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The digital divide in access to broadband internet and mental healthcare

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Khushi Kohli[1], Bhav Jain[2], Tej A. Patel[3], Hatice Nur Eken[4], Edward Christopher Dee[5] & John Torous[6]

Telemedicine has greatly improved mental healthcare access worldwide, particularly following the COVID-19 pandemic. However, the growing reliance on broadband internet-based mental healthcare raises concerns surrounding telemedicine's accessibility in communities already facing barriers in seeking mental health information and care. This study aims to (1) correspond access to broadband internet with access to several mental health resources and (2) quantify the association between social determinants of health and broadband access in the United States. For each of 3,138 US counties, we collected data for the percentage of households without broadband access, the density of various mental healthcare services, urbanization level, and percentage of households with an income below the poverty line. Two-sample *t* tests and two-proportion *z* tests were used to substantiate the association between broadband access and mental health resource availability, while multivariate linear regressions were performed to quantify the association between broadband internet access and mental health resource availability, while controlling for urbanicity level and poverty rate. Finally, geographical trends in broadband access and mental health services were visualized in QGIS. US counties with reduced broadband access have lower average densities of mental healthcare physicians, non-physician mental health practitioners, inpatient psychiatric and substance abuse treatment facilities, and outpatient facilities ($P < 0.001$). Moreover, counties with reduced broadband access are nearly three times as likely to have no mental health physicians and no outpatient facilities, over twice as likely to have no non-physician mental health practitioners, and nearly twice as likely to have no psychiatric/substance abuse hospitals ($P < 0.001$). These results suggest that expanding access to mental health resources in rural, low-income, and medically under-resourced communities is necessary in light of their reduced access to both broadband internet and mental healthcare services.

Although the prevalence of mental illness in the United States is similar between rural and urban communities, individuals in rural areas experience lower treatment rates, worse mental health outcomes, and reduced access to providers with specialized training compared with their urban counterparts.[1] Rural–urban disparities in mental health treatment rates and outcomes are well characterized in the literature and tend to be driven by reduced access to providers and treatment facilities, increased stigma and reduced education surrounding mental

A full list of affiliations appears at the end of the paper. e-mail: jtorous@bidmc.harvard.edu

health, a shortage of mental healthcare professionals trained for specialty care in rural areas, limited access to transportation and insurance, financial barriers to care, and reduced utilization of mental healthcare services in rural areas.[1] Moreover, while rural communities make up just 20% of the US population, roughly 60% of federally designated health-professional shortage areas are located in rural regions.[2]

Improving access to mental healthcare resources in rural areas remains a key health policy goal; however, numerous challenges exist in drawing more physicians and funding for rural healthcare. Indeed, as rural physicians approach retirement, studies predict a 23% decrease in rural healthcare providers by 2030.[3] Many medical students are dissuaded from pursuing rural healthcare due to fewer job opportunities for spouses, school districts with limited resources, and the possibility of a lower income, which may be a significant financial burden for physicians with large student debts.[2] Moreover, recent estimates suggest that the United States is facing a shortage of approximately 6,400 mental health providers, 1,600 of whom are needed in rural areas alone.[4] Yet physician placements and funding tend to be directed to urban facilities, which serve the majority of patients.[5]

During the COVID-19 pandemic and the resulting recession, the share of US adults reporting anxiety or depression symptoms rose from 11% to 41%, underscoring America's heightened need for mental healthcare expansion.[6] To meet the growing demand for mental healthcare in the United States, particularly in rural areas with already reduced access to mental healthcare, telemedicine was touted as an effective solution to increase equitable access to mental healthcare. By reducing travel time and expenses, reducing COVID-19 exposure risk, addressing mobility limitations, and reaching rural patients experiencing a lack of nearby in-person services, virtual mental healthcare appointments mitigated many physical and financial barriers to care.[7] As a result, telehealth utilization is now 38 times the pre-COVID-19 level.[8]

The rapid growth of telemedicine utilization highlights the importance of broadband internet access, particularly in communities facing substantial infrastructural and financial barriers to accessing mental healthcare. Access to broadband internet is integral for patients to be able to access the full functionalities of telemedicine, including synchronous video visits with a mental healthcare professional, asynchronous messaging through a patient portal, and the use of devices that remotely record vitals and symptoms. Beyond its direct uses in telemedicine, broadband internet access improves access to mental health information available online.[9] Meanwhile, reduced access to broadband in areas already experiencing mental healthcare shortages may create and exacerbate disparities in mental health treatment access. Given the intricately linked relationship between access to broadband internet and telehealth access, broadband availability may serve as a valuable proxy in characterizing access to telehealth. Yet to our knowledge, there is no formal assessment corresponding broadband internet access with access to physical mental healthcare sites, services, facilities, and personnel. Disparities in broadband access at the intersection of urbanicity and poverty are also not well understood.

Exploring patterns of geographic and socioeconomic disparities in broadband access and mental healthcare can identify particular regions and populations that may benefit from interventions designed to improve access to mental healthcare treatment. Moreover, quantifying these disparities may inform the development and scalable public health interventions designed to increase equity in access to broadband and mental healthcare resources. Therefore, in this study, we used data from the Federal Communications Commission (FCC) and the National Neighborhood Data Archive to assess associations between disparities in broadband internet access and mental health support.[10,11] We also used data from the National Center for Health Statistics and the United States Census Bureau's American Community Survey to characterize disparities in broadband access with regard to urbanicity and poverty.[12,13]

Results

Access to several forms of mental healthcare was assessed for (1) all US counties, (2) all US counties with low broadband access, and (III) all US counties with high broadband access. Counties with low broadband access were defined as those in which the percentage of households without broadband was greater than the national median of 26.5%, and counties with high broadband access were defined as those in which the percentage of households without broadband was less than the national median. Across US counties, we calculated a national average of 7.03 mental healthcare physicians, 10.86 non-physician mental health practitioners, 1.48 psychiatric and substance abuse hospitals, 19.84 pharmacies and drugstores, 1.18 inpatient psychiatric and substance abuse treatment facilities, and 12.33 outpatient facilities available per 100,000 members of the population. For US counties with a high percentage of households without broadband, we observed reduced densities of all 6 mental health services, with an average of 3.63 mental healthcare physicians, 2.86 non-physician mental health practitioners, 1.33 psychiatric and substance abuse hospitals, 19.61 pharmacies and drugstores, 0.94 inpatient psychiatric and substance abuse treatment facilities, and 11.28 outpatient facilities available per 100,000 members of the population. For US counties with a low percentage of households without broadband, we observed increased densities of all 6 mental health services, with an average of 7.43 mental healthcare physicians, 11.80 non-physician mental health practitioners, 1.50 psychiatric and substance abuse hospitals, 19.87 pharmacies and drugstores, 1.21 inpatient psychiatric and substance abuse treatment facilities, and 12.45 outpatient facilities available per 100,000 members of the population (Table 1).

A two-sided *t* test indicated that the difference in the density of mental healthcare services between counties with high and low broadband access was significant for mental healthcare physicians ($P < 0.001$), non-physician mental health practitioners ($P < 0.001$), inpatient psychiatric and substance abuse treatment facilities ($P < 0.001$), and outpatient facilities ($P < 0.001$). However, the differences were not significant for the densities of psychiatric and substance abuse hospitals or pharmacies and drugstores (Table 1).

Moreover, counties with a high percentage of households lacking broadband access were at far greater risk of having no providers of each service. Among counties with a high percentage of households without broadband, 60.14% have no mental healthcare physicians, 73.81% lack non-physician mental health practitioners, 79.08% lack psychiatric and substance abuse hospitals, 11.06% lack pharmacies and drugstores, 84.62% lack inpatient psychiatric and substance abuse treatment facilities, and 30.01% lack outpatient facilities. However, among counties with a low percentage of households without broadband, 23.32% have no mental healthcare physicians, 30.93% lack non-physician mental health practitioners, 45.94% lack psychiatric and substance abuse hospitals, 1.98% lack pharmacies and drugstores, 50.54% lack inpatient psychiatric and substance treatment facilities, and 11.12% lack outpatient facilities (Table 1). A two-proportion *z* test indicated that the differences in the percentage of high broadband access and low broadband access counties with zero providers were statistically significant for all six mental health services ($P < 0.001$).

In addition, multivariate linear regressions were performed to quantify the association between broadband internet access and access to six mental healthcare resources using urbanicity level and the poverty rate of each county as covariates. Multivariable linear regression models demonstrated that reduced broadband access was significantly associated with reduced access to all six mental healthcare services. Specifically, a 1% increase in the proportion of a county's population lacking broadband access is associated with a decrease of 0.0452 non-physician mental health practitioners ($P < 0.001$), 0.00578 psychiatric/substance abuse hospitals ($P = 0.00571$), 0.00835 inpatient psychiatric and substance abuse treatment facilities ($P < 0.001$), 0.0272 mental

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Table 1 | Density of six mental healthcare services in US counties, stratified by broadband access (two-sided *t* test and two-proportion *z* test)

		All US counties	US counties with percentage of individuals without broadband access ≥ median	US counties with percentage of individuals without broadband access < median
Mental healthcare physicians	Average count per 100,000 population	7.030413	3.629814	7.432941
	P value (two-sided *t* test)	–	<0.001	–
	Average percentage of counties with no providers	41.7782 (1,311/3,138)	60.13986 (946/1,573)	23.32268 (365/1,565)
	P value (two-proportion *z* test)	–	–	–
Non-physician mental health practitioners	Average count per 100,000 population	10.85779	2.861839	11.80427
	P value (two-sided *t* test)	-	<0.001	-
	Average percentage of counties with no providers	52.42192 (1,645/3,138)	73.80801 (1,161/1,573)	30.92652 (484/1,565)
	P value (two-proportion *z* test)	–	<0.001	–
Psychiatric and substance abuse hospitals	Average count per 100,000 population	1.482365	1.33361	1.499973
	P value (two-sided *t* test)	-	0.381	-
	Average percentage of counties with no providers	62.55577 (1,963/3,138)	79.08455 (1,244/1,573)	45.94249 (719/1,565)
	P value (two-proportion *z* test)	–	<0.001	–
Pharmacies and drugstores	Average count per 100,000 population	19.84336	19.60688	19.87136
	P value (two-sided *t* test)	–	0.242	–
	Average percentage of counties with no providers	6.532823 (205/3,138)	11.06167 (174/1,573)	1.980831 (31/1,565)
	P value (two-proportion *z* test)	–	<0.001	–
Inpatient psychiatric and substance abuse treatment facilities	Average count per 100,000 population	1.18203	0.9392741	1.210765
	P value (two-sided *t* test)	–	<0.001	–
	Average percentage of counties with no providers	67.62269 (2,122/3,138)	84.61538 (1,331/1,573)	50.54313 (791/1,565)
	P value (two-proportion *z* test)	–	<0.001	–
Outpatient facilities	Average count per 100,000 population	12.3266	11.27923	12.45058
	P value (two-sided *t* test)	–	<0.001	–
	Average percentage of counties with no providers	20.58636 (646/3,138)	30.00636 (472/1,573)	11.11821 (174/1,565)
	P value (two-proportion *z* test)	–	<0.001	–

healthcare physicians ($P < 0.001$), 0.0779 pharmacies and drugstores ($P < 0.001$), and 0.0488 outpatient facilities ($P < 0.001$) per 100,000 people (Table 2). High poverty rates were also associated with differential access to several mental healthcare services. A 1% increase in a county's percentage of people living below the poverty line was associated with a decrease of 0.0420 non-physician mental health practitioners ($P = 0.0170$) and 0.0319 mental healthcare physicians ($P = 0.0324$). However, a 1% increase in a county's poverty rate corresponded with an increase of 0.0165 psychiatric/substance abuse hospitals ($P = 0.024$), 0.0789 pharmacies and drugstores ($P = 0.0163$), and 0.0741 outpatient facilities ($P = 0.00307$) (Table 2).

In addition, county urbanicity was associated with differential access to certain mental healthcare services. More specifically, a one-point increase in a county's 2013 Urban–Rural Classification Scheme score (Table 3, as defined by the 2013 National Center for Health Statistics) was associated with a decrease of 1.08 non-physician mental health practitioners ($P < 0.001$) and 0.206 mental healthcare physicians ($P = 0.0211$). A one-point increase in a county's 2013 Urban–Rural Classification Scheme score was also associated with an increase of 2.098 pharmacies and drugstores ($P < 0.001$) and 0.409 outpatient facilities ($P = 0.00649$) (Table 2).

Finally, heatmaps were created to visualize the following variables for each US county: urbanization-level classification (Fig. 1a), the percentage of households without broadband access (Fig. 1b) and percentage of households below the poverty line (Fig. 1c), and the density of mental health physicians, non-physician mental health practitioners, psychiatric and substance abuse hospitals, pharmacies and drugstores, inpatient facilities for mental health or substance abuse care, and outpatient facilities (Fig. 2a–f). The heatmaps provided additional insights into the disparities regarding broadband and mental health service access across US counties. We found that areas in the Midwest, West, and Alaska appear to have relatively high percentages of households lacking broadband access and lower densities of mental health treatment services.

Table 2 | Estimates and standard errors quantifying the effect of county broadband access, poverty rate, and urbanization level on access to six physical mental healthcare services, sites, and personnel (two-sided *t* test)

		Estimate	Standard Error	*t*	*P* value
Non-physician mental health practitioners	Intercept	11.9062514	0.60169	19.7879	<0.001
	Percentage without broadband	−0.0451765	0.00502	−9.00421	<0.001
	Percentage below the poverty line	−0.0420054	0.01758	−2.38887	0.017
	Urbanization level (2013 Urban–Rural Classification Scheme for Counties)	−1.0817868	0.10547	−10.2568	<0.001
Psychiatric/ substance abuse hospitals	Intercept	1.00527156	0.25045	4.0139	<0.001
	Percentage without broadband	−0.0057769	0.00209	−2.7662	0.006
	Percentage below the poverty line	0.01650889	0.00732	2.25561	0.024
	Urbanization level (2013 Urban–Rural Classification Scheme for Counties)	0.00834834	0.0439	0.19016	0.849
Inpatient psychiatric and substance abuse treatment facilities	Intercept	1.15656741	0.25422	4.54949	<0.001
	Percentage without broadband	−0.0083513	0.00212	−3.93961	<0.001
	Percentage below the poverty line	−0.0018721	0.00743	−0.25199	0.801
	Urbanization level (2013 Urban–Rural Classification Scheme for Counties)	0.04736607	0.04456	1.06293	0.288
Mental healthcare physicians	Intercept	7.13480238	0.50981	13.9951	<0.001
	Percentage without broadband	−0.0271911	0.00425	−6.3963	<0.001
	Percentage below the poverty line	−0.0318896	0.0149	−2.14045	0.032
	Urbanization level (2013 Urban–Rural Classification Scheme for Counties)	−0.2062321	0.08936	−2.30779	0.021
Pharmacies and drugstores	Intercept	11.8849624	1.12215	10.5913	<0.001
	Percentage without broadband	−0.0778933	0.00936	−8.32451	<0.001
	Percentage below the poverty line	0.07884324	0.03279	2.40424	0.016
	Urbanization level (2013 Urban–Rural Classification Scheme for Counties)	2.09769597	0.1967	10.6645	<0.001
Outpatient facilities	Intercept	8.85560619	0.85676	10.3361	<0.001
	Percentage without broadband	−0.0488173	0.00714	−6.83315	<0.001
	Percentage below the poverty line	0.07419288	0.02504	2.96322	0.003

Discussion

Telemedicine has been championed as an innovative solution to improve access to mental healthcare in communities with reduced mental healthcare resources. However, whether these communities have the necessary broadband infrastructure to access the full functionalities of telemedicine has not been well studied.[14] In this study corresponding broadband access with mental healthcare access in 3,138 US counties, we found that US counties with reduced broadband access have lower average densities of mental healthcare physicians, non-physician mental health practitioners, inpatient psychiatric and substance abuse treatment facilities, and outpatient facilities. These differences were found to be statistically significant. Moreover, counties with reduced broadband access are at a far greater risk of having no providers of each service in the region, particularly mental health physicians, non-physician mental health practitioners, psychiatric and substance abuse hospitals, and outpatient treatment facilities. These findings underscore that, while telemedicine may mitigate many key barriers to in-person mental healthcare, lack of broadband access may present an additional barrier to care for individuals already living in medically under-resourced communities. In a secondary analysis, we found that broadband access tends to be lower in areas that are rural and/or have high poverty rates.

Our findings corroborate previous studies that illustrate the manifold sociodemographic disparities in access to broadband internet. For example, several studies suggested that rural areas with larger Black and American Indian/Alaska Native populations, lower educational attainment, and higher poverty rates tend to have less broadband access.[15] These results also support several previous studies that have found substantial shortages in mental healthcare professionals occurring disproportionately in rural areas.[16] In addition, this study expands on the literature by directly corresponding broadband access with

Table 3 | Summary of the 2013 Urban–Rural Classification Scheme for Counties

Urbanization level	Definition
Large central metro (1)	A county in a metropolitan statistical area (MSA) containing a population of at least 1 million that (1) contains the entire population of the MSA's largest city, (2) has its entire population within the MSA's largest city, or (3) has a population of at least 250,000 in any of the MSA's principal cities
Large fringe metro (2)	A county in an MSA with a population of at least 1 million that does not meet the conditions for a large central metro county
Medium metro (3)	A county in an MSA with a population between 250,000 and 999,999
Small metro (4)	A county in an MSA with a population less than 250,000
Micropolitan (5)	A county in a micropolitan statistical area
Non-core (6)	A county that is not located in a metropolitan or micropolitan statistical area

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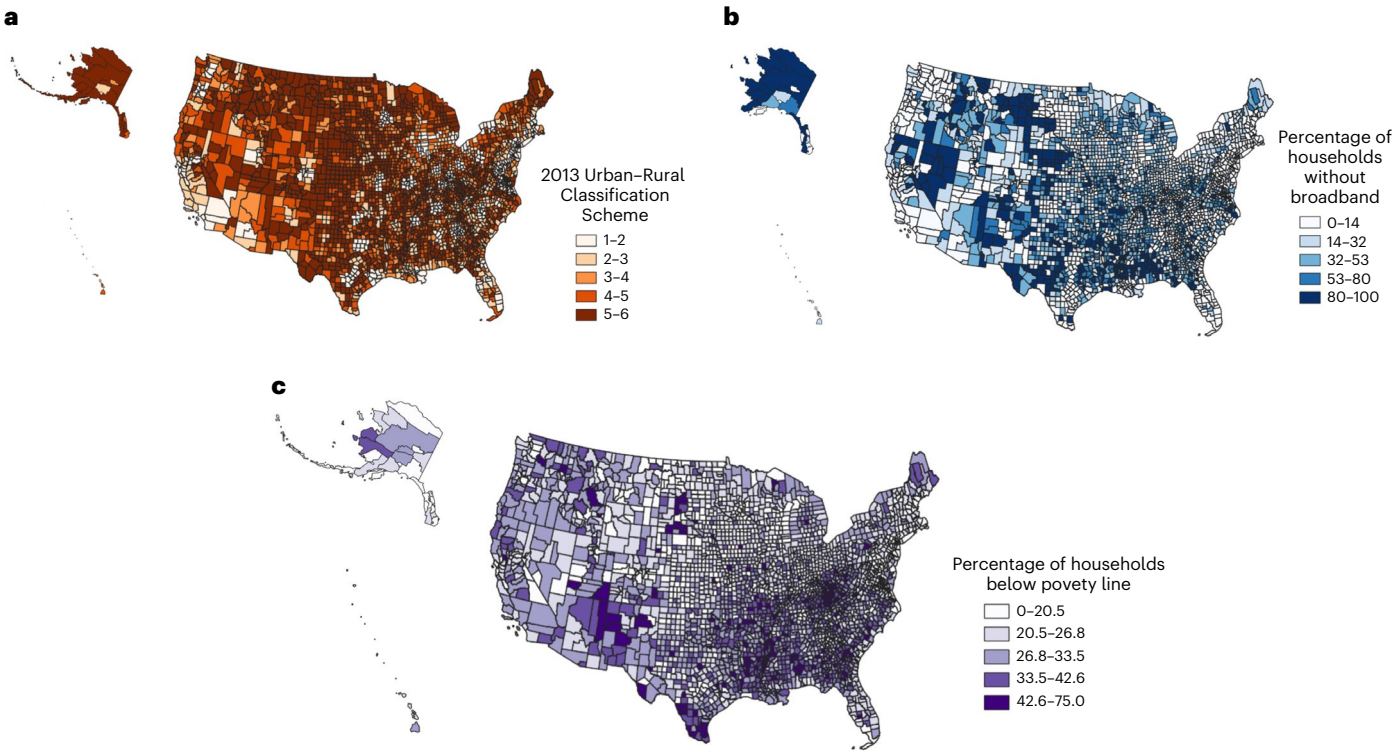

Fig. 1 | Geographical distributions of rural areas, broadband, and poverty. a, 2013 Urban–Rural Classification Scheme. **b**, Percentage of households without broadband access. **c**, Percentage of households below the poverty line.

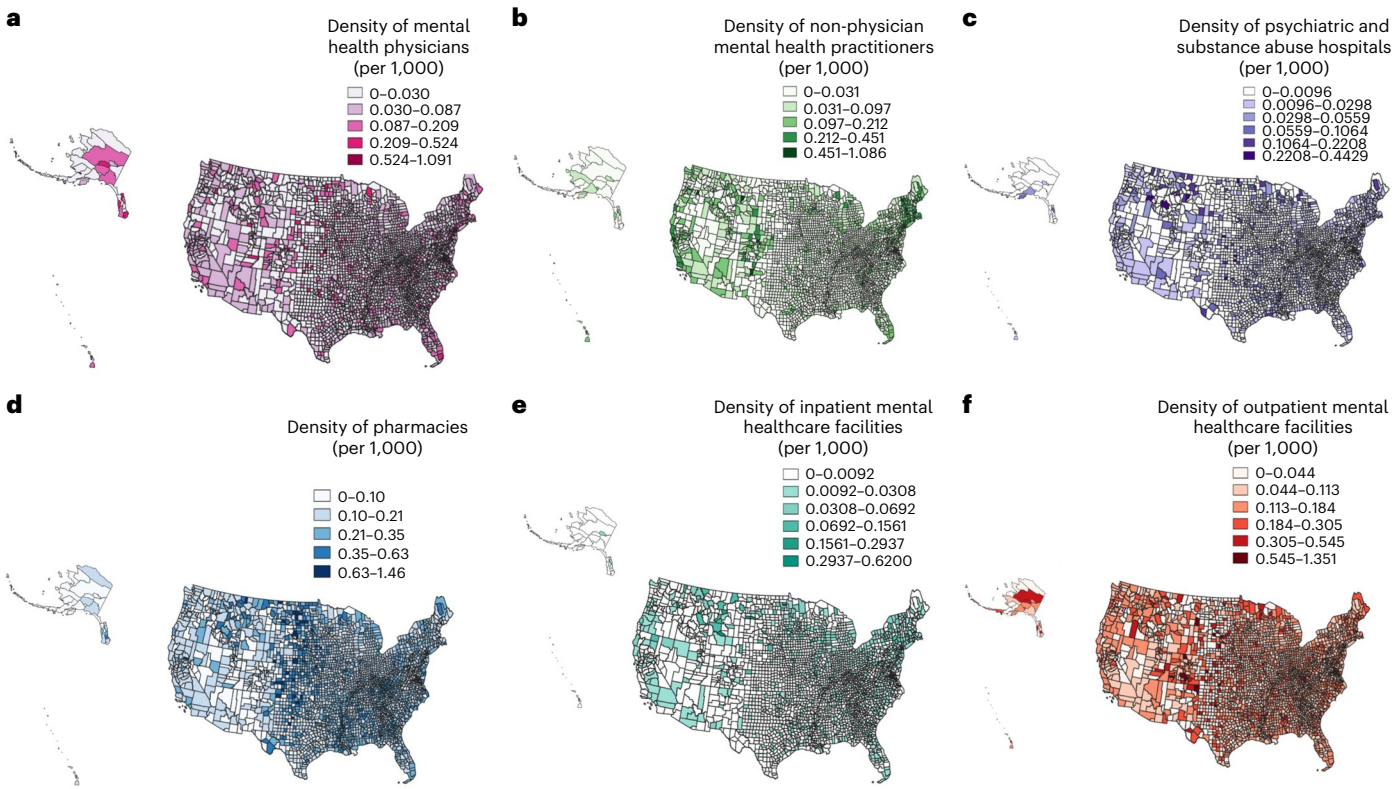

Fig. 2 | Geographical distributions of mental health and substance abuse clinicians and facilities. a, Density of mental healthcare physicians (per 1,000). **b**, Density of non-physician mental health practitioners (per 1,000). **c**, Density of psychiatric and substance abuse hospitals (per 1,000). **d**, Density of pharmacies/drugstores (per 1,000). **e**, Density of inpatient psychiatric and substance abuse treatment facilities (per 1,000). **f**, Density of outpatient facilities (per 1,000).

access to mental healthcare services at each level from diagnosis to treatment—including physicians and non-physician mental health professionals, psychiatric hospitals, inpatient and outpatient treatment facilities, and pharmacies and drugstores.

The clear association of broadband access with mental healthcare access, urbanization level, and poverty rate characterized here raises the question of whether under-resourced areas simply have lower demand for these services. However, previous studies have established that mental healthcare needs are similar in rural and urban areas. One study found mental illness incidence rates to be 17.3% in large metropolitan counties and 18.3% overall in non-metropolitan counties. The study also found rates of serious adult mental illness to range from 3.8% in large metropolitan counties to 4.7% in non-metropolitan counties.[16] Furthermore, suicide rates in the most rural communities have been found to be nearly twice those of their urban counterparts.[17] Poverty has also been linked to a higher mental illness incidence. In fact, one study found that children in the poorest households have a threefold increase in the risk of having a mental illness compared with children in the wealthiest households.[18,19] Thus, our study and previous studies highlight a clear maldistribution of both in-person and virtual mental healthcare resources.

Disparities in access to mental healthcare resources are particularly pronounced for outpatient care. In fact, counties with reduced broadband access are nearly three times more likely to have no outpatient treatment facilities, which typically offer services such as mental illness screening, outpatient counseling, substance abuse services, and trauma services accessible from the patient's home.[20] This is particularly concerning since outpatient care plays a uniquely important role in providing early mental health screening, diagnoses, and interventions due to the speed, reduced costs, and increased convenience of outpatient care. Moreover, given that many psychiatrists choose to go into outpatient services, the lack of outpatient treatment facilities may exacerbate barriers faced by rural populations in accessing mental healthcare services and prescriptions.

This issue is exacerbated by the striking disparities in access to pharmacies and drugstores in communities with reduced broadband access: counties with reduced broadband access are over five times more likely to have no pharmacies and drugstores. Thus, if broadband internet—and by extension telehealth—is not readily accessible in areas with limited outpatient services and medication access, the risk of treatment delay and serious mental illness increases dramatically.[21] Indeed, rural communities demonstrate an increased prevalence of specialized, serious, and persistent mental illnesses, including psychological distress, adolescent major depressive episodes, and suicide compared with their urban counterparts.[22] Moreover, the increased prevalence of serious mental illness in rural areas may also contribute to rural–urban disparities in the criminalization of mental health disorders.[23] Together, these findings highlight a clear need for increased and immediate access to specialized mental healthcare services in rural communities.

While we have presented a clear need for the expansion of broadband access in medically under-resourced communities, there remain many challenges in expanding both telehealth infrastructure (in the form of broadband internet) and in-person mental healthcare resources in these areas. Of particular importance, because rural businesses and homes are located far apart from one another, installing fiber-optic cables across many miles for a small number of paying customers presents internet service providers with the challenge of geographical barriers and a limited profit margin.[24] Economic barriers also prevent the expansion of healthcare facilities in rural areas.

Given the negative mental health consequences of limited access to broadband in areas with limited mental healthcare resources for screening, diagnosis, and treatment, it is imperative to develop solutions that enable more equitable access to broadband internet and telehealth in medically under-resourced communities.[25] One of the first steps that can be taken by policymakers is increased investment in broadband internet infrastructure in rural and low-income communities—including urban communities with high poverty rates—through programs such as the Broadband Infrastructure Finance and Innovation Act in the United States. In recent decades, broadband internet access has become a super-determinant of health, linking individuals to vital resources such as education, health information, food, employment, and health professionals.[9]

Another potential solution may be to invest resources into training a variety of mental healthcare personnel to be deployed in rural settings, including physicians, non-physician mental health practitioners, physician assistants, and social workers. Ideally, these professionals would be deployed in outpatient settings, where screening, prevention, and diagnosis are emphasized. Mobile phone-based technology may also serve as a key tool in improving access to mental healthcare in rural communities. An additional approach to address the issue of broadband internet and telehealth access in rural communities is integrated and collaborative care models. These models of healthcare emphasize blending mental healthcare with general medicine services and uniquely position primary care physicians and mental health professionals receiving such training to mitigate both the physical and mental health burden experienced by rural communities.[26,27] Mobile phone-based technology may also serve as a key tool in improving access to mental healthcare in rural communities. An estimated 86% of individuals with serious mental illness use a mobile phone; therefore, this technology may be harnessed in the development of mobile interventions that remotely screen for mental illness.[28] Finally, we recommend that federal and state governments provide financial assistance for initiatives that draw more physicians toward rural communities.

This study contains a few key limitations. First, the FCC broadband data used considers only the percentage of households that lack access to broadband data; therefore, the percentage of households with access to broadband outside the household in facilities such as schools, public libraries, or workplaces remains unclear and requires further study. However, utilizing a broadband source outside the home may present barriers such as transportation costs and lack of convenience; thus, accessibility to broadband internet at the household level is still relevant. A second limitation is that the most recent FCC broadband dataset used was published in 2020, before the massive expansion of broadband internet access in response to the COVID-19 pandemic. A third limitation is that the county demographic data from the American Community Survey, mental healthcare access data from the National Neighborhood Data Archive dataset, and broadband access data from the FCC were obtained from different years as each data source was last updated at a different time. Finally, as this analysis is associative rather than causative, this study cannot establish a cause-and-effect relationship between broadband access and mental healthcare access, although this would be a goal for future experiments.

In conclusion, this study presents one of the first formal analyses corresponding broadband internet access to mental healthcare resources at each level of care—from screening to treatment—across the United States. We found that US counties with reduced broadband access have reduced access to all six mental health services analyzed in this study, particularly mental health physicians, non-physician mental health practitioners, inpatient psychiatric and substance abuse hospitals, and outpatient facilities.

Methods

Data sources

Broadband access. Estimates of the percentage of households in each US county without broadband access were obtained from the FCC's Mapping Broadband Health in America platform.[10] The platform includes data from 2016 to 2020; however, only data from 2020 were used in this study to provide the most recent statistics. The FCC used data from the US Census Bureau's American Community Survey to

determine the number of households in each county with any type of broadband internet subscription and the total number of households in each county.[13]

Density of mental healthcare services. Estimates of the density of various mental healthcare services available in each US census tract were obtained from the University of Michigan's National Neighborhood Data Archive.[11,29] These estimates included the density per 1,000 residents of mental health physicians (including psychiatrists and psychotherapists), non-physician mental health practitioners (including clinical psychologists and mental health social workers), psychiatric and substance abuse hospitals, and inpatient facilities for mental health or substance abuse care. Densities were converted from per 1,000 members of the population to per 100,000 members of the population, and population-weighted county-level densities of each mental health service were subsequently computed using census tract-level data. This dataset used the North American Industry Classification System and National Establishment Time Series databases to determine the number of healthcare providers and establishments in each census tract in each year from 2003 to 2017.[30,31] Only data from US census tracts in 2017 were used here to provide the most recent statistics.

Rural–urban continuum codes. The 2013 Urban–Rural Classification Scheme for Counties developed by the National Center for Health Statistics was used to classify the urbanization level of each US county.[12] In this dataset, each county is classified into one of six categories with decreasing levels of urbanization: large central metro (1), large fringe metro (2), medium metro (3), small metro (4), micropolitan (5), and non-core (6). Category definitions are provided in Table 3.

Percentage of households with income below the poverty level. The US Census Bureau's 2019 American Community Survey provides data on the total number of households in each county with an income below the poverty level.[13] These data were used to calculate the percentage of households in each county with an income below the poverty level.

Mapping

The geography of US counties was obtained from the US Census Bureau's 2019 TIGER/Line Shapefiles.[32] Using QGIS (an open-source geographic information system) version 3.26.0, the percentage of households without broadband access, the density of mental health physicians, non-physician mental health practitioners, psychiatric and substance abuse hospitals, pharmacies and drugstores, inpatient facilities for mental health or substance abuse care, and outpatient facilities, urbanization-level classification, and poverty rates were mapped to United States county delineated in the 2019 TIGER/Line Shapefiles.[33] The mapped dataset was then used to create heatmaps visualizing each of these variables across US counties.[34]

Data analysis

The described datasets were mapped to one another in QGIS by county, resulting in a merged dataset of mental healthcare access, broadband access, urbanization level, and poverty rate for each of the 3,142 US counties. Since we excluded four counties (Aleutians East Borough, Alaska; Aleutians West Census Area, Alaska; Kusilvak Census Area, Alaska; and Oglala Lakota County, South Dakota) that did not have both mental healthcare service data and broadband accessibility data available, a total of 3,138 US counties were included in this analysis. Using data from these 3,138 counties, we computed the population-weighted average density of each type of mental healthcare provider and service in the United States. In addition, we recorded the percentage of US counties with zero providers of each mental healthcare service.

Finally, to quantify the association between broadband internet access and access to six mental healthcare resources and services (mental healthcare physicians, non-physician mental health practitioners, psychiatric and substance abuse hospitals, pharmacies and drugstores, inpatient psychiatric and substance abuse treatment facilities, and outpatient facilities), multivariate linear regressions were performed using urbanicity level and the poverty rate of each county as covariates. All data analysis was conducted in R version 4.2.1.[35]

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data used in this study are publicly available, as described in Methods.

Code availability

All code used to conduct statistical analyses of the data is available upon request.

References

1. Morales, D. A., Barksdale, C. L. & Beckel-Mitchener, A. C. A call to action to address rural mental health disparities. *J. Clin. Transl. Sci.* **4**, 463–467 (2020).
2. Jaret, P. *Attracting the Next Generation of Physicians to Rural Medicine* (AAMC, 2020); https://www.aamc.org/news-insights/attracting-next-generation-physicians-rural-medicine
3. Skinner, L., Staiger, D. O., Auerbach, D. I. & Buerhaus, P. I. Implications of an aging rural physician workforce. *N. Engl. J. Med.* **381**, 299–301 (2019).
4. Mueller J. T. et al. Impacts of the COVID-19 pandemic on rural America. *Proc. Natl Acad. Sci. USA* **118**, 2019378118 (2020).
5. Hubbard, K. Many states face shortage of mental health providers. *US News & World Report* https://www.usnews.com/news/best-states/articles/2021-06-10/northeastern-states-have-fewest-mental-health-provider-shortages (2021).
6. Perez-Lopez, D. J. *Vaccinated Adults Report Symptoms of Anxiety or Depression Less Frequently Than the Unvaccinated* (US Census Bureau, 2022); https://www.census.gov/library/stories/2022/02/frontline-workers-more-likely-to-report-symptoms-of-anxiety-depressive-disorder.html
7. Oluyede, L., Cochran, A. L., Wolfe, M., Prunkl, L. & McDonald, N. Addressing transportation barriers to health care during the COVID-19 pandemic: perspectives of care coordinators. *Transp. Res. A* **159**, 157–168 (2022).
8. Bestsennyy, O., Gilbert, G., Harris, A. & Rost, J. *Telehealth: A Quarter-Trillion-Dollar Post-COVID-19 Reality?* (McKinsey & Company, 2021); https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/telehealth-a-quarter-trillion-dollar-post-covid-19-reality
9. Benda, N. C., Veinot, T. C., Sieck, C. J. & Ancker, J. S. Broadband internet access is a social determinant of health. *Am. J. Public Health.* **110**, 1123–1125 (2020).
10. *Mapping Broadband Health in America* (FCC, 2017); https://www.fcc.gov/reports-research/maps/connect2health/#ll=40,-95&z=4&t=broadband&bbm=fixed_access&dmf=none&zlt=county
11. Khan, A. et al. *National Neighborhood Data Archive (NaNDA): Health Care Services by Census Tract, United States, 2003–2017* (ICPSR, accessed 6 January 2023); https://www.openicpsr.org/openicpsr/project/120907/version/V2/view
12. *NCHS Urban–Rural Classification Scheme for Counties* (CDC, accessed 6 January 2023); https://www.cdc.gov/nchs/data_access/urban_rural.htm
13. *American Community Survey Data* (US Census Bureau, accessed 6 January 2023); https://www.census.gov/programs-surveys/acs/data.html

14. Drake, C., Zhang, Y., Chaiyachati, K. H. & Polsky, D. The limitations of poor broadband internet access for telemedicine use in rural america: an observational study. *Ann. Intern. Med.* **171**, 382–384 (2019).
15. Zahnd, W. E., Bell, N. & Larson, A. E. Geographic, racial/ethnic, and socioeconomic inequities in broadband access. *J. Rural Health* **38**, 519–526 (2022).
16. Andrilla, C. H. A., Patterson, D. G., Garberson, L. A., Coulthard, C. & Larson, E. H. Geographic variation in the supply of selected behavioral health providers. *Am. J. Prev. Med.* **54**, S199–S207 (2018).
17. Wallis, L. Rural youths commit suicide almost twice as often as urban counterparts. *Am. J. Nurs.* **115**, 15 (2015).
18. *Poverty: Statistics* (Mental Health Foundation, accessed 6 January 2023); https://www.mentalhealth.org.uk/explore-mental-health/mental-health-statistics/poverty-statistics
19. Ridley M., Rao G., Schilbach F. & Patel V. Poverty, depression, and anxiety: causal evidence and mechanisms. *Science* **370**, aay0214 (2020).
20. *What Is Outpatient Mental Health Treatment?* (Penn Highlands Healthcare, 2021); https://www.phhealthcare.org/news/penn-highlands-healthcare-news/what-is-outpatient-mental-health-treatment
21. Yu, J. & Meng, S. Impacts of the internet on health inequality and healthcare access: a cross-country study. *Front. Public Health* **10**, 935608 (2022).
22. Gale, J., Janis, J., Coburn, A. & Rochford, H. *Behavioral Health in Rural America: Challenges and Opportunities* (Rural Policy Research Institute, 2019).
23. Sullivan, G. & Spritzer, K. The criminalization of persons with serious mental illness living in rural areas. *J. Rural Health* **13**, 6–13 (1997).
24. Reddick, C. G., Enriquez, R., Harris, R. J. & Sharma, B. Determinants of broadband access and affordability: an analysis of a community survey on the digital divide. *Cities* **106**, 102904 (2020).
25. Jain, B., Bajaj, S. S. & Cody Stanford, F. All infrastructure is health infrastructure. *Am. J. Public Health* **112**, 24–26 (2022).
26. Goodrich, D. E., Kilbourne, A. M., Nord, K. M. & Bauer, M. S. Mental health collaborative care and its role in primary care settings. *Curr. Psychiatry Rep.* **15**, 383 (2013).
27. Thornicroft, G. et al. Integrated care for people with long-term mental and physical health conditions in low-income and middle-income countries. *Lancet Psychiatry.* **6**, 174–186 (2019).
28. Young A. S. et al. Mobile phone and smartphone use by people with serious mental illness. *Psychiatr. Serv*. **71**, 280–283 (2020).
29. Rhubart D., Sun Y., Pendergrast C. & Monnat S. Sociospatial disparities in 'third place' availability in the United States. *Socius* https://doi.org/10.1177/23780231221090301 2022.
30. Feldman, M. *National Establishment Time-Series (NETS)* (accessed 6 January 2023); https://maryannfeldman.web.unc.edu/data-sources/longitudinal-databases/national-establishment-time-series-nets/
31. *North American Industry Classification System (NAICS)* (US Census Bureau, accessed 6 January 2023); https://www.census.gov/naics/
32. *TIGER/Line with Selected Demographic and Economic Data* (US Census Bureau, accessed 6 January 2023); https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-data.html
33. *QGIS* Version 3.26.0 (QGIS, accessed 6 January 2023); https://qgis.org/en/site/
34. Terrell, K. A. & St Julien, G. Air pollution is linked to higher cancer rates among Black or impoverished communities in Louisiana. *Environ. Res. Lett.* **17**, 014033 (2022).
35. R: The R Project for Statistical Computing Version 4.2.1 (R Foundation, accessed 6 January 2023); https://www.r-project.org/

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Correspondence and requests for materials should be addressed to John Torous.

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[1]Harvard University, Cambridge, MA, USA. [2]Stanford University School of Medicine, Stanford, CA, USA. [3]University of Pennsylvania, Philadelphia, PA, USA. [4]Department of Psychiatry, University of Pittsburgh Medical Center, Pittsburgh, PA, USA. [5]Department of Radiation Oncology, Memorial Sloan Kettering Cancer Center, New York, NY, USA. [6]Department of Psychiatry, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA.
✉e-mail: jtorous@bidmc.harvard.edu

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Corresponding author(s): Bhav Jain

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Imaging type(s)	
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Area of acquisition	

Diffusion MRI ☐ Used ☐ Not used

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Preprocessing software	
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