Research Report

Developing and Validating a Climate Vulnerability Index for British Columbia

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Executive Summary

Background

Climate vulnerability refers to the degree to which a system, such as a community or an ecosystem, is susceptible to, and unable to cope with, the adverse effects of climate change. It consists of three main components: exposure, sensitivity, and adaptive capacity.

- **Exposure** is the extent to which the system is subject to climate-related hazards like floods or heatwaves.
- **Sensitivity** is the degree to which the system is affected by these hazards, which can depend on population characteristics such as the health and age of the community.
- **Adaptive capacity** is the ability of the system to adjust and respond to these climate challenges, influenced by the availability of resources to mitigate harm from climate threats.

Purpose

The purpose of this study is to map climate vulnerability across British Columbia by developing and validating a province-wide climate vulnerability index that measures exposure, sensitivity, and adaptive capacity.

Methods

To map climate vulnerability in British Columbia, we employed a multi-step process. First, we collected a wide range of demographic, environmental, and health-related factors from multiple administrative and publicly available data sources. These data were then processed to impute missing data and aggregate all variables to a common unit of analysis (i.e., the Forward Sortation Area [FSA] level).

Once data were prepared, a two-step principal component analysis (PCA) was used to reduce the complexity of the dataset, distilling it into principal components that effectively captured the core aspects of climate vulnerability in terms of exposure, sensitivity, and adaptive capacity. For visual representation, choropleth maps were created at the FSA level.

Finally, descriptive and univariate linear regression were used to (a) characterize the spatial variation in climate vulnerability and (b) assess agreement between climate vulnerability index scores and subjective perceptions of climate vulnerability collected from survey data.

Results

We developed a climate vulnerability index with three sub-indices measuring exposure, sensitivity, and adaptive capacity.

- **The Exposure Index** was derived from ***(a)*** 10-year average annual precipitation levels (2011-2020), ***(b)*** the number of extreme heat events based on current heat alert thresholds from 2009-2022, ***(c)*** PM2.5 concentrations (2011-2020), and ***(d)*** average summer mean temperature changes in 2020s and 2050s respectively compared to average summer temperature over the years 1998-2014.
- **The Sensitivity Index** was derived from ***(a)*** median age, ***(b)*** change in median age by 2046, and ***(c)*** the incidence of chronic diseases, cancer, and mental health conditions.

  The Adaptive Capacity was derived from **(a)** 10-year average annual Landsat greenness (2009-2019), **(b)** 10-year average noise level (2009-2019(, **(c)** building density at 100 m, **(d)** facility index - facility density index at 1000m, **(e)** access to employment, **(f)** average proximity to health facility score, **(g)** average proximity to public park, **(h)** average CANBICS bikeability score, **(i)** total community gaming grant, **(j)** average community gaming grant, **(k)** median personal income, **(l)** number of employed residents, **(m)** average household size, **(n)** number of residents who live alone, **(o)** number of residents who are single, **(p)** Gini index on adjusted household income (2020), **(q)** number of people with a postsecondary degree, **(r)** number of non-1-year-movers, **(s)** percentage of private dwellings, **(t)** percentage of the population below the low-income measure, **(u)** population change by 2046, **(v)** population density per square kilometre, **(w)** shelter-cost-to-income ratio, **(x)** number of English speakers, **(y)** number of non-minority residents, **(z)** number of non-indigenous residents, **(aa)** average room per dwelling, and **(ab)** number of non-immigrants.

Using this data, we examined the spatial distribution of Climate Vulnerability Index values. These analyses showed that Northern and Interior British Columbia exhibit higher climate vulnerability compared to the Lower Mainland and Island regions. This pattern appears to arise due to higher exposure inland, and higher adaptive capacity in the lower mainland and other highly populated areas. Furthermore, we observed that higher population density was associated with less climate vulnerability, while older age, higher income levels, and higher BC Gaming Grants Funding were associated with higher vulnerability.

Additionally, we examined the agreement between climate vulnerability and subjective perceptions of climate risks measured using self-reported survey data. These analyses showed that individuals living in areas with higher climate vulnerability had lower levels of climate anxiety but were nevertheless more likely to perceive a high likelihood of local devastation due to climate change.

Conclusion

Our study highlights the feasibility of mapping climate vulnerability, as well as the uneven distribution of vulnerability across British Columbia. Furthermore, we highlight important patterns of risk perception associated with climate vulnerability, including a lack of agreement between climate anxiety levels and climate vulnerability scores. Taken together, these studies highlight the need for continued interventions to promote climate awareness and empower climate resilience initiatives across British Columbia – particularly in the Interior and Northern regions.

About the Mental Health and Climate Change Alliance

The Mental Health and Climate Change Alliance is a community of interdisciplinary researchers, healthcare providers, and community organizers committed to identifying and addressing the adverse impacts of the climate crisis on mental health.

As a Canadian Not-for-Profit organization incorporated under the Canada Not-for-Profit Corporations Act, the MHCCA’s purposes are to (1) conduct equity-based climate distress monitoring, (2) incubate novel interventions and policy ideas to address the mental health impacts of climate change, and (3) facilitate knowledge exchange and mobilization to support Canadian's experiencing climate-related ecological distress.

Visit www.mhcca.ca for more information.

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Introduction

In British Columbia (BC), the signs of climate change are clear and undeniable, and the consequences for local communities are already observed on a population level. The province is confronted with a diverse array of impacts: coastal areas are grappling with the challenges of rising sea levels and increasingly frequent storm surges, which lead to erosion and pose flooding risks that threaten residential homes and key infrastructure; inland, especially in areas rich with forests, the incidence of wildfires is escalating [1]. These fires are not only more severe but also more frequent, presenting direct threats and causing extended damage to both the natural environment and the economic stability of these regions.

Shifts in weather patterns, including changes in precipitation and extreme temperatures, are influencing water resources, agriculture, and wildlife, thereby disrupting established livelihoods and practices [2,3]. These environmental shifts present considerable challenges for communities that lack the resources or the capacity for rapid adaptation, thereby increasing their vulnerability to the impacts of climate change.

Indeed, the influence of climate change on BC's communities is shaped not only by environmental hazards but also by the socioeconomic and demographic characteristics of these communities. Factors such as social and economic deprivation, an aging demographic, limited healthcare services, and a high prevalence of chronic health conditions intensify the vulnerability to climate-related impacts [4].

The need to systematically identify and assess climate-related vulnerability – thereby enhancing the province's readiness to cope with both the immediate and long-term climate-related risks – is made increasingly apparent by recent crises experienced by the province. These include the deadliest heatwave on record, unprecedented wildfires, and devastating floods. Each of these emphasizes the urgent and critical need for BC to strengthen its resilience and adapt to the ongoing realities of climate change [5–7].

Conceptualizing Vulnerability

Understanding climate vulnerability is essential for addressing the effects of climate change on communities. It involves evaluating three main components: the risk level a community faces (exposure), the potential severity of impact (sensitivity), and the community's resilience (adaptive capacity) [8]. This triad forms the basis for assessing vulnerability and is widely acknowledged in public health [8–10].

- **Exposure** refers to the extent to which a community is subjected to environmental hazards, such as extreme heat events, flooding, and wildfire smoke. These hazards present direct risks to the health and safety of the population and the structural integrity of critical infrastructure.
- **Sensitivity** is concerned with the attributes of a community that determine how it is affected by exposure to hazards. This includes factors like the median age of the population and the prevalence of health conditions, which cover a range of issues from chronic diseases to mental health concerns, as well as overall mortality rates. These factors dictate a population's susceptibility to the detrimental effects of climate-related hazards.
- **Adaptive Capacity** is characterized by the socioeconomic and sociodemographic factors at the community level, such as the availability and equitable distribution of resources, economic robustness, and the strength of social networks and governance. This capacity determines a community's ability to prepare for, respond to, and recover from the impacts of climate-related hazards. Together, these components create a comprehensive framework for assessing and addressing the varied risks posed by climate change to different communities.

Together, these components create a dynamic model of climate vulnerability, which can be understood in a nuanced and precise way. Understanding vulnerability as a function of exposure, sensitivity, and adaptive capacity is key to creating practical and targeted interventions that can make a difference in enhancing the readiness of various systems to adapt to climate change.

Importance of Mapping Climate Vulnerability

Mapping climate vulnerability index scores provides an essential tool for decision-makers to effectively prioritize and tailor interventions to mitigate the impacts of climate change. These scores, which are the result of a thorough analysis of exposure, sensitivity, and adaptive capacity, offer a nuanced perspective on the varying degrees of climate vulnerability across different regions and communities. By graphically representing these scores, decision-makers can identify regions with heightened vulnerability, facilitating a focused approach in the allocation of resources and the implementation of adaptation strategies. This approach ensures that interventions are not just efficient but also equitable, catering to the needs of those who face the greatest risks. Moreover, mapping these scores assists in pinpointing specific contributing factors to high vulnerability in certain areas, enabling decision-makers to customize interventions to address these particular challenges.

For example, areas that are highly exposed to environmental hazards might benefit from investments in infrastructure resilience, while regions with high sensitivity due to demographic factors might require the expansion of healthcare services and support systems. Ultimately, the use of climate vulnerability scores in mapping provides a data-driven foundation for strategic decision-making, enabling a proactive and informed approach to building climate resilience and advancing adaptation planning.

Efforts to Map Climate Vulnerability

The existing body of literature on efforts to map climate vulnerability underscores an increasing reliance on maps that integrate climate data with biophysical and socioeconomic data to articulate and visualize the risks associated with climate change [8,11,12]. These maps are critical in directing attention to areas most likely to experience significant societal impacts from climate change and in guiding adaptive interventions. With significant funding from initiatives like the Green Climate Fund and other climate adaptation financing mechanisms, these maps and spatial decision-support tools have become key in informing how resources are allocated for maximum effectiveness.

In a comprehensive systematic review of 84 studies on social vulnerability to climate impacts conducted by Sherbinin et al. [11], the literature reveals a collaborative and interdisciplinary approach to mapping climate vulnerability. These studies encompass a wide range of geographical areas and scales, and they differ in their frameworks, data sources, methodologies, and thematic focuses. Summarizing findings from this review, the literature on climate vulnerability mapping typically reflects the adoption of frameworks from the Intergovernmental Panel on Climate Change [13], with a preference for linear index aggregation and a consistent approach in the selection and application of climate and socioeconomic data. Despite these prevailing trends, the literature also points out several challenges in the field, such as a notable number of studies lacking projections of future climate and socioeconomic conditions. Additionally, there is difficulty in adequately capturing uncertainty, challenges in validating the maps produced, and a frequent disconnect between the studies and meaningful engagement with policymakers, particularly in those studies that are intended to have policy relevance.

In response to these identified challenges, the literature proposes a series of recommendations to enhance the effectiveness of climate vulnerability mapping. These recommendations include the integration of projections for future climate and socioeconomic scenarios, the adoption of more sophisticated methods for characterizing uncertainty, improvements in map validation techniques, and an increased focus on engaging with policy frameworks [11]. Together, these suggestions from the literature not only shed light on the current state of climate vulnerability mapping but also chart a path for its future enhancement, aiming to improve its relevance and application in both research and policy-making spheres.

Methods

With the overarching goal of delineating climate vulnerability throughout British Columbia, our endeavor was to construct a climate vulnerability index using existing open-access data sources. Our methodology paralleled that of Yu et al. [8], entailing a multi-step process: (1) data compilation from various sources, (2) geospatial data processing onto a standardized geographic unit—the Forward Sortation Area (FSA), (3) principal component analysis to distill the data to its most critical elements, (4) interpretation of geographic patterns, and (5) cartographic representation of climate vulnerability across different geographies. It is pertinent to note that we formulated two variants of climate vulnerability indices: the first draws from historical data observations, while the second expands upon the first by integrating projections of future temperature, population, and age demographics.

Moreover, we linked climate vulnerability index scores with secondary survey data that gauged subjective perceptions of climate risk to examine if there was a correlation between climate vulnerability scores and increased anxiety or concern regarding climate change [14].

Data Sources

Data sources used to construct the climate vulnerability index included those listed in **Table 1**.

Table 1. Data Sources

Concept	Climate vulnerability component	Data source	Time	Geographic level
Median age of the population	Sensitivity	StatCan	2021	Dissemination area
Average age of the population	Sensitivity	StatCan	2021	Dissemination area
Median personal income	Adaptive capacity	StatCan	2021	Dissemination area
Median household income	Adaptive capacity	StatCan	2021	Dissemination area
Average household size	Adaptive capacity	StatCan	2021	Dissemination area

Number of residents who live alone	Adaptive capacity	StatCan	2021	Dissemination area
Number of residents who are single	Adaptive capacity	StatCan	2021	Dissemination area
Gini index on adjusted household income (2020)	Adaptive capacity	StatCan	2021	Dissemination area
Median employment income	Adaptive capacity	StatCan	2021	Dissemination area
Median household after-tax income (2020)	Adaptive capacity	StatCan	2021	Dissemination area
Percentage of private dwellings	Adaptive capacity	StatCan	2021	Dissemination area
Percentage of the population below the low-income measure	Adaptive capacity	StatCan	2021	Dissemination area
Total population	Adaptive capacity	StatCan	2021	Dissemination area
Population density per square kilometre	Adaptive capacity	StatCan	2021	Dissemination area
Shelter-cost-to-income ratio	Adaptive capacity	StatCan	2021	Dissemination area
Number of English speakers	Adaptive capacity	StatCan	2021	Dissemination area
Number of Indigenous residents	Adaptive capacity	StatCan	2021	Dissemination area
Number of non-Indigenous residents	Adaptive capacity	StatCan	2021	Dissemination area
Average room per dwelling	Adaptive capacity	StatCan	2021	Dissemination area
Number of non-immigrants	Adaptive capacity	StatCan	2021	Dissemination area
Number of non-minority residents	Adaptive capacity	StatCan	2021	Dissemination area
Number of non-1-year-movers	Adaptive capacity	StatCan	2021	Dissemination area
Number of people with a high school diploma	Adaptive capacity	StatCan	2021	Dissemination area
Number of people with a postsecondary degree	Adaptive capacity	StatCan	2021	Dissemination area
Number of employed residents	Adaptive capacity	StatCan	2021	Dissemination area
Projected 2020s summer mean temperature change	Exposure	PCIC	2018	BC weather stations
Projected 2050s summer mean temperature change	Exposure	PCIC	2018	BC weather stations

Number of extreme heat events	Exposure	Environment and Climate Change Canada	2009-2022	BC weather stations
Air pollution index: 10-year average PM2.5	Exposure	CANUE	2011-2020	BC postal code
3-year average land temperature	Exposure	CANUE	2019-2021	BC postal code
10-year annual average max temperature	Exposure	CANUE	2011-2020	BC postal code
10-year annual average precipitation	Exposure	CANUE	2011-2020	BC postal code
10-year average annual Landsat greenness	Adaptive capacity	CANUE	2009-2019	BC postal code
10-year average noise level	Adaptive capacity	CANUE	2009-2019	BC postal code
Building density at 100m	Adaptive capacity	CANUE	2019	BC postal code
Facility index - facility Density Index at 1000m	Adaptive capacity	CANUE	2019	BC postal code
Access to employment	Adaptive capacity	CANUE	2019	BC postal code
Average proximity to health facility score	Adaptive capacity	CANUE	2019	BC postal code
Average proximity to public park	Adaptive capacity	CANUE	2019	BC postal code
Average CANBICS bikeability score	Adaptive capacity	CANUE	2021	BC postal code
Projected median age change between 2046 and 2023	Sensitivity	BC Stats	2022	Local health area
Projected population change between 2046 and 2023	Adaptive capacity	BC Stats	2022	Local health area
Total community gaming grant	Adaptive capacity	BC Government	2022	BC electoral district
Average community gaming grant	Adaptive capacity	BC Government	2022	BC electoral district
Vulnerability in early childhood - communication (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area

Vulnerability in early childhood - emotional (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area
Vulnerability in early childhood - cognitive (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area
Vulnerability in early childhood - physical (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area
Vulnerability in early childhood - social (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area
Vulnerability in early childhood - one or more areas (Kindergarten)	Sensitivity	BC Community Health Data	2013-2016	Local health area
Life expectancy in years - total (All ages)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Potential years of life lost index - smoking-attributable deaths (35 to under 75 years)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Potential years of life lost index - drug-induced deaths (Age under 75 years)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Potential years of life lost index - alcohol-related deaths (Age under 75 years)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Potential years of life lost - accidental falls (Age under 75 years)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Potential years of life lost - motor vehicle accidents (Age under 75 years)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Infant mortality rate per 1000 live births (<1 year)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Low birth rate per 1000 live births (<1 year)	Sensitivity	BC Community Health Data	2011-2015	Local health area
Asthma age-standardized prevalence rate per 100 population (5-54 years)	Sensitivity	BC Community Health Data	2015	Local health area

Chronic obstructive pulmonary disease (COPD) age-standardized prevalence rate per 100 population (45+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Diabetes age-standardized prevalence rate per 100 population (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Heart failure age-standardized prevalence rate per 100 population (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Hypertension age-standardized prevalence rate per 100 population (20+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Asthma age-standardized incidence rate per 1000 population (5-54 years)	Sensitivity	BC Community Health Data	2015	Local health area
Chronic obstructive pulmonary disease (COPD) age-standardized incidence rate per 1000 population (45+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Diabetes age-standardized incidence rate per 1000 population (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Heart failure age-standardized incidence rate per 1000 population (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Hypertension age-standardized incidence rate per 1000 population (20+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Number of general practitioners per 100 000 population (All ages)	Sensitivity	BC Community Health Data	2009-2010	Local health area
Number of specialists per 100 000 population (All ages)	Sensitivity	BC Community Health Data	2009-2010	Local health area

Number of supplementary practitioners per 100 000 population (All ages)	Sensitivity	BC Community Health Data	2009-2010	Local health area
Consumption of alcohol per capita (number of standard drinks per day)	Sensitivity	BC Community Health Data	2016	Local health area
Injury hospitalization count (All ages)	Sensitivity	BC Community Health Data	2006-2011	Local health area
All-cause cancer incident cases (all ages)	Sensitivity	BC Community Health Data	2008-2012	Local health area
Depression incident counts (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Asthma incident counts (5-54 years)	Sensitivity	BC Community Health Data	2015	Local health area
Chronic obstructive pulmonary disease (COPD) incident counts (45+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Hypertension incident counts (20+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Heart Failure incident counts (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area
Diabetes incident counts (1+ years)	Sensitivity	BC Community Health Data	2015	Local health area

Data Processing

After collecting each variable, we manipulated data from seven distinct sources to assemble the final analysis-ready dataset within RStudio. Once the data were loaded, we explored missingness in the data. To impute missing data, we deployed the k-Nearest Neighbors (kNN) algorithm, which identifies the most similar observations with complete data to infer the missing values.

After missing values were imputed, we summarized data from multiple years into a single-point estimate (i.e., annual averages). These variables included average annual noise level, precipitation, and maximum temperature data.

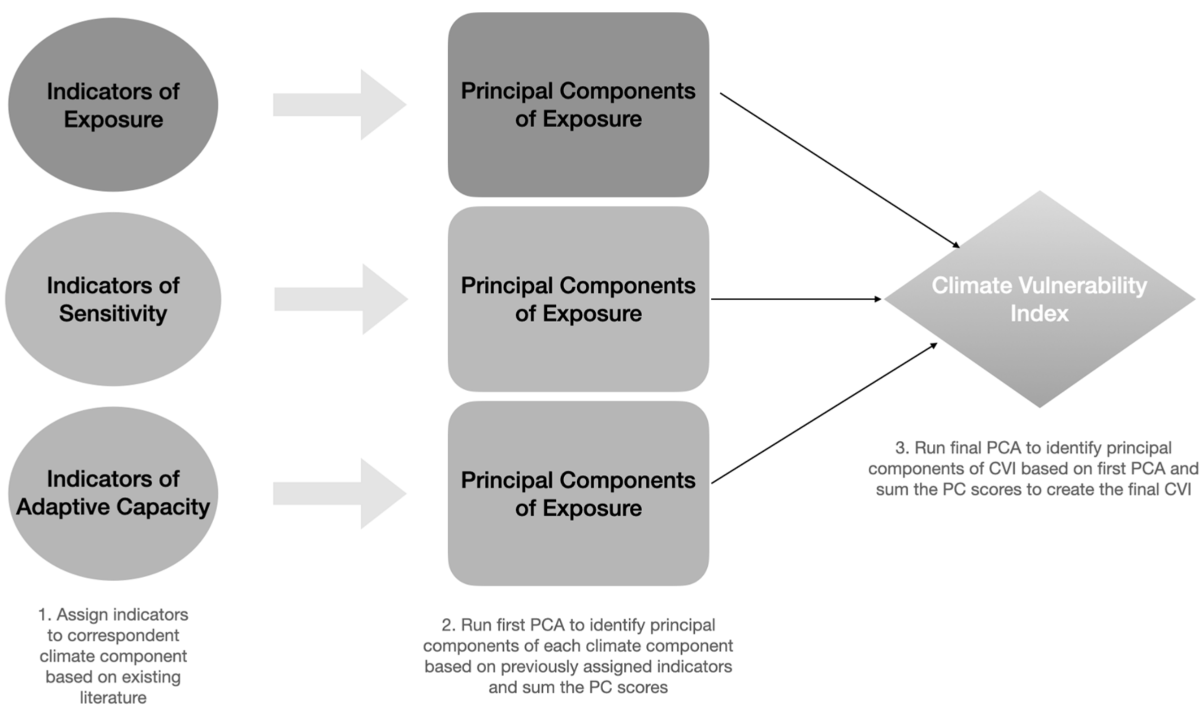
Our next step was to harmonize the data into a common geographic data type. In this case, we selected the FSA Level. The geographical boundary files and coordinates were sourced from the BC Data Catalogue.

The culmination of these data processing steps was a unified dataset where each row corresponded to an FSA (totaling 193 FSAs) and each column represented a variable listed in **Table 1**.

Item Reduction

To pinpoint the most salient variables in our dataset, we applied a two-tiered principal component analysis (PCA) to condense our data's dimensionality (**Figure 1**). PCA is a statistical method that reduces the complexity of data by converting a set of related variables into a smaller number of uncorrelated variables known as principal components [12]. These components capture the essence of the data's variability, with the first few retaining most of the variation present in the original dataset. The technique simplifies data analysis by reducing the number of dimensions without losing significant information and allows for the interpretation of underlying patterns through component scores, which relate back to the original variables [12].

Figure 1. Flow chart of PCA and creation of Climate Vulnerability Index



Initially, we segregated the dataset into three subsets corresponding to variables measuring exposure, sensitivity, and adaptive capacity (refer to **Table 2**).

Table 2. Items Selected

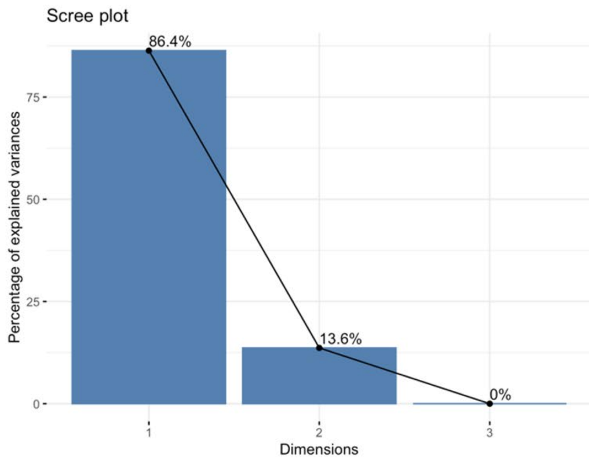
Exposure	Sensitivity	Adaptive Capacity
Selected		
• Number of extreme heat events • 10-year average PM2.5 • 10-year annual average precipitation • Projected 2020s summer mean temperature change • Projected 2050s summer mean temperature change	• Median Age • Median Age Change 2023-2046 • Early Childhood Communication • Early Childhood Emotion • Early Childhood Cognition • Early Childhood Physical • Early Childhood Social • Early Childhood General Vulnerability • Life Expectancy • Smoking-Related PYLL (Potential Years of Life Lost) • Drug-Related PYLL • Alcohol-Related PYLL • Fall-Related PYLL • Vehicle Accident PYLL • Infant Mortality Rate • Low Birth Rate • Asthma Prevalence (5-54) • COPD Prevalence (45+) • Diabetes Prevalence • Heart Failure Prevalence • Hypertension Prevalence (20+) • Asthma Incidence (5-54) • COPD Incidence (45+) • Diabetes Incidence • Heart Failure Incidence • Hypertension Incidence (20+) • GP Count per 100k • Specialist Count per 100k • Supplementary Practitioner Count per 100k • Alcohol Consumption Per Capita • Injury Hospitalizations • Cancer Incidence • Depression Incidence • Asthma Incidence (5-54) • COPD Incidence (45+) • Hypertension Incidence (20+) • Heart Failure Incidence • Diabetes Incidence	• Population Change 2023-2046 • Personal Income • Household Size • Solo Residents • Single Residents • Gini Index (2020) • Employment Income • Private Dwellings % • Low-Income Population % • Population Density • Housing Affordability Ratio • English Speakers • Indigenous Population • Non-Indigenous Population • Rooms per Dwelling • Non-Immigrants • Non-Minority Population • Stable Residents • University Degree Holders • Employed Population • Landsat Greenness (10-Year) • Noise Level (10-Year) • Building Density • Facility Density Index • Employment Accessibility • Health Facility Proximity • Park Proximity • Bikeability Score • Gaming Grant Total

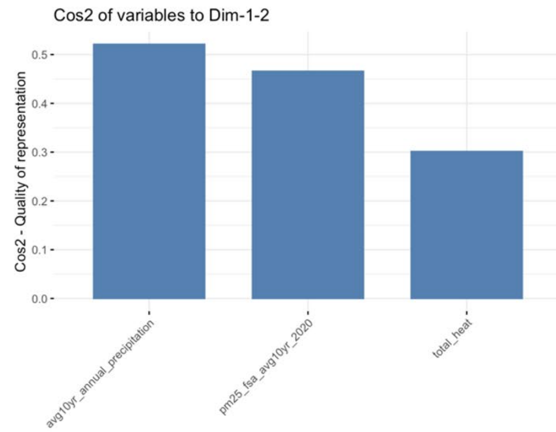
Exposure	Sensitivity	Adaptive Capacity
Not Selected		
• 3-year average land temperature • 10-year annual average max temperature	• Average Age	• Gaming Grant Average • Median Household Income • Population Total • High School Graduates • After-Tax Income (2020)

Following the literature, with particular reference to Yu's study, variables were allocated to represent exposure, sensitivity, and adaptive capacity, respectively. For exposure, we included environmental factors such as average annual PM2.5 concentrations, frequency of extreme heat events (as defined by the BC Centre for Disease Control's heat alert criteria [15]), average annual precipitation, and projected temperature changes for the 2020s and 2050s. Sensitivity examined community health and demographic data, analyzing how different groups are impacted by environmental exposures. Adaptive capacity assessed demographic and community attributes that reflect the community's potential to adapt to environmental changes, with certain variables adjusted to inversely indicate vulnerability. We standardized variables to ensure equitable influence in the PCA.

The initial PCA phase reduced the variables for the three vulnerability components to 2-3 principal dimensions, as indicated by their respective scree plots (illustrating the variance explained by the dimensions). For instance, **Figure 2** elucidates that the initial two dimensions' account for the entirety of the variance within the exposure factors. Conversely, **Figure 3** delineates the contribution of each individual factor to the first two dimensions, offering insight into the impact of each variable on the culminating PCA score for exposure. The supplementary scree plots and factorial contribution diagrams are appended to the appendix for detailed reference.

Figure 2 and Figure 3. Variance captured by dimensions in observed exposure and factorial contributions to dimensions 1 and 2





Subsequently, these new dimensions representing exposure, sensitivity, and adaptive capacity were further condensed to formulate both the observed and projected climate vulnerability indices (as shown in **Table 3**). These indices encompass three dimensions, collectively accounting for over 90% of the variance. We then calculated the combined PCA scores for each dimension of the climate components for every FSA, thereby establishing the new climate vulnerability indices (see the formula below).

Equation 1. Climate Vulnerability Index calculation formula

$$PC_d\ score = \sum_{i=1}^{n} \beta_{PC_{d,i}} \times X_i$$

$$CVI\ score = \sum_{d=1}^{n} PC_{d,i} scores$$

d is the d-th dimension or principal component of climate vulnerability;

X_1, X_2, ..., X_i are standardized components for a given observation;

$\beta_{PC_{d,i}}$ is the loading (coefficient) for the i-th variable for d-th PC dimension.

This methodology afforded us the ability to distill intricate climate vulnerability data into principal components, thereby facilitating a multifaceted and nuanced understanding of the contributing factors.

Table 3. Dimensionality reduction table

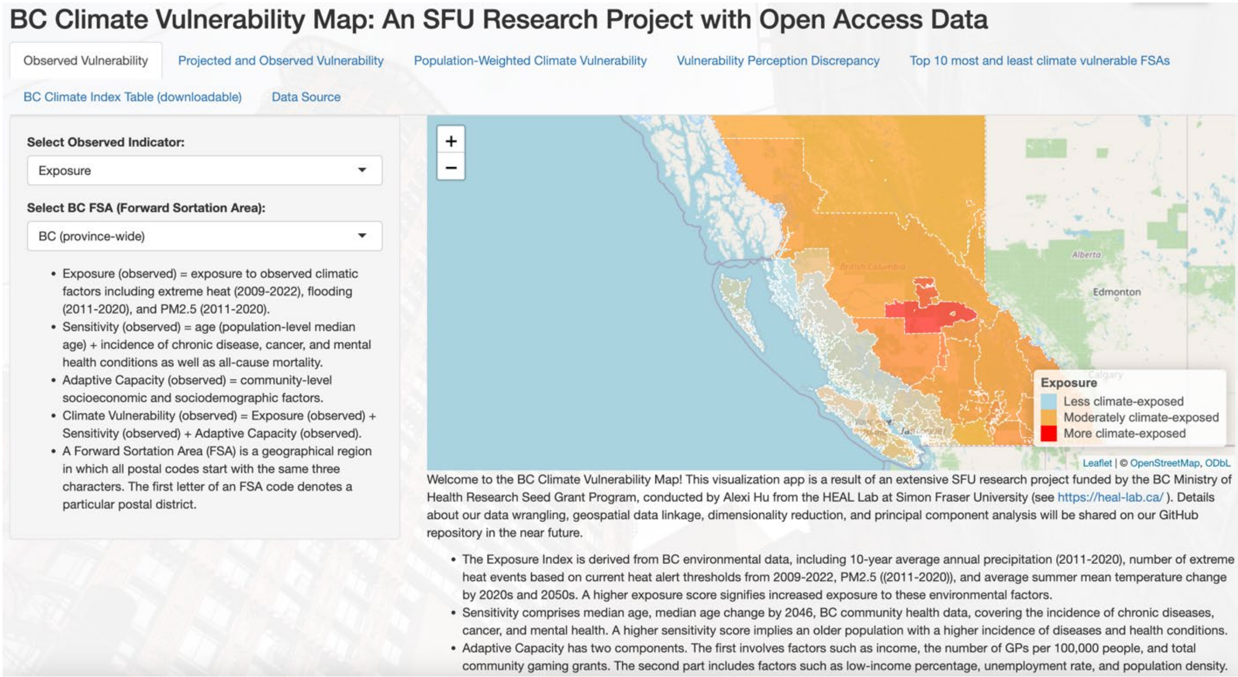
	Components	Dimensions
Observed climate vulnerability	• Exposure: 100% variance by dimensions 1 and 2 • Sensitivity: 89% variance by dimensions 1 and 2 • Adaptive capacity: 91% variance by dimensions 1, 2, and 3	• 90% variance by dimensions 1, 2, and 3.
Projected and observed climate vulnerability	• Exposure: 96% variance by dimensions 1 and 2 • Sensitivity: 88% variance by dimensions 1 and 2 • Adaptive capacity: 91% variance by dimensions 1, 2, and 3.	• 91.1% variance by dimensions 1, 2, and 3

Recognizing exposure's substantial influence on PCA scores, we formulated population-weighted climate vulnerability index scores to assess the overall community impact of climate change. This advanced method, the PWCV, refines the traditional index by incorporating demographic data, thus providing a more comprehensive risk evaluation. The PWCV approach involves multiplying the vulnerability score of each FSA by its population size to generate an overall impact score. The PWCV model is invaluable in pinpointing where the most people are at risk, ensuring resource allocation aligns not only with high vulnerability levels but also with the number of individuals affected. By centering on the human aspect of climate risks, the PWCV model is instrumental in formulating effective and equitable climate policies.

Mapping

To visually represent the dimensions of climate vulnerability, we created a suite of choropleth maps at the FSA level for each component. These maps were generated employing the “ggplot” and “geom_sf” packages in R, utilizing a color gradient to depict the spectrum of vulnerability levels across various regions effectively. For added accessibility and to facilitate interactive data exploration, we also designed and launched a web-based application using R Shiny (available at https://mhcca.ca/climate-vulnerability), integrating the "leaflet" package for dynamic mapping capabilities (illustrated in **Figure 4**).

Figure 4. R Shiny web application for climate vulnerability



Statistical Analysis

Aim 1. FSA Characteristics Associated with Increased Vulnerability

To investigate the relationships between climate vulnerability and FSA characteristics, we conducted univariate linear regression analyses. We included population density and variables not selected for (Table 2) in the PCA to avoid multicollinearity (see **Table 4** for reference).

Table 4. Descriptive statistics of FSA characteristics and climate vulnerability

Variable	Mean (standard deviation)
Observed climate vulnerability	-3.22 (3.62)
Observed and projected climate vulnerability	-2.90 (3.84)
Population density	4121.60 people per sq. mile (5442.40)
Average age	43.65 (3.61)
Total community gaming grant in 2022	1,730,614 CAD (1,383,050)
Median household income	94,525.63 CAD (18,428.9)

N = 193

Aims 2. Assessing Alignment Between Climate Vulnerability Index Scores and Subjective Perceptions about Climate Change

To validate the climate vulnerability index, we also compared it against subjective perceptions of climate risk by linking climate vulnerability data with previously collected survey data.

Table 5. Descriptive statistics of linked items from CDMS and climate vulnerability

Variable	Mean (standard deviation)
Observed climate vulnerability	1.14 (3.52)
Observed and projected climate vulnerability	0.99 (3.86)
Clayton climate change anxiety scale score	1.67 (0.79)
Perception of local devastation due to climate change	n (%)
Very unlikely	466 (28.6%)
Somewhat unlikely	268 (16.4%)
Somewhat likely	484 (29.7%)
Very likely	357 (21.9%)
Don't know or unsure	55 (3.4%)

N = 1630

Linkages were based on their shared FSA identifiers, with individuals as the unit of analysis in the linked dataset (referenced in **Table 5**). There were ten FSAs not represented in the CDMS dataset, attributed to the online and self-enrollment nature of the survey. We explored the association between climate vulnerability index values and ***(a)*** perceptions of local devastation due to climate change and ***(b)*** Clayton climate change anxiety scale scores. Univariate linear regression was used for this analysis.

Results & Discussion

Primary Findings

We developed a climate vulnerability index with three sub-indices measuring exposure, sensitivity, and adaptive capacity.

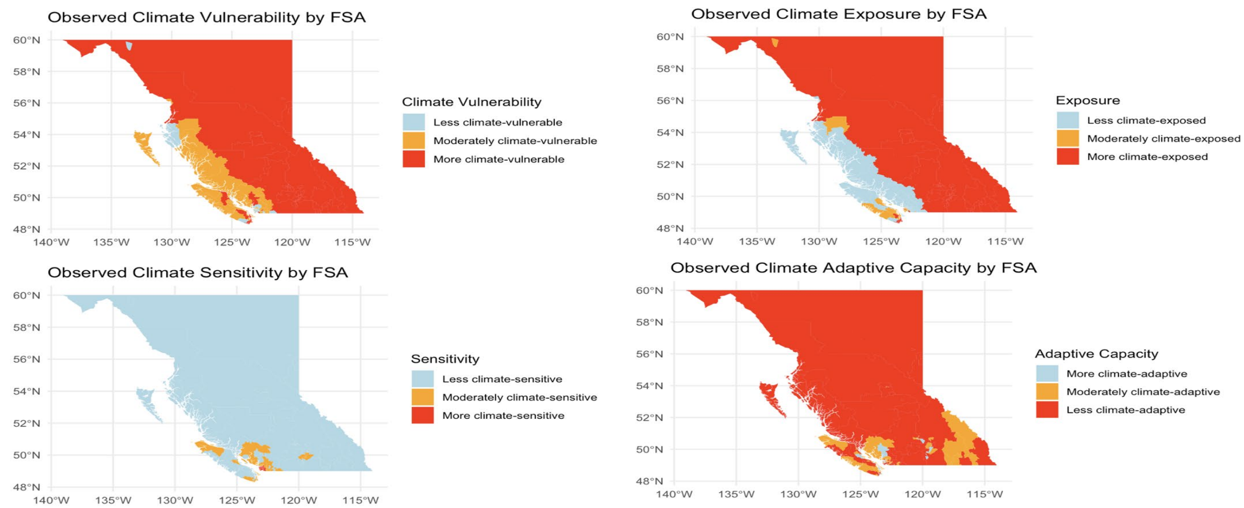
- **The Exposure Index** was derived from ***(a)*** 10-year average annual precipitation levels (2011-2020), ***(b)*** the number of extreme heat events based on current heat alert thresholds from 2009-2022, ***(c)*** PM2.5 concentrations (2011-2020), and ***(d)*** average summer mean temperature changes in 2020s and 2050s respectively compared to average summer temperature over the years 1998-2014.

- **The Sensitivity Index** was derived from ***(a)*** median age, ***(b)*** change in median age by 2046, and ***(c)*** the incidence of chronic diseases, cancer, and mental health conditions.
- **The Adaptive Capacity** was derived from **(a)** 10-year average annual Landsat greenness (2009-2019), **(b)** 10-year average noise level (2009-2019(, **(c)** building density at 100 m, **(d)** facility index - facility density index at 1000m, **(e)** access to employment, **(f)** average proximity to health facility score, **(g)** average proximity to public park, **(h)** average CANBICS bikeability score, **(i)** total community gaming grant, **(j)** average community gaming grant, **(k)** median personal income, **(l)** number of employed residents, **(m)** average household size, **(n)** number of residents who live alone, **(o)** number of residents who are single, **(p)** Gini index on adjusted household income (2020), **(q)** number of people with a postsecondary degree, **(r)** number of non-1-year-movers, **(s)** percentage of private dwellings, **(t)** percentage of the population below the low-income measure, **(u)** population change by 2046, **(v)** population density per square kilometre, **(w)** shelter-cost-to-income ratio, **(x)** number of English speakers, **(y)** number of non-minority residents, **(z)** number of non-indigenous residents, **(aa)** average room per dwelling, and **(ab)** number of non-immigrants.

The comprehensive climate vulnerability index data and associated visualizations are available for review at https://mhcca.ca/climate-vulnerability.

Utilizing observed data, we generated static maps for the three vulnerability components and the aggregate climate vulnerability (**Figure 5**). Importantly, the composition of the final PCA scores reveals that exposure is a more significant vulnerability component than sensitivity and adaptive capacity. As such, the coastal region—including Vancouver Island, the Sunshine Coast, and the Lower Mainland—demonstrates lower climate vulnerability compared to Northern and Interior BC (where climate risks related to temperature and precipitation are higher).

Figure 5. Observed climate exposure, sensitivity, adaptive capacity, and overall vulnerability by FSA



In detail, Northern, Interior BC, and a few areas in Greater Victoria and the Lower Mainland are more susceptible to climate-related hazards such as extreme heat, air pollution from wildfire smoke, and heavy precipitation. Conversely, the coastal region is less affected by these hazards. On the other hand, Northern and Interior BC exhibit less climate sensitivity due to smaller populations, which may result in a lower incidence of health conditions.

Further, despite most of BC showing limited adaptive capacity, certain FSAs in the Lower Mainland, including Metro Vancouver and Squamish, demonstrate a relatively higher capacity.

In assessing the shift in climate vulnerability under future climate and demographic projections and considering population weight, three additional static maps are presented in **Figure 6**.

While the projected climate vulnerability mirrors the current geographical trends, both the observed and projected Population-Weighted Climate Vulnerability (PWCV) maps reveal a divergent pattern. Regions such as Kelowna, Vernon, Kamloops, and Prince George display an amplified vulnerability due to the combination of heightened climate risks and larger populations.

Figure 6. Projected and observed climate vulnerability and population-weighted climate vulnerability by FSA

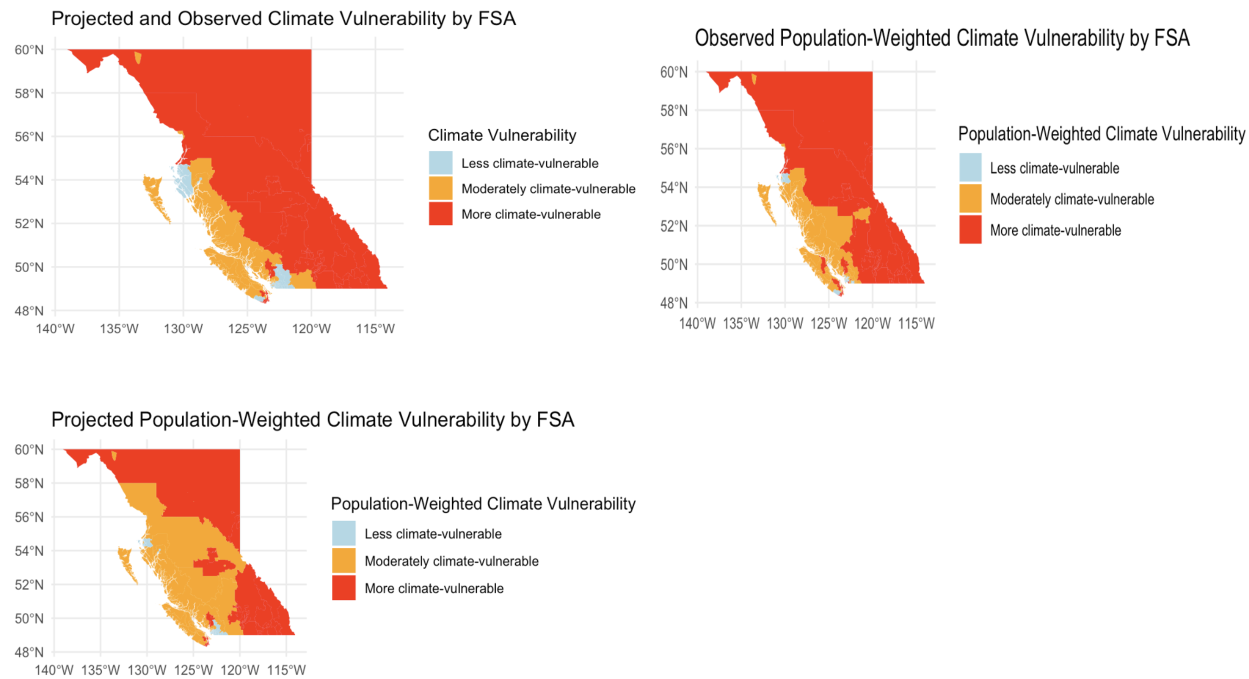


Table 6 lists the top 10 most and least vulnerable FSAs for observed and projected climate conditions, indicating a concentration of the most vulnerable FSAs within Northern and Interior BC, while the least vulnerable FSAs reside in the Southwest.

Table 6. Top 10 most and least observed and projected climate-vulnerable FSAs

Top 10 most observed vulnerable FSAs	Top 10 most projected vulnerable FSAs
V2J - Batnuni Lake	V1R - Trail
V2K - Prince George	V1H - Vernon
V2N - Prince George	V1V - Kelowna
V1H - Vernon	V1P - Kelowna
V2M - Prince George	V2K - Prince George
V1V - Kelowna	V2J - Batnuni Lake
V2L - Prince George	V2L - Prince George
V1R - Trail	V2N - Prince George
V1P - Kelowna	V2H - Kamloops
V2H - Kamloops	V2M - Prince George
Top 10 least observed vulnerable FSAs	**Top 10 least projected vulnerable FSAs**
V5E - Burnaby	V0S - Port Renfrew
V3R - Surrey	V6T - Vancouver
V7C - Richmond	V5P - Vancouver
V3X - Surrey	V5X - Vancouver
V5X - Vancouver	V7C - Richmond
V0S - Port Renfrew	V5E - Burnaby
V5P - Vancouver	V3R - Surrey
V3W - Surrey	V3X - Surrey
V6T - Vancouver	V3W - Surrey
V3V - Surrey	V3V - Surrey

Table 7 presents a detailed account of the FSAs with the highest and lowest scores for observed and projected climate components.

Table 7. Top 10 FSAs with the highest and lowest observed and projected climate component scores

Top 10 - Exposure	Top 10 – Sensitivity	Top 10 - Adaptive Capacity
V2J - Batnuni Lake	V6T - Vancouver	V0W - Atlin
V2M - Prince George	V5T - Vancouver	V0V - Prince Rupert
V2L - Prince George	V6E - Vancouver	V0L - Hanceville
V2N - Prince George	V6B - Vancouver	V0S - Port Renfrew
V2K - Prince George	V5N - Vancouver	V0T - Vancouver
V2G - Williams Lake	V5L - Vancouver	V4S - Mission
V2B - Kamloops	V5V - Vancouver	V0C - Fort St. John
V2C - Kamloops	V7X - Vancouver	V8C - Kitimat
V3Z - Surrey	V7Y - Vancouver	V0K - Kamloops
V1H - Vernon	V5X - Vancouver	V4X - Abbotsford
Bottom 10 - Exposure	**Bottom 10 – Sensitivity**	**Bottom 10 - Adaptive Capacity**
V2J - Batnuni Lake	V6T - Vancouver	V0W - Atlin
V2M - Prince George	V5T - Vancouver	V0V - Prince Rupert
V2L - Prince George	V6E - Vancouver	V0L - Hanceville
V2N - Prince George	V6B - Vancouver	V0S - Port Renfrew
V2K - Prince George	V5L - Vancouver	V0T - Vancouver
V1R - Trail	V6H - Vancouver	V0C - Fort St. John
V2B - Kamloops	V6C - Vancouver	V4S - Mission
V2G - Williams Lake	V6Z - Vancouver	V0K - Kamloops
V2C - Kamloops	V5N - Vancouver	V8C - Kitimat
V1C - Cranbrook	V7X - Vancouver	V4X - Abbotsford

Table 8 shows the top 10 most and least vulnerable FSAs based on observed and projected PWCV. The complete rankings are accessible via our R Shiny application. The inclusion of population data markedly alters the vulnerability landscape, with densely populated areas like Kelowna, Vernon, and Victoria emerging as significantly more vulnerable.

Table 8. Top 10 most and least vulnerable FSAs, using observed and projected population-weighted climate vulnerability

Top 10 most vulnerable FSAs, using observed population-weighted data	**Top 10 most vulnerable FSAs, using projected population-weighted data**
V1V - Kelowna	V1V - Kelowna
V1P - Kelowna	V4V - Kelowna
V4V - Kelowna	V1W - Kelowna
V1W - Kelowna	V1P - Kelowna
V1H - Vernon	V1Y - Kelowna
V2N - Prince George	V1H - Vernon
V2K - Prince George	V4T - Westbank
V1S - Tobiano	V1S - Tobiano
V1Y - Kelowna	V8W - Victoria
V1B - Vernon	V1R - Trail
Top 10 least vulnerable FSAs, using observed population-weighted data	**Top 10 least vulnerable FSAs, using projected population-weighted data**
V3W - Surrey	V3S - Surrey
V3V - Surrey	V4N - Surrey
V3X - Surrey	V3W - Surrey
V6X - Richmond	V3X - Surrey
V3T - Surrey	V3V - Surrey
V3R - Surrey	V3T - Surrey
V6Y - Richmond	V2Y - Langley
V5H - Burnaby	V2T - Abbotsford
V5X - Vancouver	V4P - Surrey
V7C - Richmond	V4X - Abbotsford

Describing Communities with High/Low Vulnerability (Aim 1)

Table 9, derived from the univariate linear regression models, highlights the associations between the characteristics of FSAs and their climate vulnerability in BC. A significant negative correlation is observed between population density and climate vulnerability, indicating that FSAs with denser populations tend to be less vulnerable. This relationship is statistically robust both at present ($\beta = -2.02$, $p < 0.001$) and is projected to intensify in the future ($\beta = -7.45$, $p < 0.001$). Additionally, median household income inversely correlates with climate vulnerability, suggesting that FSAs with higher income levels are less affected by climate impacts, a trend consistent in both current (β = -3.66, $p < 0.01$) and future projections (β = -6.23, $p < 0.001$).

Table 9. Univariate linear regression models between FSA characteristics and climate vulnerability

Exposure variables	Observed climate vulnerability Coefficient (std. error)[a]	Observed and projected climate vulnerability Coefficient (std. error)
Population density	-2.02 (4.59)***[b]	-7.45 (5.08)
Average age	0.19 (0.07)**	0.31 (0.07)***
Total community gaming grant in 2022	2.52 (1.89)	6.18 (1.96)**
Median household income	-3.66 (1.40)**	-6.23 (1.44)***

Note: [a] Std. error = standard error; [b] *** p-value < 0.001, ** < 0.01, * < 0.05

On the contrary, FSAs with an older average population age are positively correlated with climate vulnerability, reflecting a higher risk at present (β = 0.19, $p < 0.01$) and an increase projected for the future (β = 0.31, $p < 0.001$). The total community gaming grant in 2022, while not significantly associated with current climate vulnerability, demonstrates a positive relationship with projected future vulnerability (β = 6.18, $p < 0.01$).

These findings underscore that factors like population density and income are protectively related to climate vulnerability, whereas variables such as average age and social needs funding are indicative of higher future vulnerability. The statistical significance of these results lends weight to their reliability and suggests a reduced likelihood of these patterns occurring by chance.

Assessing Alignment with Subjective Perceptions (Aim 2)

Table 10 details the relationships between various factors from the CDMS data and climate vulnerability. The Clayton climate change anxiety scale score is negatively correlated with current climate vulnerability (β =-0.33, $p < 0.01$), implying that individuals with higher anxiety scores may be from less climate-vulnerable FSAs. However, this association is not observed for projected future vulnerability, where the relationship is not statistically significant (β =-0.06, p = NS).

In terms of perceptions of local devastation, those who view it as somewhat unlikely have significantly lower current climate vulnerability (β =-0.78, $p < 0.01$) in comparison to those who consider it very unlikely. This perception, however, does not significantly impact the combined observed and projected vulnerability (β = -0.32, p = NS). In contrast, individuals who perceive local devastation as very likely show a significantly positive correlation with both current climate vulnerability (β =0.71, $p < 0.01$) and future vulnerability (β =1.17, p

< 0.001) compared to those who consider local devastation due to climate change very unlikely. In other words, individuals exhibiting higher scores of climate-related anxiety tend to reside in FSAs that are more susceptible to climate vulnerability. Taken together, these results indicate that the anticipation of local devastation is somewhat associated with local climate vulnerability.

Table 10. Univariate linear regression models between CDMS items and climate vulnerability

Exposure variables	**Observed climate vulnerability Coefficient (std. error)[a]**	**Observed and projected climate vulnerability Coefficient (std. error)**
Clayton climate change anxiety scale score	-0.33 (0.11)**[b]	-0.06 (0.12)
Perception of local devastation		
Very unlikely	Ref	Ref
Somewhat unlikely	-0.78 (0.27)**	-0.32 (0.18)
Somewhat likely	0.03 (0.23)	0.57 (0.25)*
Very likely	0.71 (0.25)**	1.17 (0.27)***
Don't know or unsure	-0.22 (0.50)	0.36 (0.55)

Note: [a] Std. error = standard error; [b] *** p-value < 0.001, ** < 0.01, * < 0.05

Strengths and Limitations

This study has several strengths. First, we collected a wide range of indicators from multiple data sources to measure key components of climate vulnerability, including exposure, sensitivity, and adaptive capacity. Second, our use of principal component analysis allowed us to identify the most salient indicators of spatial variation. Third, by combining administrative data and survey data we are able to understand the agreement between these different data sources as indicators of climate vulnerability.

This study also has limitations. First, we rely on existing administrative and publicly available data, which may not fully capture all relevant aspects of climate vulnerability. This is especially true given that we leveraged principal component analysis, which while reducing the complexity of the data can also oversimplify the complex relationships between variables. For example, this method assumes linear relationships and may not capture non-linear interactions among variables that are significant for climate vulnerability. Furthermore, the data from various sources vary in completeness, accuracy, and time period – all of which threaten validity. Second, while the use of imputation methods like k-Nearest Neighbors (kNN) helps address missing data, imputation methods can also produce bias. Third, aggregating data to the Forward Sortation Area (FSA) level may oversimplify the variability within smaller geographic units. This could lead to a loss of detail and potential underestimation or overestimation of climate vulnerability in specific areas. Fourth, our analyses are primarily descriptive, and further research is needed to understand the nature of relationships between variables – particularly in a multivariable context. Fifth, the retrospective data as well as the projections for climate vulnerability introduce considerable uncertainty into our data. Finally, the survey data used to map subjective perceptions of climate risks are from an online convenience sample and are not considered geographically or demographically representative. For these reasons, our results should be interpreted with caution, and ongoing efforts are needed to refine our understanding of climate vulnerability.

Future Research

To build upon the findings of the current Climate Vulnerability Index study and address its limitations, several avenues for future research are recommended:

- **Public Participation and Community Engagement**: Engaging with communities directly affected by climate change can provide valuable insights. Future research should include participatory approaches where community members contribute to data collection, analysis, and interpretation.

- **Enhanced Data Collection**: Future studies should focus on gathering more comprehensive data sets that capture a wider array of variables influencing climate vulnerability. This includes collecting real-time data and incorporating qualitative insights from local communities to deepen the understanding of climate vulnerability.

- **Incorporation of Socioeconomic and Health Data**: Future studies should integrate more detailed socioeconomic and health data. This would allow for a more comprehensive analysis of how these factors interplay with climate vulnerability.

- **Advanced Imputation Techniques**: While the k-Nearest Neighbors (kNN) algorithm was employed in this study, future research could explore more sophisticated imputation methods to address missing data, such as machine learning algorithms that can handle complex data structures and patterns.

- **Finer Spatial Resolution**: To overcome the limitations posed by data aggregation at the FSA level, future studies should aim for finer spatial resolution. This could involve analyzing data at the neighborhood or block level to capture more localized variations in climate vulnerability.

- **Broader Geographical Scope**: Expanding the research to include other regions, both within and outside of British Columbia, would provide comparative insights and enhance the generalizability of the findings.
- **Longitudinal Studies**: To better understand how climate vulnerability evolves over time, longitudinal studies are necessary. These studies would track changes in climate vulnerability over extended periods, offering insights into long-term trends and the efficacy of adaptation measures.
- **Dynamic Modeling of Future Projections**: Given the uncertainties associated with projected climate data, future research should utilize dynamic modeling techniques. These models can incorporate various scenarios based on different climate change projections, offering a range of possible future outcomes.
- **Multivariate Statistical Analysis**: Moving beyond PCA and univariate analyses, future research should employ multivariate statistical techniques. These could include regression models that account for interactions among variables, providing a more nuanced understanding of the factors contributing to climate vulnerability.
- **Policy Impact Assessment**: To ensure the practical applicability of research findings, future studies should also focus on assessing the impact of various policy interventions on reducing climate vulnerability. This could involve simulation studies or policy trials.

By addressing these areas, future research can significantly advance our understanding of climate vulnerability, leading to more effective and targeted climate adaptation strategies.

Conclusion

This report on mapping climate vulnerability in British Columbia has provided valuable insights into the region's susceptibility to climate change. The development and application of the Climate Vulnerability Index have highlighted critical areas of concern, particularly in Northern and Interior BC, where increased vulnerability is evident.

However, as underscored throughout the report, the findings must be interpreted within the context of the study's limitations. These include reliance on existing data sets, the potential oversimplification inherent in PCA, challenges in data imputation, and the generalizability of the findings due to data aggregation at the FSA level. Despite these limitations, the study provides a foundational step towards understanding and addressing the impacts of climate change in British Columbia.

In doing so, the Climate Vulnerability Index developed for British Columbia offers a valuable tool for both researchers and urban planners in various ways. For researchers, the index serves as a comprehensive dataset to analyze the multifaceted aspects of climate vulnerability, enabling a deeper understanding of how different factors like exposure, sensitivity, and adaptive capacity interplay in varying geographical contexts. This can spur further academic inquiries into climate change impacts and resilience strategies.

For urban planners and policymakers, the index provides a critical, evidence-based foundation for decision-making. By identifying regions with heightened vulnerability, planners can prioritize and tailor adaptation and mitigation strategies to address specific needs, such as reinforcing infrastructure in high-risk areas or enhancing healthcare and social support in sensitive communities. Moreover, the index can guide resource allocation, ensuring that funding and efforts are directed towards areas with the greatest need.

Finally, the index can be instrumental in community engagement and education efforts, helping to raise awareness about climate risks and fostering a collaborative approach to building climate resilience.

References

[1] BC Government. Climate Preparedness and Adaptation Strategy: Actions for 2022-2025. 2022.

[2] The Intergovernmental Panel on Climate Change. Climate Change 2021—The Physical Science Basis. Chemistry International 2021;43:22–3. https://doi.org/10.1515/ci-2021-0407.

[3] Gershunov A, Shulgina T, Clemesha RES, Guirguis K, Pierce DW, Dettinger MD, et al. Precipitation regime change in Western North America: The role of Atmospheric Rivers. Sci Rep 2019;9:9944. https://doi.org/10.1038/s41598-019-46169-w.

[4] Schneider S, Sarukhan J, Adejuwon J, Azar C, Baethgen W, Hope C, Moss R, Leary N, Richels R, Van Ypersele JP. Overview of impacts, adaptation, and vulnerability to climate change. Climate change, 2001.

[5] B.C. Corners Service. Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in B.C. 2022.

[6] Insurance Bureau of Canada. British Columbia floods cause $450 million in insured damage 2022.

[7] Henderson SB, McLean KE, Lee MJ, Kosatsky T. Analysis of community deaths during the catastrophic 2021 heat dome: Early evidence to inform the public health response during subsequent events in greater Vancouver, Canada. Environmental Epidemiology 2022;6:e189. https://doi.org/10.1097/EE9.0000000000000189.

[8] Yu J, Castellani K, Forysinski K, Gustafson P, Lu J, Peterson E, et al. Geospatial indicators of exposure, sensitivity, and adaptive capacity to assess neighbourhood variation in vulnerability to climate change-related health hazards. Environ Health 2021;20:31. https://doi.org/10.1186/s12940-021-00708-z.

[9] Schmeltz MT, Marcotullio PJ. Examination of Human Health Impacts Due to Adverse Climate Events Through the Use of Vulnerability Mapping: A Scoping Review. IJERPH 2019;16:3091. https://doi.org/10.3390/ijerph16173091.

[10] McDermott-Levy R, Scolio M, Shakya KM, Moore CH. Factors That Influence Climate Change-Related Mortality in the United States: An Integrative Review. IJERPH 2021;18:8220. https://doi.org/10.3390/ijerph18158220.

[11] De Sherbinin A, Bukvic A, Rohat G, Gall M, McCusker B, Preston B, et al. Climate vulnerability mapping: A systematic review and future prospects. WIREs Climate Change 2019;10:e600. https://doi.org/10.1002/wcc.600.

[12] Abson DJ, Dougill AJ, Stringer LC. Using Principal Component Analysis for information-rich socio-ecological vulnerability mapping in Southern Africa. Applied Geography 2012;35:515–24. https://doi.org/10.1016/j.apgeog.2012.08.004.

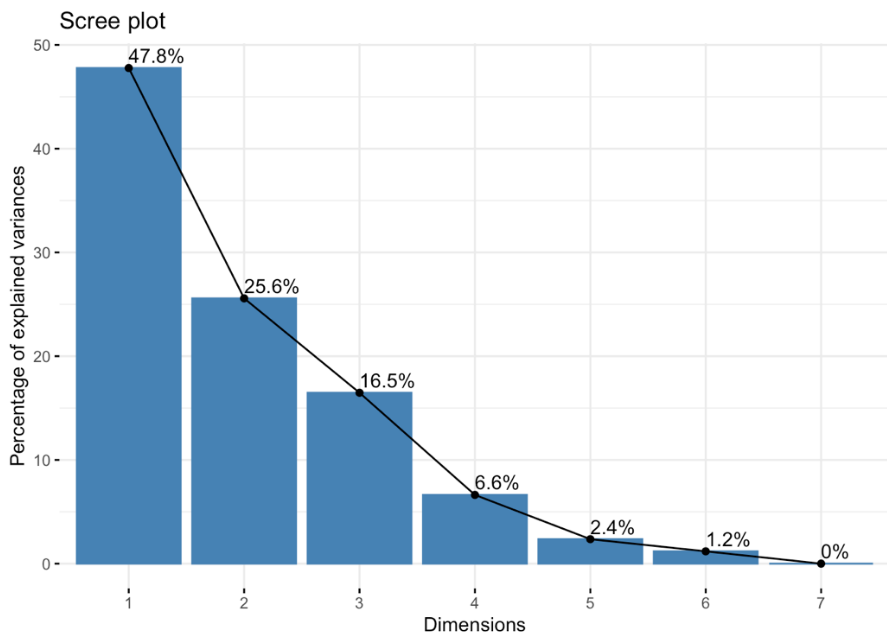
[13] Intergovernmental Panel On Climate Change (Ipcc). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 1st ed. Cambridge University Press; 2023. https://doi.org/10.1017/9781009325844.

[14] Bratu A, Card KG, Closson K, Aran N, Marshall C, Clayton S, et al. The 2021 Western North American heat dome increased climate change anxiety among British Columbians: Results from a natural experiment. The Journal of Climate Change and Health 2022;6:100116. https://doi.org/10.1016/j.joclim.2022.100116.

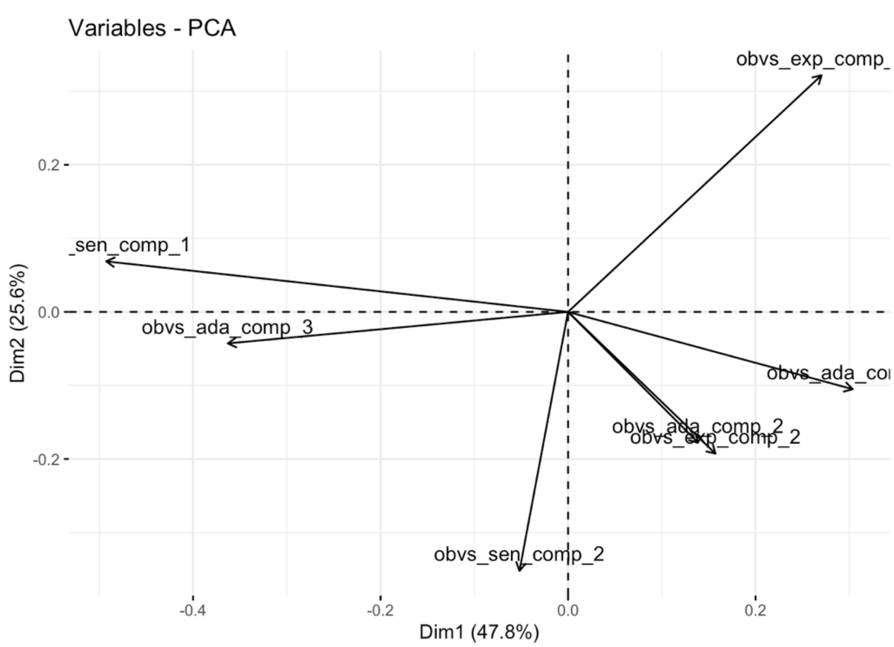
[15] McLean K, Stranberg R, MacDonald M, Richardson G, Kosatsky T, Henderson S. Establishing Heat Alert Thresholds for the Varied Climatic Regions of British Columbia, Canada. IJERPH 2018;15:2048. https://doi.org/10.3390/ijerph15092048.

Appendix

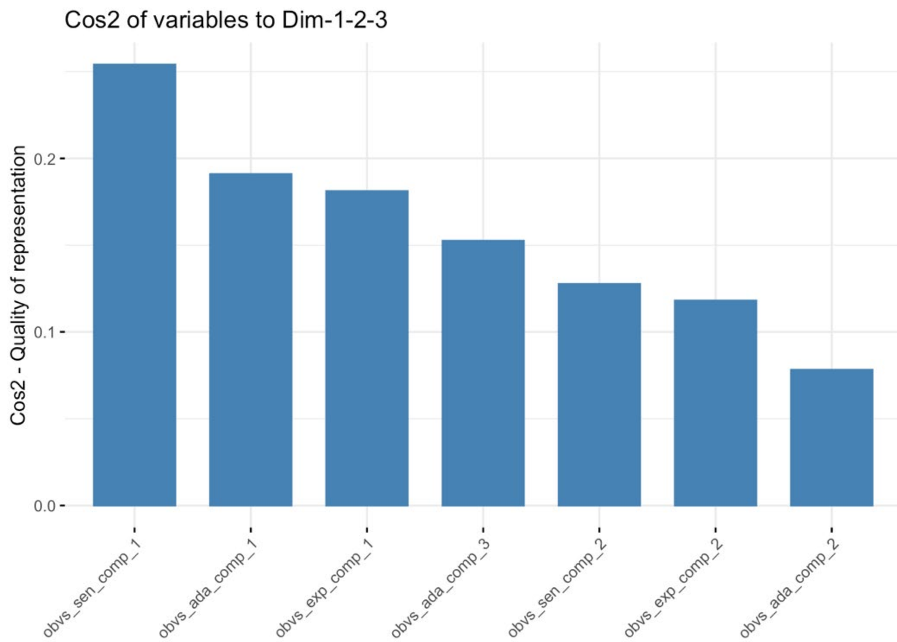
Observed climate PCA: scree plot



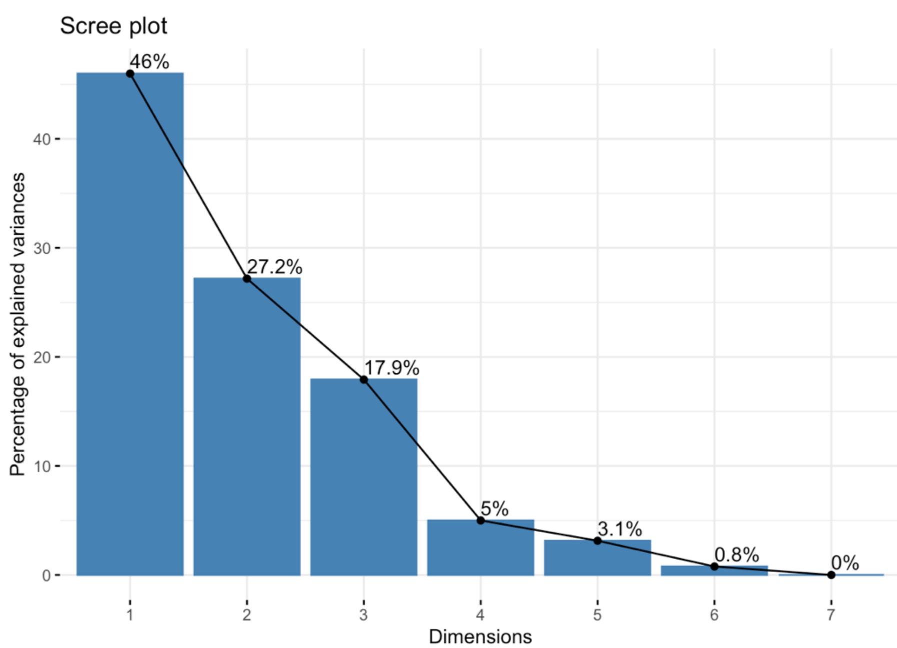
Observed climate PCA: variable plot



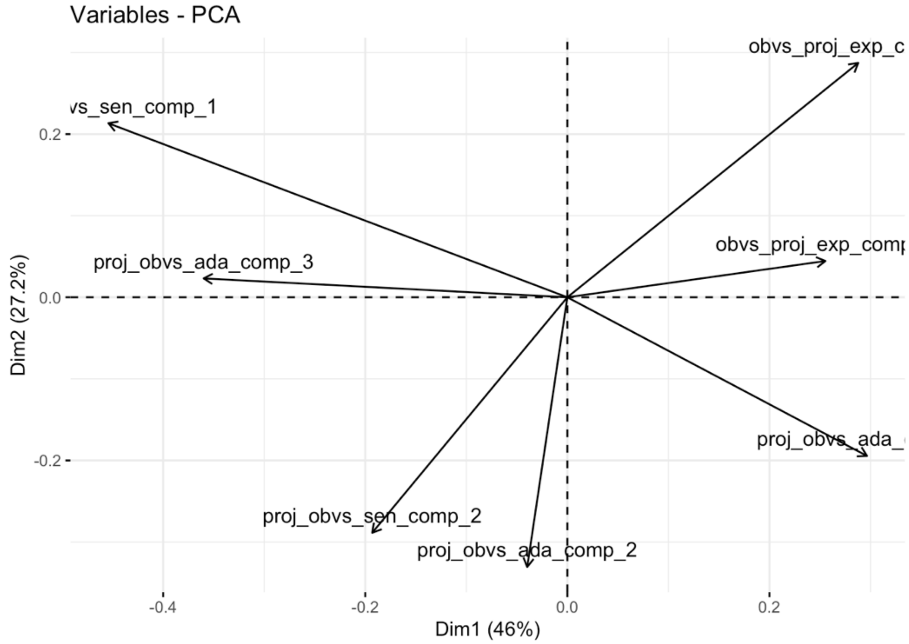
Observed climate PCA: factorial contribution plot



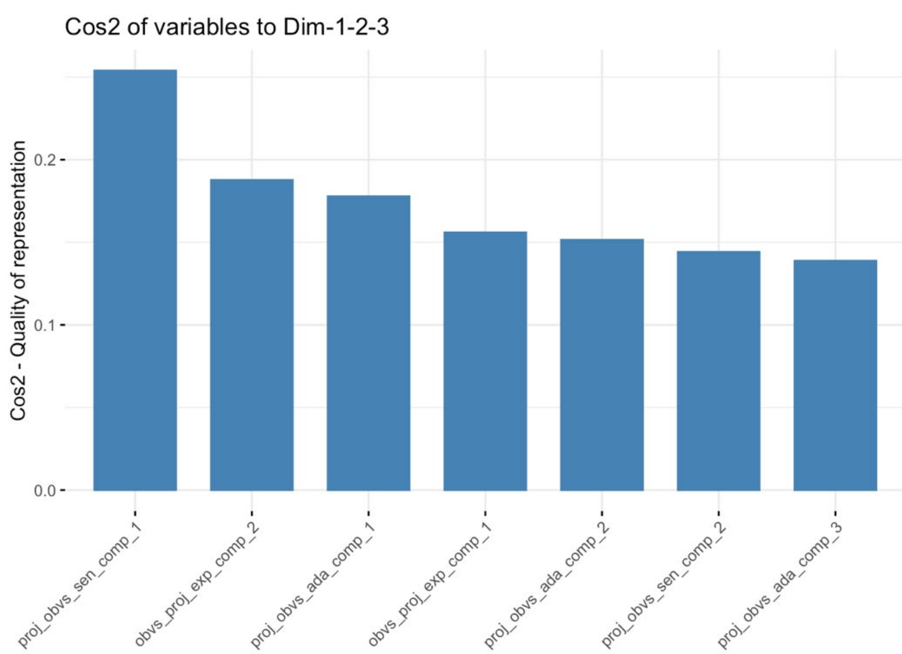
Projected and observed climate PCA: scree plot



Projected and observed climate PCA: variable plot



Projected and observed climate PCA: factorial contribution plot



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