BMJ Global Health

Incorporating resilience when assessing pandemic risk in the Arctic: a case study of Alaska

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To cite: Tiwari S, Petrov A, Mateshvili N, *et al*. Incorporating resilience when assessing pandemic risk in the Arctic: a case study of Alaska. *BMJ Glob Health* 2023;**8**:e011646. doi:10.1136/bmjgh-2022-011646

Handling editor Seye Abimbola

Received 27 December 2022
Accepted 14 May 2023

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ABSTRACT

The discourse on vulnerability to COVID-19 or any other pandemic is about the susceptibility to the effects of disease outbreaks. Over time, vulnerability has been assessed through various indices calculated using a confluence of societal factors. However, categorising Arctic communities, without considering their socioeconomic, cultural and demographic uniqueness, into the high and low continuum of vulnerability using universal indicators will undoubtedly result in the underestimation of the communities' capacity to withstand and recover from pandemic exposure. By recognising vulnerability and resilience as two separate but interrelated dimensions, this study reviews the Arctic communities' ability to cope with pandemic risks. In particular, we have developed a pandemic vulnerability–resilience framework for Alaska to examine the potential community-level risks of COVID-19 or future pandemics. Based on the combined assessment of the vulnerability and resilience indices, we found that not all highly vulnerable census areas and boroughs had experienced COVID-19 epidemiological outcomes with similar severity. The more resilient a census area or borough is, the lower the cumulative death per 100 000 and case fatality ratio in that area. The insight that pandemic risks are the result of the interaction between vulnerability and resilience could help public officials and concerned parties to accurately identify the populations and communities at most risk or with the greatest need, which, in turn, helps in the efficient allocation of resources and services before, during and after a pandemic. A resilience–vulnerability-focused approach described in this paper can be applied to assess the potential effect of COVID-19 and similar future health crises in remote regions or regions with large Indigenous populations in other parts of the world.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ A focus on vulnerabilities is prevalent, especially in potential impact assessments targeting geographically or socioeconomically marginalised communities. The strengths of these communities are rarely considered, and the combined evaluation of their strengths and weaknesses is almost absent.

WHAT THIS STUDY ADDS

⇒ This study builds on conventional social vulnerability research by advancing an integrated analytical framework that incorporates both vulnerability and resilience features of Alaskan communities.

⇒ This study results suggest that regardless of vulnerabilities, the more resilient a community is, the lesser the impact of pandemic, epidemiology wise, in that community.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results of this study highlight the need for incorporating resilience indicators with the vulnerability assessment conventionally used to explain the potential pandemic impact, thereby aiding in the accurate identification of the population at greater risk, which in turn, helps in prioritising the allocation of resources and services.

INTRODUCTION

A large amount of research on the COVID-19 pandemic around the world emphasises the disproportionate burden of the pandemic among racial/ethnic minorities, the poor, the elderly and people with disabilities, low educational attainment and comorbidities, among others.[1–5] The word 'vulnerable' is often used to indicate these disproportionately impacted populations. Moreover, COVID-19 has broadened the definition and scope of vulnerability that include not only a population with certain socioeconomic or health characteristics but also the marginalised and disadvantaged communities that are more likely susceptible to overwhelming epidemiological outcomes (i.e., higher case, morbidity and mortality rates).[2 5] Thus, researchers have assessed a variety of communities' characteristics to identify the groups at most risk during the COVID-19 pandemic and its aftermath.[6–8] In other words, the discourse on vulnerability to COVID-19, or any other pandemic,

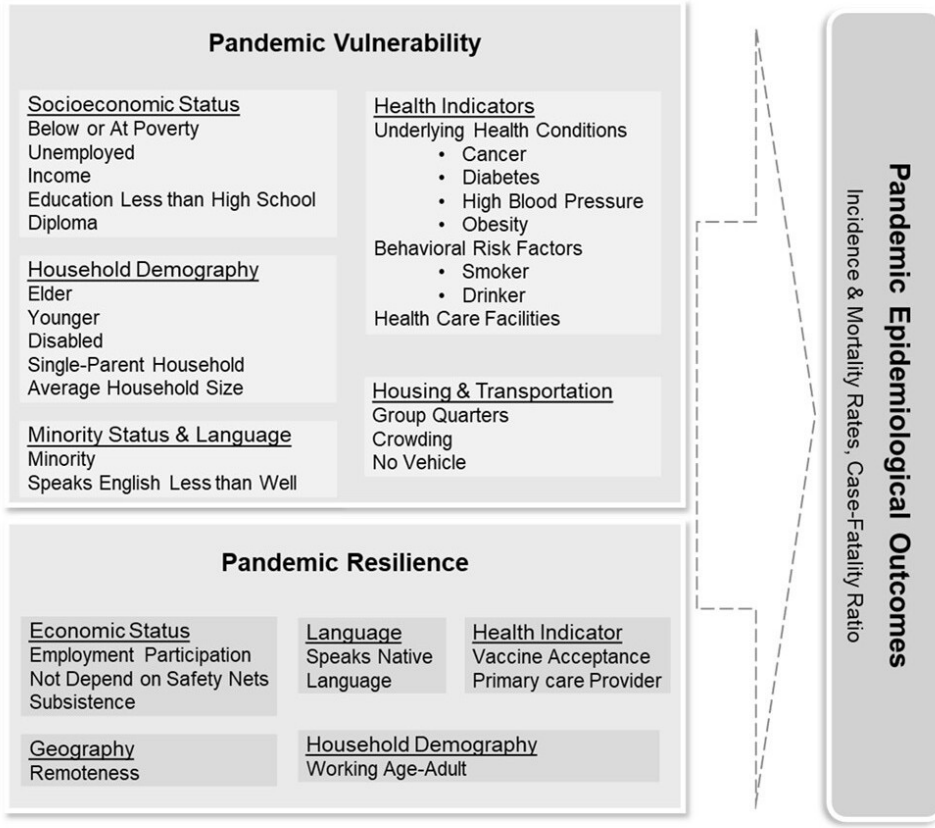

Figure 1 A pandemic vulnerability–resilience framework.

is largely about the susceptibility of an individual or a community to the negative effects of disease outbreaks.

In the context of the COVID-19 pandemic, numerous studies have assessed vulnerability through various indices calculated using a confluence of societal factors.[9–17] Most of these studies examine the relationship between the vulnerability index and COVID-19 outcomes and discover that highly vulnerable areas have higher COVID-19 incidence and mortality rates. Furthermore, vulnerability indices have also been used as a tool to highlight disparities in COVID-19 vaccination coverage and vaccine hesitancy.[18–20] One consistent thread found in these studies is the development or modification of the vulnerability indices using simple to sophisticated statistical methods such as arithmetic mean,[16] percentile ranking,[11 15] regression analysis,[14 17 18] principal component analysis,[12] factor analysis,[9] machine learning algorithms,[10 13] etc. The common societal indicators used by these studies to develop the indices include age, poverty, race or ethnicity, education, population with comorbidities, overcrowded households, and hospital density, among others.

Researchers have also worked to understand and convey the distinct challenges and vulnerabilities the Arctic, including Alaska, already has and could be amplified due to COVID-19 and future pandemics.[21–23] This study, likewise, focuses partly on the vulnerability of the Arctic populations with respect to the pandemic. Pre-existing conditions that exacerbate the vulnerability of Arctic residents include geographic barriers that limit access to health services, underdeveloped civic infrastructure, larger populations with underlying medical conditions (such as hypertension, diabetes, heart disease, tuberculosis, hepatitis, obesity), lower socioeconomic status, inadequate housing, poor sanitation, lack of clean water, etc.[22 23] Due to these challenges, previous pandemics such as smallpox, cholera, the 1918 influenza, tuberculosis and the 2009 H1N1 influenza had a disproportionate impact on the Arctic and its residents, especially its Indigenous population.[22 24 25]

Despite their existing vulnerabilities, Arctic communities have persevered through COVID-19 with less dire consequences than the rest of the world. Developed countries such as the USA and the UK had very high cumulative confirmed COVID-19 death rates (i.e., above 315 per 100 000),[26] which were 2–3 times as high in some Arctic countries and Indigenous communities.[27–29] Among 7.5 million Arctic residents,[30] as of 1 December 2022, there were 29 325 confirmed COVID-19 deaths.[27] Out of these, about 26 000 (i.e., 285 per 100 000) deaths were ascribed to Northern Russia.[27] Greenland, Faroe Islands, Iceland, Northern Canada and Northern Norway reported just under 60 deaths per 100 000 population, cumulatively.[27] Alaska and Northern Sweden had over 180 cumulative deaths per 100 000.[27] Meanwhile, in Canada and Alaska, the case fatality ratio (CFR) was substantially lower in the Indigenous population compared with the non-Indigenous population.[28 29] The lessened socioeconomic and health impacts of COVID-19 across

Table 1 Alaska Pandemic Vulnerability Index variables

Category	Description	Source
Socioeconomic indicators	Percentage of population whose ratio of income in 2019 to poverty level is ≤1	American Community Survey (ACS) 5-year estimates (2015–2019)
	Percentage of unemployed civilian population 16 years and above	ACS 5-year estimates (2015–2019)
	Percentage of population 25 years and above with less than a high school diploma	ACS 5-year estimates (2015–2019)
	Per capita income (in 2019 inflation-adjusted dollars)	ACS 5-year estimates (2015–2019)
Household composition and size and disability	Percentage of population 65 years and above	ACS 5-year estimates (2015–2019)
	Percentage of population under 18 years	ACS 5-year estimates (2015–2019)
	Percentage of civilian non-institutionalised population with a disability	ACS 5-year estimates (2015–2019)
	Percentage of single parent households with children under 18 years	ACS 5-year estimates (2015–2019)
	Average household size	ACS 5-year estimates (2015–2019)
Minority and language	Percentage of minority (except non-Hispanic white alone or American Indian and Alaska Native alone)	ACS 5-year estimates (2015–2019)
	Percentage of the population 5 years and above who speak English less than well	ACS 5-year estimates (2015–2019)
Housing and transportation	Percentage of population in institutionalised group quarters	ACS 5-year estimates (2015–2019)
	Percentage of households with more people than the room	ACS 5-year estimates (2015–2019)
	Percentage of households with no vehicle available	ACS 5-year estimates (2015–2019)
Health indicators	Crude prevalence (data value in %) of cancer (excluding skin cancer) among adults aged≥18 years	BRFSS (Behavioral Risk Factor Surveillance System) (Year: 2019)
	Crude prevalence (data value in %) of diagnosed diabetes among adults aged≥18 years	BRFSS (Year: 2019)
	Crude prevalence (data value in %) of high blood pressure among adults aged≥18 years	BRFSS (year: 2019)
	Crude prevalence (data value in %) of obesity among adults aged≥18 years	BRFSS (year: 2019)
	Crude prevalence (data value in %) of binge drinking among adults aged≥18 years	BRFSS (year: 2019)
	Crude prevalence (data value in %) of current smoking adults aged≥18 years	BRFSS (year: 2019)
	Estimates of healthcare facilities (ie, hospitals, urgent care facilities and pharmacies) per 100 000 population	Homeland Infrastructure Foundation-Level Data

the Arctic and its Indigenous population can largely be attributed to livelihoods based on subsistence activities, traditional practices and knowledge, remoteness, effective vaccination campaigns, proactive community leadership and engagement, self-determination and other factors.[31–33] These factors represent the Arctic communities' strengths, making them remarkably resilient against COVID-19 or potentially other pandemics.

To date, studies assessing pandemic risk exposure are limited in scope as a community's strengths are rarely taken into account, and the combined evaluation of vulnerability and resilience is almost absent. Further, in the literature, resilience is often treated as the simple inverse of vulnerability, that is, communities with lower vulnerability are generally considered highly resilient.[34–36] Categorising Arctic communities, without considering their geography, socioeconomic, cultural and demographic uniqueness, into the high and low continuum of vulnerability using the universal societal indicators will undoubtedly result in the underestimation of these communities' capacity to prevent, withstand and recover from pandemic exposure. For instance, the poverty rate, a universal economic indicator, is likely limited when evaluating Arctic communities' risk exposure. Family relations and subsistence activities are among the various ways of coping with income limitations in these communities.[37] Thus, an asset-based approach that refocuses research from community deficiencies to its strengths may provide a better alternative for a comprehensive pandemic risk assessment. This study, by recognising vulnerability and resilience as two separate but interrelated dimensions, evaluates the Arctic communities'

Table 2 Alaska Pandemic Resilience Index variables

Category	Description	Source
Economic factors	Employment participation rate (%) of the population 16 years and above	American Community Survey (ACS) 5-year estimate (2015–2019)
	Percentage of households with no social security income	ACS 5-year estimate (2015–2019)
	Percentage of households with no public assistance income	ACS 5-year estimate (2015–2019)
	Subsistence estimate: per capita harvest (lb)	Division of subsistence, Alaska Department of Fish and Game, Report: Estimated harvests of fish, wildlife and wild plant resources by Alaska region and census areas 2017. Note: for Fairbanks North Star Borough, per capita harvest contained a combination of Fairbanks North Star Borough and portions of the Denali Borough and Southeast Fairbanks Census Area (as stated in the report)
Household demography	Percentage of population aged from 20 to 54 years	ACS 5-year estimate (2015–2019)
Language	Percentage of population 5 years and above speaking native North American language	ACS 5-year estimate (2011–2015)
Geography	Percentage of an isolated population	Calculated for the block groups' population based on road connectivity using ArcGIS Pro. Block groups through which primary and secondary roads have not passed were considered isolated block groups. Block groups data were from ACS 5-year estimate 2015–2019, roads were from data.gov.
Healthcare factors	Percentage of the population having at least one dose of COVID-19 vaccine (proxy to vaccination acceptance)	Centers for Disease Control and Prevention, (data as of 7 March 2022, 6:00 Eastern Time),
	Estimate of primary care providers (primary care physicians plus other primary healthcare providers) per 100 000 population	County Health Rankings & Road Maps (year: 2019). Primary Care Physicians include MDs, and DOs except for obstetrics/gynaecology, Other primary healthcare providers include nurse practitioners, physician assistants and clinical nurse specialists.

capacity to address current and future pandemic risks. In particular, this study advances a vulnerability–resilience framework that combines the strengths and weaknesses of Alaskan communities into one integrated conceptual model. Based on the framework, this study aims to develop indices of vulnerability and resilience and assess them integratively concerning COVID-19 epidemiological outcomes.

The combined assessment of vulnerability and resilience is necessary as this technique accurately identifies the populations and communities at most risk or with the greatest need, which, in turn, helps public officials and local organisations to efficiently allocate resources and services as well as take mitigation and recovery measures customed to local realities. This can be a particularly important tool as future global pandemics from novel viruses will likely continue due to globalisation, human migration, urbanisation and climate change around the world.

Alaska as a case study

Remote regions and the world's margins, such as the Arctic, are rarely found in the focus of global health research. Yet, they present important cases for understanding health disparities, social and environmental determinants of health in general and of the COVID-19 pandemic in particular.[23 38] The Arctic, Northern circumpolar region, covers Iceland, Greenland, the Faroe Islands and parts of Canada, Finland, Norway, Russia, Sweden and the USA (Alaska). Common features representing the Arctic Indigenous populations include their distinct cultures, languages and knowledge, traditional livelihoods based on subsistence, and deep connection to their homeland.[39]

Alaska was chosen as a case study to develop and apply the Arctic pandemic vulnerability–resilience framework. The framework incorporates vulnerability and resilience indices because of (a) the availability of data and (b) Alaska's geography, demography, cultural heritage, population health and socioeconomic conditions are indicative of the other Arctic and remote regions. Thus, the framework and indices developed for Alaska in this study can be replicated and refined for other Arctic or remote regions to assess the risks of COVID-19 or future pandemics.

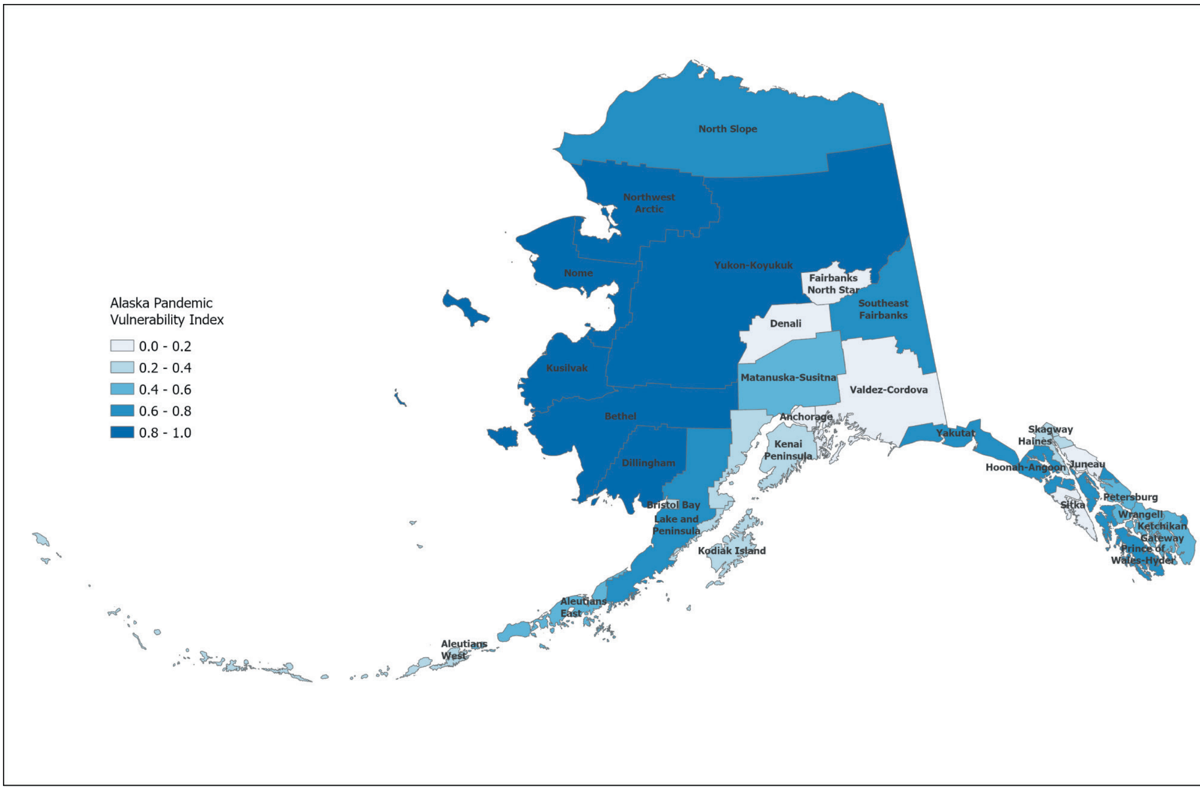

Figure 2 Alaska Pandemic Vulnerability Index.

Alaska is the largest state in the USA. It comprises 29 boroughs and census areas inhabited by 733 391 people.[40] Out of these, an estimated 21.9% are Indigenous (ie, American Indian and Alaska Native in alone or combination).[40] Approximately 50% of the Indigenous population of Alaska lives either in remote or Northern regions of the state.[40] The North and Northwest of Alaska are home to the Inupiaq and St. Lawrence Island Yupik. While Eyak, Tlingit, Haida, Tsimshian, Yup'ik and Cupik, Alutiiq, and Unangax Indigenous peoples live further in the south.[41] Most Athabaskan People reside in Alaska's interior.[41]

Research has shown that in the USA, ethnic minorities, including the Indigenous Peoples, and individuals with lower socioeconomic status are more likely to have comorbidities and limited access to healthcare and resources, thereby increasing their susceptibility to diseases.[42 43] According to recent study by Ward *et al*,[44] in Alaska, the risk of death due to COVID-19 for an American Indian and Alaska Native person is 2.9 times higher than for a white individual. Furthermore, Alaska's population as a whole is relatively vulnerable compared with the rest of the USA in socioeconomic and health indicators. In 2018, Alaska ranked 23rd out of 50 US states in the economic hardship index developed using 6 indicators: unemployment, dependency, education, crowded housing and poverty.[45] Moreover, around 38.8% of Alaskans have underlying health conditions such as obesity, heart disease, chronic pulmonary obstructive disease, diabetes and chronic kidney disease.[46] It is broadly acknowledged that the prevalence of these health burdens among Alaska Indigenous Peoples stems from the detrimental effects of colonialism on traditional food systems, healing practices, sense of identity, healthy ways of knowing and access to healthcare.[47–49] Therefore, these socioeconomic disadvantages and health disparities, as one of the causes of the disproportionate impact of COVID-19,[50] are considered in this study while developing the vulnerability index.

Even though vulnerable, Alaskan communities have curtailed adverse COVID-19 impacts due to the strong measures taken for its containment at the early stages of the pandemic, remoteness (ie, two-thirds of the land area is unreachable by road or ferry), livelihoods based on subsistence activities and a relatively low concentration of people aged 65 or above (12.52%) compared with the USA (16.3%).[32 51–53] Further, the Alaska Native Tribal Health Consortium's COVID-19 awareness programme in different Native languages and a higher vaccination rate have significantly reduced the risk for COVID-19-associated hospitalisation and deaths.[31 32]

Alaska launched mass vaccination campaigns as early as December 2020 and led the USA in vaccination rates in January 2021.[31] By June 2021, over 55% of adults (ie, 16 years old and older) living in Aleutians East Borough, Juneau City and Borough, Skagway Municipality, Sitka City and Borough, Nome Census Area and Yukon-Koyukuk Census Area had completed the primary series of COVID-19 vaccination.[54] These early higher vaccination rates can largely be accredited to strong vaccine-distribution networks, tribal cultural values that put emphasis on protecting and honouring elders, culturally

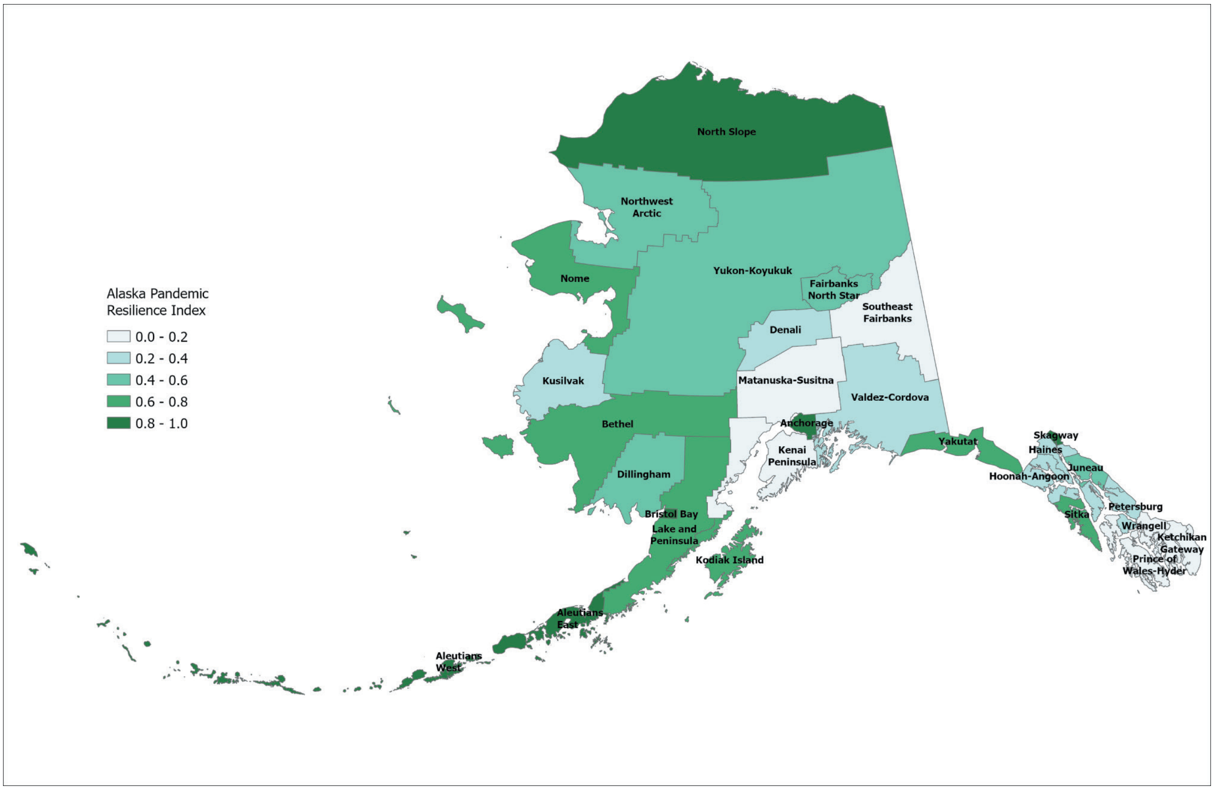

Figure 3 Alaska Pandemic Resilience Index.

tailored awareness strategies to overcome vaccine hesitancy, self-governance that allowed the tribal groups to establish their campaigns and priorities, and the door-to-door vaccine outreach to medically fragile individuals.[55–57]

METHODS

This study presents a pandemic vulnerability–resilience framework, as shown in Figure 1, to highlight multidimensional aspects underlying the varied COVID-19 epidemiological outcomes. In other words, a pandemic vulnerability–resilience framework is an integrated approach that brings together the key societal factors that influence, to the greatest extent, the degree to which a community is susceptible to and able to prevent or cope with the effects of COVID-19 or future pandemics. The framework includes socioeconomic, demographic, health, language proficiency and other indicators. For example, we choose to categorise population with knowledge of specific languages as both vulnerability (i.e., percentage of the population that speaks English less than well) and resilience measures (i.e., percentage of the population that speaks Native languages) based on the role these languages play on individuals and community well-being. Limited English proficiency is one of the key barriers to healthcare access and is often connected to poorer health status in minority populations.[58–60] At the same time, Indigenous ways of knowing, encapsulated in Indigenous languages, play an essential role in reclaiming and advancing the physical, mental, emotional and spiritual health and well-being of Indigenous People.[61–63] Based on the framework, we developed vulnerability and resilience indices for Alaska at the census areas and boroughs level. These indices are called the Alaska Pandemic Vulnerability Index and Alaska Pandemic Resilience Index.

To develop the indices, this study used the Cutter *et al*'s ranking method adopted by the US Centers for Disease Control and Prevention (CDC) to calculate the Social Vulnerability Index (SVI).[64–66] CDC's SVI is a place-based measure that considers 15 social characteristics of an area influencing its capability to cope with hazardous events such as a chemical spill, a natural disaster or a disease outbreak. In computing the indices, we applied a similar approach with a set of variables tailored to the social, demographic, economic, healthcare and cultural context of Alaska (and other remote and Northern areas with large Indigenous populations). Descriptions of the variables used, and their data sources, are given in Tables 1 and 2.[52 67–71]

The Alaska Pandemic Vulnerability Index reflects how susceptible an Alaska census area or borough is to the negative effects of the pandemic. The Alaska Resilience Pandemic Index indicates how capable the same census area or borough is to deal with that adversity. For calculating the vulnerability index, first, each variable (listed in table 1) was ranked from highest to lowest. While calculating the vulnerability index, unlike other variables, per capita income and healthcare facilities estimates per 100 000 were ranked from lowest to highest as their higher value indicates lower vulnerability. We then computed the percentile ranks using equation (1) and

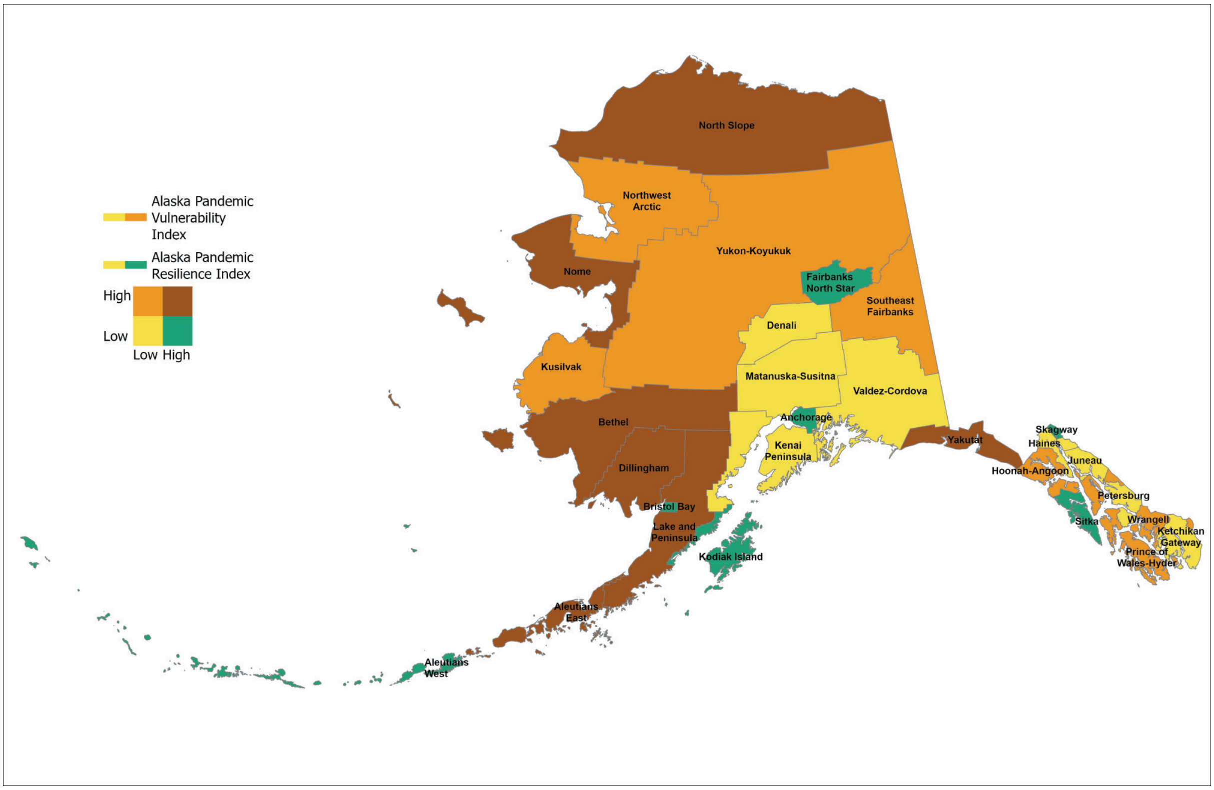

Figure 4 Bivariate map showing Alaska Pandemic Vulnerability and Resilience Indices scores simultaneously.

linearly combined (i.e., summed) the rankings of these variables, and finally, the summed values were again ranked which represents the scores for the index. The index scores range from 0 to 1. The higher the values of the index, the more vulnerable a census area or borough is and vice versa.

$$\text{Percentile ranking (R)} = \frac{\text{rank} - 1}{N - 1} \qquad (1)$$

The same approach was applied to create scores for the resilience index using variables listed in Table 2. Each census area or borough received a percent rank from 0 to 1, where 0 refers to the least resilient and 1 refers to the most resilient census area or borough. Pandemic vulnerability and resilience indices then were assessed combinedly using a four-quadrant matrix.

To better understand whether vulnerability and resilience indices are associated with pandemic outcomes, this study performed a simple exploratory assessment and descriptive analysis (Spearman correlation coefficient) of both indices with COVID-19 cases, death and CFR. Even though the statistical meaningfulness of such analysis is limited due to the small sample size (ie, 26), any indication of a relationship will warrant further research into the usefulness of the proposed vulnerability–resilience framework, particularly resilience indicators, for remote places' risk assessment due to COVID-19 or future pandemics. Cumulative COVID-19 cases and deaths per 100 000 and CFR for Alaska by census area and boroughs were calculated based on the confirmed number of cases and deaths, as of 1 July 2022, and the population count extracted from the Alaska Department of Health COVID-19 cases dashboard.

Patient and public involvement

In this study, neither patients nor public were involved.

RESULTS

We mapped both pandemic indices scores to examine whether any spatial patterns exist. For mapping purposes, we classified the scores of both vulnerability and resilience indices into five categories: 0.0–0.2 equals very low, 0.2–0.4 equals low, 0.4–0.6 equals medium, 0.6–0.8 equals high and 0.8–1.0 equals very high.

Alaska Pandemic Vulnerability Index

Figure 2 clearly shows that census areas and boroughs with very high and high vulnerability were mostly concentrated in Northern and Western Alaska, except for Bristol Bay, Kodiak Island and Aleutians Boroughs. Higher poverty, unemployment and comorbidities rates, lower educational attainment and per capita income, a considerable percentage of the elderly and disabled population, a sizeable proportion of crowded and single-parent households, lack of access to a vehicle and no existence of healthcare facilities were the main reasons for very high and high vulnerability scores of these census areas. Bristol Bay, Kodiak Island and Aleutian West ranked low in vulnerability, while Aleutian East ranked medium.

Most of the census areas and boroughs in the interior, South-central and Southeast Alaska, such as Kenai

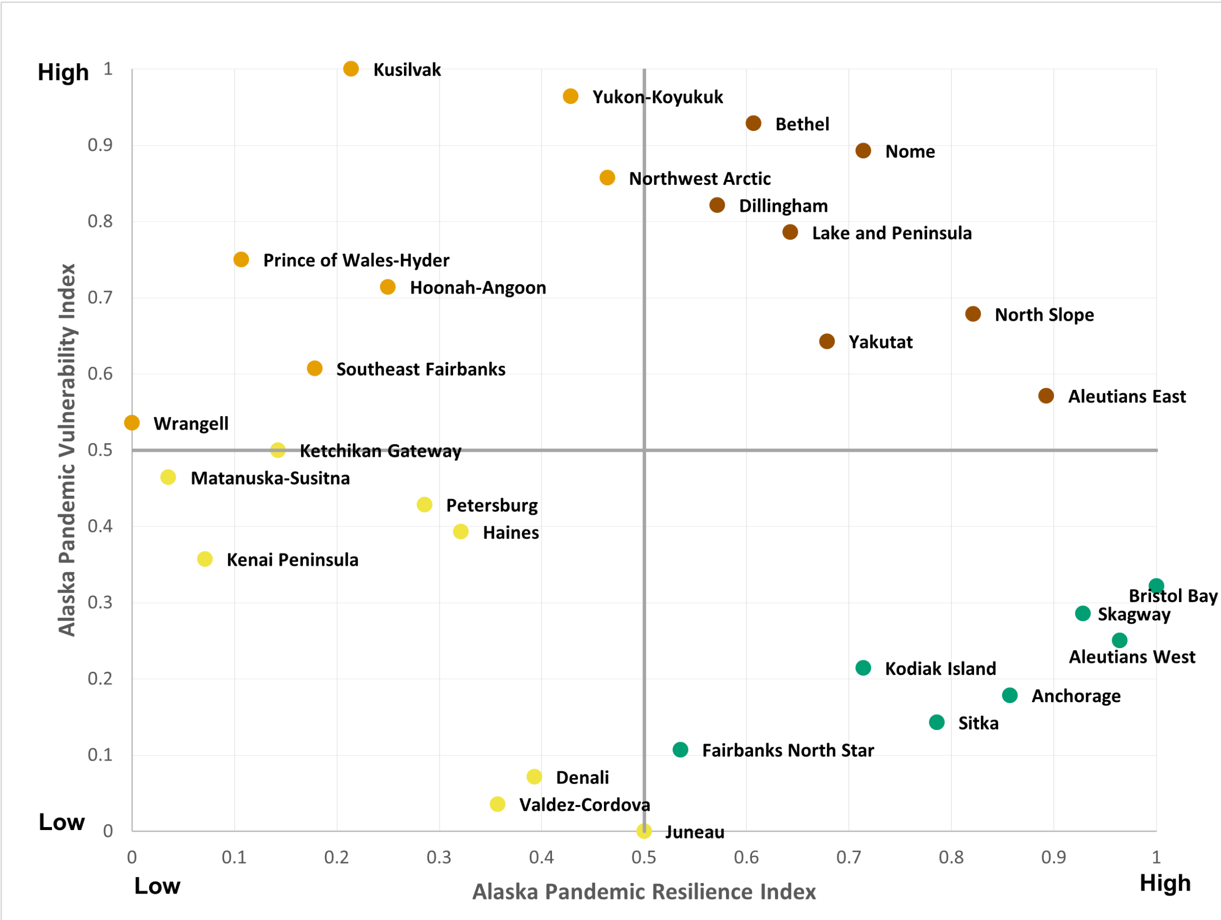

Figure 5 Four-quadrant typology of Alaska Pandemic Vulnerability and Resilience Indices.

Peninsula, Matanuska-Susitna, Anchorage, Denali, Fairbanks North Star, Valdez-Cordova, Haines, Skagway, Sitka, Juneau, Petersburg, Wrangell, Ketchikan, had very low to medium vulnerability scores. Southeast Fairbanks, Yakutat, Hoonah-Angoon and Prince of Wales-Hyder had high vulnerability scores. In particular, Southeast Fairbanks and Prince of Wales-Hyder census areas were highly vulnerable according to socioeconomic indicators. These census areas also had a substantial proportion of the population who were disabled and lived in larger households. While Yakutat, Hoonah-Angoon and Prince of Wales-Hyder census areas ranked high in vulnerability based on healthcare indicators.

Alaska Pandemic Resilience Index

With regard to resilience (Figure 3), census areas and boroughs located in North and Southwest Alaska (other than Kusilvak) ranked very high to medium. Northern boroughs such as North Slope, Nome and Northwest Arctic had higher harvests per capita, and a sizeable proportion of the population living in isolated areas and speaking native North American languages. Both Aleutians Islands had higher employment participation (about 81%) and vaccination rates, and a significant proportion (approximately 60%) of the working-age population between 20 and 54 years. While Bristol Bay and Dillingham had higher (ie, more than 350) primary care providers per 100 000 population compared with other boroughs and census areas. In the Southwest, a significant percentage of Alaskans live in isolated areas.

Interior, South-central and Southeast Alaska (except for Anchorage, Skagway, Yakutat and Sitka) had medium to very low resilience. Skagway and Anchorage scored high in almost all the resilience indicators. Yakutat and Sitka had higher vaccination rates and percentages of the population living in isolated areas. Also, Sitka was among other boroughs with higher primary care providers per 100 000 population.

Integrated vulnerability–resilience assessment

To accurately assess the severity of a potential impact resulting from the pandemic using the integrated vulnerability–resilience framework, we evaluated the vulnerability and resilience indices combinedly. Figures 4 and 5 reveal several categories of regions based on a combination of vulnerability and resilience indices. High vulnerability and low resilience areas include Kusilvak, Prince of Wales-Hyder and Southeast Fairbanks. These areas are at risk of being severely affected by COVID-19 or future pandemics. Areas with medium vulnerability and very low resilience, such as Wrangell, Ketchikan Gateway and Matanuska-Susitna, could also be susceptible to a

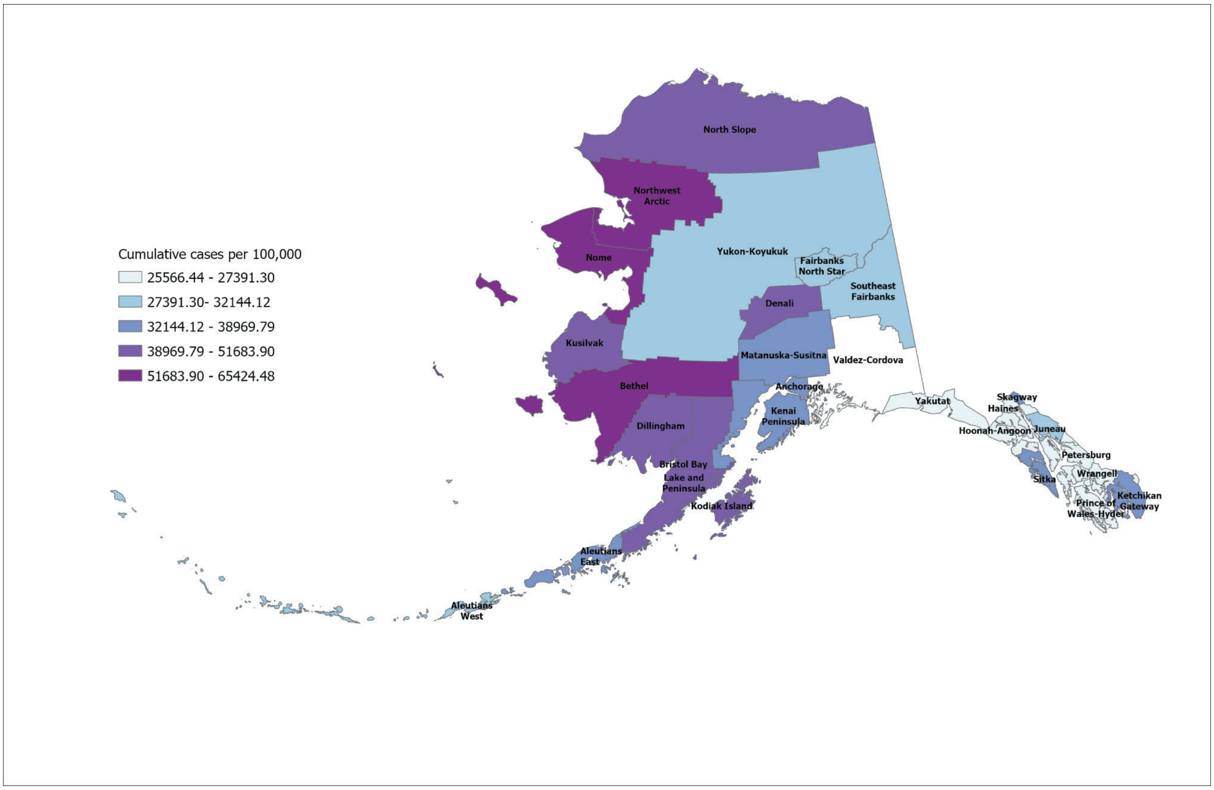

Figure 6 Cumulative cases per 100 000 population by Alaska's census areas or boroughs.

pandemic outbreak. Even though Bethel, Nome and North Slope had very high and high vulnerability scores, these areas also were very high and high in resilience, thereby would have capacities to cope with and recover from a pandemic. Similarly, Aleutians East (medium vulnerability and very high resilience), Skagway and Aleutians West (low vulnerability and very high resilience), Kodiak Island (low vulnerability and high resilience), Anchorage (very low vulnerability and very high resilience), Sitka (very low vulnerability and high resilience) and Fairbanks North Star and Juneau (very low vulnerability and medium resilience) would probably be less impacted by the pandemic.

Vulnerability–resilience assessment and COVID-19 epidemiological outcomes

We examined key epidemiological parameters to compare the computed vulnerability and resilience indices with the outcomes of the COVID-19 pandemic (February 2020 through July 2022). Figures 6–8 represent the cumulative COVID-19 cases and deaths per 100 000 and CFR for Alaska by census area and boroughs. Table 3 shows the indices category and corresponding COVID-19 epidemiological outcomes.

Very highly vulnerable areas, as identified by vulnerability indices, located in Northern and Western Alaska, such as Kusilvak, Yukon-Koyukuk, Northwest Arctic, North slope Dillingham, Bethel and Nome, had high cumulative COVID-19 cases (about 51 000 on average) per 100 000 population. However, Northern census areas, including North Slope, Nome and Northwest Arctic, had fewer cumulative deaths (142.4, 50.0 and 196.8) per 100 000 and lower CFR (0.3%, 0.1% and 0.3%) than the rest of Alaska as these highly vulnerable areas ranked very high, high and medium in terms of resilience.

There was a significant difference in CFR among very highly vulnerable regions, such as Bethel (0.4), Dillingham (0.6) and Yukon-Koyukuk (0.7). The main reason for this difference could be their rank in resilience, that is, Dillingham and Yukon-Koyukuk ranked medium in resilience, while Bethel ranked high. However, Kusilvak, being very high in vulnerability and low in resilience, had a lower CFR of 0.3. Kusilvak is a remote area, dominated by Indigenous populations whose livelihoods are heavily based on subsistence activities. Remoteness, proactive leadership, use of Indigenous knowledge, less interregional worker movement along with a higher vaccination rate[54] might have led to a lower CFR.

High vulnerable areas with very low resilience, such as Prince of Wales-Hyder and Southeast Fairbanks and medium vulnerable areas with very low resilience, such as Wrangell and Matanuska-Susitna (exceptions include Ketchikan Gateway), also had very high and high cumulative deaths (ranging between 161 and 418) per 100 000 and CFR (ranging between 0.6 and 1.2) compared with other Alaska boroughs. Ketchikan had medium number of deaths (151.1) per 100 000 population and a medium CFR (0.4).

Highly resilient areas with medium, low and very low vulnerability, such as Sitka, Kodiak Island, Aleutians Islands and Skagway (except Anchorage), had lower

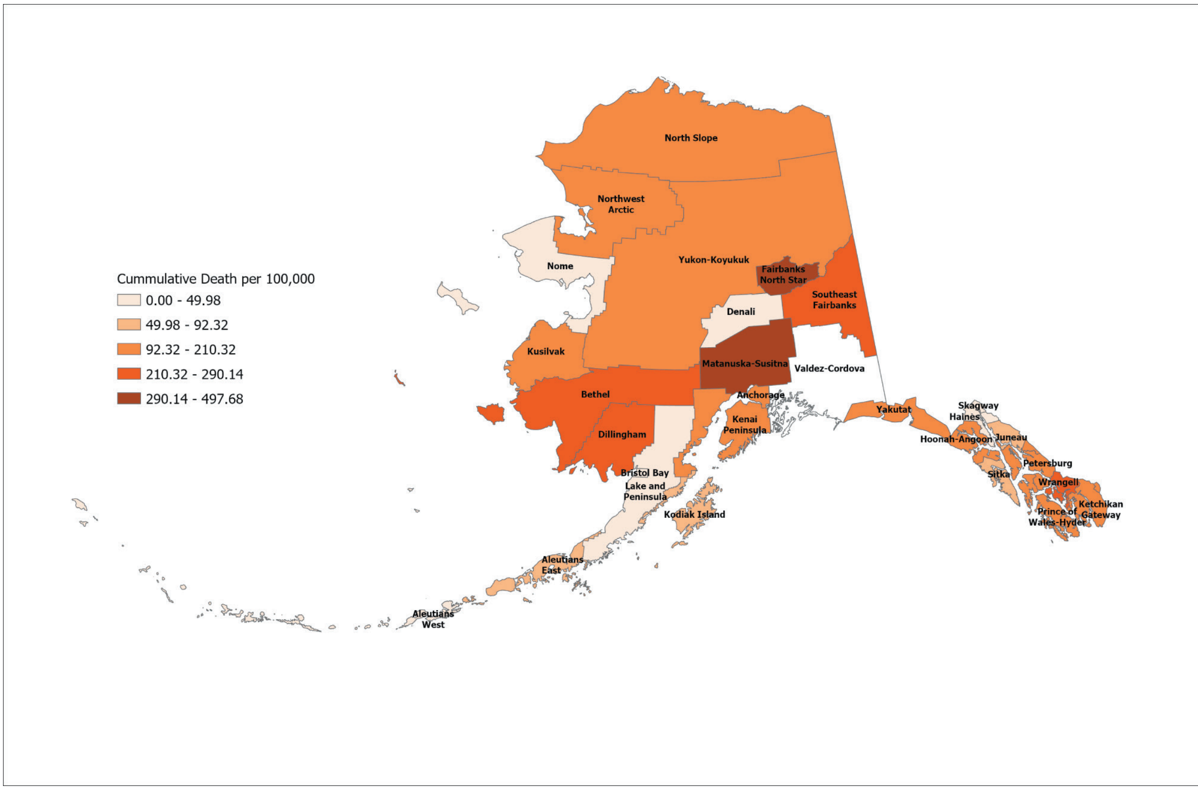

Figure 7 Cumulative death per 100 000 population by Alaska's census areas or boroughs.

cumulative cases and death per 100 000 as well as CFR. Anchorage, a very highly resilient area with very low vulnerability, had higher cumulative cases (38 969.8) per 100 000 but medium cumulative deaths (189.9) per 100 000 and CFR (0.5%) compared with other highly resilient census areas. The main reasons could be higher population density, exposure to interregional population movements and early loosening of COVID-19 restrictions.

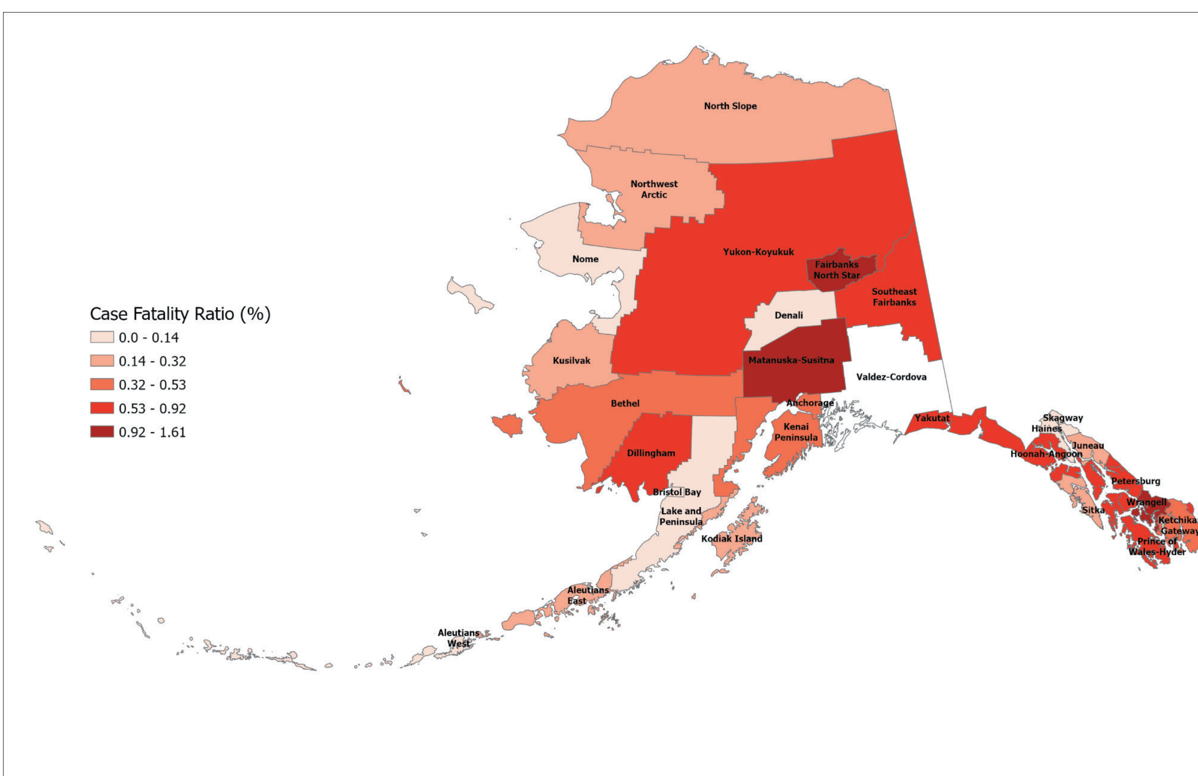

Figure 8 Case fatality ratio by Alaska's census area or boroughs.

Table 3 COVID-19 epidemiological outcomes by Alaska pandemic indices

Vulnerability category	Resilience category	Census areas or boroughs	Cumulative cases per 100 000	Cumulative death per 100 000	Case fatality ratio
Very high	Low	Kusilvak	51 683.9	168.4	0.3
Very high	Medium	Dillingham	40 541.1	244.1	0.6
		Northwest Arctic	65 424.5	196.8	0.3
		Yukon-Koyukuk	29 349.9	210.3	0.7
Very high	High	Bethel	58 876.3	228.4	0.4
		Nome	63 344.7	50.0	0.1
High	Very low	Prince of Wales-Hyder	25 681.1	161.2	0.6
		Southeast Fairbanks	31 321.6	290.1	0.9
High	Medium	Yakutat and Hoonah-Angoon	25 632.6	183.4	0.7
High	Very high	North Slope	48 403.2	142.4	0.3
Medium	Very low	Ketchikan Gateway	34 134.2	151.1	0.4
		Matanuska-Susitna	33 875.6	417.3	1.2
		Wrangell	25 979.2	279.8	1.1
Medium	Low	Petersburg	25 566.4	153.1	0.6
Medium	Very high	Aleutians East	34 552.0	89.9	0.3
		Bristol Bay and Lake Peninsula	42 792.4	41.2	0.1
Low	Very low	Kenai Peninsula	33 206.7	178.9	0.5
Low	Low	Haines	27 391.3	39.5	0.1
Low	High	Kodiak Island	40 475.5	92.3	0.2
Low	Very high	Aleutians West	32 144.1	35.5	0.1
		Skagway	34 995.8	0	0
Very low	Low	Denali	46 495.0	47.7	0.1
Very low	Medium	Fairbanks North Star	30 865.6	497.7	1.6
		Juneau	31 932.2	65.7	0.2
Very Low	High	Sitka	34 287.1	70.6	0.2
Very Low	Very High	Anchorage	38 969.8	189.9	0.5

Both Juneau and Fairbanks North Star Boroughs ranked very low in vulnerability and medium in resilience. However, Juneau had relatively lower cumulative death (65.7) per 100 000 population and CFR (0.2) than Fairbanks North Star (497 cumulative deaths per 100 000 and 1.6 CFR). The main reason behind this difference in the COVID-19 outcomes could be that Juneau ranked low in socioeconomic disadvantages and had a very high vaccination rate, and greater number of primary care providers and healthcare facilities per 100 000 population compared with Fairbanks North Star.

We computed Spearman correlation coefficients (Table 4) to find whether the COVID-19 epidemiologic outcomes are statistically associated with the Alaska Pandemic Indices. The Alaska Pandemic Resilience Index demonstrates a negative and significant relationship with cumulative deaths per 100 000 and CFR. The resilience index is positively associated with the cumulative cases per 100 000. Due to the contagious nature of the COVID-19 variants, even the resilient areas experienced rapid growth in COVID-19 cases. From 31 January 2021 to July 2022, when Delta and Omicron were more dominant,[72] Alaska reported more than 219 000 new cases

Table 4 Spearman correlation coefficients

	Cumulative cases per 100 000	Cumulative death per 100 000	Case fatality ratio (%)
Alaska Pandemic Vulnerability Index	0.24	0.32	0.22
Alaska Pandemic Resilience Index	**0.42**	**–0.49**	**–0.60**

Values in bold are different from 0 with a significance level alpha≤0.05. Coefficients must be interpreted with caution due to few observations (ie, N=26).

corresponding to an increase of 412.3%. As the correlation matrix indicates a weak and not significant correlation between the vulnerability index and COVID-19 confirmed cases, deaths and CFR, it is not clear from our analysis whether the vulnerability is a useful measure for assessing pandemic outcomes. Thus, results suggest that irrespective of vulnerability ranking, the more resilient a census area is, the lesser the cumulative death per 100 000 and CFR in that area.

DISCUSSION

This research is an effort to build an integrated analytical framework that incorporates both the vulnerable and resilient features of a community offering a fresh perspective that helps understand the degrees of potential risk exposure or the varying severity of the effects of any pandemic and future health crises on communities. Our exploratory analysis of COVID-19 epidemiological outcomes in Alaska within the context of the vulnerability–resilience framework illustrated that the more resilient census areas or boroughs had lower mortality rates and CFR and vice versa, regardless of their rank in vulnerability. This result contrasts with a large body of research reflecting socioeconomically disadvantaged communities have higher COVID-19 mortality rates than affluent areas.[14 50 73]

Even though Alaska ranked 23rd among the 50 US states in economic hardship,[45] the state has shown coping, adaptive and transformative capacities while dealing with COVID-19-related uncertainties, which are the key dimensions of social resilience.[74] At the macro level, state leaders acknowledged the past traumatic 1918 influenza experiences, recognised and respected the sovereignty of tribes and provided autonomy to tribal communities to establish their vaccine priorities and campaigns.[75] Meanwhile, Alaskan tribal communities collaborated and communicated with state public health officials at every level of the COVID-19 response.[75] At the micro level, increased community engagement and the households' continuation of subsistence activities not just for food but also for mental well-being signify a constructive way to deal with COVID-19 crises.[51] Moreover, strict adherence to COVID-19 guidelines, community-centred behaviour and higher vaccination acceptance rates reflect the Alaskans' ability to adjust in their everyday lives.[51 76] These coping, adaptive and transformative abilities of Alaskan communities, no doubt, have curtailed the potential loss of life.

Our assessment of the association between pandemic indices and COVID-19 outcomes is based on a small sample size. Data related to COVID-19 epidemiological outcomes and many indicators (e.g., subsistence, vaccination rates and prevalence rates of underlying health medical conditions, among others) used to calculate the indices are available for only census areas or boroughs limiting this study sample size to 26 observations. The apparent size of correlation coefficients might change as the sample size increases or data are available at a finer spatial scale. Though our research can be generalised to the Arctic and other remote regions, the concept of social resilience is a latent construct that cannot be quantified easily and is unique to every community. In-depth field studies are necessary to comprehend the role of various aspects of remote and indigenous communities, such as traditional knowledge, culture and social capital, in fostering resilience.

CONCLUSIONS

The Arctic faces socioeconomic well-being and healthcare accessibility challenges, which could have been amplified by the COVID-19 pandemic or similar public health emergencies. From the vulnerability perspective, the Arctic, including most of Alaska and Arctic regions around the world, could have been considered very sensitive to the pandemic with expectations of dire COVID-19 epidemiological outcomes. Since the beginning of the pandemic, many Arctic regions, however, had lower incidence and mortality rates and lower CFRs, potentially reflecting the Arctic's resilience.[32 77] This implies that resilience indicators must be integrated with the vulnerability assessments conventionally used to explain potential exposure to a pandemic.

Vulnerability research so far has overshadowed the understanding of an Arctic community's resilience to address and cope with pandemic risks. The assessment of the potential impacts of public health emergencies on Arctic communities is inflated and limited when evaluated exclusively through the stereotyped approach that measures only vulnerability using universal societal indicators. Consideration of the Arctic communities' assets and strengths is essential. Thus, this study presents a vulnerability–resilience framework, aiming to fill the gaps and address the need to assess the Arctic communities' exposure to pandemic risk in a more integrated way.

This study, unlike previous studies, is an effort to assess the community-level pandemic risk by considering not just the communities' existing vulnerabilities but also their resilience. In particular, we built a pandemic vulnerability–resilience framework from the conventional social vulnerability concept and applied the framework to Alaska. The framework incorporates pandemic vulnerability and resilience indices that consider features that make Alaskan communities susceptible to and able to cope with or recover from the potential effects of a pandemic. Based on the combined assessment of the vulnerability and resilience indices, we found that not all highly vulnerable census areas and boroughs were impacted with the same severity by the COVID-19 pandemic because of their resilience capacities. The insight that pandemic risks are the result of the interaction between vulnerability and resilience could help public officials and concerned parties to identify the communities at most risk accurately and allocate resources and services accordingly. A resilience–vulnerability-focused approach described in this paper can also be applied to assess the potential effect of COVID-19 and similar future health crises in remote regions or regions with large Indigenous populations in other parts of the world.

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Funding This study was supported by the Office of Polar Programs (2034886).

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository.

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