Comparative Analysis of Route and Health Care Facilities for the Emergency Patients of Pune and Bengaluru

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Abstract

A comparative analysis of timely medical admission for emergency patients in two mega cities of India, Bengaluru and Pune has been analyzed using geo informatics based open-source tools. The road network has been initially classified as primary, secondary, tertiary and service categories. These categories have been merged into a single layer for homogeneous routes for the cities. To visualize the effect of traffic congestion the TomTom traffic data was downloaded as GeoJSON file, later converted into geo-package (GPKG). The traffic file was joined to the non-traffic merged file to assign the congestion index to the segments. Both traffic integrated and free-flow isochrones were created for 5, 10 and 15 minutes. Service area and population coverage under these isochrones were evaluated after converting isochrones into concave hull. The grid network and redundancy of Bengaluru reflects a resilient sponge with efficient elimination of penalty (nominal 1.34 %) for population coverage in 15 minutes using the available detours. Due to the dendritic road network of Pune, compensation in congestion is significantly low and impact remains high (demographic penalty of 5.14%) leaving a large population vulnerable for emergencies even after 15 minutes. The road redundancy of Bengaluru is capable of largely absorbing congestion, on contrary, the morphological constraints pose a challenge for Pune leading to vulnerability in emergency medical access support.

1. Introduction

Due to large scale expansion of digitization program vast terrain of India has witnessed a transformative change in the service delivery system. Despite similarity in multiple features, variations in topology and social profile of different regions can be manifested as unique for an area. The solutions developed for one region can be compared for similarities and differences with other regions for bridging the gap between availability and the requirements. The embedded feature of public policy is now effectively utilizing the Open-source software for developing a support system for resolving the issues such as connectivity, emergency care and disaster management and service delivery, (fossunited.org/public-policy). One of the key indicators of urban planning is rapid admission of critical/ emergency patients at an equipped health care facility. For public policy the requirement of the use of intelligent ambulance technology has been discussed in literature (Pulsiri et al., 2019) The limitation is normally posed due to poor road networks, topographic challenges, constraints on approach road and traffic congestion. As a case study, two rapidly growing mega cities of India, Pune (in Maharashtra) and Bengaluru (the capital city of Karnataka) has been selected for a comparative analysis of infrastructure pertaining to the emergency health care facility for the patient admission. Among the South-Asian metropolitans, the two mega cities of India have undergone rapid urbanizing through the state of art infrastructural changes. Other than finance, the aspirational society of India is now accounting the resource support, traffic congestion (time lost in intracity travel), pollutant status (AQI), institutional support system, and ease of access at health care facility and multi / super-specialty hospitals. Bengaluru and Pune are ranked #1 (66.70) and # 2 (66.27) in terms of the Ease of Living Index (EOLI) as per the data provided by the Government of India, Bengaluru is ranked #1 (66.70) followed by Pune (66.27). The congestion index provided by TomTom has ranked both these cities as #1 and #5 in the world and #1 and #2 in India (tomtom.com/traffic-index/ranking/).

Several dynamic and static variables can be linked to the congestion in the traffic conditions. The rush hours at school and office, weekends, outside/tourist vehicle influx, inhibition due to breakdown of vehicles, route diversion, maintenance and repair can be considered as a dynamic variable. Conditions that can vary on a timescale but are unable to change the dynamic traffic flow, notably number of nodes, population density, number of lanes, access (one-way or two way), road width, bus-lanes, rail-crossings can be considered as static factors.

Although developing a decision support system (DSS) for the admission of emergency/ critical patient is highly required, challenges posed due to the underlying uncertainties may underscore the outcome of the decision. Mostly such uncertainty incorporates a lack of information or limited information about the access route, road network or traffic congestion in the vicinity of the emergency care facilities. The present paper provides a comparative picture for the two cities (Pune and Bengaluru) with respect to the network performance, spatial saturation and the derivations of equity implications from the modeling. Also, the availability of time-distance dependent service areas for the emergency and critical care patients at the nearby hospitals that can effectively attend a specified emergency forms part of the manuscript. For calculation of the coverage both static and dynamic factors reflected as traffic bottlenecks like congestion index, population and road density, urban topology and traffic components are discussed in the paper. The investigation has been enabled to understand the role of morphology and road network design on mobility, congestion, and resilience in mega cities like Bengaluru and Pune.

2. Methodology

2.1 Study Area

The two cities, Bengaluru and Pune, are known as major IT hub in India. The urban population residing in these cities have comparable financial status (per capita income). In recent years they have witnessed rapid growth in infrastructure like road network, health care facilities, educational institution and communication system.

Bengaluru (12.97° N, 77.59° E) is located on a flat Deccan Plateau of India. Geographically the scope of expansion of the city is quite high due to the absence of major obstacles like perennial rivers or mountains. The underlying conducive morphology has been supportive to build a radial and grid-like road network. As such, road network of the city manifests a "sponge" like structure, with large number of interconnected streets. Also, the city has a very high road density of 23.00 km/km² and a large road network of about 16,310 km.

Pune (18.52° N, 73.85° E), located in the west central region of Maharashtra, altogether at a different geographical setting. The terrain is on the foothills of Sahyadri mountain range acting as a barrier for expansion. Mula and Mutha rivers divides the city. The outskirt towards northwestern Pune's urban area is a crossway for other rivers Pavana and Indrayani (Sivakumar V, 2014). The barrier of natural formation is reflected in splitting habitation of the city. The divisions form separate zones with forced roads to cross at specific points like bridges and mountain passes. The distinguished features can be seen as "collapsing tree-like" road network with limited connections. The city has somewhat lower road density of 14.37 km/km², highly dependent on limited main roads and bridges, mostly restrictive as major congestion points during peak hours.

2.2 System

2.2.1 Hardware: The computations were performed using PC with Intel® Core™ i3-10110U processor running at 2.5 GHz and 16 GB of memory and a workstation running on Ubuntu 24.04 OS with dual Intel Xeon processors (20-cores each), 132 GB DDR4 RAM, and NVIDIA GPU (11 GB GDDR4).

2.2.2 Software: QGIS Version 3.44 Solothurn is used for the spatial processing, visualization, and network analyses (QGIS Development Team, 2026). Also, compatible machine with Windows 11 OS, Mac Mini M4 (macOS Tahoe 26.2) and Ubuntu 24.04 have been used for running the programs and MS Office 2019 for catering other requirements pertaining to the manuscript.

2.3 Data Sources

The data has been taken from multiple sources like Open Street Maps (OSM), Government websites. Along with this, various other sources have been utilized, providing the data at no-cost for academic research. The information regarding various data sources are outlined in subsequent sections.

2.3.1 Road Network: Using the QuickOSM plugin in QGIS, the road network was derived using the Quick query function. The dataset included primary, secondary, tertiary, and residential road classes later merged into a single layer. This has enabled us to provide a realistic representation of the potential travel paths for the ambulance.

In the study, the estimated travel time is the period covered during the travel on network-based routable road segments from the nearest location of the emergency to the hospitals. Due to the unavailability of data, some portion of the actual travel path such as initial position of patient, building entrance, small passages, pedestrian path or local lane could not be included for modelling.

2.3.2 Healthcare Facility: For both cities, location data for the Hospitals were derived using the Quick Query feature in the QuickOSM plugin. After repeated verifications from accredited agencies, a total of sixty-two (62) and fifty-five (55) hospitals capable of catering an emergency has been selected from Bengaluru metro and Pune. Later, these cities were treated as centroids for modelling.

From the available list on open platforms, after manual verifications, the government and private hospitals with critical care and trauma-handling infrastructure (capability of handling an emergency) have been included for modelling. Further qualitative classification (tiers) of the hospitals could not be done due to the inconsistency in the availability of standardized data.

2.3.3 Administrative Boundary: For both, Bengaluru and Pune the administrative boundary layers has been taken from the Municipal Spatial Data repository maintained by datameet [github.com/datameet/Municipal_Spatial_Data]. These downloaded files, originally in GeoJSON format, were converted to GeoPackage (GPKG) for efficient processing within the GIS platform. Accurate spatial referencing has been ensured using official municipal boundary layers. This has prevented the inclusion of peripheral rural areas outside the earmarked urban jurisdictions, thereby providing a consistent spatial framework for comparative analysis (Figure 1).

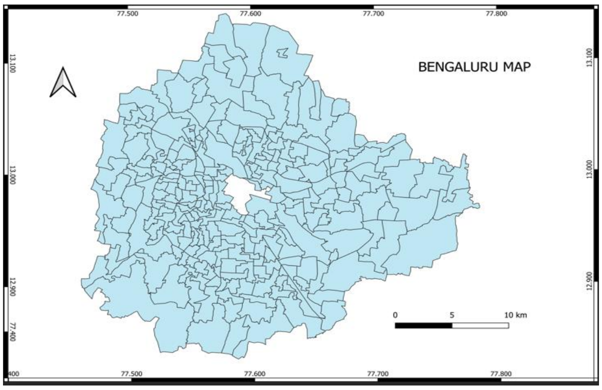

Figure 1. Administrative map of Bengaluru City

Also, the Pune City shapefile was significantly smaller as compared to Bengaluru shapefile (710 sq km.), which could have resulted in an unfair comparison. Thus, to maintain equity, some regions of the nearby city of Pimpri-Chinchwad were manually incorporated into the Pune City shapefile, resulting in an area of 742 sq km., much comparable to Bengaluru shapefile. The area integration ensured the continuity between the incorporated portion of Pimpri region with the erstwhile Pune boundary (Figure 2).

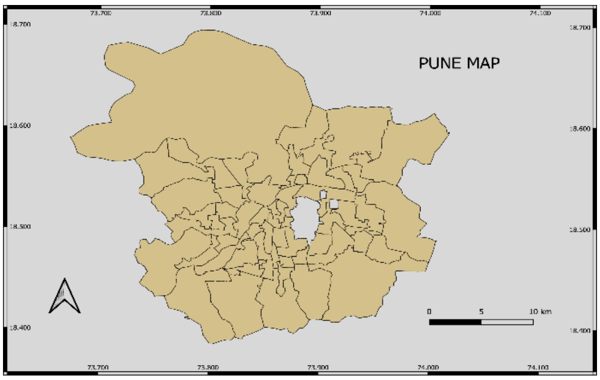

Figure 2. Administrative map of Pune City

This contribution has been peer-reviewed.
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2.3.4 Demography: The demographic data of Global Human Settlement Layer (GHSL) has been used for calculating the percent population coverage within hospital service areas isochrones. The gridded population estimates are provided, which is, derived from satellite imagery and census integration (European Union, 2025).

2.3.5 Traffic Integration: The TomTom traffic index for both the cities were utilized to retrieve the historical traffic data for the month of August 2024. The raw datasets with key traffic attributes like the **congestion index** and several related indicators have been downloaded in GeoJSON format, nested within the file structure. For subsequent processing, each GeoJSON file was converted into a GPKG file. This has enabled the road-segment geometries to directly store the relevant traffic attributes.

Traffic-weighted GPKG and the baseline non-traffic road network was integrated using **Join Attributes by Nearest** tool of QGIS. Ten (**10 m) meters maximum snapping distance has been** applied for a rigid allocation of traffic attributes. This has prevented the congestion index of a major arterial road from being incorrectly assigned to a nearby residential or service road. Such a selection of snapping distance could act as a safeguard for the heterogeneous and dense Bengaluru Road network.

Both non-traffic and the traffic-integrated network have been projected into **UTM Zone 43N (EPSG:32643)** providing a meter-level accuracy in all distance-based operations. The projection confirmed that the congestion indices are snapped precisely to their nearest road segments. A transformation of the static road network into a **historical traffic-congestion-weighted routing network** is quite effective for emergency response modelling.

The joining operation generated overlapping or duplicate geometries. The resulting integrated GPKG has been cleaned using the **Delete Duplicate Geometries** tool of QGIS. A high-resolution, non-redundant network, suitable for conservative and reliable emergency-routing analysis has been produced. Notably, the total network length of the joined layer overlapped with the original non-traffic network for both cities. This was confirmation of the consistency and integrity of the spatial join. The final validation provided a generated length of **16,310.59** and **10,662.29 km for Bengaluru and Pune respectively**.

2.3.6 Normal Time Isochrones and Traffic Integrated Isochrones: For modelling the emergency response network, native QGIS tools has been used. The OSM dataset could not provide a complete road attribute for one-way movement. In view of this, at least for a short duration or limited distance operational flexibility can be taken for the movement of emergency vehicles. This flexibility has been utilized for network continuity for accessibility modelling at a city-scale. Although such assumptions can lead to an overestimation in an area with restrictions in one-way movement or a physical barrier that cannot be surpassed. In the absence of an alternative approach such a presumption has been made despite limitations.

For reliably accounting the traffic, instead on some hidden algorithms of mapping APIs, the travel times were calculated using a precise, deterministic formula:

$$Dynamic\_Speed = \frac{Normal\_Speed}{(1+Congestion\_Index)} \quad (1)$$

Ordinary circles or fixed distances like 1 or 5 km had not been used, mainly because they may not be able to represent the driving on a busy road. In view of this the travel time has been used to map out "isochrones",.They reprsent the selected areas a person can actually reach within a specific period (number in minutes).

Both Traffic Congestion and Free-Flow based Time Isochrones were plotted to understand the effect of Traffic Congestion in the studied cities.The model derived from the August, 2024 data, estimates Dynamic Travel Time (Td). This has been worked out using the TomTom Congestion Index (Ci) via looking at road length and co-world traffic levels.

The dynamic and normal time can be derived using the equation 2 and equation 3 provided as-

$$\text{Dynamic\_Time} = (\text{Normal\_Time}) * (1 + \text{Congestion\_Index}) \quad (2)$$

$$\text{Normal\_Time} = \frac{\text{Length\_of\_Road\_Segment}}{\text{Normal\_Speed}} \quad (3)$$

The term Normal_Speed is dependent on the road characteristics. The distribution of the road categories are given in Table 1. The maximum distances reachable in **5, 10, and 15 minutes** has been mapped after linking the hospitals to the nearest roads.

For visual comparison of alternative hull outputs in QGIS, the concave hull parameter was set at alpha = 0.01. This selection of alpha value resulted in substantial neutralization of overgeneralization as compared to a convex hull. Further, the road-network-based service area of the continuous representation could still be retained. To minimize the unrealistic coverage resulting hulls were visually checked against the road network, lakes, open lands, and the restricted areas.

Road Category (OSM Highway Tag)	Normal Speed (km/h)
Motorway Link	40
Trunk Link	35
Secondary	35
Primary Link	30
Secondary Link	25
Tertiary	25
Residential	20
Tertiary Link	20
Service	15
Motorway	60
Trunk	55
Primary	45

Table 1: Baseline Free-Flow Speeds by Road Hierarchy

- **5 Minute Isochrones**: For the most critical emergencies where every minute counts.
- **10 Minute Isochrones**: Considering normal road constraints this period is reasonable standard target for emergency response.
- **15 Minute Isochrones:** For accomodating heavy traffic condition with natural ability to slow down the movement.They can be considered as the realistic reach of hospitals in a crowded city.

On main arterial roads and highways, witnessing high vehicle density, TomTom's traffic data provides a reliable measurement of congestion index. Although, most of the OpenStreetMap (OSM) network consists of low occupancy streets of residential areas, proximal roads, and dead ends, posing limitations on the output of the congestion values. Streets without an adequate TomTom observation have been assigned a congestion delay of **Ci = 0.** Under such conditions, the functionality of the model to operate at their nominal free-flow speeds could be maintained. Presumption can replicate the real emergency response characteristics. On primary corridors service vehicle (ambulances) can face inordinate delays but minimal structural congestion disturbances can be observed once they enter neighborhood-level street grids. Taking the congestion penalties at zero for minor streets, the model can avoid redundant inflating "last-mile" travel times. This can reliably identify the city's arterial network as the true bottleneck, limiting the 15-minute emergency reachability route.

Once the travel-time surfaces have been computed, **Voronoi polygons** were generated to delineate hospital catchment zones, providing the assessment of spatial dominance in the cities. Lastly, population overlays were applied to estimate the number of residents served as the overall coverage of the entire area.

3. Results and Discussion

Administrative boundaries of the cities were taken as spatial boundary and the shapefile. The road networks, healthcare facilities, and population datasets has been clipped for retaining the spatial consistency. A geospatial network analysis approach (Nicoară & Haidu, 2014) was adopted for modelling emergency ambulance routing. As an initial step, road networks earmarking primary, secondary, tertiary and residential roads were loaded using Quick query tool of inbuilt QuickOSM plugin. All four categories have been merged into a single layer referred as "merged layer". A continuous routing over both the cities has thus been ensured. The final selection of medical centres, both government and private, were taken as centroids across the city. Manual verification of the multi-speciality hospitals has also been done to align with the objectives of the study. During verification it was observed that some of the centres, presumably a medical centre with emergency handling capabilities, is lacking necessary resource support for patients during medical emergency, critical care and traumatic injuries. GIS based network analysis provides information about spatial patterns in emergency healthcare accessibility across the cities. Combining the road network with spatial distribution of hospitals, highlighted marked variability in accessibility levels between central and peripheral zones of the cities.

As far as the Voronoi polygons are concerned both cities (Bengaluru and Pune) show a distinct pattern. Although regional variations exist, Bengaluru has comparatively uniform distribution of emergency care infrastructure. In the central, southern, and western regions polygon geometries manifest highly compact catchments and dense concentration of hospitals. This feature enables residents in these core areas to travel minimal baseline distance. Further, the Voronoi catchments become significantly large towards extreme edges (peripheral areas) in eastern and northern regions. Despite a gradual transition in urban health care infrastructure of Bengaluru the features provide a balanced condition as compared to Pune. On contrary, Voronoi polygon of Pune exhibits a higher concentration of small catchments (highly skewed rigid clustering) in western central areas. The catchments towards southern region are extremely large, an underservice distress condition of emergency support. Also, other peripheral catchment areas such as northern sectors are large, exhibiting notable vulnerability. The outskirts of Bengaluru have irregular shapes with some urban patches (Ramchandran et al., 2015). The striking feature of contrasting pattern is reflected as spatial inequality of Pune as compared to Bengaluru with highest gap only at the outskirts.

3.1 Route and Network Accessibility

Unlike the distribution of emergency health care infrastructure, the roads network distribution of Bengaluru and Pune have marked similarity. Both have high dominance of residential and service roads. For the distribution pattern, road networks were classified into defined functional categories. The classified road category and their length in respective segments is provided in Table 2. As depicted in the accompanying pie charts (Figure 3 and 4), these two primary categories account for most of the overall network, comprising approximately 90% of the roads segment for each city. In transitional and specialized segments, such as link roads and motorways, constitute a negligible fraction of the infrastructure, making up barely 1% of the total network. Bengaluru can be visualized to have a spongey network structure. The worked-out road length of Bengaluru (16,310 km) is almost 1.5-times more than that of Pune (10,662 km). Bengaluru with a high road density 22.97 km/km^2 is providing multiple route options for the ambulance, an ease in access during emergency through alternative routes in case of blocks / jam on roads. Although the situation of slow mobility cannot be avoided due to the intermittent disturbances such as intersections, turns, stoppage and localized issues. Unlike Bengaluru, Pune has a Tree-like structure with lower road density of 14.36 km/km^2. The city mostly depends on the main arterial road facilitating fast movement on regular days. In case of blockage or other disturbance for access network can adversely affect the emergency response. Despite superiority of Bengaluru over Pune in terms of road layout, coverage and accessibility, the health care inequalities make new age additions as part of urban planning.

From optimal-route computation of primary and secondary road networks it is evident that the proximity and quality road connectivity for hospitals in South-central Bengaluru are supportive of emergency services. Also, it is inferred that the service providers can take advantage of shorter travel distances and various alternative routes. Similarly, the western-central region of Pune exhibits superior connectivity for the road network providing supportive conditions for emergency services. The peripheral regions of Bengaluru (outskirt) and southern region of Pune exhibit a longer network distance to the nearest major hospitals. The selective route redundancy in this area is vulnerable to pathway obstruction due to traffic congestion. Also, the northern region of both cities is lacking in the road network connectivity and the health care facilities. The access of healthcare is linked to the healthcare inequality, the lower level of access is associated with more significant levels of inequality (Jayaprakash, P et. al. 2024).

3.2 Traffic Integrated and Free-Flow Isochrone Coverage

Traffic and non-traffic service area isochrones were created for modelling different emergency response scenarios and the effect of traffic congestion therein. The analysis was done for the thresholds of 5.0, 10.0, and 15.0 min. Representative Figure of 5 minutes service area is provided in Figure 7 to 10. Lastly, desired coverage areas and population covered were worked out through converting the service areas into appropriate Concave Hulls.

Road category	Number of Road Segments in Bengaluru	Number of Road Segments in Pune
Residential	92400	42344
Service	22976	27361
Tertiary	5218	2697
Secondary	2923	1927
Primary	2072	1225
Trunk	941	1104
Primary link	342	197
Trunk link	276	207
Secondary link	210	13
Motorway	188	97
Tertiary link	139	90
Motorway link	81	4

Table 2: Road segment count among various categories for Bengaluru and Pune

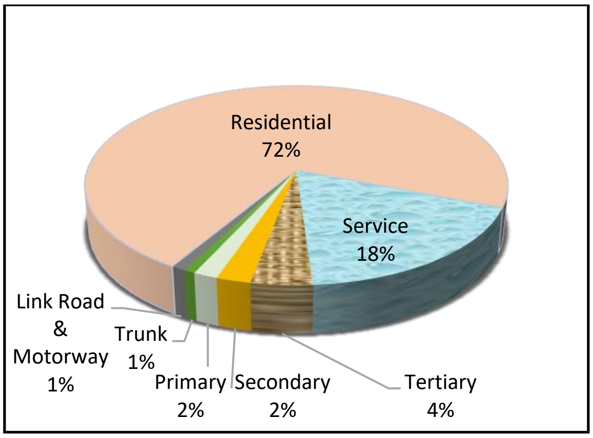

Figure 3. Pie Chart showing Road Category and Percentage of Road in each category for Bengaluru

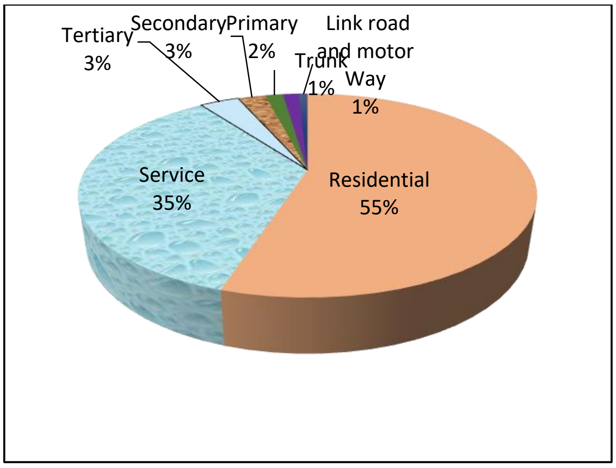

Figure 4. Pie Chart showing Road Category and Percentage of Road in each category for Pune

The statistical analysis for the Area and population percentage coverage has been carried out using PyGIS which was run on Google Colab (Jupyter Notebook) by uploading the requisite files and the final coverage analysis is provided in Figure 5 and 6.

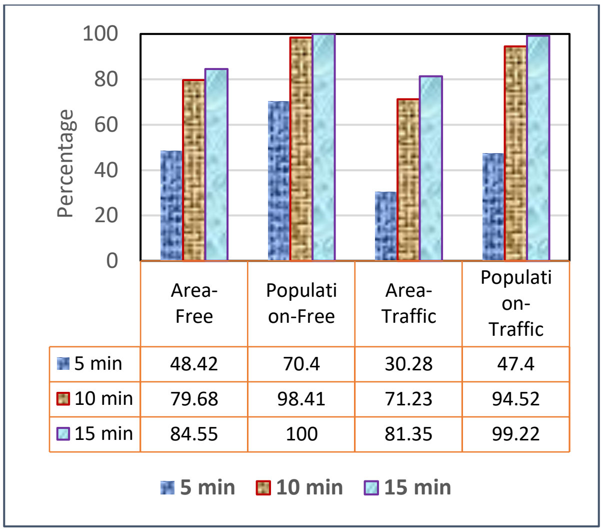

Figure 5. Comparison of area and population coverage in Bengaluru under free flow and traffic conditions

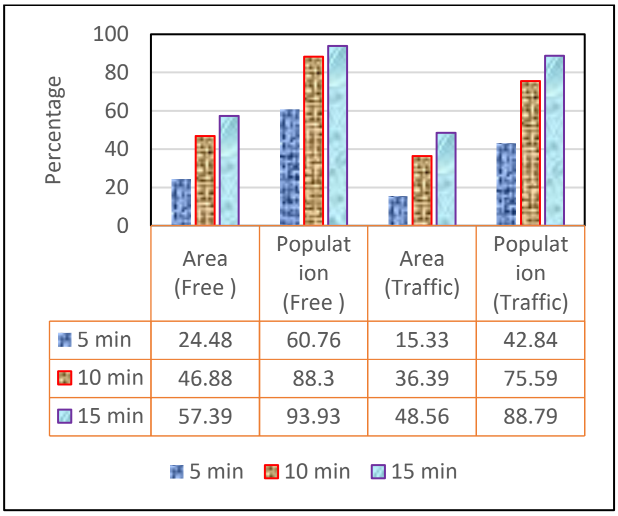

Figure 6. Comparison of area and population coverage in Pune under free flow and traffic conditions

The area and population coverage of the two cities during free flow and traffic conditions are provided in Figure 5 and 6. The area coverage for Pune in 5, 10 and 15 minutes duration under either condition is substantially lower as compared to Bengaluru. Under traffic conditions the area coverage for Pune in 5 and 10 minutes is almost 50 % of that for the Bengaluru city. Though attrition is also evident in population coverage relative change is less prominent in Pune. In 10 to 15 minutes maximum population of Bengaluru can be covered, whereas large population of Pune remain uncovered for emergency support even after 15 minutes (Figure 5 and 6).

For a reliable evaluation of the impact of urban congestion on emergency response times, the total time lost has been computed using equation (iii) for extensive **16,310.59-kilometer** of Bengaluru and **10,662.19-kilometer** of Pune’s Road network.

$$\Delta T = \mathrm{Dynamic}_{\mathrm{Time}} - \mathrm{Normal}_{\mathrm{Time}} \qquad (4)$$

In present model, the **Dynamic Time** represents a travel duration under peak-hour traffic conditions. while the **Normal Time** serves as the free-flow baseline, The dynamic time utilizes the worst-case congestion penalties for bidirectional segments.

Estimated parameters for the traffic indices are provided in Table 3. It has been worked out that the total time lost in Pune due to traffic congestion is more than 35 hours (143.63 hours for Pune and 108.05 hours for Bengaluru's) as compared to Bengaluru. This is also reflected in the delayed period in Pune. The city is experiencing almost double the average delay per kilometer, 48.6 sec/km for Pune as compared to 24 sec/km for Bengaluru, resulting in a higher city-wide penalty of 26.15%, which is roughly two times more than that of Bengaluru's 13.51%. The observations highlighted the role of network density and total length in deciding the accessibility in case of emergency. Bengaluru has an edge over Pune in this respect, offering better alternative routes, capable of mitigating the challenges posed due to constrained network at Pune.

Parameter	Bengaluru	Pune
Total Network Length (km)	16,310.59	10,662.19
Area of Shapefile (sq. km)	710	742
Total Time Lost (h)	108.05	143.63
Average Delay (sec/km)	24	48.6
City-Wide Penalty	13.51 %	26.15 %
Road Density (km/sq. km)	22.9726	14.369

Table 3: Estimated parameter (value) for traffic indices of Bengaluru and Pune

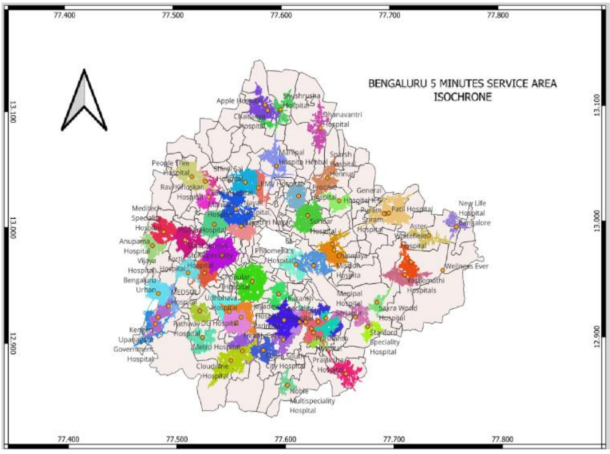

Figure 7. 5 Minute Service Area Isochrone of Bengaluru

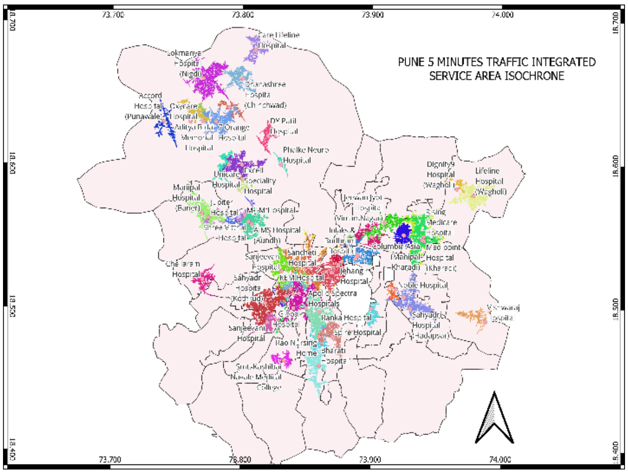

Figure 8. 5 Minute Service Area Isochrone of Pune

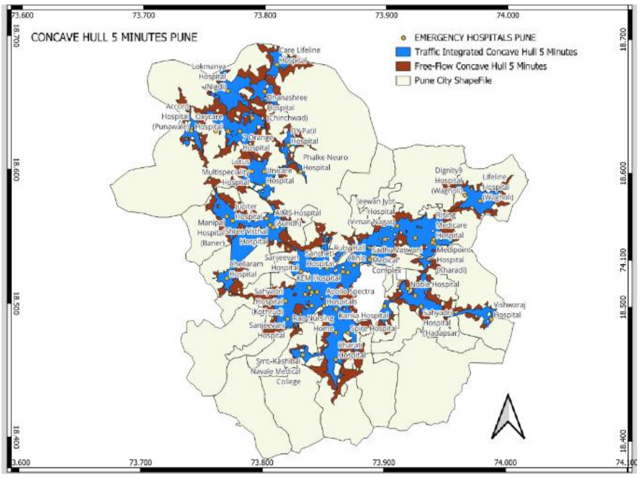

Figure 9. 5 Minute Concave Hull of Pune

3.3 Hospital Catchment and Spatial Dominance

From the Voronoi Polygons it is observed that the Bengaluru city (Fig 8) is virtually separated into different areas that are served through the associated hospitals in case of emergency. Again, as mentioned earlier, the hospitals have smaller catchment areas in the South-Central region of the city. The strong coverage can provide an alternative option for the population residing in this area. The peripheral region of Bengaluru, exhibit shortage of medical infrastructure for catering the emergency. Contrary to Bengaluru the Voronoi Polygons (Fig 9) of Pune the catchment zone towards western central region is quite high as compared to the southern region, mostly lacking the required infrastructure.

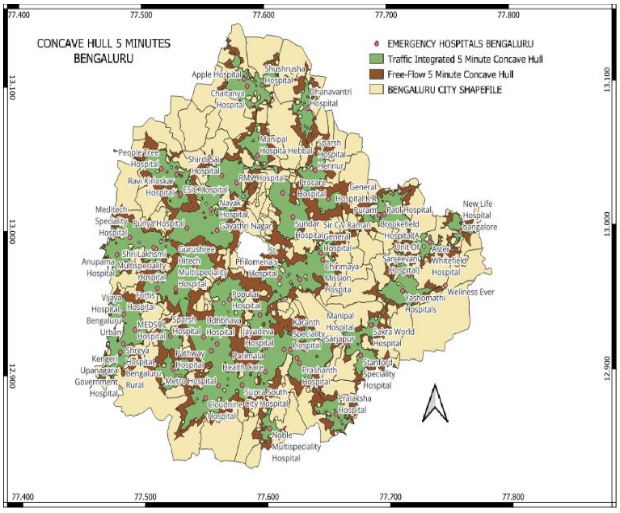

Figure 10. 5 Minute Concave Hull of Bengaluru

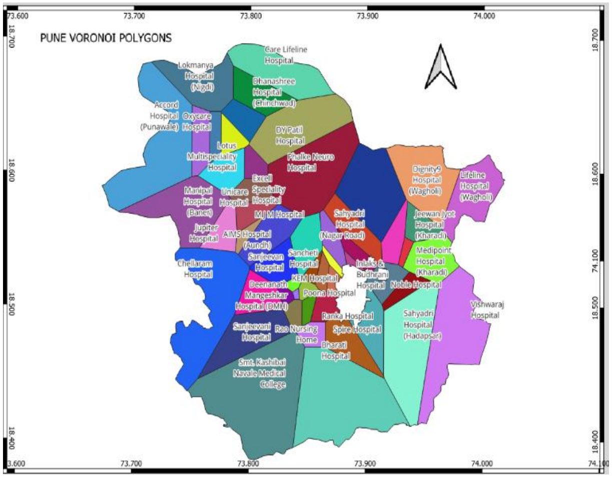

Figure 11. Voronoi Polygons Analysis of Pune

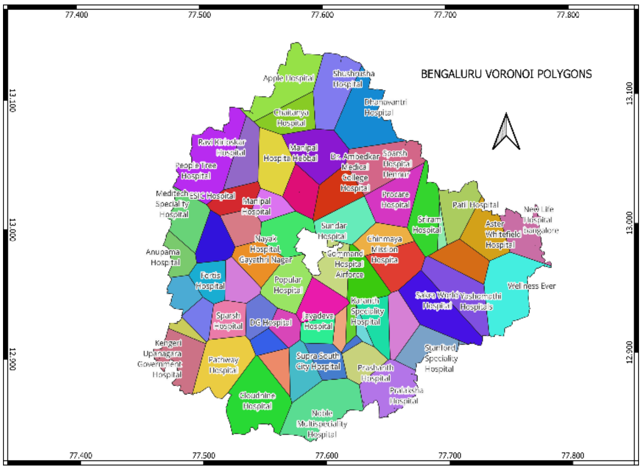

Figure 12. Voronoi Polygon Analysis of Bengaluru

4. Conclusions

The road network connectivity integrated with traffic congestion ascertained that Bengaluru has an edge over Pune for providing early emergency patient admission at a specialized hospital. The edge is partly attributed to the spongey road network structure of Bengaluru, resolving the accessibility issue through multiple routes. Due to high road density and number of hospitals, south central Bengaluru is offering a favorable condition for emergency admission of patients. Unlike Bengaluru, Pune has a tree-like road network structure having limited access potential for the arterial road. The hospital distribution in Pune is skewed with higher density in western central portion of Pune. Pune is experiencing roughly twice the average delay per kilometer, resulting in a city-wide penalty of 26.15% and 13.51% for Bengaluru and Pune.

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