Urban Digital Development: A Study of Public Free WiFi Distribution in Toronto*

Insights from Building Type, Population and Income

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Public WiFi is a vital tool for modern society, supporting economic, social, and educational development through free internet access. This study examines the influencing factors of free public WiFi distribution in Toronto using datasets from Open Data Toronto. Specifically, it investigates the relationship between building types, population, median income of each ward in Toronto, and the number of public free WiFi hotspots. Linear regression models are utilized to analyze these correlations and offer insights into the current distribution of public WiFi, including potential benefits and disadvantages. Findings indicate that areas with higher population densities or greater concentrations of public amenities tend to have more public WiFi installations, while median income does not significantly influence public WiFi deployment. Understanding these findings is crucial for policymakers and urban planners to ensure the equitable development of digital public Internet infrastructure.

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*Code and data are available at: https://github.com/BerniceBao/Free-Public-WiFi-Distribution-in-Toronto.

1 Introduction

In the digital age, access to the internet has become increasingly essential for participation in economic, social, and educational activities. With the continuous progress of science and technology, public WiFi, which can be easily and wirelessly connected to the Internet at a low cost, is gradually improving and promoting to all corners of the world. Nowadays, public free WiFi has emerged as a crucial tool in bridging the digital divide and promoting equitable access to online resources. It fosters internet accessibility, enabling people to stay connected without constraints. It also improve the access to information, job searching, and remote work opportunities are further facilitated, enhancing the overall quality of life. In emergencies, public WiFi could also serve as a crucial communication lifeline, demonstrating its indispensable role in connecting people and providing access to vital services.(Broadbandsearch (2023)) In Canada, the Canadian Radio-television and Telecommunications Commission (CRTC) has recognized that "broadband internet access services are crucial to Canada's economic, social, democratic, and cultural fabric."("Datasharing - Toronto - Free Wi-Fi" (2019))

Recognizing its significance, this paper embarks on an exploration of the distribution of free public WiFi in Toronto, and delves into its potential influencing factors, aiming to shed light on the dynamics shaping its accessibility across different urban areas. By examining the relationship between building types, population demographics, median income, and the number of public free WiFi hotspots in different wards of Toronto, this study seeks to uncover the underlying factors driving the spatial distribution of public WiFi infrastructure. Utilizing datasets sourced from Open Data Toronto, our analysis employs rigorous statistical methods, including linear regression models, to explore the correlations between various socio-economic variables and the availability of public WiFi. Through this approach, we aim to offer insights into the benefits and potential drawbacks of current public WiFi distribution strategies, with a particular focus on understanding the role of population density and the presence of public amenities in driving WiFi deployment. By elucidating these factors, we aim to provide valuable analysis

for policymakers and urban planners tasked with ensuring the equitable provision of digital public Internet infrastructure.

Our findings reveal intriguing patterns regarding the relationship between population density, public amenity concentration, and the presence of public WiFi installations. Notably, areas with higher population densities or greater concentrations of public amenities tend to exhibit a higher prevalence of public WiFi hotspots. However, our analysis also suggests that median income levels do not significantly influence the deployment of public WiFi infrastructure. These findings underscore the importance of considering diverse socio-economic factors in shaping strategies for the equitable development of digital public Internet infrastructure in urban areas. This paper contributes to our understanding of the factors influencing the distribution of public WiFi in urban settings. By elucidating the relationship between socio-economic variables and public WiFi deployment, our study offers valuable insights that can inform the development of more equitable and inclusive digital infrastructure policies, and also provide readers with a lens to comprehend the symbiotic relationship between technology and urban living.

This research is divided into five main parts: `Introduction`(Section 1), `Data`(Section 2), `Model` (Section 3), `Results` (Section 4), and `Discussion` (Section 5). Section 2 provides a detailed explanation of the two databases used for analysis, data processing, including visualization of variables of interest. Section 3 proposes a simple linear regression model to be applied to our two variables of population and income separately. Section 4 presents the findings from the analysis, and Section 5 takes a deeper look at those findings, concluding with a summary of all of the analysis in this paper on the distribution of public free WiFi in Toronto and a discussion of bias and next steps.

2 Data

In this section, We explore the R-based data collection process and generate the visualizations in the RStudio environment (R Core Team 2022; RStudio Team 2021). All the datasets studied in this paper come from "Open Data Toronto" (Gelfand 2022), a data source allowing researchers and policymakers to access and utilize the data which can be downloaded for free from its website and GitHub repository, in order to finish various statistical analyses, research studies, and decision-making processes. The two main datasets used in this paper are "City of Toronto Free Public WiFi" (2024), which provides descriptive data such as the location and building type of Toronto free public WiFi, and "Ward Profiles - 25 Ward Model" (2024), which contain economic, population and other social information of all 25 wards in Toronto collected in 2021.

The analysis benefits from additional functionalities harnessed from various R packages such as `tidyverse` (Wickham et al. 2019) installed to gain access to other important R packages, `here` (Müller 2020) created a path to specific saved files, `readr` (Wickham, Hester, and Bryan 2024) read and imported data, `ggplot2` (Wickham 2016) made the data visualizations, `knitr` (Xie 2023) and `dplyr` (Wickham et al. 2023) manipulated and cleaned data, and `modelsummary`

(Arel-Bundock 2022) to create summary tables. Further insights into the deployment of these packages will be expounded upon in the ensuing subsections.

2.1 First Dataset: Location and description data of Toronto free public WiFi

The dataset "City of Toronto Free Public WiFi" (2024), is an open-source resource provided by Toronto's Department of Information Technology. It collects location information and descriptive data for free public WiFi locations in the City of Toronto and is regularly updated, with the latest update on April 15, 2024. This dataset includes various details such as address, building type, building name, zip code, and ward information.

Of particular interest in our analysis are the variables "building type," "ward," and "ward number," which serve as the main focus of our study. Analyzing public WiFi distribution by building type helps us identify areas with concentrated internet access and those that may require additional infrastructure development to ensure equitable access across communities. Similarly, examining ward and ward number distributions provides insights into the natural distribution of public WiFi in Toronto, laying the groundwork for further exploration of associated social factors.

To streamline our analysis, we conducted data cleaning by retaining only relevant columns related to building type, ward, and ward number. Additionally, we performed basic data cleaning procedures to remove non-WiFi-related building data and NA values, enhancing the clarity and accuracy of our analysis. Subsequently, we utilized knitr to generate the Table 1 table for further analysis:

Table 1: Sample of cleaned wifi data

Building Type	Ward	Ward Number
Arena	Etobicoke North	1
Arena	Don Valley East	16
Arena	Willowdale	18
Arena	Humber River-Black Creek	7
Arena	Humber River-Black Creek	7
Arena	Humber River-Black Creek	7
Arena	Parkdale-High Park	4
Arena	Etobicoke-Lakeshore	3
Arena	Etobicoke-Lakeshore	3
Arena	Don Valley East	16

Table 1 shows reoughly the building types, ward and ward number of all buildings with public WiFi in Toronto. To facilitate a clearer understanding of the distribution of public WiFi across

different building types, we grouped the data by building type and summarized the number of free WiFi hotspots associated with each category showed in Table 2.

Table 2: Sample of building type data

Building Type	Number of Free Wifi
Library	99
CRC	50
Arena	11
None	9
Arena,CRC,OPB	7
CRC,OPB	7
Arena,CRC	6
AIRB,CRC,OPB,WB	2
A,AIRB,CRC,OPB,WB	1
A,AIRB,WB	1

This process involved grouping the data by building type and calculating the total count of free WiFi instances within each category. By organizing the data in this manner, it aimed to provide an overview of the prevalence of public WiFi across various types of buildings, including arenas, libraries, community recreation centers (CRC), Outdoor Pool Building (OPB), Artificial Ice Rink Building (AIRB), and Washroom Building (WB).

From Table 2, we know that there are 198 free public WiFi location in the City of Toronto in total. Further breakdown shows that there are 100 free public WiFi location that are set in library, 74 free public WiFi location that are set in Community Recreation Centre(CRC), 27 free public WiFi location that are set in Arena, 17 free public WiFi location that are set in Outdoor Pool Building (OPB). Since the same WiFi may cover multiple buildings, the sum of the number of public WiFi corresponding to each building type is greater than the total number of public WiFi in Toronto. The four building types mentioned above have the largest number of public WiFi, covering almost 90% of total.

2.2 Second Dataset: 2021 Ward Profiles based on the 25-Ward model

We expanded our analysis beyond building types to include population and income data for each ward in Toronto. Demographic factors such as age, household size, and cultural background can influence the demand for and usage patterns of public WiFi, with higher population densities generally indicating greater internet demand. Additionally, areas with lower median incomes may face barriers to internet access due to affordability issues or insufficient infrastructure investment.

To incorporate this data, we utilized the ward profile dataset ("Toronto Ward Profiles" 2023) published by City Planning, based on 2021 Census data and last updated on January 3, 2024. This dataset includes demographic, social, and economic information such as population, age, race, language, and median household income. Median household income, representing pre-tax income a family receives from employment, investment and government support. Median income is used in our research because it is less sensitive to very high and very low income values than the average.

Focusing on the impact of population and income on free WiFi distribution, we narrowed our analysis to these two variables. While initial data provided valuable insights, we sought further clarity through digital analysis. To quantify the performance of free WiFi across different building types, we created a new variable by combining it with the first dataset, labeled "number of free WiFi," then getting Table 3 to facilitate deeper investigation:

Table 3: Sample of final ward data

Population	Income	Ward Number	Number of Free Wifi
115120	38135	1	12
117200	45345	2	5
139920	65575	3	13
104715	49440	4	9
115675	45055	5	8
107355	41265	6	6
111200	37675	7	14
114820	45915	8	8
104730	45670	9	6
135400	80730	10	6

Table 3 reveals key insights into the population, median income and amount of public WiFi of Toronto's 25 wards. It highlights variations in population size, median income, and the number of free WiFi hotspots across these wards. For instance, Etobicoke-Lakeshore (Ward 3) boasts the highest population count at 139,920, while Scarborough North (Ward 23) records the lowest at 94,025. Similarly, Spadina-Fort York (Ward 10) ranks highest in median household income at 80,730 dollars, contrasting with Humber River-Black Creek (Ward 7), which reports the

lowest income at 65,458 dollars. In terms of free WiFi availability, Humber River-Black Creek (Ward 7) leads with 14 hotspots, whereas both Etobicoke Centre (Ward 2) and Willowdale (Ward 18) have the fewest, each with 5.

It intuitively shows the social developments of 25 neighbourhoods in Toronto, including population, median income, and number of WiFi, providing data support for the following study of the linear relationship between the three. It is important to note that, according to the database, more populated neighborhoods do not necessarily have more median income, as well as the number of free WiFi. This observation underscores the complexity of urban dynamics and highlights the need to analyze each variable independently to understand its impact on public WiFi distribution.

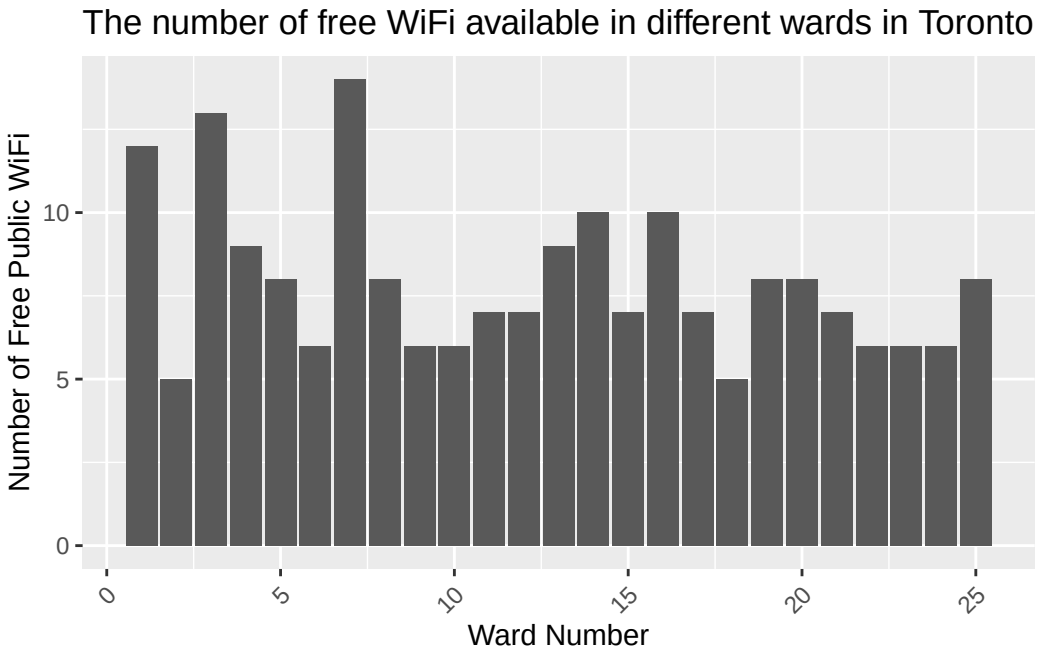

Figure 1: The number of free WiFi available in different wards in Toronto

Figure 1 illustrates the disparities in public WiFi distribution across Toronto's wards, highlighting variations in coverage levels. Specifically, Ward 1, Ward 3, and Ward 7 stand out with substantially higher numbers of public WiFi hotspots compared to the median value of 8. Ward 1, with 12 hotspots, Ward 3, with 13 hotspots, and Ward 7, with 14 hotspots, each exceed the median by more than 1/3, indicating significantly more extensive coverage in these areas. In contrast, the number of public WiFi hotspots in other wards remains relatively consistent and does not exhibit any significant shortages. This observation suggests that while certain wards benefit from robust public WiFi infrastructure, others may experience disparities in access, highlighting the need for targeted interventions to promote equitable Interncet connectivity across all neighborhoods in Toronto.

3 Model

After conducting data analysis of the two dataset, we have observed that there might be a correlation between the population of a ward and the number of free public WiFi in this ward, as well as the median income of a ward and the number of free public WiFi in this ward. To gain further insights and give resaonable advise about future Toronto public free WiFi distribution, we construct two linear regression models, tested the two hypotheses separately.

In the section below, the final models are detailed investigated here.

3.1 Model set-up

Define Y as the dependent variable, which is the number of free public WiFi in a ward, and X as the independent variable, which is the population of a ward in the first model, or the median income of a ward in the second model. Then β_0 is the intercept, representing the expected number of free WiFi hotspots when the population or income is zero, β_1 is the slope coefficient, indicating the change in the number of free WiFi hotspots for a one-unit increase in population or in income. ϵ is the error term, representing the random variability in the number of free WiFi hotspots that is not explained by population or income.

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

3.2 Model justification

Our goal of the linear regression model is to estimate the values of β_0 and β_1 that minimize the sum of squared errors between the number of public free WiFi of a ward (Y) and the population or the median income correspounding ward (X) in the data sets. By minimizing this sum of squared errors, the linear regression model can produce the best-fit line to describe the linear relationship between the two variables, allowing for the estimation of Y values based on known X values.

In addition, the statistical significance of β_1 can be assessed using a t-test, which tests whether the estimated coefficient is significantly different from zero. If the p-value of the t-test is less than a chosen significance level, we can conclude that there is a significant relationship between the population of a ward and the number of free public WiFi in this ward, as well as the median income of a ward and the number of free public WiFi in this ward.

4 Results

4.1 Building Type

Societal need for public Wi-Fi differs according to building types

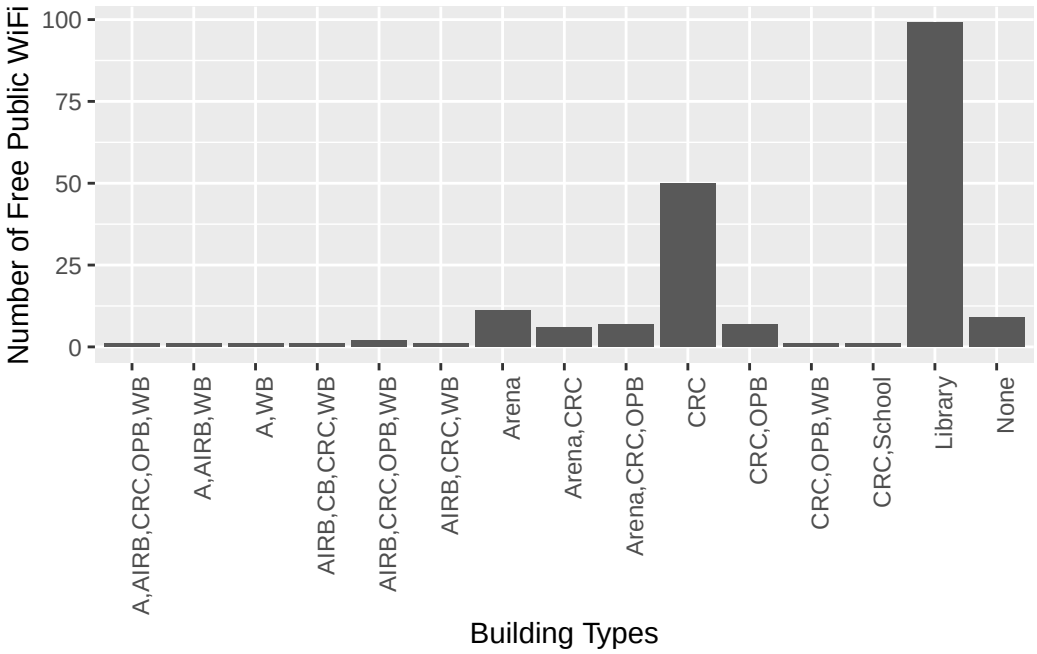

Figure 2: The number of free WiFi in Toronto by building type

From Figure 2, we can find out significant trends regarding the distribution of free WiFi across different building types in Toronto. Libraries emerge as crucial hubs of connectivity, boasting the highest number of free WiFi hotspots with a total of 99 instances. This underscores the pivotal role that libraries play in providing accessible internet resources to the community, serving as essential spaces for education, research, and digital inclusion initiatives. Additionally, Community Recreation Centers (CRC) also exhibit a substantial presence of free WiFi, with 50 hotspots identified. These centers serve as vital community hubs where residents can engage in recreational activities, access social services, and participate in educational programs.

The type of building can often reflect the different needs of modern people for WiFi, and having more public WiFi coverage proves that it has a stronger degree of Internet digitization needs. For example, libraries have embraced technology, expanding their offerings beyond books to include a rich array of digital resources. Public WiFi is now a vital tool for students, researchers, and casual readers, facilitating access to online databases, ebooks, and collaborative group projects. Moreover, Community Recreation Centre have transformed into dynamic

digital hubs, serving as venues for social gatherings and work. Here, individuals can check emails, work remotely, and stay informed about current events, all while enjoying a cup of coffee.

The prevalence of free WiFi in libraries and CRCs highlights their significance as inclusive spaces that support lifelong learning, social interaction, and access to digital resources for all members of the community. This underscores the importance of investing in these institutions to ensure equitable access to internet connectivity and promote digital inclusion in urban environments.

4.2 Population

Higher population density correlates with increased distribution of free public WiFi

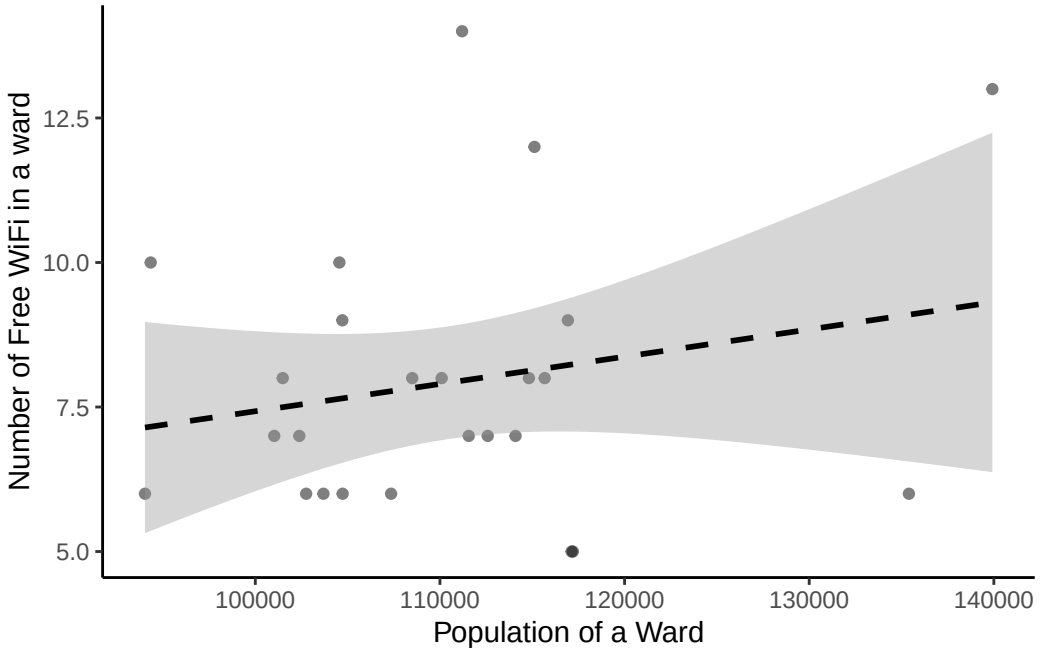

Figure 3: Linear regression model of the number of Free public WiFi by the populations of all wards in Toronto.

The first linear regression model, as illustrated in Figure 3, explores the relationship between the number of free public WiFi locations in a ward and the population of corresponding ward across Toronto, which is a slight positive correlation. The scatterplot depicts the general trend of increased number of public WiFi as bigger population, further emphasized by the regression line. The model indicates that as the population of a ward gets bigger, the number of free public WiFi increases as well.

Table 4: A summary table of the first linear regression model

	Population of a Ward
(Intercept)	2.71
	(5.04)
Population	0.00
	(0.00)
Num.Obs.	25
R2	0.045
R2 Adj.	0.003
AIC	117.7
BIC	121.4
Log.Lik.	−55.873
RMSE	2.26

Table 4 displays the coefficients of the predictor variables of the linear regression model. The coefficient for population (0.00) from Table 4 indicates that there is no statistically significant linear relationship between the population of a ward and the number of free public WiFi locations it hosts, as the coefficient's p-value exceeds conventional thresholds for significance. This finding suggests that the population size alone may not be a strong predictor of the availability of free public WiFi in Toronto's wards. The model's low R-squared value of 0.045 and adjusted R-squared value of 0.003 indicate that only a very small proportion of the variability in the number of free public WiFi locations can be explained by the population size of the wards. The model's RMSE (Root Mean Square Error) of 2.26 suggests that the model's predictions deviate from the actual values by an average of 2.26 free public WiFi locations.

In summary, while we attempts to assess the relationship between population and the availability of free public WiFi, its findings indicate that population alone is not a strong predictor of the number of free public WiFi locations in Toronto's wards, but there is still a slightly positive correlation between the two.

4.3 Income

Income levels have limited influence on availability of free public Wi-Fi

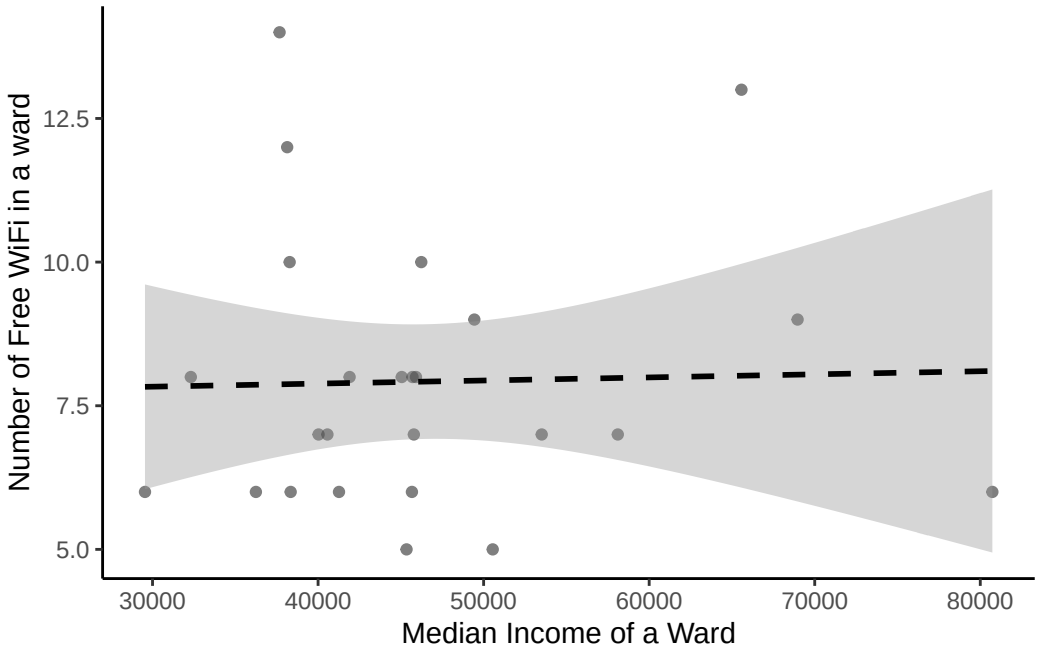

Figure 4: Linear regression model of the number of Free public WiFi by the Average Income of all wards in Toronto.

The second linear regression model, as illustrated in Figure 4, explores the relationship between the number of free public WiFi locations in a ward and the median income of corresponding ward in Toronto, which shows very limited correlation. The scatterplot shows that all the points distributed very scattered and disordered, and cannot find a general trend of increased or decreased number of public WiFi as bigger population. Also the regression line is almost parallel to the x-axis. The model indicates that there is nearly no relationship between the median income of a ward and the number of free public WiFi locations it hosts.

Table 5 displays the coefficients of the predictor variables of the linear regression model. The coefficient for income is 0.00, suggesting that there is virtually no change in the number of free WiFi locations with an increase in median income. Additionally, the R-squared value of 0.001 indicates that only a negligible proportion of the variance in the number of free WiFi locations can be explained by median income. The adjusted R-squared value of -0.043 further suggests that the model's predictive power is very low.

Overall, these findings suggest that median income alone may not be a significant predictor of the number of free WiFi locations in a ward, highlighting the need for further exploration of other factors that may influence public WiFi distribution in urban areas.

Table 5: A summary table of the second linear regression model

	Median Income of a Ward
(Intercept)	7.67
	(2.02)
Income	0.00
	(0.00)
Num.Obs.	25
R2	0.001
R2 Adj.	−0.043
AIC	118.9
BIC	122.5
Log.Lik.	−56.437
RMSE	2.31

Based one the two linear regression models, we can conclude that the population of a ward has slightly positive correlation with the number of Toronto public WiFi, but there is no observable correlation between the number of Toronto public WiFi and the median household income in a ward.

5 Discussion

5.1 Findings and advice

The findings of this study shed light on the intricate relationship between public Wifi distribution and urban social characteristics in Toronto. The intricate dynamics surrounding public WiFi distribution in Toronto encompass a multitude of factors that interact to shape urban wareless Internet connectivity. Beyond simplistic correlations, this study delves into the interplay between the distribution of public WiFi, income, population, and building types.

Firstly, while median income is often presumed to be a determining factor in access to resources, this study challenges that assumption. The negligible impact of income on the availability of free WiFi locations suggests that other factors may hold greater significance. This could include the allocation of resources by municipal authorities, the presence of community initiatives, or the density of public amenities, all of which may influence WiFi accessibility independently of income levels.

Secondly, the study sheds light on the role of infrastructure and community engagement in shaping public WiFi distribution. For instance, areas with higher population densities or greater concentrations of public amenities, such as libraries or community centers, may naturally attract more public WiFi installations due to higher foot traffic and demand. Additionally, community-led initiatives or partnerships between local organizations and internet service providers could contribute to the expansion of WiFi networks in underserved areas.

Moreover, the study underscores the importance of considering the diverse needs and preferences of communities when planning WiFi infrastructure. Factors such as cultural diversity, language barriers, and digital literacy levels may influence the effectiveness of public WiFi initiatives and require tailored solutions to ensure inclusivity.

Overall, the intricate dynamics surrounding public WiFi distribution in Toronto highlight the need for a and context-sensitive approach to urban connectivity. By understanding and addressing the multifaceted factors at play, policymakers, urban planners, and community advocates can develop more effective strategies to bridge the digital divide and foster a truly equitable society.

Here are some extra analysis as advice:

Equitable Access to Public WiFi: A Necessity, Not a Luxury

One of the central themes emerging from our analysis is the importance of equitable access to public WiFi. While public WiFi hotspots are widely available across Toronto, our study reveals disparities in their distribution. Certain building types, such as libraries, community centers, and parks, emerge as hubs of connectivity, while others lag behind. This discrepancy underscores the need for deliberate efforts to ensure that all neighborhoods, regardless of socioeconomic status, have access to reliable internet connectivity.

Addressing Differences caused by population density

Another significant finding is the variation in public WiFi distribution across population density found by linear regression model. Although median income of a ward doesn't play a big role in the distribution of public free WiFi, wards with bigger population tend to have more extensive coverage compared to less crowed places. This disparity suggests that access to public WiFi is not evenly distributed across the city, potentially exacerbating existing inequalities, since fewer public WiFi leads to less Internet conections and usages, making it increasingly difficult for networks development in the region. To address this issue, policymakers should prioritize investment in underserved communities, ensuring that all residents have access to essential digital resources.

Implications for Urban Policy

The findings of this study have several implications for urban policy and planning. Firstly, policymakers should prioritize the equitable distribution of public WiFi infrastructure, particularly in underserved neighborhoods. This may involve targeted investment in community centers, libraries, and public spaces to ensure that all residents have access to reliable internet connectivity. Secondly, urban planners should integrate considerations of digital equity into their decision-making processes. By prioritizing projects that promote connectivity and digital inclusion, cities can create more resilient and equitable communities. Finally, community engagement and collaboration are essential for addressing the digital divide. By involving local residents in the planning and implementation of public WiFi initiatives, cities can ensure that solutions are tailored to the specific needs of each community.

5.2 Bias and ethical concerns

As we delve into the analysis of public WiFi distribution in Toronto, it is important to navigate through various biases and ethical considerations that may influence our findings and subsequent policy recommendations. We explore three points that underscore the importance of addressing bias and ethical concerns in our research.

Measurement Bias

An important consideration is measurement bias, which arises from inaccuracies or inconsistencies in measuring or reporting variables such as population, median income, and the number of free WiFi locations. For example, relying on self-reported revenue data can introduce errors and discrepancies across wards. To address measurement bias, we must employ reliable data collection methods and validate our findings by cross-referencing with multiple sources.

Sampling Bias

If the sample size is not representative of the Toronto population, or if certain groups are excluded or underrepresented in our analysis, then sampling bias poses a significant risk to the validity of our findings. By ensuring that our sample is inclusive and representative, we can

mitigate the effects of sampling bias and draw more accurate conclusions about the relationship between population, income, and public WiFi distribution.

Ethical Considerations

Ethical considerations are crucial in any research effort, especially when it comes to the collection and analysis of personal data. In the context of public WiFi distribution, we must prioritize the privacy of individuals, including anonymizing personal information, and adhere to strict privacy regulations to safeguard the confidentiality and rights of participants.

In conclusion, navigating bias and ethical considerations is essential for producing meaningful and actionable insights into research of public WiFi distribution in Toronto. By acknowledging these challenges, we can enhance the validity and integrity of our research findings and contribute to the development of more equitable policies.

5.3 Weaknesses & Next Steps

A significant limitation of our study is the complexity of the factors that influence the distribution of public WiFi in Toronto. While we strive to gather data sets on population, median income, and the number of free WiFi locations, it is important to recognize that the influencing factors are multifaceted and interdependent. The true determinants of public WiFi distribution likely include a wide range of socioeconomic, infrastructural, and community-related factors that are difficult to accurately capture through quantitative analysis alone.

To address this limitation, we must employ a holistic approach that combines qualitative research methods, stakeholder interviews, and community engagement initiatives to gain a deeper understanding of the potential drivers of public WiFi distribution. Through a combination of quantitative and qualitative analysis, we can spot subtle dynamic changes and develop more strategies to improve public WiFi connectivity in Toronto.

6 Appendix

For enhancement, I take advantage of shiny, which is to quickly add some interactivity to our graphs according to the simulated data. Here(Figure 5) is the screnshot of my shiny work, and the interactive graph is is in the folder “Enhancement - Shiny Plot”.

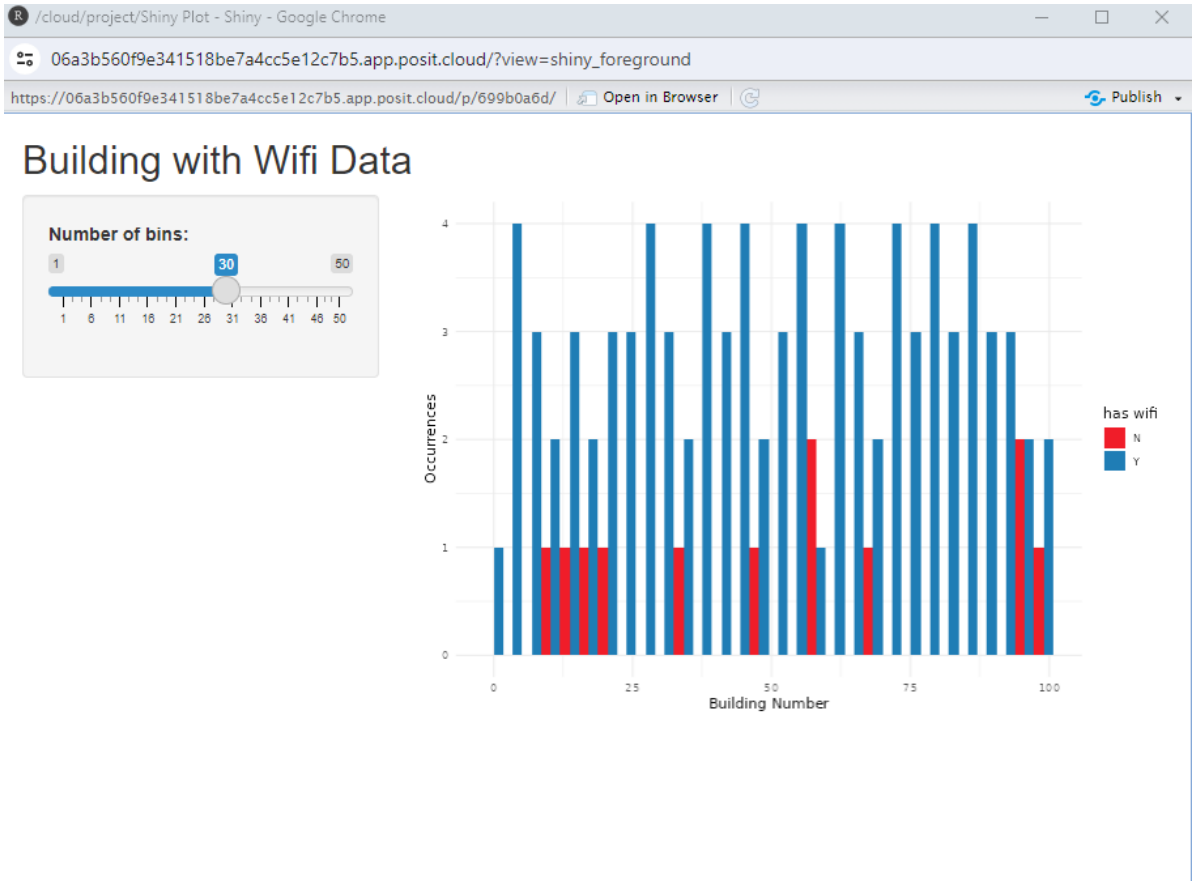

Figure 5

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