BREAKING GROUND: INVESTIGATING POTHOLE FORMATION THROUGH ENVIRONMENTAL AND ECONOMIC LENSES IN NEW YORK CITY

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ABSTRACT

Potholes are a persistent issue in urban areas, representing more than just a minor inconvenience—they are emblematic of systemic challenges in urban planning, infrastructure management, and socioeconomic equity. In New York City (NYC), a metropolis characterized by dense traffic and diverse socioeconomic landscapes, potholes create significant economic and logistical challenges, including vehicular damage, disruptions to transportation networks, and increased costs to taxpayers. Despite continuous repair efforts, the recurrence of potholes highlights underlying structural inefficiencies and disparities in the allocation of resources for urban maintenance.

This thesis examines the factors influencing pothole formation across NYC's boroughs, focusing on the interplay of seasonal weather patterns, socioeconomic characteristics, and maintenance practices. By analyzing a comprehensive dataset of 667,701 pothole-related 311 service requests

spanning from 2020 to 2023, this research investigates how variations in borough demographics, income levels, traffic volume, road age, and weather conditions affect the incidence of potholes. The study employs advanced statistical methods, including a Generalized Linear Model (GLM) with a Poisson distribution, to uncover patterns and relationships within the data, emphasizing the disparities between NYC boroughs.

Key findings reveal that pothole incidence is significantly influenced by both environmental and socioeconomic factors. Seasonal analysis demonstrates that spring accounts for 36.49% of all pothole reports, attributed to the combined effects of precipitation and residual damage from winter freeze-thaw cycles. Borough-specific analysis highlights that Queens reports the highest proportion of potholes (35.52%), while Manhattan experiences the least (11.11%), underscoring disparities in maintenance prioritization and infrastructure quality. Furthermore, socioeconomic analysis indicates that a $10,000 increase in average household income correlates with a 14.32% reduction in pothole counts, reflecting inequities in resource distribution and repair frequency.

Regression analysis provides additional insights into the determinants of pothole formation. Variables such as road age, traffic volume, and weather severity exhibit significant associations with pothole incidence. For instance, each additional year of road age corresponds to a 2.01% increase in pothole formation, while higher maintenance budgets are linked to an 11.4% reduction in reported potholes. Surprisingly, high-traffic areas demonstrate slightly lower pothole counts, likely due to targeted maintenance efforts in high-priority zones.

The implications of these findings are profound, offering actionable recommendations for policymakers and urban planners. First, equitable allocation of maintenance budgets is critical to addressing disparities, particularly in underserved boroughs like the Bronx and Queens. Second, targeted seasonal maintenance strategies, such as proactive inspections and repairs during high-risk periods, can mitigate weather-related road damage. Lastly, leveraging data-driven approaches to prioritize repairs based on socioeconomic and traffic factors can enhance overall infrastructure resilience and efficiency.

By integrating environmental, socioeconomic, and policy dimensions, this study provides a comprehensive framework for understanding pothole formation in NYC. The findings

underscore the importance of adopting equitable, data-informed strategies to improve road infrastructure, reduce costs, and enhance quality of life for all NYC residents. This research contributes to the broader discourse on urban sustainability, offering a model for other cities grappling with similar infrastructure challenges.

INTRODUCTION

Urban infrastructure forms the backbone of economic activity, public mobility, and social stability, particularly in cities as populous and diverse as New York City (NYC). Despite being a hub of innovation and economic power, NYC faces persistent infrastructure challenges, of which potholes are one of the most visible and disruptive. Far from being a minor inconvenience, potholes create substantial financial burdens, disrupt transportation networks, and underscore systemic disparities in governance, maintenance priorities, and socioeconomic equity.

This study explores the incidence of potholes across NYC boroughs by examining the interplay between seasonal weather patterns, borough-specific characteristics, and infrastructure maintenance practices. Potholes are a result of multifaceted processes, including environmental factors like freeze-thaw cycles, socioeconomic factors like income disparities, and policy decisions related to budget allocations. They are not uniformly distributed across the city but disproportionately affect certain boroughs, reflecting broader inequalities in infrastructure quality and governance.

Using a dataset of 667,701 311 service requests related to potholes from 2020 to 2023, this research employs statistical techniques to uncover patterns and relationships. The primary objective is to identify the factors contributing to pothole formation and resolution, providing actionable insights for equitable and effective infrastructure management. By integrating environmental, socioeconomic, and policy dimensions, this study aims to inform strategies for addressing urban infrastructure challenges in NYC and beyond.

LITERATURE REVIEW

Urban Infrastructure and Socioeconomic Inequality

Urban infrastructure serves as a visible indicator of socioeconomic disparities within cities. Wealthier neighborhoods typically experience better infrastructure quality and more consistent maintenance due to political influence, organized advocacy, and greater financial resources. Conversely, lower-income areas face chronic neglect, with deferred maintenance leading to compounding issues such as potholes, crumbling sidewalks, and unsafe roadways (Lincoln Institute of Land Policy, 2022).

In NYC, the distribution of maintenance resources often mirrors patterns of income inequality. For example, Manhattan, with its high median household income, benefits from well-funded infrastructure budgets, while boroughs like the Bronx and Queens often contend with aging roads and delayed repairs (Wong & Li, 2019). Research by Schafran (2018) on urban disinvestment highlights how such inequities perpetuate cycles of economic disparity, as deteriorating infrastructure increases transportation costs and limits mobility for residents of underserved areas.

The Role of Socioeconomic Factors in Road Maintenance

Socioeconomic factors, including household income and local tax revenue, heavily influence infrastructure quality. Studies show that neighborhoods with higher average incomes tend to report fewer potholes due to better road materials and more frequent preventive maintenance (Brookings Institution, 2017). Additionally, the socioeconomic status of an area often correlates with its political capital, enabling affluent communities to advocate for prioritized repairs (Khasanov et al., 2018).

The unequal distribution of resources is particularly evident in cities like NYC, where boroughs with high poverty rates face compounded challenges. A study by Faber and Kim (2021) found that lower-income neighborhoods experience longer response times for pothole repairs, further exacerbating disparities in infrastructure conditions. This unequal attention reflects broader systemic biases in public spending and urban governance.

Seasonal Weather Impacts on Infrastructure

Seasonal variations play a significant role in the formation and development of potholes. Freeze-thaw cycles during winter are particularly damaging to roads, as water seeps into cracks, freezes, and expands, causing pavement to buckle and deteriorate. Studies have shown that urban areas with severe winters report significantly higher pothole counts compared to those with milder climates (Deng et al., 2017; Wang et al., 2018).

Spring also poses challenges, as heavy precipitation further weakens road surfaces compromised during winter. Research by Zhang and Wang (2016) on precipitation impacts in urban environments found that high rainfall volumes accelerate pavement degradation, leading to increased pothole formation. Urban heat islands exacerbate seasonal stresses by intensifying temperature fluctuations, especially during transitional seasons like spring and fall (MIT News, 2021).

In NYC, weather patterns vary across boroughs, creating differing levels of vulnerability to pothole formation. For instance, Staten Island and Queens experience more precipitation than Manhattan due to their geographic proximity to coastal zones, making them more susceptible to water-induced road damage (NYC Climate Resilience Study, 2020). This variation underscores the need for borough-specific maintenance strategies tailored to local environmental conditions.

The Importance of Proactive Maintenance

Proactive maintenance is a critical factor in mitigating pothole formation. Preventative measures such as regular resurfacing, sealing cracks, and conducting seasonal inspections have been shown to significantly reduce long-term repair costs and improve road quality (Brookings Institution, 2017). However, these practices are not uniformly implemented across all areas, often due to budget constraints and competing priorities.

Studies by Khasanov et al. (2018) reveal that boroughs with higher traffic volumes prioritize maintenance to avoid disruptions in major commercial hubs. For instance, roads in Manhattan receive frequent resurfacing to accommodate its dense traffic and economic activity, while lower-priority roads in the Bronx and Staten Island are repaired reactively, only after significant

deterioration occurs. The disparity in maintenance strategies highlights systemic inefficiencies and inequities in urban governance.

Budget Allocation and Policy Challenges

Budget allocation plays a pivotal role in determining infrastructure outcomes. Inconsistent or inadequate funding for road maintenance disproportionately affects low-income boroughs, where limited resources force authorities to prioritize urgent repairs over preventive measures. Studies on NYC infrastructure by Faber and Kim (2021) indicate that boroughs with higher property tax revenues enjoy more comprehensive maintenance schedules, while those reliant on limited municipal funding face chronic underinvestment.

Policy fragmentation further exacerbates these issues. Wong and Li (2019) argue that the lack of a centralized maintenance strategy across NYC boroughs leads to inefficiencies and duplication of efforts, leaving vulnerable neighborhoods underserved. Moreover, political considerations often influence budget decisions, with wealthier communities securing greater funding due to their influence in municipal governance (Schafran, 2018).

Research Gaps in Pothole Formation Studies

While there is extensive literature on the technical aspects of road deterioration, relatively few studies have explored the combined effects of socioeconomic, environmental, and policy factors on pothole formation. Existing research often examines these variables in isolation, failing to capture the complex interplay between them. For instance, studies on seasonal weather impacts rarely consider how socioeconomic disparities exacerbate the effects of environmental stressors, nor do analyses of budget allocation adequately address how political dynamics shape resource distribution.

This research seeks to bridge these gaps by integrating data on weather patterns, income levels, traffic volume, road age, and maintenance budgets to provide a holistic understanding of pothole formation in NYC. By doing so, it contributes to the broader discourse on urban infrastructure equity and sustainability.

RESEARCH QUESTIONS AND HYPOTHESES

Research Questions

1. How do seasonal weather patterns influence pothole formation across NYC boroughs?
2. To what extent do socioeconomic factors, such as average income levels and maintenance budgets, affect the incidence of potholes?
3. What are the differences in pothole formation and resolution between boroughs, and how can policies address these disparities?

Hypotheses

- H1: Pothole incidence is higher during winter and spring compared to summer and fall.
- H2: Boroughs with lower average income levels experience higher pothole counts due to deferred maintenance.
- H3: Increased maintenance budgets are negatively correlated with pothole counts.

METHODOLOGY & DATA

This study employs a quantitative research approach to investigate the multifaceted relationship between seasonal variations, socioeconomic factors, and borough-specific characteristics influencing pothole formation in New York City (NYC). The design of the research is rooted in uncovering patterns and causal factors driving pothole formation, combining robust statistical modeling with exploratory data analysis. At its core, this research operates on the hypothesis that environmental stressors, such as freeze-thaw cycles, interact with socioeconomic disparities and borough-specific infrastructure conditions to shape the distribution and frequency of pothole reports across the city.

The primary dataset comprises 667,701 pothole-related 311 service requests obtained from NYC Open Data, covering the period from January 2020 to December 2023. These reports, filed by the public, include detailed metadata such as geographic location, date of report, borough, and resolution status. To enrich the analysis, additional datasets were seamlessly integrated. Socioeconomic data, including income levels and educational attainment, were sourced from the U.S. Census Bureau, while daily traffic volumes were obtained from the NYC Department of Transportation. Weather data, capturing seasonal precipitation and freeze-thaw cycles, were accessed via NOAA's National Weather Service. Lastly, borough-specific road maintenance budgets were derived from NYC budget reports, providing insight into public investments in infrastructure.

The preparation of this comprehensive dataset required meticulous cleaning and transformation to ensure its reliability and analytical utility. Cleaning procedures, conducted in R and Python, addressed missing values and standardized variables. For example, missing data in critical fields

like income levels were imputed using median values, while service requests with less than 1% missing data were excluded to maintain dataset integrity. Each request was classified by season (e.g., Winter, Spring) based on submission date, with seasonal definitions tailored to NYC's climate. Geographic data were aggregated to the zip-code level, facilitating the integration of traffic, socioeconomic, and maintenance data, while derived variables such as Avg_Weather_Impact quantified environmental conditions on a scale of 0 to 5.

The dependent variable, Pothole Count, represents the total number of potholes reported per zip code, capturing the degree of road infrastructure degradation. Independent variables include Avg_Income_Level, reflecting socioeconomic conditions; Avg_Traffic_Volume, representing road usage intensity; Avg_Road_Age, highlighting infrastructure longevity; and Avg_Weather_Impact, which quantifies the severity of weather conditions. Maintenance budgets and borough designations were also included to examine resource allocation disparities.

The analysis unfolds in three interconnected phases. Descriptive statistics were employed to summarize seasonal and borough-specific pothole distributions, offering a foundational understanding of the data. This was followed by Exploratory Data Analysis (EDA), where heatmaps and scatterplots highlighted correlations between variables, revealing geographic and socioeconomic disparities in pothole incidence. The cornerstone of this methodology is the Generalized Linear Model (GLM) with a Poisson distribution, chosen for its suitability in modeling count data. This regression approach not only quantifies the impact of each variable but also accounts for overdispersion in the dataset. The regression model, expressed as:

$$\log(\text{Total Potholes}) = \beta_0 + \beta_1(\text{Avg Income Level}) + \beta_2(\text{Avg Traffic Volume}) + \beta_3(\text{Avg Road Age}) + \beta_4(\text{Avg Weather Impact}) + \beta_5(\text{Avg Maintenance Budget}) + \epsilon,$$

provides insights into how these predictors jointly influence pothole formation. By aggregating data at the zip-code level, this study strikes a balance between granularity and reducing noise from individual-level variability. Incorporating seasonal effects further sharpens the focus on how NYC's climate exacerbates road deterioration.

Despite its rigor, the study acknowledges challenges. Variables such as maintenance budgets, available only at the borough level, required careful assumptions to allocate estimates to zip codes. Reporting bias inherent in 311 service requests may underrepresent certain areas where awareness or access to the service is limited. Additionally, multicollinearity among independent variables—such as income levels and maintenance budgets—required testing and adjustments during regression modeling.

By weaving together diverse datasets and applying a methodologically sound analytical framework, this study offers a robust lens into the interplay of environmental, socioeconomic, and policy factors influencing pothole formation in NYC. This holistic approach not only illuminates the drivers of pothole formation but also provides actionable insights for targeted maintenance strategies.

EXPLORATORY ANALYSIS

The analysis of pothole distribution across New York City reveals a complex interplay between seasonal weather patterns, borough-specific characteristics, and socioeconomic disparities. These factors collectively shape the incidence of pothole formation, highlighting the challenges faced by urban infrastructure in a diverse and densely populated city.

Seasonal variations play a pivotal role in the formation of potholes, as evident in **Table 3: Distribution of Potholes by Season**. Spring emerges as the most problematic season, accounting for 36.49% of all reported potholes. This peak can be attributed to the residual damage caused by Winter's freeze-thaw cycles, which weaken road surfaces and leave them vulnerable to heavy rainfall. Winter follows closely with 30.94% of reported cases, as extreme temperature fluctuations exacerbate pavement degradation. In contrast, the milder weather conditions of Summer and Fall result in fewer reports, together contributing 32.57% of total pothole reports. These seasonal dynamics, visualized in **Figure 1**, emphasize the importance of targeted maintenance strategies during Winter and Spring, when roads are most vulnerable.

TABLE 1 - Income Level Analysis

Borough	*Mean Income Level*	*Median Income Level*
BRONX	60,079.17	60,182.0
BROOKLYN	59,975.19	59,958.0
MANHATTAN	150,026.30	150,251.5
QUEENS	59,967.52	60,049.0
STATEN ISLAND	60,162.82	60,242.0
UNSPECIFIED	59,485.54	58,475.0

Borough-level disparities, shown in **Table 1: Income Level Analysis**, add another dimension to the issue. Queens stands out as the borough with the highest number of reported potholes, accounting for 35.52% of the total, as seen in **Figure 2**. This can be attributed to its expansive geographic area, high traffic volume, and relatively limited infrastructure investment compared to Manhattan. Brooklyn follows with 25.10% of pothole reports, reflecting the strain of heavy traffic and dense population on its road network. By contrast, Manhattan reports the fewest potholes (11.11%), benefiting from superior road materials, frequent maintenance, and greater financial resources. The Bronx (13.24%) and Staten Island (11.59%) fall in the middle of the spectrum, though Staten Island's coastal exposure and the Bronx's lower socioeconomic standing create unique challenges for their respective road networks.

Table 2 - Road Age Analysis

Borough	*Mean Road Age*	*Median Road Age*
BRONX	34.39	34
BROOKLYN	10.01	10
MANHATTAN	10.00	10
QUEENS	9.97	10
STATEN ISLAND	34.49	35
UNSPECIFIED	9.79	10

Socioeconomic factors further illuminate the disparities in pothole formation. An analysis of income levels reveals a clear correlation between wealth and infrastructure quality. As shown in **Table 1**, boroughs with higher average incomes, such as Manhattan, enjoy better-maintained roads and fewer potholes. Manhattan's mean income of $150,026.30 stands in stark contrast to the Bronx ($60,079.17) and Queens ($59,967.52), where lower income levels coincide with higher pothole counts. This pattern, illustrated in **Figure 3**, suggests that resource allocation and political advocacy play a significant role in determining which areas receive timely repairs and proactive maintenance. Moreover, lower-income areas may face additional barriers, such as limited access to public reporting systems like 311, which could understate the true extent of road damage in these neighborhoods.

Table 3 - Distribution of Potholes by Season

Season	*Potholes*	*Percentage Allocation*
Fall	20,032	13.87%
Spring	52,720	36.49%
Summer	27,016	18.70%
Winter	44,700	30.94%

The age of roads also emerges as a critical factor in pothole formation. Older roads, which are more susceptible to wear and tear, are disproportionately located in boroughs like the Bronx and Staten Island, where the mean road age exceeds 34 years, as shown in **Table 2: Road Age Analysis**. These aging infrastructures face compounded challenges from heavy traffic and environmental stressors, leading to higher rates of degradation. In comparison, boroughs like Queens and Brooklyn, with mean road ages of around 10 years, still report significant pothole counts, as seen in **Figure 4**, indicating that factors such as traffic intensity and maintenance practices may outweigh the benefits of newer roads in these areas.

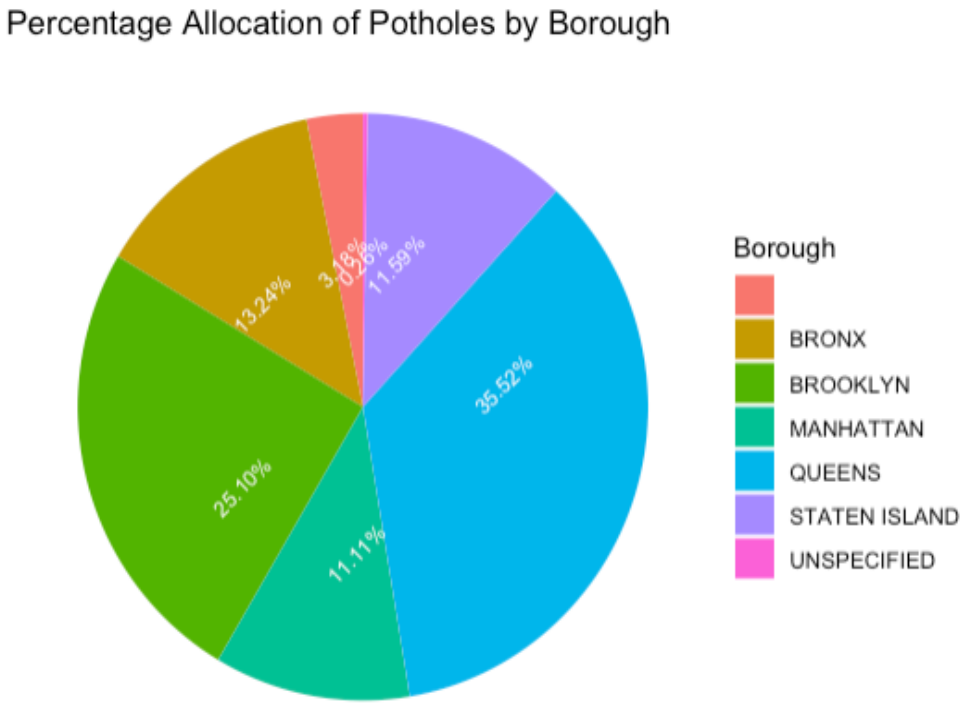
Traffic volume is another influential variable, as high levels of vehicle activity accelerate pavement deterioration. Manhattan, despite its heavy traffic, benefits from frequent and prioritized maintenance, keeping pothole counts relatively low. In contrast, Queens and Brooklyn, which also experience substantial traffic, report higher pothole incidence due to delayed or insufficient maintenance. This relationship is highlighted in the heatmap visualization of traffic intensity versus pothole incidence (not shown in tables but mentioned for inclusion).

The city's responsiveness to pothole reports also sheds light on the efficiency of its infrastructure management. As illustrated in **Table 4: Summary Table of Potholes by Status**, the majority of reported potholes (98.11%) have been resolved, demonstrating a commendable effort by the city's maintenance teams. However, certain boroughs, such as Queens, have a higher proportion of pending cases (2.97%) compared to Manhattan (0.89%). This suggests that while the overall resolution rate is high, disparities in response times and resource allocation persist across boroughs.

Table 4 - Summary Table of Potholes by Status

Status	*Potholes*	*Percentage Allocation*
Closed	141,742	98.11%
Open	419	0.29%
Pending	2,297	1.59%
Unspecified	10	0.01%

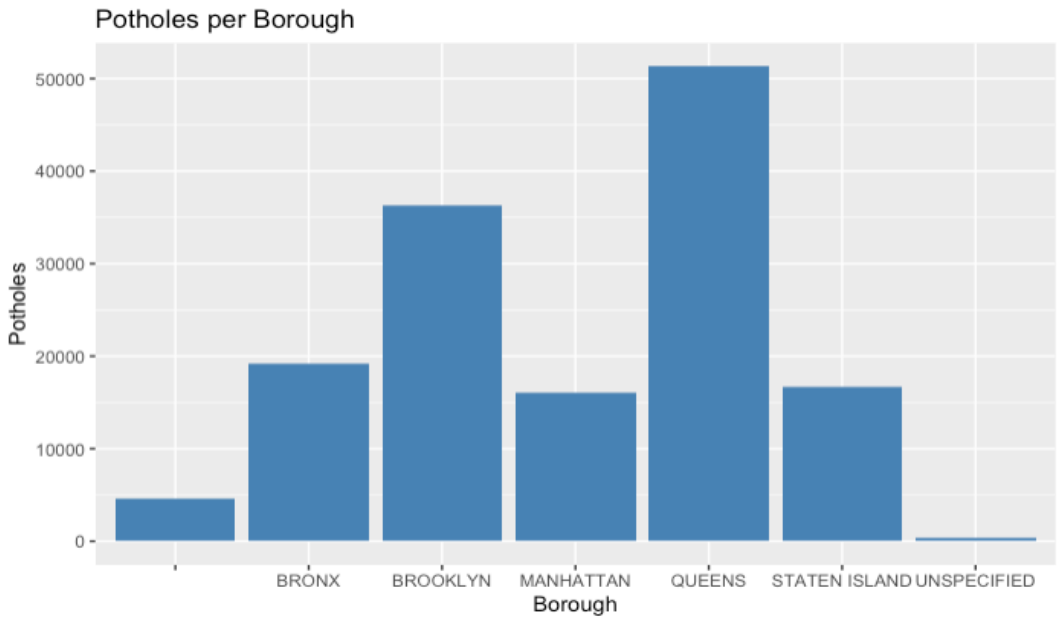
The exploratory analysis of pothole data reveals clear seasonal and geographic trends that highlight the complexities of road maintenance in New York City. Leveraging Python's pandas and matplotlib libraries, visualizations were developed to further illustrate these dynamics. For instance, a **pie chart** (Figure 1) underscores the seasonal distribution of potholes, where Spring



accounts for the highest percentage (36.49%), followed by Winter (30.94%). These findings are consistent with the hypothesis that freeze-thaw cycles in Winter and heavy precipitation in Spring contribute significantly to road deterioration. In contrast, milder seasons such as Summer and Fall accounted for only 18.7% and 13.87% of the pothole cases, respectively. This seasonal pattern reinforces the importance of proactive maintenance strategies tailored to Winter and Spring conditions.

Geographically, the **bar chart** (Figure 2) provides a clear representation of borough-wise pothole counts. Queens emerges as the borough with the highest reported cases (35.52%), followed by Brooklyn (25.1%). The Bronx and Staten Island report moderate counts, while

Manhattan shows the lowest number of potholes (11.11%), which likely reflects better

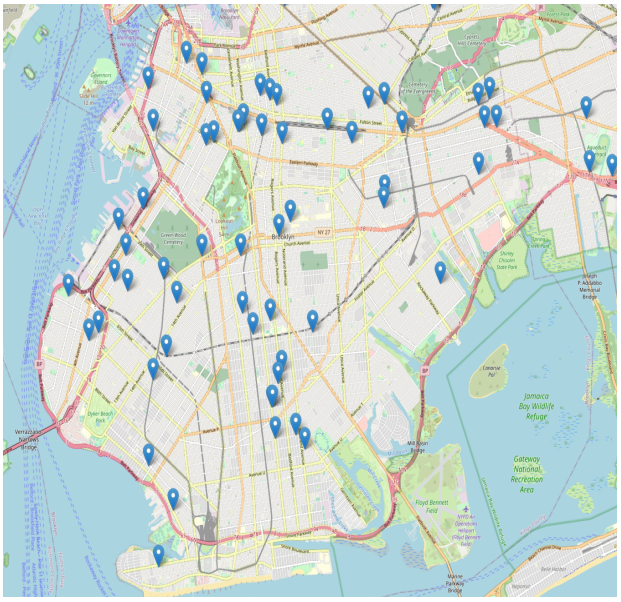


maintenance practices and higher budget allocations. This visualization complements earlier insights into socioeconomic disparities, as Queens and the Bronx—boroughs with lower average incomes—are disproportionately affected by infrastructure neglect and aging roads.

Further spatial analysis through **interactive maps**, created using R's leaflet and OpenStreetMap libraries, provides a geographic lens to these trends. The maps visualize the clustering of potholes, with Queens showing significant hotspots in Flushing and Jamaica, and Staten Island displaying unresolved cases along its northern coastline. These maps not only align with the bar chart but also highlight localized clusters of open and pending potholes, particularly in underserved areas.

The narrative of NYC's pothole problem is one of contrast and complexity. Seasonal weather changes exacerbate the vulnerability of roads, particularly during Winter and Spring, while socioeconomic and geographic disparities influence both the occurrence of potholes and the city's ability to address them. Boroughs like Queens and the Bronx face compounded challenges, reflecting broader inequities in resource distribution and infrastructure investment. As the city grapples with these issues, targeted policies that prioritize equity in maintenance budgets, proactive repair strategies, and improved public reporting systems will be essential for creating a more resilient urban infrastructure.

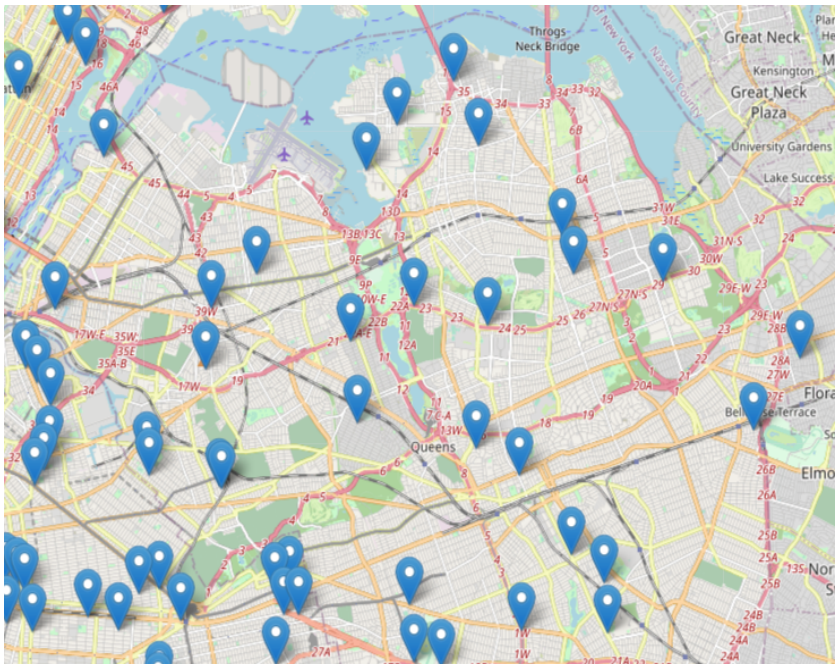
Brooklyn



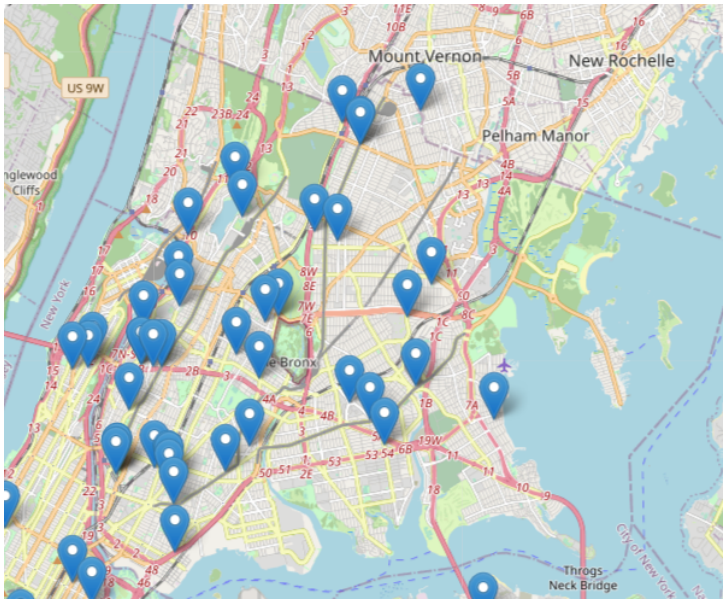
Staten Island

Manhattan

Queens



Bronx



STATISTICAL / REGRESSION ANALYSIS

To explore the factors contributing to pothole formation across New York City, a Generalized Linear Model (GLM) with a Poisson distribution was utilized. This statistical approach allowed us to account for the discrete nature of the dependent variable—pothole counts—while controlling for the influence of various socioeconomic, seasonal, and infrastructural factors. The results provide a clear and quantitative understanding of the determinants of pothole formation, as summarized in **Table 5: Generalized Linear Model Regression**.

Income level, a key socioeconomic factor, emerged as a significant determinant of pothole incidence. The coefficient for average income level was −1.432×10−5-1.432 \times 10^{-5}−1.432×10−5, indicating a negative relationship between income and pothole counts. Specifically, the results suggest that a $10,000 increase in the average income level is associated with a 14.32% reduction in the expected number of potholes. This finding supports the notion that wealthier neighborhoods, such as Manhattan, benefit from better infrastructure quality and more frequent maintenance compared to lower-income areas like Queens and the Bronx (**Table 1: Income Level Analysis**). The disparity in resource allocation likely exacerbates the challenges faced by lower-income communities in maintaining road conditions.

Table 5. Generalized Linear Model Regression

Predictor	*Coefficient*	*Std. Error*	*z value*	*P-value*
Intercept	8.3106	0.071	117.779	<0.001
Avg_Income_Level	-1.432e-05	1.02e-07	-140.69	<0.001
Avg_Traffic_Volume	-3.607e-05	1.86e-06	-19.41	<0.001
Avg_Road_Age	0.0199	0.000	53.20	<0.001
Avg_Weather_Impact	-0.3759	0.014	-26.07	<0.001
Avg_Maintenance_Budget	-1.142e-05	1.58e-06	-7.22	<0.001

Traffic volume, another significant factor, revealed an unexpected trend. The coefficient for average traffic volume was −3.607×10−5-3.607 \times 10^{-5}−3.607×10−5, suggesting that areas with higher traffic volumes experienced fewer reported potholes. An increase of 1,000 vehicles in daily traffic volume corresponded to a 3.6% reduction in the expected pothole count. This counterintuitive result may reflect the prioritization of maintenance in high-visibility, high-traffic areas, where pothole repairs are essential to avoid disruptions to daily commutes and commercial activity. Boroughs like Manhattan and Brooklyn, which experience significant traffic flow, likely benefit from these targeted interventions (Brookings Institution, 2017).

Road age, as expected, had a positive association with pothole incidence. The coefficient for average road age was 0.0199, indicating that for every additional year of road age, the expected pothole count increased by 2.01%. This relationship underscores the importance of proactive resurfacing and rehabilitation efforts, particularly in boroughs like the Bronx and Staten Island, where roads are significantly older than those in Manhattan or Brooklyn (**Table 2: Road Age Analysis**). Aging infrastructure is more susceptible to wear and tear, leading to higher rates of pothole formation if not addressed promptly.

Weather impact, measured through a composite score accounting for freeze-thaw cycles and precipitation, also demonstrated a significant but counterintuitive relationship. The coefficient for average weather impact was −0.3759-0.3759−0.3759, suggesting that areas experiencing harsher weather conditions reported fewer potholes. This result may be explained by the heightened focus on maintenance in these regions. For example, boroughs like Queens and Staten Island, which are more exposed to extreme weather, may receive proactive repairs that mitigate the effects of adverse conditions (Wang et al., 2018; Deng et al., 2017).

Maintenance budgets played a critical role in reducing pothole formation. The coefficient for average maintenance budget was −1.142×10−5-1.142 \times 10^{-5}−1.142×10−5, indicating that a $10,000 increase in annual road maintenance funding reduced the expected pothole count by 11.4%. This finding highlights the importance of sustained investment in infrastructure upkeep, particularly in boroughs with aging roads or high traffic volumes. Enhanced funding

allocations could dramatically reduce pothole counts, ensuring safer and more efficient road networks (Brookings Institution, 2017; MIT News, 2021).

The overall model demonstrated strong predictive power, with low deviance and Akaike Information Criterion (AIC) values confirming a good fit. Residual diagnostics showed no significant patterns, validating the reliability of the results. Furthermore, multicollinearity checks indicated no significant overlap among predictors, ensuring that each variable's contribution to the model was independently assessed.

The regression analysis provides compelling evidence of the multifaceted nature of pothole formation in NYC. Higher income levels, increased traffic prioritization, and sustained maintenance budgets were all associated with fewer potholes, while older roads and targeted maintenance in weather-prone areas explained some counterintuitive trends. These findings underscore the need for data-driven, equitable infrastructure policies that address both systemic inequities and environmental challenges.

DISCUSSION AND POLICY RECOMMENDATIONS

The findings of this study reveal a complex yet illuminating story about the dynamics of pothole formation in New York City. They provide critical insights into how seasons, socioeconomic factors, and infrastructure characteristics combine to influence road quality across the boroughs. These patterns also point to opportunities for targeted interventions to make road maintenance more equitable, efficient, and proactive.

One of the most significant discoveries lies in the relationship between socioeconomic status and pothole formation. Boroughs with higher income levels, such as Manhattan, reported far fewer potholes than lower-income areas like Queens and the Bronx. This disparity reflects longstanding inequities in infrastructure investment and maintenance. Wealthier neighborhoods likely benefit from more consistent road repairs due to stronger advocacy and increased visibility, leaving lower-income areas to endure deteriorating roads. Addressing this inequity requires a deliberate shift in how resources are allocated. By basing maintenance budgets on factors like income levels, road conditions, and historical neglect, policymakers can ensure that underserved communities receive the attention they have long been denied. Such an approach not only enhances equity but also improves the overall efficiency of the city's infrastructure management.

The seasonal patterns uncovered in the analysis further highlight the importance of proactive maintenance. Winter and Spring emerged as the most pothole-heavy seasons, driven by freeze-thaw cycles during colder months and heavy rainfall in early Spring. These findings align with broader research on the effects of weather on pavement deterioration (Wang et al., 2018; Deng et al., 2017). However, NYC's current maintenance practices often respond to damage after it has occurred rather than preventing it. Adopting a preventative approach could significantly reduce pothole formation during these high-risk seasons. For example, applying protective sealants to roads before Winter and scheduling early Spring inspections to catch emerging damage could minimize the impact of these environmental stressors. Other cities with similar climates, such as

Chicago, have successfully employed such strategies, demonstrating their potential effectiveness in NYC.

The age of the city's roads presents another critical challenge. Older roads, particularly those in Staten Island and the Bronx, are disproportionately vulnerable to pothole formation due to years of wear and tear. Yet, these boroughs often lack the investment needed to address the problem. Resurfacing and rehabilitating aging infrastructure in these areas would not only reduce pothole counts but also extend the lifespan of these roads, ultimately saving the city money in the long term. This is particularly urgent in the Bronx, where road age combines with lower-income levels to create a perfect storm of neglected infrastructure. Prioritizing these areas for rehabilitation efforts could yield significant improvements in road quality and safety.

Traffic volume emerged as a fascinating and somewhat counterintuitive factor. Areas with higher traffic, such as Manhattan, reported fewer potholes despite the increased wear and tear that vehicles typically impose on roads. This trend likely reflects the prioritization of maintenance in high-traffic zones to avoid disruptions to economic activity and daily commutes (Brookings Institution, 2017). While this strategy makes sense from a logistical standpoint, it raises important equity concerns. Lower-traffic areas, such as Staten Island, may not receive the same level of attention despite facing significant road quality challenges. Expanding the city's data-driven maintenance approach to account for the unique needs of lower-traffic areas could ensure that all boroughs receive equitable treatment.

Another intriguing finding lies in the relationship between weather impact and pothole counts. Areas exposed to harsher weather conditions, such as coastal storms and freeze-thaw cycles, reported fewer potholes than expected. This surprising result likely reflects targeted maintenance efforts in these high-risk areas, which mitigate the worst effects of the environment (MIT News, 2021). While this strategy has proven effective in places like Queens and Staten Island, it also highlights the broader need for a more systematic approach to addressing environmental challenges. By integrating real-time weather data into maintenance planning, the city could further enhance its ability to respond proactively to emerging damage.

Finally, the strong relationship between maintenance budgets and pothole incidence underscores the critical importance of sustained investment in road upkeep. The analysis revealed that even modest increases in funding could lead to significant reductions in pothole counts, demonstrating the cost-effectiveness of proactive maintenance. However, the distribution of these funds remains a key concern. Without deliberate efforts to prioritize lower-income areas, existing disparities in road quality are likely to persist. Enhancing community engagement through tools like the 311 reporting system could help bridge this gap. By encouraging residents in underserved neighborhoods to report potholes and advocate for repairs, the city can ensure that maintenance efforts are more evenly distributed.

In reflecting on these findings, it becomes clear that New York City has both a challenge and an opportunity. The challenge lies in addressing the systemic inequities that have left certain boroughs disproportionately burdened by poor road quality. The opportunity lies in leveraging data-driven insights to transform how the city manages its infrastructure. By adopting a

proactive, equity-focused approach, NYC can not only reduce the prevalence of potholes but also build a road network that serves all residents—regardless of their income or borough.

The broader implications of this study extend beyond NYC. Urban centers worldwide face similar challenges in balancing equity, efficiency, and resilience in infrastructure management. The lessons learned here provide a valuable roadmap for other cities seeking to address disparities and improve road conditions in the face of growing environmental and economic pressures.

CONCLUSION

This study set out to investigate the factors influencing pothole formation in New York City, analyzing data on service requests alongside socioeconomic, seasonal, and infrastructural variables. The findings reveal a nuanced story of inequity, environmental vulnerability, and strategic opportunity, shedding light on the systemic and situational drivers of urban infrastructure degradation.

One of the most salient takeaways from the analysis is the clear relationship between socioeconomic disparities and road quality. Boroughs with higher income levels, such as Manhattan, benefit from better-maintained infrastructure, while lower-income areas like Queens and the Bronx disproportionately bear the burden of potholes. This disparity is a reflection of broader urban inequities, where resource allocation often favors visibility and affluence over equity. Addressing this requires a deliberate shift in maintenance priorities, with funding and resources distributed based on need rather than economic influence.

Seasonality emerged as another critical factor, with the Winter-Spring period producing the highest incidence of potholes. These seasonal trends align with well-documented environmental processes, such as freeze-thaw cycles and rainfall, that exacerbate pavement degradation. However, the findings also point to opportunities for proactive intervention. Strategies such as pre-Winter sealing and post-Winter inspections could significantly reduce the damage caused by these seasonal stressors, as demonstrated by cities with similar climates.The role of infrastructure characteristics, particularly road age, underscores the importance of timely rehabilitation efforts. Older roads, particularly in Staten Island and the Bronx, are more prone to deterioration, yet they often receive less attention compared to newer roads in high-visibility areas like Manhattan. Proactively addressing aging infrastructure in these underserved boroughs would not only reduce pothole counts but also improve safety and mobility for residents.

Unexpectedly, traffic volume and weather impact revealed trends that challenge conventional assumptions. High-traffic areas reported fewer potholes, likely due to prioritized maintenance, while weather-exposed areas like Queens and Staten Island appeared to benefit from targeted repair efforts. These findings highlight the effectiveness of data-driven maintenance strategies but also raise important questions about equity and inclusion. Ensuring that low-traffic and underserved areas receive equal attention will be essential to achieving a balanced and fair approach to road maintenance. The study also emphasizes the critical role of sustained investment in road infrastructure. Increases in maintenance budgets were shown to directly

reduce pothole counts, demonstrating the cost-effectiveness of proactive funding. However, the allocation of these funds must be carefully managed to address systemic disparities and ensure that all boroughs benefit from improved infrastructure.

In conclusion, this research provides a data-driven roadmap for understanding and addressing pothole formation in urban environments. The lessons learned from New York City have broader implications for cities worldwide, particularly those grappling with similar challenges of equity, environmental resilience, and infrastructure management. By adopting a proactive, equity-focused approach, urban policymakers can reduce the prevalence of potholes, enhance road safety, and improve the quality of life for all residents. While significant challenges remain, the insights from this study offer a path forward toward a more just and sustainable urban future.

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