Accessibility of Immunization Across Calgary

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1. Indicator Title

Access to Vaccination Sites Relative to Income in Calgary.

2. Domain description: social health and wellness

The Social Health and Wellness Domain aims to analyze the social and environmental conditions that impact community health, well-being, safety, and overall quality of life. This domain focuses on access to public services, equitable infrastructure, and community safety across Calgary. With emphasis on spatial and systematic discrepancies, this domain's objective is to identify inequities affecting the city's most underserved groups, ultimately intending to guide future resource distribution and promote a more equitable, resilient Calgary for all.

3. Indicator Description

The access to vaccination sites indicator examines the spatial dimensions of public health equity, exploring whether income influences the accessibility of immunization services. This analysis compares the spatial distribution of vaccination sites with median household income across Calgary's Community Service Areas (CSAs) to identify potential disparities in the availability of services. Namely, this indicator seeks to answer the question: *To what extent does household income affect access to immunization within Calgary?*

Preventive care, such as vaccination, is a vital part of community health, well-being, and safety. Immunization protects individuals by preventing the onset and spread of serious illnesses before they occur. The benefits of immunizations are clear, notably increasing life expectancy (Shattock A.J. et al. 2024), while safeguarding individuals from deadly diseases and significantly reducing illness-related disability, complications, and mortality (Orenstein W.A. & Ahmed R. 2017). Beyond individual protection, vaccinations create community-wide benefits through a phenomenon known as herd immunity. Herd immunity is created through mass immunization; the protective effects can be felt both directly by vaccinated individuals and indirectly by those unable to receive vaccines, such as immunocompromised people and infants (Doherty M. et al. 2016). Following the implementation of a widespread vaccination campaign, the mortality and morbidity rates of 13 vaccine-preventable diseases have fallen by over 92% (Roush S.W. & Murphy T.V. 2007). Notably, smallpox, the only human disease to be eradicated, was eliminated through widespread vaccination efforts (Henderson D.A. 2011). In opposition, for over two decades, Canada had achieved eradication of the measles virus; 2023 marked the beginning of a global measles increase due to low vaccination coverage (McNichol J. et al. 2025).

The broader success of immunization relies on the achievement of equitable and widespread coverage. Access to immunization is often strongly affected by socioeconomic factors; individuals residing in low-income areas are 27% less likely to receive full immunization coverage than those in high-income areas (Ali H.A. et al. 2022). These disparities are often driven by limited financial resources, poor access to healthcare facilities and a lack of education or targeted outreach programs related to preventive care. Unequal access not only increases mortality and morbidity of disease, but also undermines community protections and the efficacy of herd immunity, prolonging disease outbreaks and creating excess difficulty in stopping global disease spread (Chang A.Y. et al. 2018). Additional economic challenges fall upon low-income communities, as disease often prevents individuals from working, leading to greater financial hardships and threats to income security (Thorpe J. et al. 2020).

Health resilience plays a major role in the sustainability of our city. Preventing illness reduces the long-term strain on healthcare systems, allowing public health resources to be utilized more efficiently. Healthier populations require fewer emergency services, produce less medical waste and maintain the well-being of the populations (Boccalini S. 2025). Endemic and pandemic preparedness from widespread vaccination coverage promotes resilient and better-equipped cities, averting or mitigating public health crises. Access to vaccination is a critical indicator of social health and wellness, working to highlight how the spatial patterns and location of vaccination sites may reinforce or reduce health inequalities to guide the City of Calgary to a more equitable and sustainable future.

4. Methods

4.1. Software:

The main analysis for this project was conducted using ArcGIS Pro; further statistical analysis was completed with Excel.

*4.2. Dataset*s:

A combination of public datasets were used in this analysis, including datasets from the City of Calgary's Open Data Portal as well as Statistics Canada.

The following datasets were sourced for the City of Calgary's Open Data Portal: Vaccination Site Locations: point data detailing locations offering Covid-19, respiratory syncytial virus (RSV), tetanus diphtheria and pertussis (TDAP), as well as pneumococcal vaccinations. Calgary Equity Index – Median Income: a polygon layer of median income by community service area (CSA) using the 2021 federal census. The 2021 Federal Census Population and Dwellings by Community polygon layer, depicting populations by community, was sourced from Statistics Canada.

4.3. Workflow and Spatial Analysis

The methods used in this project were chosen to provide a meaningful way to analyze spatial accessibility to vaccination sites across Calgary. There are many effective approaches to accessibility, including the Two-Step Floating Catchment Area (2SFCA) method, which offers a detailed assessment of accessibility (Khakh et al. 2019). However, without a network or travel time dataset, this approach was infeasible. Instead, this analysis employed a modified proximity-based approach using Euclidean distance as well as buffer zones to represent possible service areas. Population catchments were estimated assuming a uniform distribution of individuals within each community. While this approach simplifies real-world distributions and travel patterns, it provides a transparent and comprehensible analysis of access to vaccination to depict general patterns and trends across the city.

4.3.1 Building the Map

The first step was preparing and cleaning the data to input it into ArcGIS. Every layer was then projected into NAD 1983 UTM Zone 11N, one of Alberta's standard projected coordinate systems (University of Alberta 2025). Additionally, each layer was clipped to the study extent, the City of Calgary, using the median income layer as a guide. Following this, catchment areas were defined using the Buffer tool with a 1 km radius around each vaccination site. 1 Km was chosen as a plausible walking distance based on Frank et al.'s 2007 study, identifying 800 meters to 1 km as a standard acceptable walking distance.

These buffers were used to approximate each site's service area: centroids were created for each CSA using ArcGIS's Feature to Point tool in order to analyze access from the centre of each CSA. These centroids were then used to compute the nearest distance from each CSA to the closest vaccination site. After this, the buffer layer was intersected with the population polygons to estimate the number of residents living within 1 Km of a vaccination site. To complete this estimation, two new fields were calculated: the original area of the community and the area covered by the catchment. Using these fields, the population each vaccination site served was found using the following Python 3 script:

```
!Population! * (!INT_Area_m2! / !DA_Area_m2!)
```

Where population is the total population of the community, INT_Area_m2 is the area covered by the catchment in meters squared, and DA_Area_m2 is the area of the community in meters squared.

With this information, accessibility scores were calculated. For this analysis, accessibility is defined as the number of vaccination sites per 1,000 people. Specifying the number of individuals allows for normalization of the values, permitting cross-comparison among different areas of the city. Accessibility scores were calculated by creating and calling the following simple Python 3 function:

Expression box:

```
calc(!Sum_Pop_in_Piece!)
```

Where Sum_Pop_in_Piece is the population within the catchment area.

Calculation box:

```
def calc(pop):
    if pop is None or pop == 0:
        return 0
    return 1000.0 / pop
```

The function has a dual purpose: eliminating and replacing null values with 0, and calculating the accessibility score. Lastly, median income was then joined using the Add Join tool, linking socioeconomic status with physical access.

4.3.2: Statistical Analysis

To test for statistically significant differences in access, the accessibility scores for each CSA were divided into quartiles using the following Python 3 script:

Expression box:

```
quartile(!Median_Income!)
```

where Median_Income is the median income value for each CSA

Calculation block:

```
def quartile(income):
    if income <= 37499.6168
        return 1
    elif income <= 47359.4187:
        return 2
    elif income <= 58594:
        return 3
    elif income <= 73533.519:
        return 4
```

These values were found within the symbology tab of the layer, using the Natural Breaks (Jenks). This classification method was chosen because of its ability to minimize variation within classes and maximize variation between classes.

After exporting the table including the quartiles, median income, access score, and mean sights per 1000 individuals, an ANOVA test was performed, yielding F and F crit values along with a P value. Box plots and scatter plots were then made in ArcGIS Pro.

5. Results

Table 1: Output of an ANOVA: Single Factor data analysis completed with Excel. The analysis used Vaccination Sites Per 1000 Individuals (MVS) for each Quantile range; values were taken from an export table from ArcGIS Pro.

Source of Variance	Square sum	Degrees of freedom	Mean square	F-value	p-value	F crit value
Between Groups	6.4704	3	2.1568	2.5215	0.0574	2.6255
Within Groups	371.2316	434	0.8554			
Total	377.702	437				

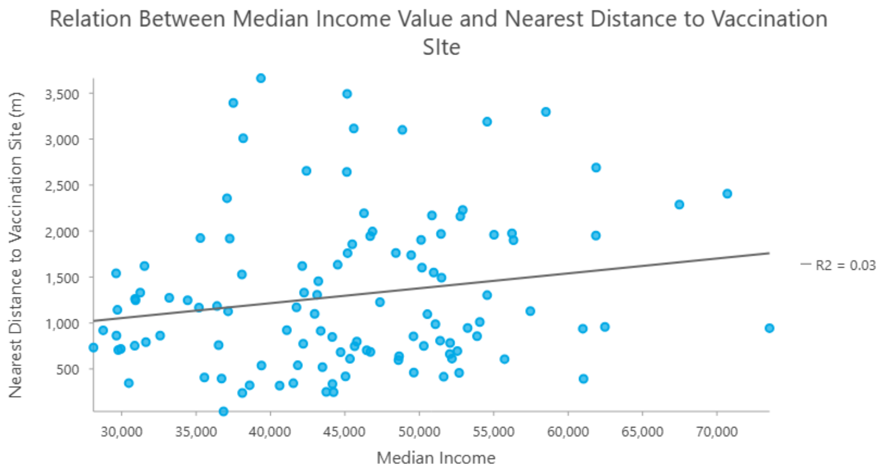

Figure 1: Relationship Between Median Income Value and Nearest Distance to Vaccination Sites. Nearest distance was calculated in meters using ArcGIS's Near tool, with proximity based on the centre of each community service area. The scatter plot was created with ArcGIS Pro and shows an R^2 value of 0.03 and a slope of +0.016.

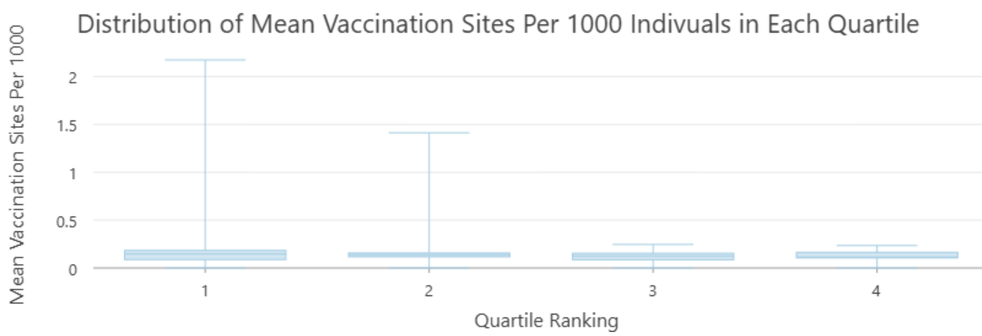

Figure 2: Distribution of Mean Vaccination Sites per 1,000 Individuals per Quartile Ranking. Mean vaccination sites per 1000 people (MVS) was calculated using ArcGIS Pro's proximity, buffer, and field calculation tools. The box plot with whiskers was created using ArcGIS Pro. Whiskers indicate range of data distribution and variability including outliers. Quartile 1 has a maximum MVS of 2.17, a minimum of 0 and a median of 0.15; Quartile 2 shows a maximum MVS of 1.41, a minimum of 0 and a median of 0.14; Quartile 3 has a maximum MVS of 0.25, a minimum of 0 and a median of 0.13; Quartile 4's maximum MVS is 0.23, its minimum is 0 and median in 0.12.

In order to analyze how, and if, vaccination access varied across income levels, vaccination site accessibility was compared across four income quartiles in Calgary. Throughout this analysis, the mean vaccination sites per 1000 individuals (MVS) is considered to represent the access score of each CSA. The one-way ANOVA results (Table 1) compared MVS across the quantiles. A p-value of more than 0.05, as seen in Table 1 ($p = 0.057$), indicates that there is no statistically significant difference in access to immunization sites between the income quantile groups (Shreffler J. & Huecker M.R. 2025).

Further supporting this conclusion, a low R^2 value (0.03) shown in Figure 1 indicates that income does not strongly predict immunization access across Calgary. Interestingly, a slight trend is indicated by the positive slope (0.016), suggesting that lower-income areas have slightly higher vaccination site availability (Fig.1). However, because the slope value is quite low, this trend is considered to be weak.

Figure 2 identifies that the median access score between quartiles remains fairly consistent, with the lowest (quartile 1) and highest (quartile 4) income groups differing by only 0.03 mean sites per 1000 people.

The maximum values between these two quartiles have a greater difference of 1.94 mean sites per 1000 people.

6. Visualization and Maps

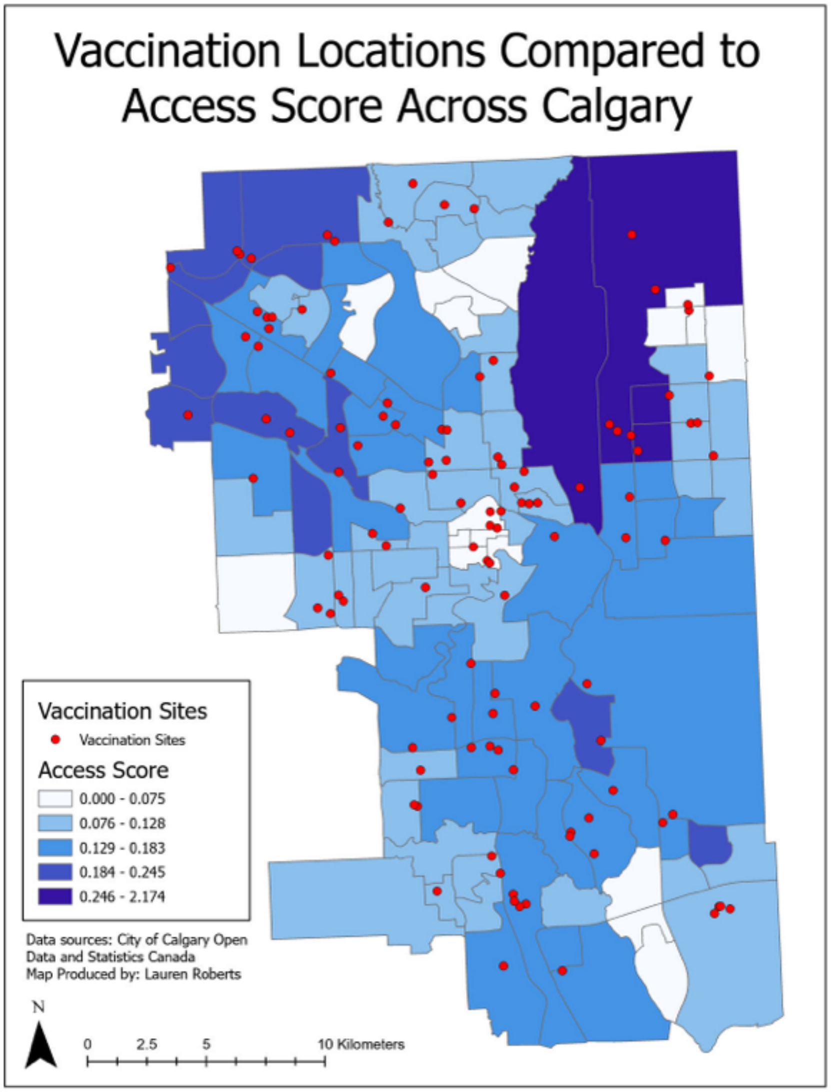

Figure 3: Map of Vaccination Locations Compared to Access Score Across Calgary. The map was created using ArcGIS Pro using NAD83 CSRS UTM Zone 11N. Access scores range from 0 – 2.174. Access scores are shown across the community service areas (CSAs) of Calgary.

Figure 3 illustrates the spatial distribution of vaccination access scores throughout Calgary, with vaccination site points overlaid. Areas with higher access scores represent communities that are located either near to, or have a greater number of vaccination-providing facilities within a reasonable proximity. This map works to visually highlight the spatial patterns of accessibility and how this public service is distributed across the city. The inclusion of the immunization site locations helps the reader to easily identify service clusters and potential access gaps.

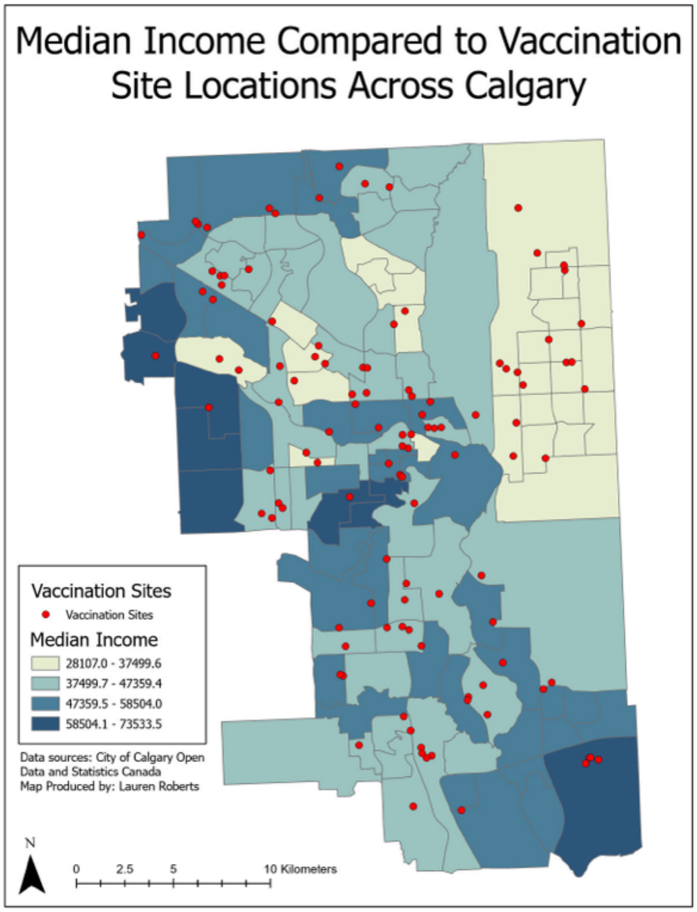

Figure 4: Map of Median Income Compared to Vaccination Site Locations Across Calgary. The map was created using ArcGIS Pro using NAD83 CSRS UTM Zone 11N. Median income levels are shown across Calgary's community service areas (CSAs).

Figure 4 depicts the spatial relationship between median household income levels and vaccination site locations. This visualization offers insights into the socioeconomic geographies in Calgary. Overlaying vaccination site locations creates a visual linkage between income and site locations, allowing for the identification of any patterns of distribution. When compared with Figure 3, patterns of equity in public health infrastructure become more apparent. The purpose of this map lies in its ability to contextualize immunization access with socioeconomic conditions, creating depth, in and understanding of, the conditions that potentially affect immunization access and Figure 3.

When viewed together, these maps help to provide a clear understanding of the relationship between vaccination accessibility and the socioeconomic conditions that may affect it.

7. Discussion

The results of this analysis indicate that there is no statistically significant difference in access to vaccination sites across Calgary, with minimal variation seen between low- and high-income groups. The low R^2 value (0.03; Fig.1) as well as the non-significant ANOVA results ($p = 0.057$; Table 1) suggest that income is not a strong determinant of proximity-based access to immunization services within Calgary. Interestingly, a weak pattern emerged in Figure 1, where low-income areas were slightly closer to, or had a larger quantity of, immunization facilities than high-income areas. This may be due to city expansion projects, where new high-income developments are created on the peripheral edges of Calgary. New developments may lack established vaccination facilities, possibly resulting in lower access and father travel distances. Figures 3 & 4 support this hypothesis, as vaccination sites appear more concentrated in established neighbourhoods, while fewer are located on Calgary's expanding southern edges.

When considering the suitability of Calgary, these findings are encouraging. Vaccination is a keystone in preventative medicine and public health; inequities in coverage or accessibility increase the population's vulnerability to disease outbreaks (Zeng et al. 2021). As vaccination supports long-term public health, sustainable immunization systems ensure that positive health effects are sustained over time (Myemba D.T. et al. 2025), even in the face of endemics and pandemics. Calgary's relatively equitable site distribution therefore supports the development of a healthier, more resilient population, aiding Calgary in its path to sustainability. Equitable access to vaccination sites creates increased vaccination coverage, results in a lower burden on the general medical system, allowing the city to minimize preventable disease-related costs (Rappuoli R. et al. 2019). Fostering disease protection and management creates long-lasting social and health sustainability.

Overall, this indicator reflects a positive trend towards greater sustainability within Calgary. While minor variations in access remain, the general pattern of equitable spatial distribution across all income quartiles demonstrates progress towards a more inclusive preventive care system, supporting the City's broader goals of social health and wellness.

8. Conclusion and Recommendations

This analysis assessed the relationship between access to vaccination facilities and median household income in Calgary, using both statistical and spatial methods to assess patterns of equity in preventative care. The results found that vaccination access is generally well-distributed across income groups with no statistically significant difference between low- and high-income areas. These findings suggest that Calgary's preventive health infrastructure supports spatially equitable access to vaccination services, positively contributing to the city's sustainability. The low R^2 value suggests that there is little to no causal relationship between income and spatial access, answering the question of this study: *To what extent does household income affect access to immunization within Calgary?*

However, it is important to note that this analysis is not a comprehensive depiction of access. Although Calgary's spatial access is adequate, there are many other factors impacting an individual's ability to receive immunization, including transportation, mobility level, mental health, gender, education and more (Ali H.A. et al. 2002) (Popovian et al. 2022). All of these compounding factors need to be addressed to create true, long-lasting sustainability within Calgary.

Although current spatial accessibility levels are strong, there remain opportunities for continued improvement. Portable and mobile vaccination programs have demonstrated efficacy in increasing vaccination access and uptake, especially for mobility-impaired individuals, underserved areas, and transient populations. In addition to increasing access, when implemented in the United States, these programs showed significant medical savings of up to $3.70 USD for every dollar spent during dedicated vaccination events (Chen W et al. 2020). This method also provided coverage for children who may have otherwise remained unvaccinated (Chen W et al. 2020). Mobile clinics also avert many logistical and social barriers for impaired individuals by using pop-up clinics and door-to-door outreach (Ketel C. et al. 2023). In addition to mobile programs, outreach programs and transparent vaccination campaigns should be continued with the goal of increasing education on the benefits of preventive medicine.

Further research should explore the social and behavioural dimensions of immunization access, possibly including transit and travel times. Ultimately, the goal of further research should be to complete a comprehensive analysis of vaccine access, considering more compounding factors than income alone.

9. References

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