks and inequalities that can increase vulnerability. Nonetheless, not all rural areas face the same problems, and non-rural areas can have challenges. To be useful in influencing policy, a tool to identify more and less resilient areas is necessary. This Commentary reviews key forms of risk and constructs a county-level index of resilience for the United States which helps to identify countries with limited resilience. Further, it argues that health care resilience should be conceptualized in terms of broader regions than counties since health care facilities' referral regions are larger than individual counties; resilience needs to be understood at that level. The index, read at the level of counties and referral regions, can contribute to identification of immediate problems as well as targets for longer term investment and policy response.

Keywords Health systems · Rural · Resilience

1 Introduction

The COVID-19 pandemic has demonstrated the importance, and the limited resilience of, rural healthcare systems (RHS) in the US. While initial cases of COVID-19 and associated deaths were in urban centers, with the only 1/5 of the first 100,000 deaths being in rural areas, by the second 100,000 deaths, nearly half were occurring in rural communities. Both population characteristics and strains on rural healthcare systems contributed to these changes in mortality (Vestal, 2020).

Rural populations tend to be older, poorer and have higher rates of comorbidities such as smoking and obesity when compared to non-rural populations, outlining how the pandemic was a particular challenge for rural populations as well as demonstrating the importance of recognizing differences in rural and non-rural populations (Paul et al., 2020). The employment of rural communities in the agricultural and food processing industries as well as correctional facilities, over half of which are in rural areas, posed an additional risk as both produce work conditions highly conducive to further COVID-19 spread (Infectious Disease Society of America, 2020). RHS, which faced significant financial and workforce challenges even prior to the pandemic, were placed under further intense pressure.

The Department of Health and Human Services under the Biden-Harris administration recognized these concerns, committing significant amounts of funding to increase COVID-19 vaccination rates in rural communities, improve access to testing and mitigation, and provide financial relief for rural hospitals. For rural communities facing deteriorating healthcare access, this temporary funding is welcome. However, it likely does not match the sheer magnitude of needed investment in RHS. Nor does it permanently address some of the underlying challenges these systems face.

Improving health system infrastructure and support systems in rural communities requires an understanding of the unique limitations that rural healthcare systems face, as well as the more prevalent underlying health disparities that rural populations often experience relative to urban jurisdictions. Systemically, RHS assume a greater degree of resource and operational efficiency than in many urban healthcare

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systems; amidst crises, when rural healthcare labor becomes stretched and resources utilized, rural care facilities become quickly saturated, and take longer to recover back to baseline functionality than suburban or urban systems (Peters 2020).

Despite these established population health and social vulnerability concerns, and a great deal of research on the particular problems of rural healthcare (Afifi et al, 2022), few formalized benchmarks exist that allow policymakers to comparatively evaluate rural health system resilience. This is a critical deficiency for emergency preparedness, policy, and response, and leaves policymakers and other actors less equipped to comparatively evaluate the unique needs of rural, suburban, and urban health systems, respectively. While data limitations and considerable uncertainty regarding US population health will complicate any effort to rectify this limitation, an initial comparative framework at the county-level can offer an initial glimpse regarding rural health system resilience to disruption relative to others. Ultimately, such a schematic can better indicate which systems are at greatest risk of patient saturation and the possible imposition of crisis standards of care before disasters such as a human pathogen arrive. This article sets out to develop such a presentation.

1.1 Resilience and rural healthcare systems

Hollnagel et al. (2013) define resilience in healthcare as "a health care system's ability to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions". The capacity of a system to recover and adapt to disruption is an essential component of health system resilience, whereby healthcare practitioners and infrastructure are compelled to adjust to emergent conditions with patient intake in order to avoid triage-driven decision-making. Without effective recovery and adaptation, where health systems reduce overall utilization or develop efficiencies around new limitations, hospitals may become oversaturated. Possible downstream outcomes include requests to transfer patients to other facilities, potentially hundreds of miles away, or adherence to 'crisis standards of care', where many patients are stabilized yet not fully allowed to recover via inpatient resources. Both of these scenarios may result in worse health outcomes for patients (Cleveland Manchanda et al., 2020).

Similar definitions of health system resilience are noted below in Table 1, framing health system resilience as a holistic emergent property of healthcare providers, workers, infrastructure, institutions, and governance structures – all of which provide explicit value to the provision of patient and population healthcare, and seek to drive health system recovery away from heightened utilization and towards more sustainable levels of patient care. When encountering a disruption to one or more of these systems, the capacity for a healthcare system to deliver acute or preventative health services is impacted, where aggregate system resilience informs whether and how the provision of healthcare recovers and adapts to such disruption.

Kruk et al. (2015)	Health system resilience is the capacity of health actors, institutions, and populations to prepare for and effectively respond to crises; maintain core functions when a crisis hits; and, informed by lessons learned during the crisis, reorganize if conditions require it
Panter-Brick and Leckmann (2013)	Resilience is a process to harness resources to sustain well-being
Ager, Annan and Panter-Brick (2013)	Structural resilience is building robust structures in society that provide people with the wherewithal to make a living, secure housing, access good education and health care, and realize their human potential
Southwick et al. (2014)	Definitions of resilience range from a stable trajectory of healthy functioning after a highly adverse event; a conscious effort to move forward in an insightful and integrated positive manner as a result of lessons learned from an adverse experience; the capacity of a dynamic system to adapt successfully to disturbances that threaten the viability, function, and development of that system; and to a process to harness resources in order to sustain well-being
Kruk et al. (2017)	Resilience emphasizes the functions health systems need to respond and adapt to health shocks, introducing a dynamic dimension into more static health system models which can help the system cope with surges in demand and adapt to changing epidemiology and population expectations of care
Wagnild and Collins (2009)	Resilience is the ability to adapt or "bounce back" following adversity and challenge and connotes inner strength, competence, optimism, flexibility, and the ability to cope effectively when faced with adversity

By any definition, a pandemic is an exogenous shock that substantially alters the needs, incentives, and capacities of many components of local, regional, and national healthcare systems. In a pandemic, disruptions to limited

Table 1 Metrics and Data sources

Metric	Metric type	Source and data	Metric description	Number of counties included in data	Rationale for inclusion
PCPs per capita	System capacity	HRSA area health resources and AMA physician masterfile (via county health rankings) (2019)	Draws on the AMA physician master file and the area health resources file (AHRF) to estimate the number of primary care physicians per 100,000 population in a county. Primary care physicians are defined as general practitioners, internal medicine, pediatrics, and other non-specialists	3142	PCPs are among the first medical practitioners responding to Covid-19 cases and other health emergencies, especially in rural areas. The number of PCPs available in a county is thus critical to a county's capacity to weather health emergencies
Hospital beds per capita	System capacity	Health and human services data hub (2022)	Data are derived from annual hospital reports to CMS regarding hospital capacity. We then matched individual hospitals to their counties and then summed all beds within the county across all hospitals. We then calculated the number of beds per capita using 2020 population data from ACS	3142	The number of available, staffed hospital beds is a key measure of how many patients a local health system can manage overall. Areas with fewer hospital beds per capita will need to turn patients away or heavily triage care
ICU beds per capita	System capacity	Health and human services data hub (2022)	Data are derived from annual hospital reports to CMS regarding hospital capacity. We then matched individual hospitals to their counties and then summed all ICU beds within the county across all hospitals. We then calculated the number of ICU beds per capita using 2020 population data from ACS	3142	The number of available, staffed ICU beds is a key measure of how many patients a local health system can manage at short notice. Areas with limited ICU beds have limited capacity to mount responses to acute health emergencies
Percent of population uninsured	Access to care	Small area health insurance estimates (SAHIE) (2019)	Estimates the percentage of individuals among the total population without access to health insurance. Includes all counties except Kalawao county, HI, a small island community with fewer than 100 individuals	3141	Inadequate access to health insurance is often a deterrent for receiving adequate medical care. Areas with high percentages of uninsured are associated with worse underlying health and will receive an influx of sicker patients who put off care until their conditions have significantly worsened

Table 1 (continued)

Metric	Metric type	Source and data	Metric description	Number of counties included in data	Rationale for inclusion
Risk-adjusted mean reimbursements for medicare enrollees	Access to care	Dartmouth atlas of health care (2019)	Uses the centers for medicare and medicaid services (CMS) medicare claims database to estimate the mean, annual amount of medical spending for all medicare enrollees within a county. Rates of spending are adjusted to the age, sex and race distribution of the national medicare population using the indirect method. First, the national event rate for each age-sex-race category was computed. These rates were then applied to the © population to produce the expected number of events in the county. This adjustment helps standardize spending across areas with different distributions of risk factors	3139	Risk-adjusted mean reimbursements for medicare patients are widely used as a proxy for the overall cost of receiving care in a county. Patients may defer care in costlier areas, creating a sicker underlying population and restricting patient access to emergency care
% of Population with a long, solo driving commute	Access to care	American community survey, 5-year estimates (2016–20)	Derived from a question on the ACS survey asking individuals about the length of their commute. long, solo driving commutes are considered those that last over half an hour, require a car, and are conducted alone	3138	Infrastructure in rural areas is widely dispersed, often slowing or deterring access to care until a condition has severely worsened. The percentage of a population with a lengthy, solo driving commutes acts as a proxy for assessing the role geography plays in restricting care access
SVI index ranking	Risk mitigation	CDC social vulnerability index (2018)	The social vulnerability index (SVI) uses U.S census data to determine the relative social vulnerability of every county the SVI ranks each tract on 14 social factors and groups them into four related themes: socioeconomic status, household composition and disability, minority status and language, and housing and transportation. Each tract receives a separate ranking for each of the four themes, as well as an overall ranking. We use the overall ranking for each county	3142	The social vulnerability index acts as a proxy for understanding how social, economic, racial, and other disparities negatively impact a community during a health emergency. The SVI index is widely used as a proxy for a county's underlying ability to mitigate and respond to health risks

Table 1 (continued)

Metric	Metric type	Source and data	Metric description	Number of counties included in data	Rationale for inclusion
% Fully vaccinated against SARS-CoV-2	Risk mitigation	Vaccination coverage by county (via Covid Act now) (December 2021)	Defines fully vaccinated as all eligible adults (18 +) who have received a full dosage of the Covid-19 vaccine (two doses for Moderna/Pfizer, one dose for the J and J vaccine). Data are downloaded from Covid Act now, a nonprofit organization that partners with state and federal public health agencies to track Covid infections, deaths, and vaccinations. Some counties and state governments (particularly new hampshire) do not effectively track vaccinations, leading to a small number of counties (21) missing in the data	3121	The Covid-19 pandemic continues to strain health systems globally, with full vaccination the most effective tool for reducing infections and severe illness. Counties with low vaccination rates are at greater risk of being overwhelmed by a health emergency and thereby have less resilience. Covid-19 vaccination also reflects broader lack of compliance with public health measures, which likewise increases a county's risk

staffing pools (e.g., callouts, forced quarantine, etc.) can have outsized effects upon RHS ability to deliver care to patients and can mean that they prematurely reach patient saturation, particularly during times of heightened disease incidence. Existing heightened risk factors within rural populations could result in health systems becoming suddenly and unexpectedly inundated with new cases – overstretching bed and labor availability (Vestal, 2020). RHS often lack access to larger, more resilient, supply chains. Many have limited testing capacity and send tests to commercial labs that can take multiple days to return results. Often understaffed outside crisis, they can face serious workforce problems. RHS that lack slack can consequently experience system collapse and suboptimal and dangerous triage-based health care decision-making (Vestal, 2020). States like North Dakota, which has less than 20 ICU beds in the state (limited to hospitals in Dickinson, Fargo, and Bismark) saw the consequences of these concerns when patients had to be transferred as far as South Dakota or Montana to get the level of care needed (Vestal, 2020).

Many RHS lack resilience against external and internal stressors, so adding additional labor and resources can improve the capacity for the system to recover from spikes in demand for care that are inevitable in current and future crises. Because of potentially significant costs associated with adding a resilience component to RHS, careful resilience analytics and tradeoff analyses should be driving resource allocation. However, resilience is difficult to quantify due to the complex and diverse nature of its definition especially in attempting to compare across distinctly different communities.

Many remote, island or rural communities may exist within 'healthcare deserts' with 80% of the rural population in the United States being designated as medically underserved (Health Resources & Services Administration). Beyond being healthcare deserts, many rural communities exist within ICU deserts where 63% of rural hospitals are without any ICU beds, leaving 1 ICU bed available for approximately every 9500 rural Americans (The Chartis Group for Rural Health, 2020).

Data analysis conducted using susceptibility indicators taken from sources such as the US Census Bureau's American Community Survey (ACS), County Business Patterns, and US Centers for Disease Control and Prevention's National Vital Statistics System indicate that upwards of 33% of rural counties in the continental 48 states were highly susceptible to COVID-19. Existing issues facing rural health systems, such as rural hospital closures, increased vulnerability of rural health systems. These hospital closures, such as the closing of 62 hospitals with Emergency Departments from 2012 to 2018, saw the median distance to access an Emergency Departments increase from 3.3 miles to 24.2 miles as the crow flies during the same period

(Government Accountability Office, 2020). Pre-pandemic hospital closures further saw the loss of 2066 inpatient beds and 6347 full-time-employee equivalents from 2013 to 2017 further increasing the vulnerability of rural communities to health emergencies such as pandemics (Government Accountability Office, 2020). These closures have resulted in low-income and elderly patients, notable at-risk populations during the COVID-19 pandemic, being more likely to delay care because of transportation concerns (Medicaid and CHIP Payment and Access Commission, 2021). COVID-19 has resulted in half of the rural hospitals seeing negative operating margins and further magnified existing factors that contribute to hospital closures, further outlining the unique resilience concerns faced by rural health systems (ASTHO Staff, 2021).

Outside of these preexisting vulnerabilities, the COVID-19 pandemic exacerbated specific issues that include infrastructure limitations, poor population health, and long distances to access advanced healthcare when compared to non-rural health systems (Sharma, 2020). This susceptibility was driven by physician shortage, lack of mental health services, high disability, lower insurance rates, poor internet access inhibiting telemedicine use, and a lack of social capital hindering local recovery efforts (Peters, 2020). Insurance rates in particular demonstrated challenges within rural communities where individuals are more likely to be uninsured because individuals are often in jobs that do not offer insurance, resulting in limits to where many rural residents can go for care (Medicaid and CHIP Payment Access Commission, 2021). It is specifically this susceptibility, paired with the lack of resilience, that indicates the crucial need for a change in policy.

In short, is evident that RHS have different needs and challenges than their urban and suburban counterparts. Specifically, RHS are often resource-constrained or possess limited disposable resources, infrastructure, finances, and healthcare workforce relative to the needs of the surrounding region. They are designed for maximum efficiency with what resources they have available, can depend on transfers for critical cases, and have little slack or redundancy to adapt given a sudden internal shock (e.g., loss of labor) or exogenous disruption (e.g., a mass casualty event).

Given this, many RHS emphasize such efficiency within their labor force. RHS nurses are asked to perform more diverse functions on a regular basis than their urban or suburban counterparts. RHS in general needs more generalist approaches instead of more specialized skill sets in nurses and other healthcare workers (Skillman et al., 2013). Rural RNs, compared to their urban counterparts, are more likely to work full time and to be employed in public/community health, long-term care, and ambulatory care. They are also 3.5 times more likely to have a greater commute to work and are less likely to pursue baccalaureate or higher degrees in nursing which is reflected in the lower salary they receive (Skillman et al., 2006).

Community Health Centers (CHC) face other staffing and operating concerns because of the pandemic. Staffing furloughs, reduced hours, and decreased services in these health centers have resulted in the loss of revenue and the temporary closure of 1954 sites since May 8, 2020 (Infectious Disease Society of America, 2020). These staffing and operating affiliated concerns particularly demonstrate rural health concerns as CHC are key to providing healthcare to rural communities as well as other support services such as translation and transportation services for community members (Infectious Disease Society of America, 2020). Within a pandemic-specific context, these Community Health Centers are invaluable in reducing hospital burdens as they triaged patients and accounted for 90% of COVID-19 testing (Infectious Disease Society of America, 2020). While many of these closures are considered temporary, the vulnerability of these centers demonstrates unique concerns of rural communities when addressing how to build resilient health systems.

Another key concern throughout the COVID-19 pandemic has been a lack of access to personal protective equipment (PPE). With the majority of PPE (masks, gloves, ventilators, etc.) being allocated to urban health systems, this resource disparity further increased the vulnerability of rural health system resilience during an unprecedented year. Limits on stockpiling and the greater market power of larger healthcare providers suggest that this might recur in future crises.

An integral component of resilience, especially in rural healthcare settings, is the quality of care and the psychological well-being of healthcare workers. Preventing burnout and helping support the mental health of both healthcare workers and patients is a particular challenge due to existing shortages of qualified behavioral health professionals in rural environments (GAO, 2021). Concrete actions taken within healthcare systems to reduce the prevalence of provider burnout are essential to ensuring the quality of care and avoiding adverse implications to the resilience of the health workforce and its patients (Shah et al., 2020). Current RHS analysis relies on conventional parameters available at state and county-levels. These existing parameters include; disease incidence (daily new cases), disease case hospitalization rate (percentage of confirmed positive individuals requiring hospitalization or ICE admission), and an assessment of an RHS' labor and resources (counts of routine service beds, ICUS, and labor). These metrics have proven to be insufficient and demonstrate a shortage of rural research on COVID-19 due to ongoing issues with limited data on rural regions (Mueller et al., 2021).

It is evident that additional data and assessment are required to comprehensively understand the resilience challenges of RHS. This may be accomplished through three

different approaches. One approach would be to include shifting hospital labor and resource saturation expectations. Currently, rural nurses/practitioners perform a huge number of functions often simultaneously and saturation is reached at 75% bed utilization for an RHS compared to 85–90% for urban health systems. Other approaches include incorporating population health and comorbidity demographics by analyzing unique population health dynamics such as the prevalence of risk factors and comorbidities, and understanding resilience in terms of catchment i.e., size of the facility and an average distance of population to available routine service and ICU beds.

2 Methods

This paper creates an index measuring the resilience of rural health systems in response to disruptive health events. We overlay county-level data with HRRs to capture both local conditions, such as a county's underlying health risk, and the nature of healthcare referrals, which usually cover larger areas than a single county and are particularly important for an issue involving critical care such as COVID-19.

2.1 Data

To create our index, we draw on eight metrics spanning three categories that reflect health system resilience: System Capacity, Access to Care, and Risk Mitigation.

System Capacity refers to the ability of health systems to meet the demand for care. It is estimated using three metrics: the number of primary healthcare providers per capita, the number of ICU beds per capita, and the number of total hospital beds per capita. Data for the number of primary healthcare providers per capita in a county are drawn from the Area Health Resources File (2019), a publicly available source for information on health system infrastructure created by the Health Resources and Services Administration. Data for the number of hospital beds and ICU beds per capita are drawn from the Health and Human Services Data Hub on hospital utilization (2022). We aggregate data from individual hospitals at the county-level, summing the available beds at all facilities within a county's boundaries.

Access to Care refers to the ability of individuals in a county to receive care. We proxy this ability along two dimensions: financial access to care and physical access to care. Financial access is estimated using the percentage of uninsured individuals within a county (drawn from the 2019 Small Area Health Insurance Estimates) and by the local, risk-adjusted mean reimbursements for Medicare enrollees in 2019. The latter is a widely used proxy for local cost of care produced by the Center for Medicaid and Medicare Services and the Dartmouth Atlas of Healthcare (Chetty et al. 2016). We estimate physical access using the percentage of individuals in a county who commute alone in cars for more than half an hour from the 5-year American Community Survey (2016–20) via the County Health Rankings Data base at the University of Wisconsin Population Health Institute. This measure helps identify counties that require considerable travel to access healthcare facilities and other types of health infrastructure.

Risk Mitigation refers to the underlying characteristics of a county that mitigate the risk of a health emergency. We estimate this risk using two metrics: the CDC/ATSDR Social Vulnerability Index (2018) for counties and Covid Act Now estimates of county-level Covid-19 vaccination rates (July 2022). The Social Vulnerability Index (SVI) is a widely used index created by the CDC that aggregates 15 US census variables to assess community resilience to stresses on human health. The 15 variables fall across four categories of vulnerability: socioeconomic status, household composition and disability, minority status and language, and housing type and transportation. All counties are given a rank for each variable and each of these ranks is averaged to create a composite ranking for each county. We use the composite ranking in our analysis. We use county-level Covid-19 vaccination rates to estimate both a county's vulnerability to Covid-19 outbreaks and as a proxy for adherence to public health guidelines. We define vaccination rates as the percentage of individuals who have received a full dose of a Covid-19 vaccine out of the total county population as of July 2022.

All 8 metrics are tabulated at the county-level and merged into one dataset using FIPS codes. Each metric, its date and source, and our rationale for its inclusion can be found in Table 1. Our combined dataset includes data for 3113 counties, ~ 99% of all counties in the United States, and excludes US territories. Our missing 29 counties lack one of our eight data points at the county-level, most commonly Covid-19 vaccination data. All states have most counties included except for New Hampshire, which lacks reliable county-level Covid-19 vaccination data and is thereby excluded from our analysis.

To create a standardized resilience index, we created a percentile rank for each county for each individual measure, then averaged all percentile ranks together within our three resilience categories, and then averaged each county's categorical rank for a final, single measure of county resilience.

We modeled the creation of our standardized resilience index on the methodology used by the CDC's Social Vulnerability Index (one of the metrics included in our study). Like the SVI, we first created percentile ranks for each county across all 8 of our variables (i.e., for each variable we compared all counties against one another and assigned them a ranking). Percentile ranks allow us to standardize each of our variables along a 0–100 range. We then grouped the percentile rankings into our three umbrella categories for

health system resilience: System Capacity, Access to Care, and Risk Mitigation, and calculated the average percentile ranking for each category. For example, to estimate a county's average percentile ranking for Access to Care, we calculated the mean of the percentile rankings for uninsured rate, the risk-adjusted mean reimbursement for Medicare enrollees, and the % of the population with a solo driving commute over 30 min. To create a final, overall score, we then calculated the mean of each county's average percentile ranking for System Capacity, average percentile ranking for Access to Care, and average percentile ranking for Risk Mitigation. This approach evenly weights the three categories we identify as crucial to rural health system resilience when calculating a county's overall index score. Thus, all counties receive a percentile ranking for each variable, an averaged percentile ranking for our three categories, and an overall index score for their health system resilience.

Our method is summarized in the three equations below. The first equation displays our formula for calculating percentile ranks for each of our 8 variables. R represents the percentile rank of each county for its respective variable; p_v represents the percentile of each county for its respective variable; n represents the total number of counties. The second equation shows our formula for averaging percentile ranks (R_i) within each umbrella category to create a categorical score (S_c). The third equation shows our formula for averaging categorical scores (S_{c_i}) to create our final overall index score for a county's health system resilience (S_r).

$$\mathrm{R} = \frac{p_v}{100(\mathrm{n}+1)} \tag{1}$$

$$S_{c=}\frac{1}{n_r}\sum_{i=1}^{n_r} R_i \tag{2}$$

$$S_{r=}\frac{1}{n_c}\sum_{i=1}^{n_c} S_{c_i} \tag{3}$$

3 Results

Our index allows for conclusions to be drawn regarding the impact of rurality on health system resilience throughout the COVID-19 pandemic. Fig. 1 illustrates that rural counties in the South, South East, and North West tend to perform

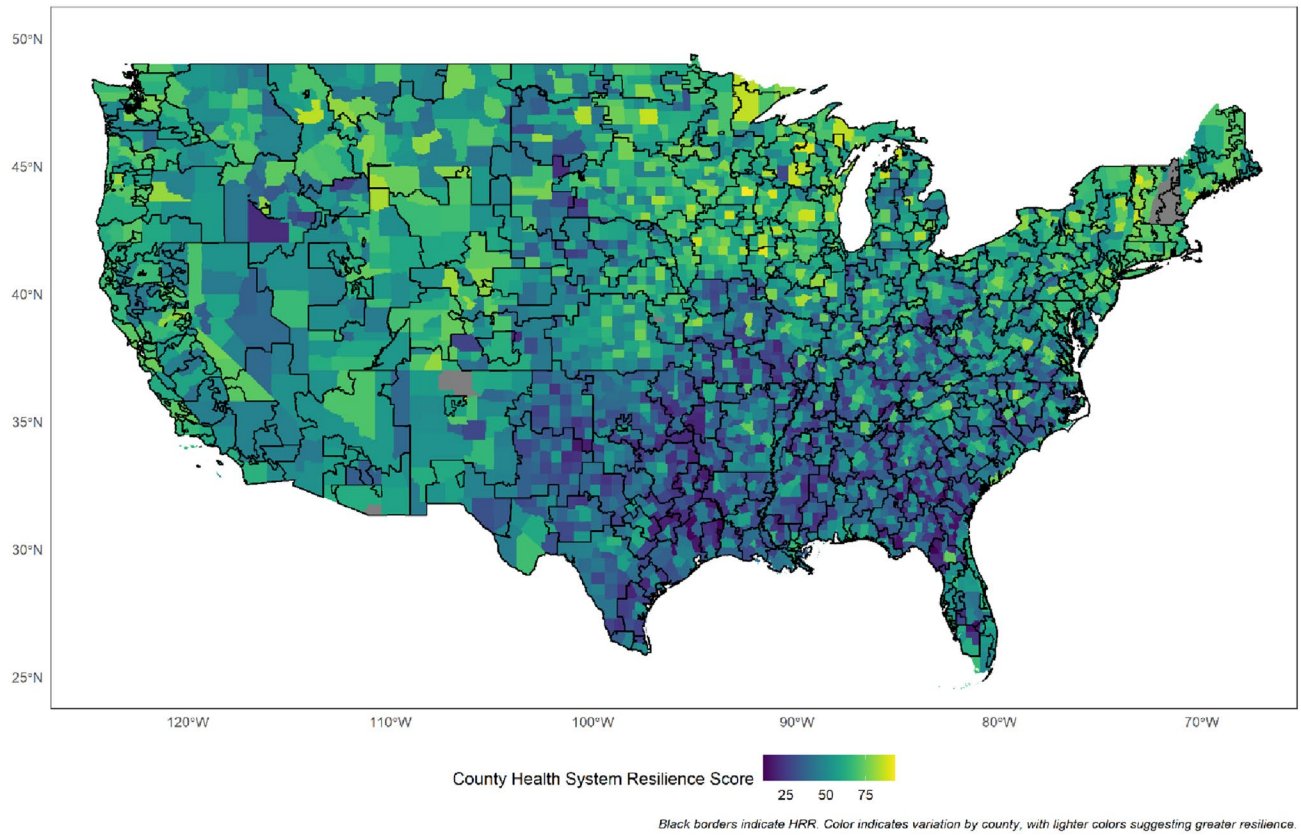

Fig. 1 Health System Resilience Index, *Note* Black borders indicate HRR. Colors indicate variation by county; darkest colors are counties with the lowest resilience scores. Gray indicates counties that are omitted due to missing data

poorly in a higher number of categories compared to their urban counterparts. The darker lines denote the HRRs. Particular areas of concern are entire HRRs with high levels of vulnerability- HRRs in which the whole set of healthcare providers could be overwhelmed by care needs in a health emergency.

Figure. 1 identifies weak health system resilience in individual counties around the country. System-level weaknesses are identified by ranking three categories of health system resiliency—system robustness, access to care, and underlying health risk—and summing the number of categories in which a county ranks in the bottom quartile. In other words, it shows compounding and serious risks. The HRR boundaries are then drawn in thick lines in order to show the rough boundaries of healthcare referral networks.

The most presumptively threatened areas are HRRs that are primarily made up of high-vulnerability areas because they combine a variety of risks across one healthcare system (e.g., referral region). They are concentrated in the South and parts of the rural Midwest. Both the county-level index and the HRRs show the interconnectedness of risks: for example, having substantial healthcare capacity is unlikely to compensate for underlying risks and inequality. Having substantial healthcare capacity in part of an HRR cannot necessarily compensate for high levels of underlying risks across that HRR because the capacity might be easily overloaded.

4 Discussion

While much public health data, and emergency preparedness and response policy, is determined at the county-level, many healthcare systems in rural areas span more than one county, which limits the usefulness of county-level analysis. The interaction of HRR borders with county-level vulnerabilities is thus important. It is unreasonable to expect most rural counties to be self-sufficient in healthcare. They are part of broader healthcare systems, which can be very large areas in thinly populated regions. The likelihood of catastrophic stressors on healthcare in rural areas comes from the interaction of county-level vulnerability and resilience within HRRs, with dependencies within and between health systems potentially generating cascading systemic disruption if not adequately resolved (Linkov et al., 2022). Thus, an HRR with a dense concentration of healthcare systems surrounded by relatively resilient counties will be more resilient than one with a dense concentration of healthcare resources surrounded by less resilient counties.

The greatest dangers, found mostly across the South, will be in HRRs with consistently high levels of vulnerability. Those regions, we can expect, will rapidly run out of critical care, and even health care, resources. Put another way, the highest risks we saw were in HRRs where the anchor is a micropolitan area serving a rural area. In those areas, such as the high plains states and much of the south, the rural counties have very limited health infrastructure and their service center does not have much surge capacity.

This approach still has limitations. We chose to use HRRs for our map of health systems because they are the normal referral networks. Hospital Service Areas, which are considerably larger, tend to include larger cities and might put health care system vulnerability in a different light. We do not have a clear measure of the ability of healthcare providers to transfer staff, e.g., using medical specialists outside their field. Another issue that cannot be worked out quickly with available data is the effects of delayed care. The best data on care are claims data (Medicare or private), but that is not always easily available and is usually at least several months old. It might be used to estimate the total backlog of delayed care in an area from the first year of the pandemic. Many counties had missing COVID-19 vaccination data, and there is some variation in how this data are collected due to variations in state and local policy. Key measures of healthcare access, e.g., effective measurement of healthcare acceptability and disparities, are not collected by county. Better measures of cost and other barriers to access would be very helpful in understanding rural healthcare.

Given this evident resilience disparity, a data-driven methodology that assesses resilience-based challenges for RHS is needed to better assess (a) what single-points-of-failure exist within the RHS operations and labor pool, (b) the conditions when those points of failure are leveraged, and (c) the balance of efficiency compared to resilience-based investments in designing RHS crisis response (Jin et al., 2021). From this, it is possible to derive a targeted strategy to improve RHS resilience by indicating the specific labor and resource support needed to meet the diverse healthcare needs of disparate rural populations through pandemic crises.

5 Conclusion

The resilience of rural health care, run as it is under challenging geographic, workforce, and economic circumstances, is widely known to be a problem for public policy. The COVID-19 pandemic underlined the extent to which rural health care resilience is a distinct problem, but also one that varies a great deal between different rural areas.

The rural health care resilience index that we present here shows the resilience of different health care markets and allows us to better increase resilience and prepare for threats. It has a number of advantages that make it useful for policymakers in understanding and attempting to build resilience in the face of COVID-19 and future, as yet unanticipated, challenges. Focusing on HRR-level resilience puts

the attention on the particular ways health care systems operate and patients flow, while the population data anticipates vulnerability. It shows the need for state and federal policymakers to not just engage with the particular vulnerabilities of rural health, but also to the diversity of challenges within rural areas and the mutually reinforcing vulnerabilities of many.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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