CHAPTER 97

Mapping EV Infrastructure: Insights from Correlation and Regression Analysis

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ABSTRACT

Electric Vehicles (EVs) are emerging as a transformative solution for achieving sustainable transportation, offering numerous benefits such as low carbon emissions, high energy efficiency, and reduced reliance on non-renewable resources. However, to fully realize the potential of EVs in fostering sustainable mobility, the development of a well-planned and efficient charging infrastructure is critical. This infrastructure not only addresses range anxiety for EV users but also ensures convenience and accessibility, which are key factors for widespread adoption. This research aims to analyse and identify strategic locations for EV charging infrastructure using Geographic Information System (GIS) tools, specifically QGIS. A comprehensive approach will be undertaken, involving the collection of primary data through structured questionnaires and personal interviews with stakeholders, including EV users, urban planners, and policymakers. Secondary data, such as demographic, traffic flow, and land use data, will also be incorporated to ensure a robust sampling process. The analysis will focus on land suitability and multi-criteria decision-making (MCDM) to evaluate and prioritize locations based on factors like accessibility, population density, energy demand, and environmental considerations. By integrating these parameters, the research will identify strategic location for developing charging infrastructure. In addition, the study will propose suitable amenities and services, such as rest areas, retail outlets, and maintenance facilities, to enhance user experience and encourage EV adoption. The findings aim to provide a strategic roadmap for urban planners and policymakers, contributing to the creation of a sustainable and user-friendly EV ecosystem.

Keywords: GIS; EV charging infrastructure; Location analysis; Proximity analysis; Range anxiety.

1.0 Introduction

Climate change has gained political prominence throughout the world with carbon dioxide pollution bringing about environmental degradation, dwindling supply of water, and increased coastal flooding. The automobile sector in India is one of the fastest in growth, and since India is the world's most populated country, higher emissions originate from it.

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Private vehicles contribute to 12% of the world greenhouse gases emissions while transport vehicles cause higher emissions, accounting for 22%. Hence, the EV infrastructure talk is being done as a panacea for these emissions. The study carries out correlation and regressional tests to analyze variables influencing the needs for EV infrastructure. Regression analysis is used to analyze development factors, while Spatial surveys using GIS technology are used to analyze the household needs regarding the location and land use study for charging station. It is focused on Balewadi and Hinjewadi areas of Pune for determining strategic locations for charging stations of electric vehicles.

EVs resolve many environmental and economic issues inasmuch as they offer major benefits over internal combustion engine vehicles (ICEVs) by replacing fossil fuels with electricity. But problems like range anxiety, charging time, price sensitivity, government schemes, and inadequate charging infrastructure slow down its acceptance. Despite advancements in battery technology, expansion of charging networks still lags behind. In a way to improve user experiences for themselves and further influence the buying decision-making process, it is vital to plan EV charging stations well. While elements influencing EV adoption have received much treatment qualitatively, the quantitative analysis has received little attention. The most significant research gap is about effective locations for stations relative to applied EV adoption. As all surveys indicate, these specific barriers include the time taken to charge, the installation costs, and a lack of standardization.

Infrastructure gaps were identified in Balewadi and Hinjewadi by surveying users on charging station usage, EV integration into local economies, and adoption rates. Factors included demographics, frequency of charging, distance to station, and the problem of range anxiety. Therefore, it is very important to develop highly developed charging stations to meet increasing EV demand. The adoption of PEVs, including PHEVs and BEVs, could change the entire energy sector in India. However, since India depends on coal for the bulk of its electricity, there needs to be a systematic transition. More than two-wheeler demand in India is placed after that of China, and this preference for two-wheelers is likely to continue through at least 2035. Government initiatives such as the National Electric Mobility Mission Plan (NEMMP 2020) aimed to deploy 400,000 passenger BEVs by 2020, creating a basis for further research on modern EV infrastructure.

1.1 Scope of research

The use of Plug-in Electric Vehicles (PEVs), such as PHEVs and BEVs, can redefine India’s energy profile and decrease environmental footprint. But with the dominant power being coal, the transition needs to be well-planned. Two-wheelers overwhelm India’s market because of value for money and efficiency, and demand is not likely to slump until 2035. Notwithstanding gradual penetration of EVs (slightly more than 1%), the government has strived to adopt through measures such as NEMMP 2020. Further studies are pivotal to enhancing infrastructure for EVs and hastening growth.

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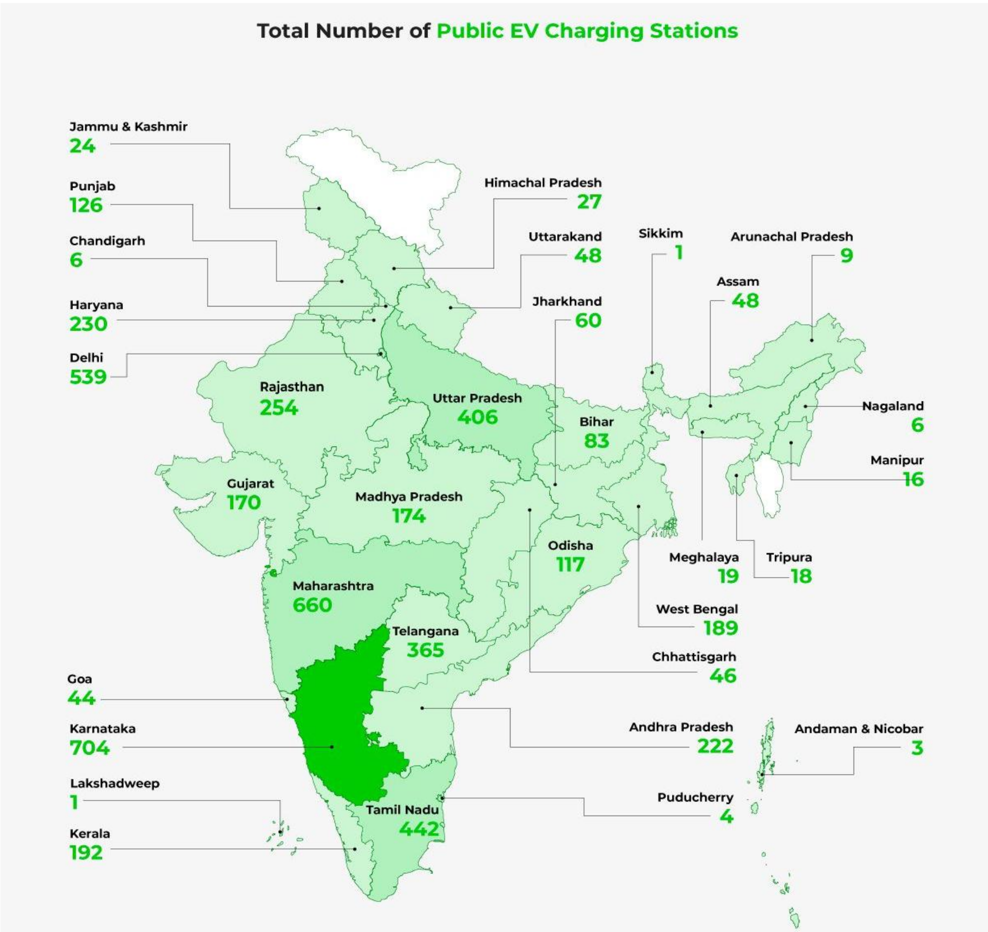
1.2 Objective of research

- Use GIS to analyze the transportation infrastructure, population density, and EV distribution. Use GIS analysis for the identification of the optimal locations for laying charging stations for EVs.

Figure 1: Total No. of Public EV Charging Stations in India (Bharadwaj, 2023)



- Studying the EV facilities of Pune.
- Promote the adoption of EVs to minimize carbon footprints.
- Explore the technical components of the EV infrastructure.
- Guarantee economic viability in accordance with government policies.
- Recommend the preferable locations based on a variety of parameters.

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2.0 Systematic Literature Review

This review is a systematic study on charging infrastructure planning for the electric vehicle (EV), focusing on its optimization with Tools in GIS. This study was developed and reported under the adherence to the PRISMA-P standards. This systematic review brings together research across diverse fields around EV charging infrastructure, GIS-based spatial analysis & Correlation & Regression Analysis. The papers considered are from 2015 until December 2023. A thorough search for additional studies from the gray literature, which included conference papers, research reports and thesis, expert opinions and relevant journals, was conducted. Two complementary methods were employed: retrospective method: review of citation lists of included articles, and search through Google Scholar. Studies were eliminated for the following reasons: a) while having a focus on EV infrastructure, there were no methodologies on GIS or spatial analysis b) in the planning of charging infrastructure, there was neither consideration for accessibility, user preferences, nor environmental impact; or c) if it is book chapters, systematic reviews, scoping reviews, or letters to the editor, then it was not available for full-text access. There exists no language restriction; however, due to accessibility issues, non-English articles were also precluded.

A literature survey was conducted by using various up-to-date electronic bases to find suitable studies from 2015 to December 2023. The main databases used for the literature search were Scopus, IEEE Xplore, ScienceDirect, Web of Science (WOS), and Google Scholar. Other search terms included "electric vehicle charging," "EV infrastructure planning,'' ''GIS for charging stations," AND ''multi-criteria decision-making for EVs.'' Some new MeSH terms, information from notable experts, and articles related to the actual topic of study were used as well. The syntax study involved three main components: First was "electric vehicle'' OR ''EV adoption'' OR ''EV charging infrastructure" OR "EV stations placement" OR "EV charging site selection." The second one was GIS OR ''geographic information system,''spatial analysis,'' ''multi-criteria decision-making," OR simply MCDM. The third was ''charging station optimization," "EV range anxiety," "charging infrastructure accessibility," OR ''land-use suitability analysis."

The research team out of NICMAR conducted an all-around intensive search using key terms across a number of databases, including Scopus, IEEE Xplore, ScienceDirect, Web of Science, and Google Scholar. Titles and abstracts were reviewed for relevance, after identifying articles. Then two reviewers analyzed the full texts of the remaining articles according to pre-established inclusion and exclusion criteria. Disagreement was resolved by authors' consensus; thus, no articles were eliminated due to lack of consensus. Initially, from 80 articles found, 65 survived after removal of duplicates, with 50 falling too far away from the subject of study to be included. The full text of the remaining 15 articles was reviewed and included in the final analysis, thus ensuring that a solid reference base was created for the study.

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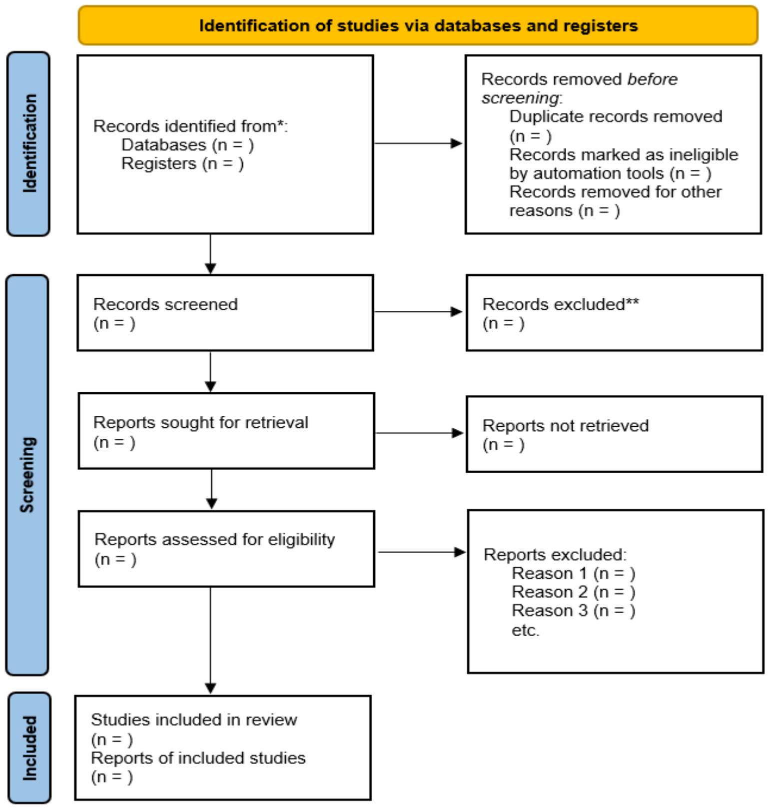
3.0 Methodology

Figure 2: Literature methodology



3.1 Questionnaire survey

A structured survey of users and non-users of electric vehicles in Pune collected feedback regarding favorable charging locality, duration of session, costing, complete infrastructure problems. Online and offline surveys were taken, field visits were set to Baner and Hinjewadi, and interviews were conducted with urban planners to collect the data.

3.2 Correlation and regression analysis

This method looks into factors affecting EV charging demand in Pune based on correlation analysis to evaluate associations between various important variables, for instance, EV density versus charging demand, while regression analysis will be within the ambit of predicting future demand using historical survey data, existing station data, and GIS-based traffic reports.

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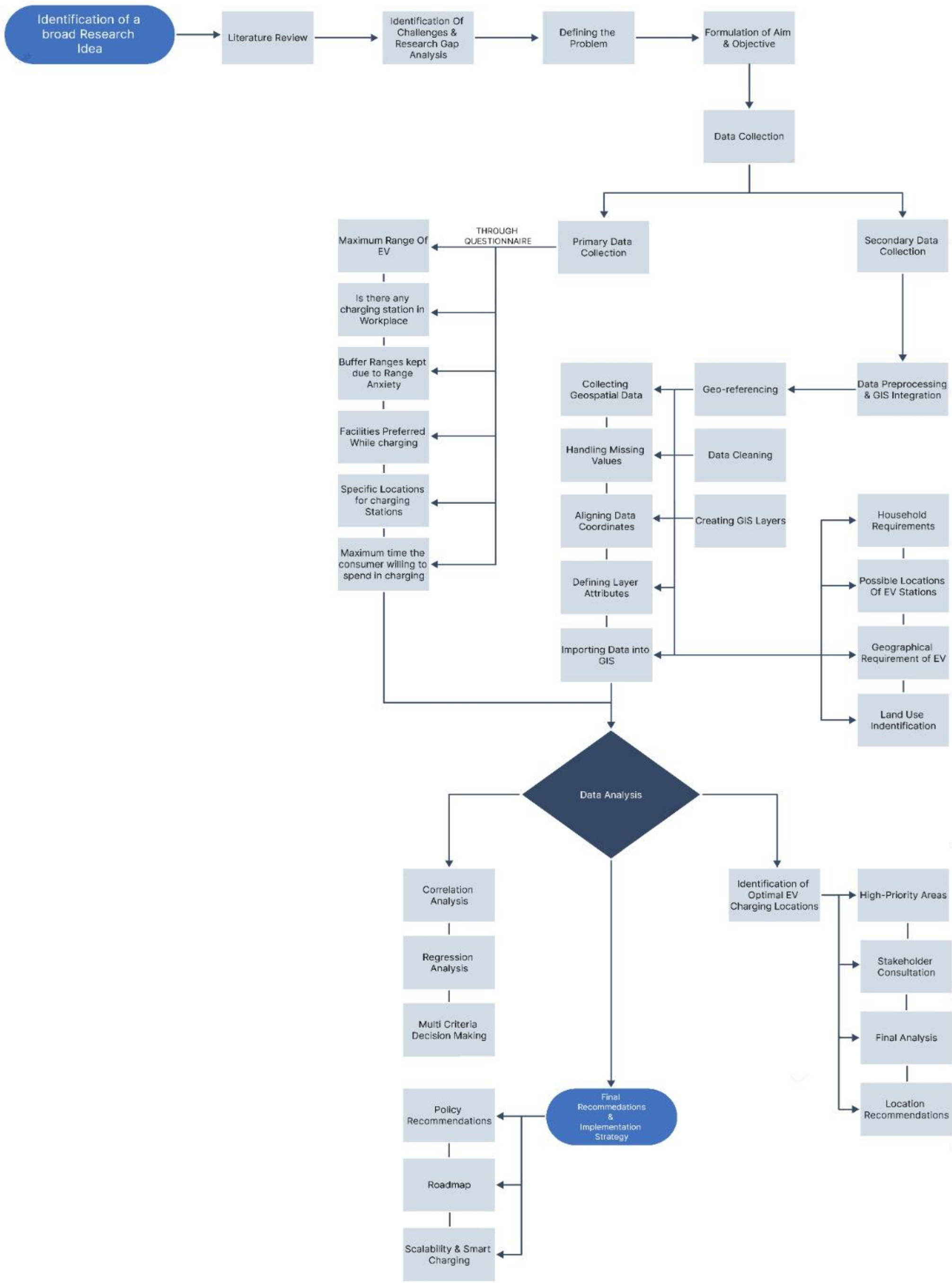
Figure 3: Research methodology



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3.3 Geograghic information system analysis

In this study, GIS tools overlay spatial data to visualize and systematically select charging station sites for electric vehicles by mapping road networks, population densities, and commercial zones. This proximity analysis helps calculate the distances between these potential sites and other important areas, which guarantees that the EV charging stations are all within easy reach for their users.

4.0 Data Collection

4.1 Sampling method

The systematic sampling technique was employed to guarantee reliable data for regression and correlation analysis. A standard formula involving population size, margin of error, z-score, and confidence level was used for the calculation of the sample size. Based on census data and an estimated growth rate, the population of the 20-50 age group in Balewadi and Hinjewadi was anticipated for 2025, thus leading to a predicted sample of 350 respondents.

Sample Size = $z^2\ X\ p\ (1-p)/e^2\ /1+\left(\frac{z^2 X\ p(1-p)}{e^{2N}}\right)$

According to the 2011 Census, the population of Balewadi & Hinjewadi was 31,972 & 23,995 of which 3,995 were in the age group 0-6 years. As my study is on EV vehicle usage, I have to take into account only the age group 20-60 years, excluding younger age groups. So, in 2011, an estimated 13,666 & 11,400 people were in the 20-50 age group. Assuming an annual growth rate of 1.5% to 2.5%, we can estimate the population in 2025

Using the formula: Pt = P0 × (1+r) ^t

Where: P0=13,666 & 11,400 (population in 2011)

r = growth rate (1.5% to 2.5% per year)

t = 14 years (2025 - 2011)

Estimated Population in 2025

With a 1.5% growth rate → 14000 & 13000 people

With a 2.5% growth rate → 16000 & 15500 people

By averaging the 1.5% and 2.5% growth rates, the estimated sample size for both areas turns out to be around 350.

4.2 Questionnaire survey

A total of 400 responses were analyzed in the survey study (taking into consideration the aim of 350), which were collected online and offline in Balewadi and Hinjewadi, which are major business and IT hubs. The survey focused on respondents who were either professionals or self-employed and investigated demographic variables along with charging habits and expectations of infrastructure for the placement of an EV charging station. A pilot study (50 responses) was conducted to revise the sampling for accuracy.

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These questions were designed to measure the following:

EV Ownership	Whether respondents owned an electric vehicle (Yes/No).
Maximum Range of EV	Different range options were provided to understand vehicle capabilities.
Charging Station Usage	How frequently respondents used charging stations.
Range Anxiety:	Whether respondents experienced concerns about their vehicle running out of charge before reaching a charging station.
Preferred Charging Infrastructure Location	Where respondents would like charging stations to be placed (e.g., residential areas, commercial hubs, highways, workplaces, etc.).
Additional Facilities at Charging Stations	Preferences for amenities such as WiFi, co-working spaces, cafes, rest areas, or other conveniences that could enhance user experience.
Willingness to Spend on Charging	How much respondents were willing to pay for charging services.
Availability of Nearby Charging Facilities	Whether respondents had access to any existing recharging facilities in their vicinity.

5.0 Data Analysis

5.1 Questionnaire analysis

Ownership of electric vehicles: 55.06% (223 respondents) own an EV, while 44.94% (182 respondents) do not, thus indicating room for market expansion. Driving an electric car should be based on charging preferences: 65.47% of EV drivers prefer home charging, thus highlighting the lack of public charging stations in the country. Travel distance to a charging station: 73 of the respondents have chance to travel 5-10 km more to reach it, with 57 respondents wanting charging stations within a much shorter distance due to a fear of range anxiety. The EV range: Most people drive between 100 km-200 km on a daily basis while long-range EVs seldom appear due to high battery costs coupled with high charging convenience constraints. Preferred charging speed: 73% wish for a charging duration of 30 minutes or shorter, which fuels the needs for fast-charging technology. Infrastructure changes: Majority, that is, 89.24% of them said they find it difficult to access charging stations, except for only 0.9% of EV drivers who said they never face such issues. The drivers follow the next factor which influences charging station choice: Proximity (151), speed (191) to charge, and cost are the most considerable reasons taken into account for an electric car to recharge. Amenities that people demand the most include restrooms (148), wi-fi-enabled work pods (145), cafes/restaurants (137), and waiting lounges (178). The most abundant charging stations could be located on parking lots (176), malls (98), highways (162) and some residential areas (149). The speed of charging is a major factor here: one of the significant worries owing to range anxiety is that only 73% of the respondents would wish for a charging duration within 35 minutes at the maximum, dropping to 62% at a limit of 45 minutes. Barriers to the adoption of EVs: High up-front cost (102), lack of after-care support (43) and inadequate charging stations (24).

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5.2 Correlation and regression analysis

- *Sub Model 1.1: How often do you use public charging vs how much do you currently pay*
  R2 = 0.166: The cost per kWh only explains 16.6% of the variance in the frequency of charging in public stations.
  Improvement in RMSE: 1.370 → 1.255: Very slightly more accurate.
  The model was highly significant (F-statistic=29.125; a probability below 0.001).
  Coefficient=0.495: For every unit increase in cost per kWh, the use of public charging increases by 0.495 units.

Summarizing, the logic links higher prices to locking the public charging point. It could be ambitious demand areas that are short on private charging points and are therefore generally convenient. Aside from this, charging behavior is also influenced by a number of other factors.

- *Sub Model 1.2: Public Charging Usage vs. Near Office Spaces, Speed of Charging and Price Paid per kWh*
  R^2 = 0.301: 30.1% of public charging frequency variation is explained by charging near offices, speed, and price per kWh.
  F-statistics = 10.118, $p < 0.001$: Model is highly significant.

Key findings:

Charging near offices (0.535, p = 0.008): Significant positive impact—closer workplace charging increases public charging usage.
Speed of charging (0.260, p = 0.331): No significant effect.
Price per kWh: Certain price points (e.g., 3 & 4**)** increase public charging use, while others do not.

Conclusion: Workplace charging boosts public charging reliance, cost matters more than speed, and pricing strategies should be optimized to encourage EV adoption. Expanding workplace charging infrastructure could improve usage patterns.

Sub Model 1.3: Maximum Time Willing to Spend at a Charging Station vs. Price Currently Paying per kWh.

A low R2 value of 0.088 shows that an estimated 8.8% of the variation in waiting time is accounted for by price per kWh, thus implying a weak relationship. The F-statistic for the model of 14.153 is not less than the 0.001 significance threshold, signifying that in a statistical sense, the model is quite significant, though price isn't such a strong predictor. Key takeaways: A coefficient of 0.194 at an alpha of 0.001 indicates that, ceteris paribus, with increases in price per kWh, the waiting time increases by a slight amount, although this amount is very small. There is a very slight improvement in RMSE at values of 0.708 and 0.739, respectively. Conclusion: Price per kWh really does hold only a small leverage factor in determining how long the users will wait, though one would guess that much stronger influences may be speed, convenience, or necessity.

Sub Model 2.1: Proximity vs Restrooms: The results further indicate that restroom availability is an important predictor of how people value a location with an 17.8% variance

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accounted for in the roster. The significance of a positive coefficient is that people will go for options closer to such amenity provision for selecting sites for public infrastructure. This model performs significantly ($p < .001$), which means with high confidence that restroom availability is one of the strong transitory determinants for preference regarding closeness, implying that users will consider restroom convenience in deciding the locations for charging stations, public facilities, and transit stops.

Sub Model 2.2: Restrooms vs Willingness to pay: The association between the willingness to pay extra for the availability of restrooms in charging stations is quite weak, with the willingness to pay accounting for 7.5% of the variance in restroom availability. R^2 is used to show that the slight adjustments to quite a big portion of what is unexplained could be accounted for by which the linear regression function was adjusted, as in comparison: Excellent=0.7-0.9; Good=0.4-0.69; Fair=0.19-0.39; and Poor=0.1-0.19. A sort of contrasting explanation would include the meaning that the ANOVA under R^2 explains the total variability in the response data around the mean.

Sub Model 2.3: Wifi Working pods vs Time to spend in charging stations: The linear regression model has been developed to understand the relationship between Wi-Fi working pods and the time to spend in charging stations by fitting a linear equation to the observed data. Information from an A NOVA table summarizes in the following way: R^{2} Interpretation of the table states 8.0%: The model demonstrates 8 percent of the variability in terms of how much time people would spend at a charging station, given the fact that they were interested in Wi-Fi-enabled work pods. It affirms the conclusion that while these pods have some effect, it is not very notable regarding the period of stay at a charging station. Adjusted $R^{2}= 0.074$: The lower adjusted R^{2} indicates that while work Wi-Fi-enabled pods contribute something toward the model, they are not good predictors of time spent. RMSE 0.711 vs 0.739: F-statistic: 12.686,p\' <0.001→ indicates model significance, dening their association as non-random between wait time at a charging station and Wi-Fi-enabled work pods. The very low R^{2} suggests that many other factors could explain variance in time spent waiting at a charging station. Intercept=1.625 will be the maximum time users will wait at the charging station in cases when Wi-Fi-enabled working pods do not exist by default. Coefficient of Wi-Fi Enabled Working Pods=0.429: A positive correlation could be seen, as maximum waiting time to charge increased with increasing interest in working pods.

Analysis for non-EV users:

Sample: 172 respondents, including users and non-users.

Key Insights:

The majority of respondents do not know much about EVs.

Charging station availability is a great concern that harbors EV adoption.

A vast majority of respondents think that the better charging infrastructure would encourage future EV purchases.

Key findings: While the level of awareness regarding electric vehicles among the 79%

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driving 120-150 km a week is encouraging, it is not a match for those that support it. Most of them drive an EV with a range of 250-400 km. Electric vehicles have a lower running cost, low service cost (less number of parts), no oil change, little brake wear, etc. Lower carbon dioxide emissions and a decrease in reliance on fossil fuels when renewables charge them. This means that the existing electric vehicles are capable of meeting daily travel needs, but better accessibility to charging facilities will ensure higher levels of adoption.

5.3 GIS integration analysis

5.3.1 Data gathering

Relevant data pertaining to EV sites for currently operational charging stations are included in the datasets collected, which were easily integrated with the already in existent fuel stations, petrol pump locations, thus making available existing charging stations mapping the existing network. Facilities include proximity to parking, office, commercialization hubs, and residential areas.

5.3.2 Techniques that analyze GIS

Overlay Analysis: This analyzes the land use, traffic movement, existence of stations, and amenities with different layers. It prioritizes areas that have a heavy population of commercial hub areas and very busy areas. The result of this analysis will give major areas of the first wave deployment for EV stations.

Proximity Analysis: Normative distances include the categories of residing and commercially centered by train tracks or highways or malls, offices, and parking. This directly informs the infrastructure placement to enrich the experience of end users.

Scoring system for site selection: The candidate site will be ranked as: Proximity to Major Roads (easy access earns higher scores). Traffic Density (high traffic areas get priority). Land Use Suitability (influenced by zoning regulations). Amenities nearby (shops, banks, and public transport). Electric Grid Strength (stability of power supplied). Safety & Security (well-lit, staff presence in areas). Distance from Existing Stations to Each Other (to make sure coverage is maximized). The final stage of analysis selects location with high scores as optimum sites for the deployment of EV stations.

5.3.3 Findings of great importance

Commercial spaces, IT parks, malls, and public pay parking are the most promising areas. Stations are conveniently placed near highways and centers of cities. Distribution of charging stations therefore is even, thereby reducing range anxiety among electric vehicle users in Pune. Summary of considerations inherent in the shortlisted final sites vary among factors such as traffic density, population density, existence of charging facilities, petrol pumps, and occupational sites.

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- Uniform coverage throughout Pune means fewer gaps.
- After thorough Spatial and Non-Spatial Analysis we found out probable EV locations where various factors were concluded like traffic, population density of EV vehicle in that area, existing EV station, petrol pumps & working spaces.
- Green rectangles: Probable location for EV station.
- Red recangles: Existing EV stations.

Figure 4: Probable EV Station Location in Hinjewadi Phase III

Source: Compiled by author

Figure 5: Probable EV Station Location & Existing EV Stations in Hinjewadi Phase II

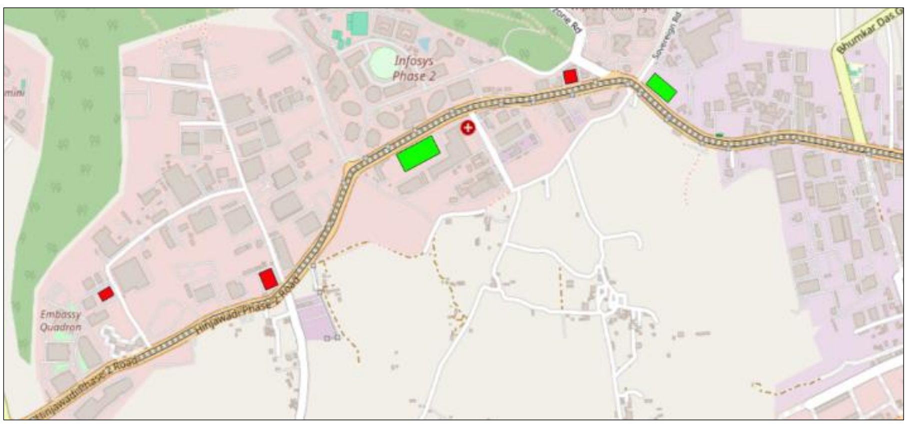

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Figure 6: Existing HPCL Petrol Pump in Hinjewadi Phase II

Source: Compiled by author

Figure 7: Existing BPCL Petrol Pump in Pimple Nilakh

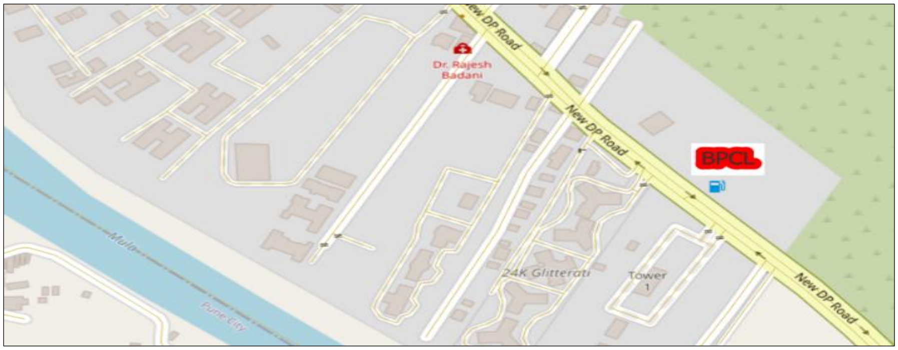

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Figure 8: Probable EV Location & Existing HPCL Petrol Pump & EV Station in Hinjewadi Phase II

Source: Compiled by author

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Figure 9: Existing MNGL Gas Station in Balewadi

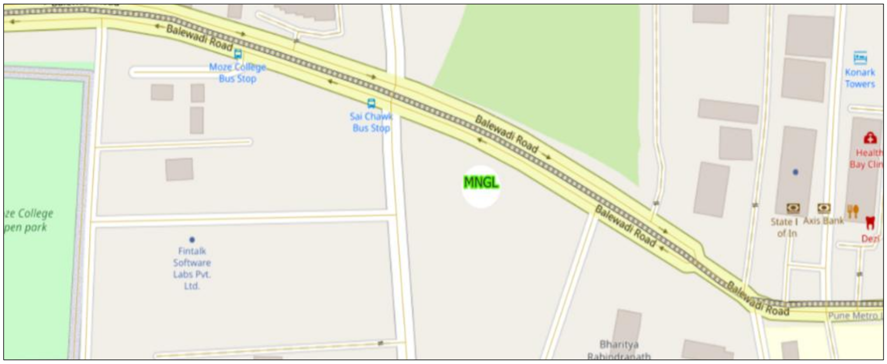

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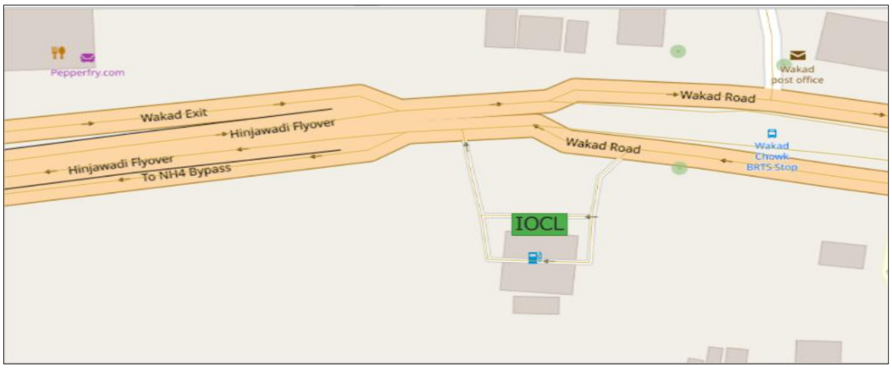
Figure 10: Existing IOCL Petrol Pump in Wakad



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6.0 Results

The present work falls within a GIS study intended for identifying for electrification the best sites for Balewadi and Hinjewadi of Pune in India. It will facilitate the efforts of Tata and other interested parties to strategically site their own stations in accord with the pressing needs of the present user. The study also leans toward brimming with high-traffic sites, that is, commercial complexes, residential buildings, and major thoroughfares so as to make access quite easy and minimize range anxiety for the EV users. Survey statistics show that the majority of users preferred charging points located in the vicinity of workplaces and commercial districts, thus providing for integration into their infrastructural everyday driving patterns. In addition to that, the study suggests factors responsible for user experience at charging stops. Suggestions from the participants include:

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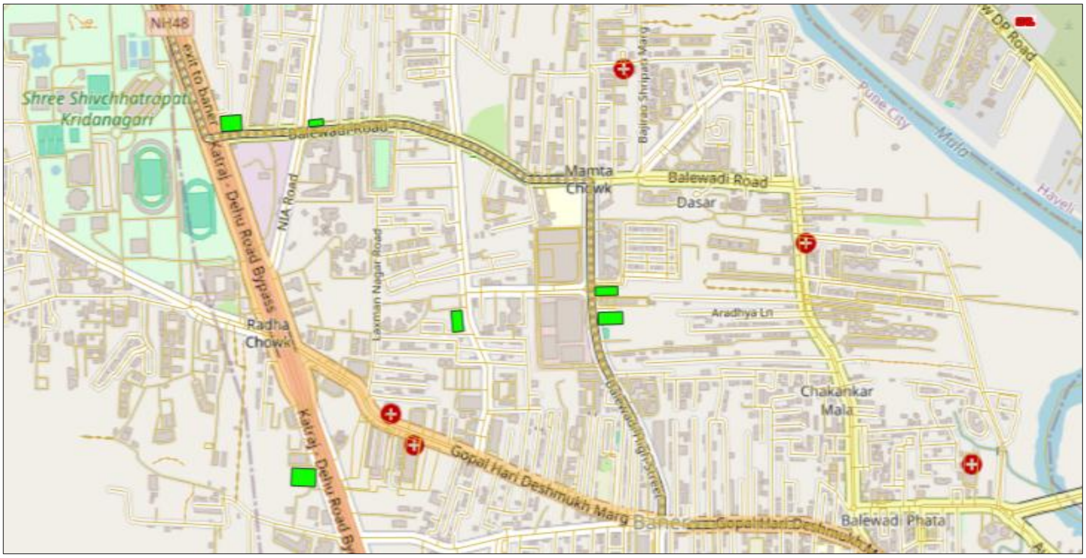
- Toilets: Essential for comfort while waiting for charging.
- Wi-fi-enabled work pods: Allowing users to productively spend their time while waiting.
- Cafeteria or outlets for quick food: Beneficial to users during long charging hours.
- Waiting lounge: Providing space for users while their vehicles are charging.

Figure 11: Probable EV Station Location in Balewadi



Source: Compiled by author

From the regression and correlation analysis, it appears clear that there exists a strong preference amongst the majority of users for spending more time in the charging stations if such facilities are available. The cost per unit and rate of charge being also important factors for the public charging activity further emphasize the need for strategic locations with proper facilities.

7.0 Conclusion

The analysis suggests that Balewadi and Hinjewadi are ideal sites for the establishment of electric vehicle (EV) charging stations. This information could further benefit businesses like Tata and other established companies regarding maximizing the installation of charging stations in high demand and user-demand areas. Then, station operators could enhance user convenience and encourage EV uptake through other incentives like restrooms, including workstations with Wi-Fi connection, and eating areas. Infrastructure provision in these zones thus requires urgent policymaker attention incentives and regulatory support. Public private partnerships can speed restrictions that should be eased for the changeover to electric mobility by accelerating

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infrastructure development efforts. Advances that continue in battery chemistry combined with good charging speed and compatibility for renewable energy source charging will also emerge as important differencers in optimizing the long-term productivity from EV charging stations.

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