# Assessing pandemic risk through a lens of vulnerability and resilience: A case of the Northwest Territories, Canada

Sweta Tiwari, Andrey N. Petrov, Michele Devlin, Mark Welford, Nikolay Golosov, John DeGroote, Tatiana Degai & Stanislav Ksenofontov

*Background: The Arctic communities are socially vulnerable, yet they also have enormous inherent resilience and adaptive capacities leading to low COVID-19 mortality rates (except for Northern Russia) compared to their national counterparts. Thus, a conventional vulnerability approach to understanding pandemic risks across the Arctic seems insufficient. This study considers vulnerability and resilience as separate but interrelated and complementary facets of a risk assessment. Based on this premise, this study introduces a pandemic vulnerability-resilience framework that synthesizes underlying factors defining the Arctic communities' susceptibility and ability to cope with and recover from disease outbreaks.*

*Methods: In particular, using North West Territories (NWT) communities as an example, we developed the pandemic vulnerability-resilience framework considering its communities' vulnerability and resilience features.*

*Results: We found that highly vulnerable Indigenous communities ranked medium or high in resilience, whereas low-resilient non-Indigenous communities ranked low in vulnerability. The primary sources of resilience to a pandemic in remote Indigenous communities are traditional country food, the strength of knowledge systems, and geographic isolation. With respect to*

Sweta Tiwari, ARCTICenter and Department of Geography, University of Northern Iowa, USA; Andrey N. Petrov, ARCTICenter and Department of Geography, University of Northern Iowa, USA; Michele Devlin, ARCTICenter, University of Northern Iowa and United States Army War College, USA; Mark Welford, United States Army War College, USA; Nikolay Golosov, Department of Geography, Pennsylvania State University, USA; John DeGroote, Department of Geography, University of Northern Iowa, USA; Tatiana Degai, ARCTICenter, University of Northern Iowa and Department of Anthropology, University of Victoria, Canada; Stanislav Ksenofontov, ARCTICenter and Department of Geography, University of Northern Iowa, USA

*vulnerability, these communities are often found to be vulnerable in socioeconomic, demographic, housing, and transportation domains.*

*Conclusion: High-resilience communities, even though highly vulnerable, have capacities to cope with or recover from the pandemic. Low-resilience communities will be less impacted by a pandemic only if they are low in vulnerability. Considering either vulnerabilities or resilience would result in the misallocation of resources thus this study recommends a combined assessment of both. Thus, the proposed pandemic vulnerability-resilience framework enables community leaders and/or government officials at different levels to identify the indicators which are below par or thresholds and plan interventions accordingly.*

## Introduction

From the onset of the COVID-19 global pandemic, the concept of vulnerability once again became popular and entrenched within several research fields, from public health and social science to medical and sustainability studies (Gatto et al., 2022; Liao et al., 2022; McGowan et al., 2022; Mude et al., 2021; Pan et al., 2020). One consistent thread found in the vulnerability-focused studies is to identify the populations or communities with disproportionate COVID-19 burden[1] (i.e., mortality and morbidity wise) through indices constructed using their socioeconomic, demographic, and health indicators, among others (Adjei-Fremah et al.,2023; Daras et al., 2021; García-Peña, 2023; Liao et al., 2022; McGowan et al., 2022; Wang et al.,2022). Given these domains' indicators, almost all these studies reached a common conclusion that the likelihood of experiencing COVID-19 mortality is much higher in marginalized, remote, and Indigenous or minority communities than in others (Adjei-Fremah et al., 2023; Daras et al., 2021; Ingram et al., 2022; Liao et al., 2022; Mude et al., 2021; Wang et al., 2022).

The Arctic, including Canada's northern territories, is one of the known remote regions in the globe with underdeveloped healthcare systems, poor civic infrastructures, a low standard of living, and a higher prevalence of underlying medical conditions, making its residents highly susceptible to COVID-19 outcomes (Arctic Council, 2020; Huot et al., 2019; Petrov et al., 2021a). Further, the Arctic is home to over one million Indigenous people who have been and continue to be socioeconomically marginalized, lacking equal access to resources needed to combat COVID-19 (Arctic Council, 2020; Coates, 2020; Young et al., 2020). In these contexts, vulnerabilities refer to characteristics of a community that increase the likelihood of susceptibility of that community to the adverse impacts of a pandemic. From a vulnerability perspective, high COVID-19 death rates are anticipated in the most deprived Arctic northern regions, particularly among Indigenous communities (Barik et al., 2022; Petrov et al., 2021b). However, for most Arctic regions (except for northern Russia), the actual COVID-19 death rates per 100,000 were much lower than expected and as compared to their national counterparts or southern parts (Tiwari et al., 2022). The lower COVID-19 death rates among the Arctic communities raise the question of whether or not the conventional vulnerability approach is useful for explaining variability in deaths across the Arctic regions.

There is no doubt that the Arctic communities are socially vulnerable, yet the communities also have enormous resilience leading to fewer COVID-19 deaths (Cook & Johannsdottir et al., 2021; Petrov et al., 2021a; Tiwari et al., 2022; van Doren et al., 2023). Resilience, in this study context, refers to the ability of a community to withstand, cope with, and recover from the adverse impacts of a pandemic. Resilience includes both inherent and adaptive capacities (Keck & Sakdapolrak, 2013). Lessons from past pandemics, traditional knowledge and medicines, and subsistence practices are Arctic communities' inherent resilience which they relied on while dealing with the COVID-19 crisis (Petrov et al., 2021a; van Doren et al., 2023). Self-determination, proactive community leadership, and strict adherence to COVID-19 health guidelines are reflective of their adaptive capacities. These adaptive activities stemmed from the previous pandemics' devastating experiences and a need to protect the most vulnerable (Banning, 2020; Richardson & Crawford, 2020; Tiwari et al., 2022).

The nuanced differences between vulnerability and resilience, and the role of resilience in managing and reducing health risks, including pandemics, in the Arctic are well understood (Adams & Dorough, 2022; Darren, 2016; Healey et al., 2019). Yet, quantitative metrics of resilience to assess pandemic risk have not been developed for the Arctic and, globally, are in their infancy (Pileggi, 2022; U.S. Census Bureau, 2022; van Doren et al., 2023). Further, when evaluating potential pandemic risks, consideration of vulnerability and resilience together is almost absent. One of the main reasons could be some prominent community resilience features, such as social and location-specific capitals, are latent constructs and spatially heterogeneous (uneven distribution) (Cutter, 2016; Kawachi et al., 2008).

This study is an effort to advance the place-based health resilience metric, i.e., a composite index of societal factors quite distinct from vulnerability indicators, for evaluating the Arctic communities' ability to cope with and recover from health adversities including pandemics. We strongly believe that vulnerability working in tandem with resilience influences pandemic outcomes and their severity. Thus, this paper considers vulnerability and resilience as separate but interrelated and complementary facets of risk assessment and presents a framework that integrates both to understand Arctic communities' risk concerning public health emergencies. In particular, this study introduces the vulnerability-resilience framework for the Northwest Territories (NWT), Canada that incorporates indices of vulnerability and resilience developed using various societal indicators tailored to its communities and assesses both indices integratively. Examination of vulnerability and resilience indicators individually and combinedly have their merits, especially helping public officials, policymakers, and/or concerned parties to identify a particular societal indicator that needs intervention for improvement and to find communities at most risk for efficient allocation of resources and services required to prepare, intervene and recover from a pandemic.

## Northwest Territories (NWT) as a case study

The availability of community-based socioeconomic data and the resemblance of the NWT geography, socioeconomic, health, and cultural characteristics with other remote regions of the Arctic informed our decision to choose NWT as a case study for designing and applying the vulnerability-resilience integrated framework. This conceptual framework can also be tailored and is applicable to remote communities with large Indigenous populations in other parts of the world.

The Northwest Territories is one of the northern Canadian Arctic regions and is bordered to the east by Nunavut, to the west by the Yukon Territory, and to the south by British Columbia, Alberta, and Saskatchewan (Wonders, 2021). While the NWT covers 1,171,918 square km, the region is inhabited by only 41,070 people, which constitutes 0.11 percent of the total Canadian population in 2021 (Statistics Canada, 2022). About 50 percent of the NWT population is Indigenous (Statistics Canada, 2022). First Nations, Inuit, and Métis represent the larger Indigenous population

(Statistics Canada, 2022). First Nations include over 25 groups, primarily Dene and Cree (James-Abra, 2022). The Inuvialuit are the main Inuit nation in the NWT. Among the remaining NWT population, about 12 percent were minorities, including Asians, Black, Arabs, and Latin Americans, and the rest mostly were European descendants (Statistics Canada, 2022). In this study, the Arctic communities refer to both Indigenous and non-Indigenous communities. For research analysis, we defined Indigenous communities as communities with more than fifty percent of their residents being Indigenous and vice versa as non-Indigenous communities.

Though the nature of a disease outbreak is nondifferential in exposure, its health consequences are unequally distributed across Canadian communities, like everywhere else, and are most pronounced among the Indigenous Peoples and communities with lower socioeconomic status than others (Huyser et al., 2022; Power et al., 2020; Spence et al., 2022; van Ingen et al., 2021). For example, the incidence rates of tuberculosis (TB) in 2016 were 23.8 and 170.1 per 100,000 among the First Nations and Inuit (Vachon et al., 2018). Whereas among the Canadian non-Indigenous population, the rate was 0.6 per 100,000 only (Vachon et al., 2018). Similarly, the First Nations had nearly triple hospitalizations rates compared to non-First Nations during the 2009 pH1N1 pandemic (Boggild et al., 2011). The prevalence rates, of not just infectious diseases but also chronic health conditions (such as diabetes, heart disease, high blood pressure, asthma, depression, cancer, obesity, etc.) in Indigenous communities, are much higher than the national average (Bruce et al., 2014; Indigenous Services Canada, 2018). A greater percentage of the First Nation and Métis Canadians living in provinces had three or more chronic conditions (Hahmann & Kumar, 2022). Besides chronic health conditions, 20 percent of provinces' Indigenous Canadians were identified as having a disability as opposed to 11 percent of non-Indigenous people (Hahmann & Kumar, 2022). Like other infectious diseases, the COVID-19 mortality rate was much higher (i.e., 1.7 times) for residents in the lowest-income neighborhoods than those in the highest-income neighborhoods (Statistics Canada, 2020). Most of the residents in low-income neighborhoods live in poverty which constrains, to the most extent, their choices for living arrangements and working conditions which significantly increases their susceptibility to infectious diseases (Statistics Canada, 2020; van Ingen et al., 2021).

Such observed disparities in disease outcomes can be more thoroughly understood within the context of pre-existing inequities in social, political, health, and economic domains, affecting access and use of resources, including healthcare services and quality of living (Hahmann & Kumar, 2022; Huyser et al., 2022; Spence et al., 2020). As per the Community Well-Being (CWB)[2] index, despite significant improvement in overall well-being in 2016 compared to 1981, the Indigenous communities scored lower in every component than non-Indigenous communities in 2016 (Indigenous Services Canada, 2019). Further, in some components, such as education and labor force activity, the gap has widened between these communities over time (i.e., from 1981 to 2016) (Indigenous Services Canada, 2019). In the NWT, Métis communities had the lowest average CWB index scores and the largest gap in the score when compared to their non-Indigenous counterparts (Indigenous Services Canada, 2019). Regarding food security, 21.6 percent of households in the NWT in 2017-18 were food insecure, and the proportion of children living in those households was 30 percent (Tarasuk & Mitchell, 2020). Moreover, the quality of healthcare services delivered to Canadian Indigenous communities in the territories was substandard due to poor civic infrastructure and shortages of healthcare providers (Hahmann & Kumar, 2022; Milligan et al., 2023; Vigneault et al., 2021). No doubt, where such a differential vulnerability exists, diseases flourish, and the above differential rates of diseases and chronic health conditions between Indigenous and non-Indigenous communities in Canada are not surprising.

Despite these challenges, the NWT has well contained the proliferation of COVID-19. As of Jan 9, 2023, the NWT had 48.34 per 100,000 fatalities and almost zero hospitalization rates per 100,000, cumulatively (COVID-19 Tracker Canada, 2020). The less severe COVID-19 outcomes, health-wise, can largely be attributed to strict adherence to COVID-19 preventive measures (such as travel restrictions, social distancing, and self-isolation), efficient contact tracing, ongoing communication efforts of the NWT government with Indigenous Peoples, and higher vaccination rates (Cochrane, 2021; Fleury & Chatwood, 2022). Since the beginning of the pandemic, the NWT government has translated the general COVID-19 public health awareness messages and guidelines into various Indigenous languages, as well as disseminated information regarding how to participate in a traditional ceremony and harvest safely on a regular basis (Cochrane, 2021; Fleury & Chatwood, 2022). The NWT government was also continuously working in conjunction with the Government of Canada, Indigenous governments, and municipal leaders to pool resources and coordinate pandemic services across the NWT (Cochrane, 2021).

In terms of COVID-19 immunization, the NWT started vaccinating its people as early as December 2020 and was leading Canada initially (ArcticCovid-UNI, 2021; Public Health Agency of Canada, 2023). On June 1, 2021, 68 percent of the NWT population received at least one dose of the COVID-19 vaccine (ArcticVax, 2021; Public Health Agency of Canada, 2023). And, by January 9, 2023, 77.4 percent of the population had completed the primary series of the COVID-19 vaccination (Public Health Agency of Canada, 2023). These higher vaccination rates were achieved through culturally safe vaccine hesitancy reduction initiatives driven by the NWT Indigenous Peoples (Government of Canada, 2023). Moreover, initiatives such as the utilization of traditional healing knowledge and medicine for both physical and mental well-being, measures taken to ensure food security (such as funding provided by the NWT government for the continuation of on-the-land-practices, and delivery of groceries, free to those who cannot afford, to all homes) and safety of community members were vital in curtailing adverse negative effects of the pandemic on people's health (Cochrane, 2021; Fleury & Chatwood, 2022). Public health measures, collaboration, communication efforts, immunization, traditional healing practices, and well-being initiatives all proved to be vital in curbing catastrophic COVID-19 death tolls in the NWT which would be inevitable without such responses.

## Data and methods

To understand the risks exposure of Arctic communities concerning pandemics and their effects, this study introduces a pandemic vulnerability-resilience framework (Figure 1) that synthesizes underlying factors defining Arctic communities' susceptibility and ability to cope with and recover from disease outbreaks. We considered NWT communities as a proxy of Arctic communities and developed the framework for the territories considering its communities' vulnerability and resilience features.

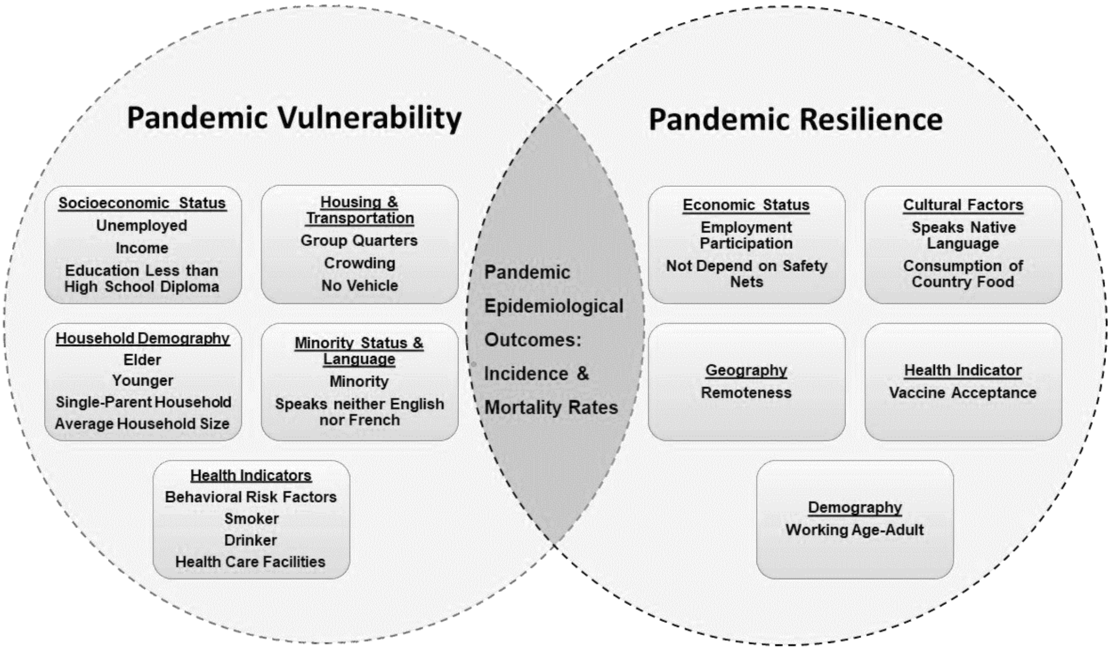


**Figure 1**. NWT Pandemic Vulnerability-Resilience Framework

Based on the framework, we developed metrics of vulnerability and resilience, which both are composite indices calculated using a common set of societal variables (i.e., representative of the Arctic in general) but at the same time tailored as per the social, demographic, economic, healthcare, geographic, and cultural context of NWT communities and availability of data. These indices are called the *NWT Pandemic Vulnerability Index* and *NWT Pandemic Resilience Index*. The lists of the variables used, and their description and data sources are given in Tables 1 and 2.

This study adopted the Cutter et al. (2012) ranking method to develop indices. This method was also employed by the U.S. Centers for Disease Control and Prevention (CDC) to calculate the Social Vulnerability Index (SVI) (CDC/ATSDR, 2018; Flanagan et al, 2011). For calculating the vulnerability index, we computed the percent ranks of each variable listed in Table 1 using equation (1). Except for median income and health care facilities estimates per 100,000, the higher percentile ranking values of each variable indicate higher vulnerability. The higher percentile rankings value of median income and health care facilities estimates per 100,000 represents lower vulnerability. Thus, we reversed the ranking of these two variables by subtracting them from one, so that their higher scores represent higher vulnerability. After making all the variables in the same order, we linearly combined (i.e., summed) the rankings of all these variables, and the summed values were again ranked representing the scores for the index that range from 0 to 1, where 0 refers to the least and 1 refers to the most vulnerable communities.

$$Percentile\ Ranking\ (R) = \frac{Rank - 1}{N - 1} \qquad (1)$$

The same percentile ranking methodology was applied to create scores for the resilience index using variables listed in Table 2. Each community received a percent rank from 0 to 1. The higher the values of the index, the more resilient a community is, and vice versa.

The pandemic vulnerability and resilience indices then were assessed together visually using a bivariate map. The bivariate map shows various combinations of resilience and vulnerability categories pinpointing communities which will be most affected and must be prioritized accordingly during the distribution of the resources needed to prevent, cope with and recover from the consequences of disease outbreaks.

**Table 1.** NWT Pandemic Vulnerability Index Variables

| Domains | Description | Source |
|---|---|---|
| Socio-economic | Unemployment Rate | NWT Bureau of Statistics (Year: 2019) |
| | Percentage of the population with less than a high school diploma | NWT Bureau of Statistics (Year: 2019) |
| | Median Total Income ($) of households in 2015 | NWT Bureau of Statistics (Year: 2019) |
| Household Composition and Size & Disability | Percentage of the Population 60 years and over | 2016 Census |
| | Percentage of the population aged 14 and younger | 2016 Census |
| | Percentage of Lone-parent families | NWT Bureau of Statistics (Year:2016) |
| | Average size of census families | 2016 Census |
| Minority and Language | Percentage of minorities (except Caucasian & Indigenous) for the population in private households | 2016 Census |
| | Percentage of the population excluding institutional residents who do not have knowledge of official languages, i.e. neither English nor French | 2016 Census |
| Housing & Transportation | Percentage of population institutionalized residents | 2016 Census |
| | Percentage of number of private households with more than one person per room | 2016 Census |
| | Percentage of the population without driver licenses | NWT Bureau Statistics (year:2019) |
| Health Factors | Crude Prevalence (Data value in %) of heavy drinkers | NWT Bureau Statistics (Year:2014) |
| | Crude Prevalence (Data value in %) of current smoking adults aged 12 years and over | NWT Bureau Statistics (Year:2014) |
| | Estimates of Health Care Facilities (i.e., health clinics, medical clinics, and hospitals) per 100,000 population | NWT Bureau Statistics/Infrastructure Profile |

**Table 2.** NWT Pandemic Resilience Index Variables

| Category | Description | Source |
|---|---|---|
| Economic Factors | Labor Force Participation Rate | NWT Bureau Statistics (Year:2019) |
| | Percentage of the population not receiving any kind of income assistance | NWT Bureau Statistics (Year:2019) |
| Demographic Factors | Percentage of the Population aged from 20 to 54 years | 2016 Census |
| Cultural Factors | Percentage of the population having knowledge of aboriginal languages in a private household | 2016 Census |
| | Percentage of Households Consuming Country Food | NWT Bureau Statistics (Year:2019) |
| Health Factor | Percentage of the population having at least one dose of COVID-19 vaccine | NWT COVID-19 Dashboard |
| Geography | Index of Remoteness | Statistics Canada (Year:2016) |

## Results

We mapped both pandemic indices scores to explore spatial patterns. For mapping purposes, the indices scores were classified 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.

### NWT Pandemic Vulnerability Index

In the Beaufort Delta region, communities (except Aklavik and Inuvik) with very high and high vulnerability index values, as shown in Figure 2, were concentrated in the east and northwest: Ulukhaktok (0.857), Fort McPherson (0.785), Tsiigehtchic (0.75), Tuktoyaktuk (0.71). Higher unemployment rates, low median income, and lower educational attainment were the main reasons for the very high and high vulnerability scores of Fort McPherson, Tuktoyaktuk, and Ulukhaktok. While Tsiigehtchic had good socioeconomic status, Tsiigehtchic as well as Fort McPherson, Tuktoyaktuk, and Ulukhaktok communities also had a considerable percentage of lone-parent families, crowded private households, heavy drinkers, and smokers.

Aklavik ranked medium, and Inuvik ranked low in vulnerability. Aklavik had a sizable proportion of lone-parent families, elderly population, and population involved in risky health behaviors, and did not own vehicles. Very low levels of vulnerability were seen in communities along the center Beaufort Delta region [i.e., Paulatuk (0.14) and Sachs Harbour (0.10)] and the south of NWT. Southern communities located in Decho and South Slave regions had medium to very low vulnerability index values. Other communities with high levels of vulnerability were located in Sahtú (except for Norman Wells), Tłı̨chǫ (except Wekweètì), and North Slave (except Yellowknife) regions. Although vulnerable, communities in Tłı̨chǫ (except Gamètì) and Sahtú regions ranked low to medium in socioeconomic vulnerability.

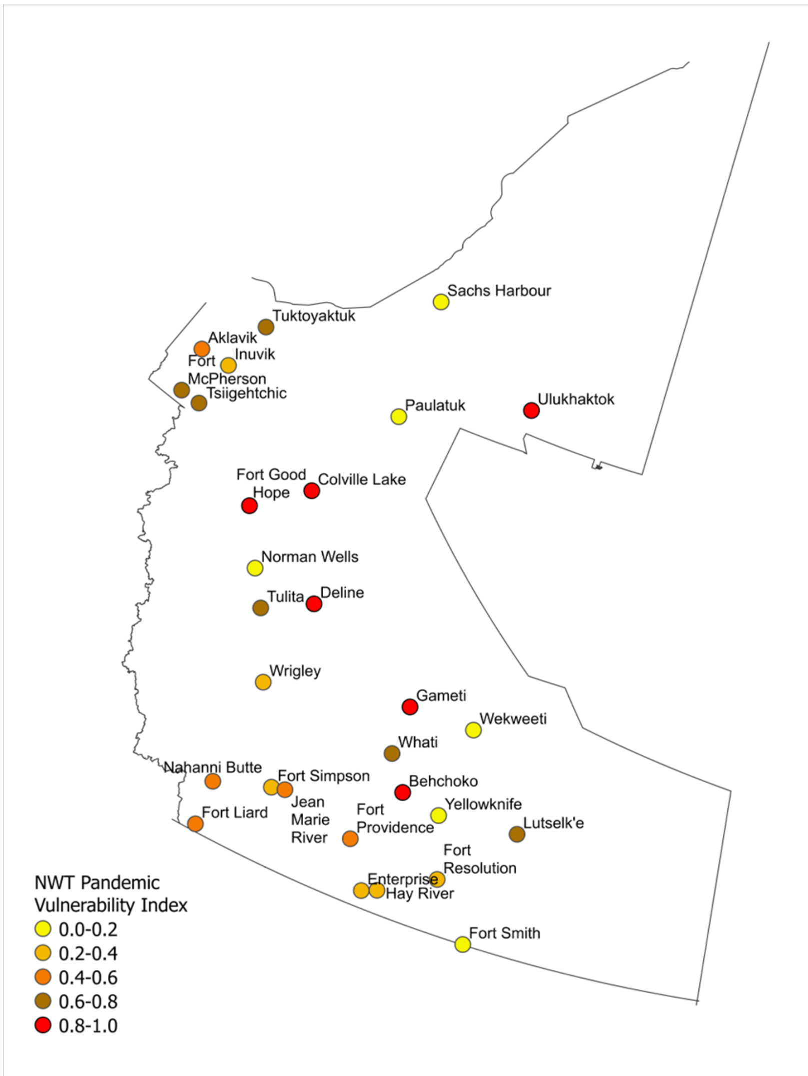


**Figure 2.** NWT Pandemic Vulnerability Index

## NWT Pandemic Resilience Index

Regionally, communities in Sahtú and Tłı̨chǫ (except Behchokǫ̀) had high resilience index values (Figure 3). Both regions are home to Indigenous Peoples, mostly Dene and Métis, and thus found to be quite resilient in cultural indicators (i.e., a higher percentage of people having knowledge of Indigenous languages and a proportion of the population consuming traditional country food). The communities of both regions also had higher COVID-19 vaccination rates. Besides these factors, communities like Délı̨nę, Norman Wells, Fort Good Hope, Tulita, Gamètì and Wekweètì had medium to very high economic resilience (i.e., measured through labor force participation rates, percentage of the population not relying on income assistance).

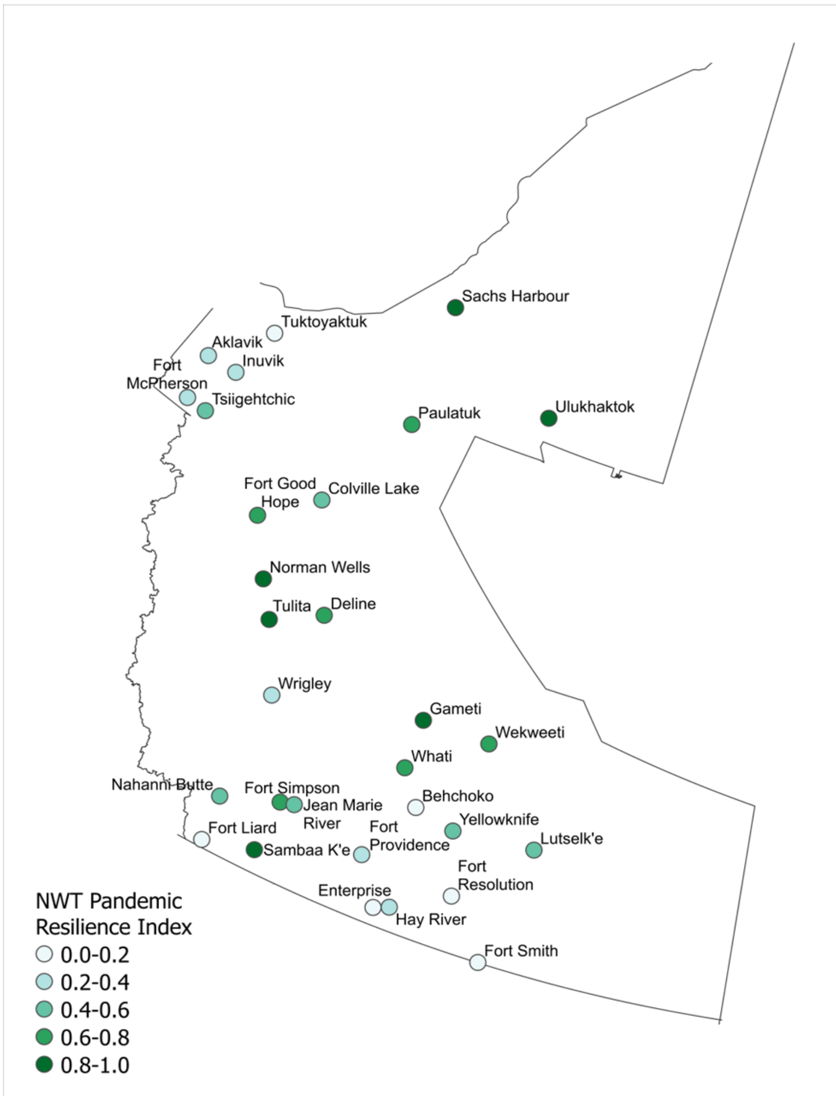


**Figure 3.** NWT Pandemic Resilience Index

Lower resilience was found across the communities in the South Slave Region as well as northwest of the Beaufort Delta region. Even though less resilient, all communities in the South Slave Region had medium to very high economic resilience and communities in northwest Beaufort had higher vaccination rates. Paulatuk, Sachs Harbor, and Ulukhaktok located in central and eastern Beaufort Delta regions had higher levels of resilience in demographic, geographic, and health indicators listed in Table 2.

In the Decho regions, Sambaake and Fort Simpson communities had higher levels of resilience, Nahanni Butte and Jean Marie River had medium-level, and Wrigley and Fort Liard had lower levels. Except in cultural indicators, Wrigley and Fort Liard communities ranked low in every resilience indicator.

Among communities in the North Slave Region, Łutselk'e ranked in medium while Yellowknife ranked high in resilience. Yellowknife is the capital of the NWT jurisdiction and the only city in the region. Thus, except in remoteness and cultural indicators, Yellowknife was highly resilient in every indicator.

**Integrated vulnerability-resilience assessment**

To accurately identify which community has the potential to be most affected if a disease outbreaks, we integratively evaluated the vulnerability and resilience (Figure 4). For the assessment, we categorized the communities using quantile into four continuums of vulnerability and resilience, combined (i.e., High-High, High-Low, Low-High, and High-High). High-vulnerability and low-resilience communities include Aklavik, Fort McPherson, Tsiigehtchic, Tuktoyaktuk, Łutselk'e, and Behchokǫ̀. Thus, these areas have a higher likelihood to be severely impacted by COVID-19 or a future pandemic. Inuvik, Fort Liard, Wrigley, Jean Marie River, and all communities in the South Slave Region could also be affected by a disease outbreak as these communities ranked low in both.

Even though Ulukhaktok, Nahanni Butte, Colville Lake, Délı̨nę, Fort Good Hope, Tulita, Gamètì and Whati communities had higher levels of vulnerability, these communities were also high in resilience, thereby they would have capacities to cope with and recover from a pandemic. Similarly, Paulatuk, Sachs Harbour, Fort Simpson, Yellowknife, Norman Wells, and Wekweètì communities which ranked high in resilience and low in vulnerability would probably be less impacted by the pandemic.

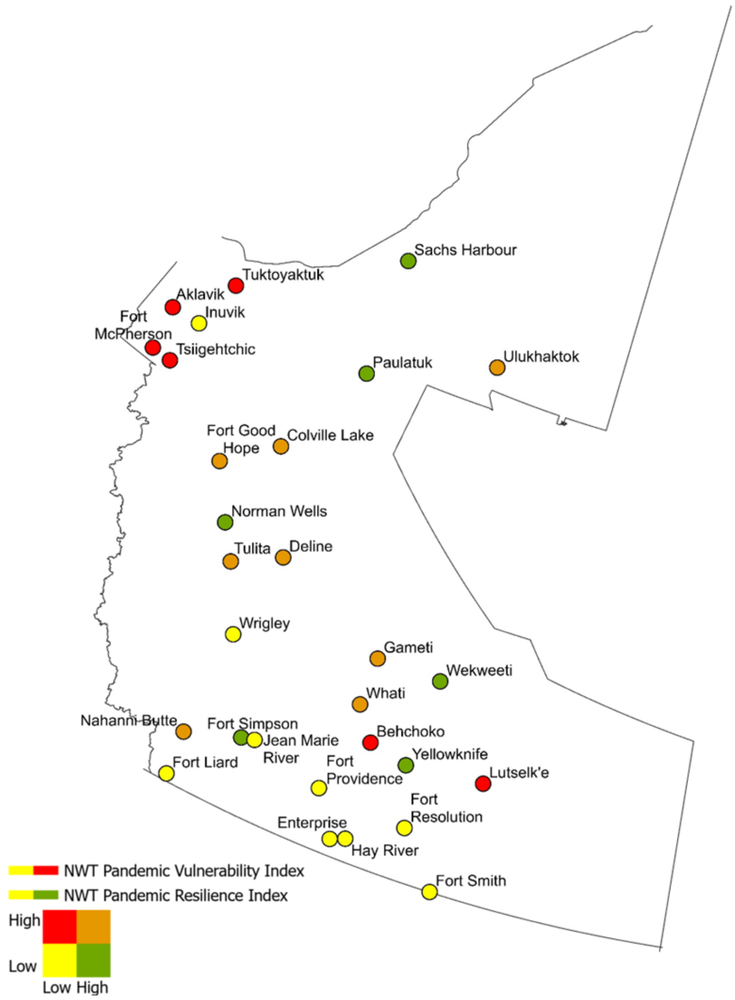


**Figure 4.** NWT Pandemic Vulnerability-Resilience Typology

To understand which domains of vulnerability and resilience (as shown in figure 4 and 5) were most influential, we chose four sample communities each representing a combined continuum of vulnerability and resilience: Colville Lake (high in both), Paulatuk (low vulnerability and high resilience), Behchokǫ̀ (high vulnerability and low resilience), and Fort Smith (low in both); and capital of the NWT, Yellowknife.

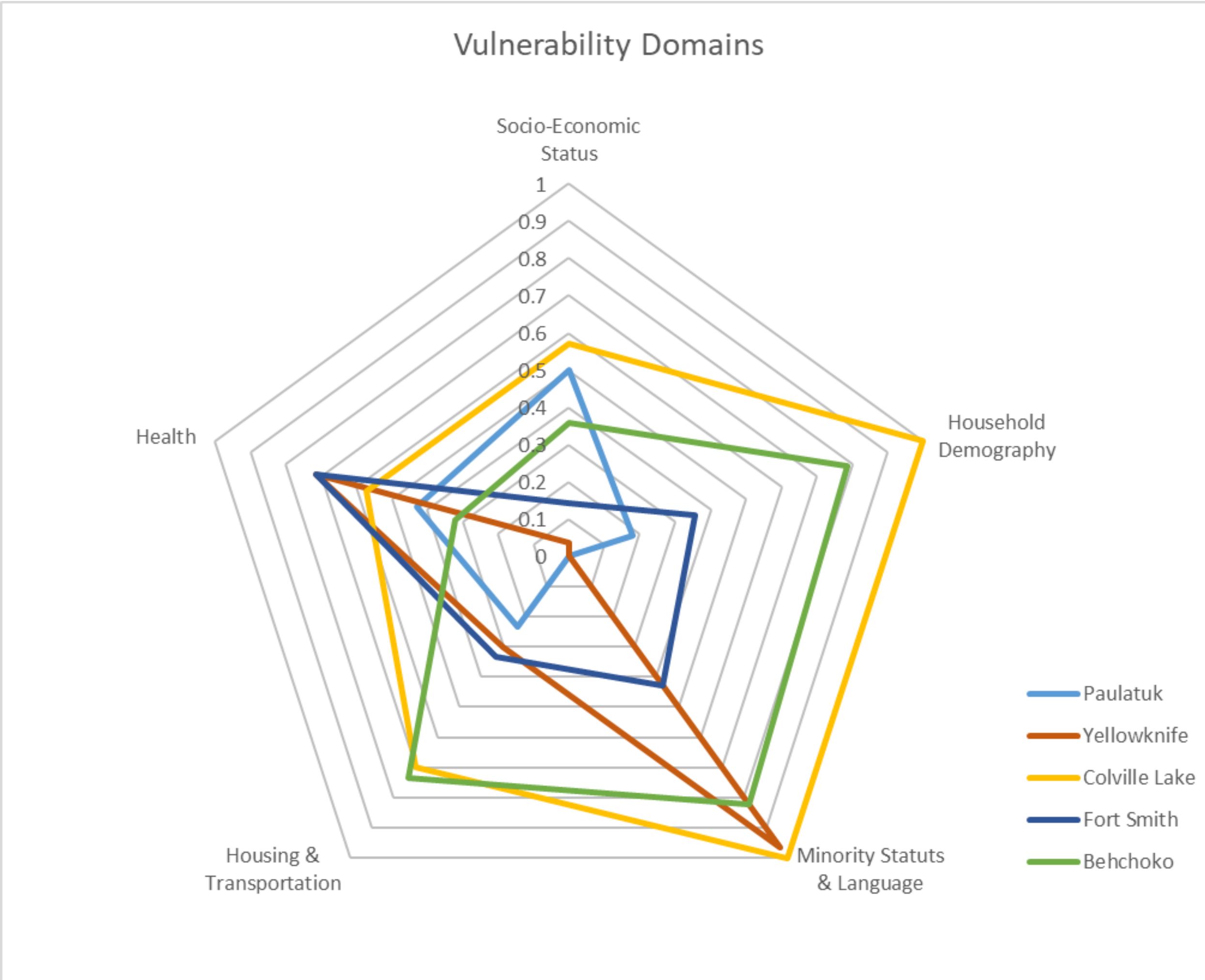


**Figure 5.** Vulnerability Domains in Selected Communities

The high vulnerability index values for Colville Lake and Behchokǫ̀ were driven by their high percentile ranking scores in three out of five domains: household demography, minority status & language, and housing & transportation. Although highly vulnerable in all domains, Colville Lake ranked high in resilience and key domains that contribute to high resilience include culture and health. Colville Lake is a small Indigenous (primarily Dene) community with a strong engagement in subsistence and connection to the land (Government of Northwest Territories, 2023). In the health domain, the community had higher vaccination rates: around 92 percent of the population had received at least one dose of the COVID-19 vaccine by the summer of 2022. In contrast, Behchokǫ̀ ranked low in resilience domains. Even though Behchokǫ̀ is a predominantly Indigenous community, very few households consumed country food, and a relatively small number of residents had knowledge of their Indigenous languages. Further, the proportion of working-age adults and labor participation rate was relatively low despite Behchokǫ̀ being one of the six main regional centers and economic hubs of the NWT. Behchokǫ̀ also had a lower vaccination rate as compared to other NWT communities.

Paulatuk had a low to medium vulnerability ranking in all domains and was highly resilient, especially in geography, demography, health, and culture domains. However, it ranked relatively low in economic resilience. Paulatuk is the home to the Inuvialuit who have continued their traditional practices such as hunting, trapping, and Arctic char fishing (Government of Northwest Territories, 2023). Paulatuk had a large percentage of households consuming country food, although Indigenous language retention was lower. Due to limited wage employment opportunities, the labor force participation rate was relatively low.

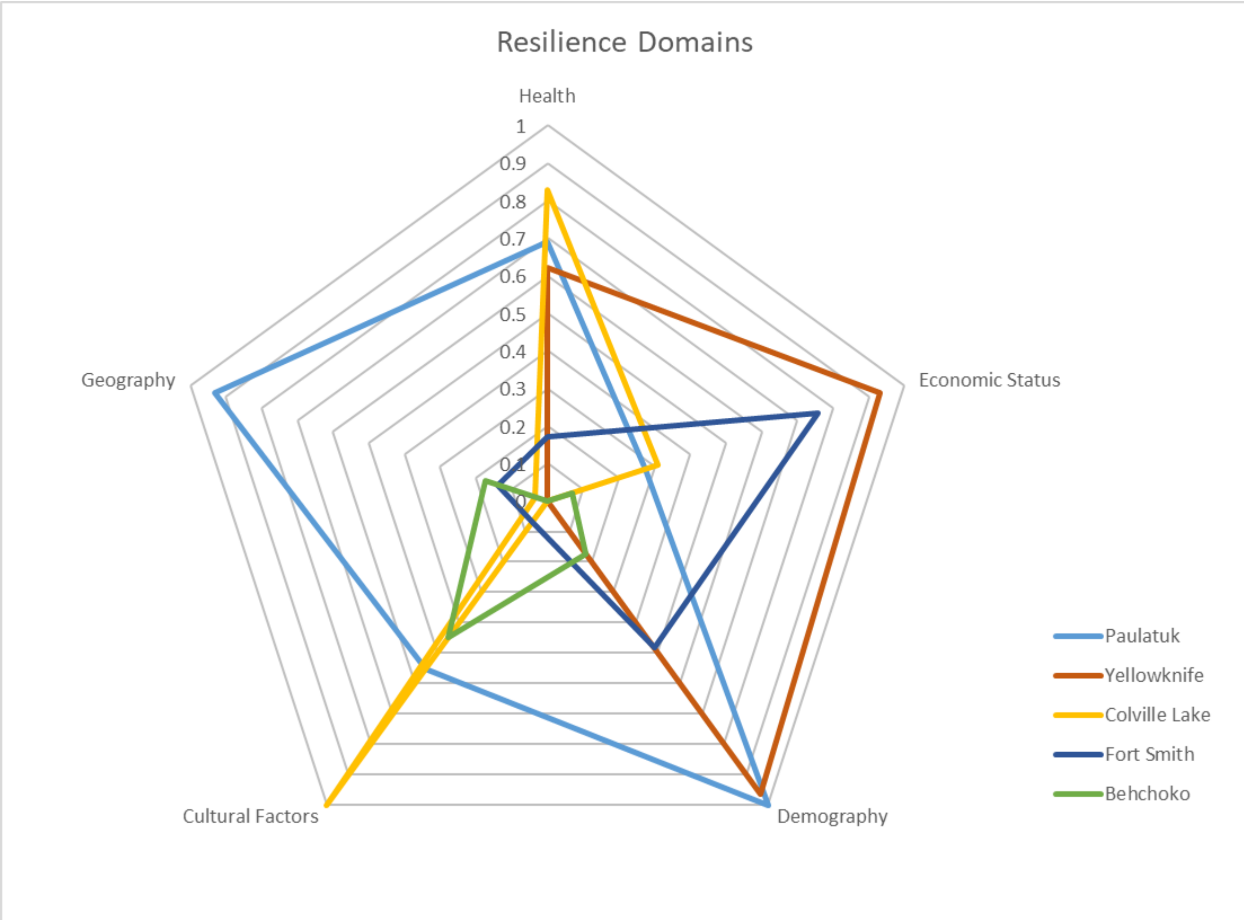


**Figure 6.** Resilience Domains in Selected Communities

Paulatuk and Yellowknife both ranked low in vulnerability and high in resilience, but these two communities are very different. Most residents in Yellowknife are non-Indigenous including other minority populations (i.e., other than Caucasian). Only a small percentage of the Yellowknife population was involved in traditional activities, consumed country food, and had knowledge about Indigenous languages. Despite low scores on the cultural domain of resilience, the strength in the economic and demographic domains was sufficient for making Yellowknife highly resilient. Further, Yellowknife ranked near the bottom in three domains of vulnerability: socioeconomic status, household demography, and housing & transportation.

For Fort Smith, though the percentile rankings for the four domains of vulnerability were generally low, the cultural, health, and geographic indicators of resilience were weak. Fort Smith is a regional hub for the South Slave Region and the headquarters of the Wood Buffalo National Park, which is well connected to the rest of Canada. The community is less vulnerable and more resilient in respect to the economic domain.

In general, for remote Indigenous communities, the main sources of resilience are traditional country food, the strength of knowledge systems, and isolation. For non-Indigenous communities, the primary domain of resilience is economic indicators. With respect to vulnerability, remote Indigenous communities are found to be vulnerable in socioeconomic, demographic, and housing & transportation domains. In non-Indigenous communities, vulnerable groups are minority communities (other than Indigenous or Caucasian) and populations who speak neither English nor French.

## Discussion and conclusion

Over the past two years, a strong research foundation has been built for understanding Indigenous communities' vulnerability to the COVID-19 pandemic (Arriagada et al., 2020; Flores-Ramirez et al., 2021; Hathaway, 2021; Huyser et al., 2021; Mendes et al., 2022; Millalen et al., 2020); whereas only a countable number of empirically based studies on community-level resilience to the pandemic exist globally (Pileggi, 2022; U.S. Census Bureau, 2022; van Doren et al., 2023). In the Canadian context, some researchers have opted to define resilience as a subset or inverse of vulnerability while others took specific approaches such as location-based case studies or specific sectors, e.g., food systems, ecological or climate change, or natural hazards (Andrachuk & Smit, 2012; Chakraborty et al., 2020; Journeay et al., 2022; Lede et al., 2021; Oulahen et al., 2015; Ross, & Mason, 2020 and many more). Less is known about whether such studies capture the outcomes or processes of resilience meaningfully in the context of a pandemic. This study proposes a pandemic resilience index, a composite metric of societal indicators used as proxies of the Arctic communities' inherent resilience needed to deal with adversities amid a pandemic.

The internal capacities of Arctic communities are distinctly different from communities in other parts of the world. For example, not only does access to country food make an Indigenous community's food secure but also supports its people's overall well-being (i.e., physical, mental, and spiritual health) by nurturing their sense of identity and belonging (Collings et al., 2016; Robin et al., 2021; Robinson, 2018). Further, households consuming country food can also be considered knowledge keepers who have preserved their ancestral wisdom of the Arctic ecosystem required to subsist off the land and of medicine, either in the form of food or herbs, required to recover one's health (Kendrick, 2013; Mead et al., 2010; Sheremata, 2018). Thus, the percentage of households consuming country food in this study is used as a proxy for self-sustaining communities with the know-how of their natural environment and traditional healing practices. Likewise, another proxy of traditional knowledge and culture is the percentage of the population-speaking Indigenous languages since language is a way of knowing and a key medium of knowledge transfer (Degawan, 2019; Patel, 2006).

A further indicator of the Arctic's inherent resilience spatially is its remoteness. Remoteness not just delayed the arrival of the pandemic in the Arctic but also provided an opportunity for Arctic communities to prepare for its eventual onset (Petrov et al., 2021a; Tiwari et al., 2022;). Like many Arctic communities, NWT capitalized on this opportunity through a massive COVID-19 awareness campaign using social media, radio, and door-to-door outreach; early monitoring of possible outbreaks using a rapid response team for contact tracing, and waste-water surveillance; instituting stand-alone government agency to pool resources and coordinate with Indigenous and municipal leaders, and massive rapid vaccination campaign, among others (Cochrane, 2021; Fleury & Chatwood, 2022; Public Health Agency of Canada, 2023). We also used the COVID-19 vaccination rate as a proxy of both immunity and the healthcare system. In addition to the individual health benefit of preventing serious illness, higher COVID-19 vaccination rates among communities are also indicative of NWT's ability to deliver immunization services despite the inhospitable weather, difficult terrain, and pandemic-created obstacles, thus justifying the use of the vaccination rate as a proxy of health domain. Vaccination success also characterizes the public readiness to accept the vaccine, which is indicative of the potential success of pandemic public health actions (Government of Canada, 2023).

Among statistical methods that have already been applied to create a vulnerability index concerning the pandemic, we relied on percentile ranking to develop both indices for four main reasons: 1) simplicity, 2) reproducibility, 3) applicability, and 4) comparability.

Simplicity in the sense that, percentile ranking is easy to understand, calculate, and interpret, irrespective of the observed scores' statistical distribution and audiences' statistical background. Data of each variable in this study are easily and freely accessible thus any researcher could reproduce the results. The same category of variables, indices, and pandemic vulnerability-resilience framework can be applied with or without modification to other Arctic communities or remote regions in other parts of the world. Moreover, communities combined ranking in vulnerability and resilience can aid in the accurate identification of the communities at the most risk thereby assisting in the prioritization and allocation of resources and services accordingly.

This study clearly suggests that highly vulnerable Indigenous communities (i.e., communities where more than fifty percent of residents are Indigenous) ranked medium or high in resilience, whereas non-Indigenous communities (i.e., communities with less than ten percent Indigenous population) with low resilience were found to be low in vulnerability. For remote Indigenous communities, the main sources of resilience are traditional country food and their isolation and key domains in which they are high in vulnerability include socioeconomic, demographic, and housing & transportation domains. Non-Indigenous communities are economically resilient and vulnerable populations in these communities are minorities (other than Indigenous or Caucasian peoples) and individuals who speak neither English nor French. High-resilience communities, even though highly vulnerable, have capacities to cope with or recover from the pandemic. Communities with low resilience will still be less impacted by a pandemic only if they demonstrate low vulnerability. Thus, we conclude that considering either vulnerabilities or resilience separately would result in the inefficient allocation of resources and recommend a combined assessment of both. Further, the proposed pandemic vulnerability-resilience framework enables community leaders and/or government officials at different levels to identify the indicators which are below par or thresholds thus providing a reference for planning interventions required for improvement.

Although policy implications of the proposed approach can be far-reaching, this analysis has some limitations, hence results need to be interpreted very carefully. First, various indicators of vulnerability (such as poverty, population with special needs and chronic or underlying medical conditions, etc.) and resilience (such as housing stock, insurance coverage, medical care capacity, etc.) are not included in the indices construction as these data are not available at a finer spatial scale and/or for small communities. The same applies to the data on the COVID-19 epidemiological outcomes, which precludes an assessment of community indices vis-à-vis outcomes. Lastly, this study strongly recommends an in-depth field study to better understand the role of the social capital components (e.g., support networks, self-determination, and community engagement) of resilience in coping and facilitating recovery from the effects of the pandemic.

In summary, since the beginning of the COVID-19 global pandemic, there has been considerable research interest in quantifying pandemic vulnerability to identify high-risk populations. From the vulnerability perspective, the Arctic was expected to experience COVID-19 morbidity and mortality at disproportionately higher rates than their national counterparts, but for most Arctic regions the actual course of the COVID-19 pandemic was the opposite. In fact, a few Arctic regions such as NWT experienced only a handful of deaths and very low mortality rates. Thus, a vulnerability approach to understanding pandemic risks that does not account for the community's resilience has been insufficient. The literature is still mired in defining resilience as the opposite of vulnerability and strewed with a variety of statistical methods to measure vulnerability. Almost no empirical measure of resilience that considers a community's unique strengths and assets exists. This study is an effort to understand pandemic risk through a lens of community resilience, in addition to vulnerability.

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## Endnotes

1. In the above-cited studies, the community-level vulnerabilities indices (such as the area deprivation index employed by Adjei-Fremah et al. (2023), small area vulnerability index by Daras et al. (2021), global vulnerability index by García-Peña (2023), and CDC social vulnerability index by Wang et al. (2022), and so on) found to be significantly associated with COVID-19 mortality and morbidity as well as socioeconomically disadvantaged communities with higher COVID-19 death or confirmed cases rates. Some common indicators used in these studies to measure a community's vulnerability include housing

quality, poverty, age, employment, chronic disease conditions, race/ethnicity, and healthcare resources.

2. CBW Index is a composite measure of community welfare assessed using seven indicators of four components: education, labor force activity, income, and housing. For more information: https://www.sac-isc.gc.ca/eng/1419864229405/1557324163264
3. Our team has employed a similar vulnerability-resilience framework to assess pandemic risk within the Alaskan context. Further information is available at https://gh.bmj.com/content/8/6/e011646.