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DEVELOPMENT OF A GIS-BASED COMPOSITE PUBLIC TRANSPORT ACCESSIBILITY INDEX

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Abstract: The increasing interest in sustainable modes of transport such as public transport has triggered the need for evaluation of accessibility to and from the transit service. Accessibility to the transit service determines the service attractiveness and hence better accessibility increases the demand. Although accessibility has been the focus of research in the past few decades, it still remains a concept that has been poorly defined and hence finding a theoretically good and operationally sound measure of accessibility is a challenging task. The objective of this paper is to develop a composite public transport accessibility index using Geographic Information System (GIS) as a case study of an Indian city, Trivandrum. This concept is a spatio-temporal GIS-based public transport accessibility model which includes travel modes of walking and bus transit, travel impedance and service coverage of the transit network. The methodology used in the study is based on the factor that the index should measure the accessibility which comes from proximity to bus stops and land use destinations and the proportion of the population served.

Keywords: Accessibility; public transport; Geographic Information System; bus transit

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INTRODUCTION

The rapid urbanization and motorization in India have triggered the transport crisis in Indian cities, characterized by congestion, air pollution, noise, greenhouse gas emission, accidents, injuries, fatalities and mobility problems. The exponential growth of private vehicles and slow-paced infrastructure development has further aggravated the transport crisis. The sustainable transportation system is expected to tackle the transport related problems and to meet the mobility requirement of people at affordable prices. Public transport is the key component of the sustainable transportation system (Albacete *et al.*, 2017) which can provide a systematic mobility option and reduce the transport related externalities. However, provision of public transport will not accomplish the expected effect until the public transport system is accessible and connected to the rest of the urban system (Tuan & Son, 2015). Among the different modes of public transportation, buses are the most preferred mode in India due to the wide presence of road network and hence ease of accessibility. Thus the demand for bus transit is largely dependent on the accessibility to the transit service.

Accessibility is the measure of ease of access to and from the transit services. Some researchers explain accessibility "to" a place while few others suggest accessibility "from" a point and few researchers explain accessibility in composite terms i.e., "to" and "from" a place. Quite a few authors have explored walk assess to transit as a measure of accessibility (Woldeamanuel & Kent, 2015) while others explain deficiencies in transport infrastructure in evaluating accessibility (Lantseva & Ivanov, 2016). Micro-accessibility and macro-accessibility were studied by van Eggermond *et al.* (2016) to investigate the role of the built environment and accessibility on vehicle ownership. Salonen & Toivonen (2013) modelled travel time to analyze the accessibility disparity between travel modes of the car and public transport. Cheng & Chen (2015) studied perceived accessibility, mobility, and connectivity of public transportation systems. For decades, accessibility has been the focus of research as it is one of the most important factors to be considered in sustainable public transportation. However, it still remains a concept that has been poorly defined and hence finding a theoretically good and operationally sound measure of accessibility is a challenging task. Historically, transport planning organizations have considered that transport problems and solutions can be determined and treated without considering the non-transport aspect of urban life. But, this perception has changed when the focus shifted from "moving vehicles" to "moving persons" (Morris *et al.*, 1979). This has led to a comprehensive modelling of travel demand, integrating spatial-land use-travel patterns for transport and urban planning.

The objectives of this paper are:

(a) To develop a composite public transport accessibility index, and
(b) To examine the accessibility levels of Trivandrum city based on the developed method.

The paper is structured as follows. Section 2 reviews the theory of accessibility and various accessibility measures. Section 3 briefly describes the study area followed by section 4 describing the methodology involved in the determination of accessibility index as a case study. Section 5 summarizes the main results and discussion and section 6 point out the concluding remarks.

CONCEPTS OF ACCESSIBILITY

The concept of accessibility can be perceived as a measure of spatial separation of human activities, i.e., it can be defined as the ease with which activities can be reached from a location using a particular transportation system (Morris *et al.*, 1979). Accessibility is defined in several ways and hence has different meanings. The well-known definitions include "accessibility is defined as the potential of opportunities for interaction" (Huang *et al.*, 2009). Accessibility accounts for land use patterns and hence the application of accessibility indicator include evaluation of transport and land use (Bhat *et al.*, 2000b), transport policy decision making, choice modelling and evaluation of spatial structure (Morris *et al.*, 1979). Accessibility was broadly classified into two by Ingram (1971): "relative accessibility" and "integral accessibility". Relative accessibility refers to the degree to which two places are connected while integral accessibility for a given point is defined as the degree of interconnection with all other points (Ingram, 1971). In reality, accessibility indicators constitute a wide family of measures which are modified according to the researcher's perspective and objectives. The literature suggests determining accessibility as a measure "to" a point, "from" a point or composite accessibility measure; each measure having its own advantages and limitations. Gulyas & Kovacs (2016) utilized accessibility for the evaluation of transport connectivity. Focusing on passenger movement through public transport, we define accessibility as the ease with which passengers can reach and find a public transport and arrive at the destination of interest.

Components of Accessibility

A number of components of accessibility can be identified from the various accessibility measures. Four main components which are required for measuring the accessibility are spatial component, temporal component, transportation component and personal component (Balya *et al.*, 2016; Geurs & van Wee, 2005; Morris *et al.*, 1979). Depending on the study area, factors affecting accessibility must also be considered for finding the accessibility measure.

(a) The spatial component determines the spatial distribution of opportunities and its quantity in each destination, the activities of the individuals, i.e., the demand for these opportunities and supply of the opportunities in the zone of individuals (i.e., origin zone).
(b) The temporal component determines how long the individual participates in an activity (work, school, shopping) and the availability of each opportunity during each time of day.
(c) Transportation component, also known as impedance component refers to the disutility of the transportation system. It includes the walking time to the station, waiting time at the station, the cost of travel, travel time, comfort and safety factors.
(d) The personal component is the requirement of each category of people. The needs depend on the age, education, physical conditions, economic, social and cultural aspects of the individuals.

For an accessibility measure to be ideal, it must take into consideration all the four components. But in practical situations, the accessibility measure takes into account one or more components depending on the study area, objective, and perspective of the study. This study focuses on the development of a GIS based composite public transport accessibility index which comes from proximity to bus stops and land use destinations and the proportion of population served.

Measures of Accessibility

The accessibility measures defined diversely determines the connection between land use and transport. Based on the review by Bhat *et al.* (2000a), accessibility measures are classified into: (a) Spatial separation measure, (b) cumulative opportunity measure, (c) Gravity measure, (d) Logsum or utility measure and (e) Time and space models. The spatial separation method is the simplest accessibility measure as the distance is the only variable considered. Cumulative opportunities measure takes account of both distance and purpose of the trip. According to Bhat *et al.* (2000a), “this measure defines a travel time or distance threshold and uses the number of potential activities within that threshold as the accessibility for that spatial unit”. Gravity measure uses both attraction and separation factor, i.e., it discusses an attractive force and the impedance of intervening space. Another approach is based on the perceived utility of traveler and is known as utility measure. In time-space models, both spatial and temporal accessibility are determined based on spatio-temporal constraints. Bhat *et al.* (2000b) has reviewed the micro-scale and macro-scale factors for inclusion in ideal accessibility measure and examined various impedance attributes, destination attributes, and traveler’s attributes. Also, Bhat *et al.* (2002) assessed various alternative accessibility measures and proposed the aggregation of various accessibility measures over purpose, time of day, mode and space.

The potential opportunities measure was used by Hansen (1959) for developing a gravity type accessibility model in which accessibility being proportional to the size of activities in the zone and inversely to the travel time or distance. Vieira & Haddad (2012) extended the Hansen's model of gravity formulation to measure accessibility to jobs in the Metropolitan Region of Sao Paulo. The opportunities considered were the number of jobs in each zone and impedance as an inverse exponential function of travel time between each pair of zones. Kalaanidhi & Gunasekaran (2013) used a composite impedance gravity measure to incorporate the effects of in-vehicle travel time, off-vehicle travel time, the stops and cost of parking in determining the accessibility. Accessibility to transit service was studied by Yatskiv *et al.* (2017) considering the travel distance and connectivity between the city and destinations.

On the other hand, Ingram (1971) used average squared distance as the spatial separation having a modified Gaussian functional form to determine the integral accessibility. While Baxter and Lenzi (1975) proposed a method for determining the relative accessibility by considering a method to arrive at an accurate distance matrix for spatial separation by incorporating the geographical constraints. Allen et al. (1993) developed an accessibility index to calculate an area’s overall accessibility level based on the spatial separation method taking travel time as the separation measure. Using this index, the overall access levels of 60 U.S. metropolitan areas were calculated and compared.

Another approach to determine the accessibility is the logsum or utility-based measure. Sweet (1997) argued that centered logsum would be a more appropriate measure of accessibility. Bhat *et al.* (2005) developed a methodology having a logsum measure with a multinomial logit model to aggregate the accessibility measures over several dimensions of interest: time of day, mode, trip purpose, and space.

Kwan’s (1998) study indicated that space-time index and integral accessibility index are distinctive types of accessibility measures which reflect the different dimensions of accessibility of individuals. Bok and Kwon (2016) focused on both spatial and temporal dimensions of public transport in which spatial factor of accessibility is identified as the specific distance from each node of transit and temporal aspect is defined by the frequency of buses. Fotini (2017) examined the individual accessibility in space and time by incorporating spatial, temporal and travel data. This proposed composite accessibility measure relies on factors like individual activity space and temporal constraints.

GIS application to accessibility

In the recent years, GIS technology has flourished and various researchers have found interest in data analysis, interpretation, storing, manage and present the spatial data. Thus GIS has been applied to evaluate the accessibility and land use opportunities (Liu & Zhou, 2015; Wang & Chen, 2015; Wang *et al.*, 2014). Al Mamun and Lownes (2001) developed a composite index to measure the accessibility of public transit using a weighing factor. Three different methods were chosen to reflect the trip, spatial and temporal component of accessibility. Huang *et al.* (2009) developed a GIS-based accessibility modelling for estimating transit demand based on the walking distance to bus stops. Pitot *et al.* (2006) use a GIS-based methodology to quantify and map accessibility to various destinations by walking or public transport. The methodology discusses the land use and public transport accessibility index (LUPTAI) as a decision-making tool to optimize land use and transport integration. Saghapour *et al.* (2016) introduced a measure of accessibility by incorporating population density. The public transport network model was used in a GIS environment to identify the service coverage of public transport modes. Shah & Adhvaryu (2016) adapted the Public Transport Accessibility Level (PTAL) methodology developed by Transport for London (TfL) to the case study of Ahmedabad, India, taking into account average walk speed and time, distance to transit stops, and peak hour transit frequencies and GIS was used for mapping the PTAL. Spatial transit accessibility modelling was performed in GIS by Balya *et al.* (2016) for an Indian metropolitan city. GIS was used to develop accessibility catchments through the buffering process of various radius to identify accessibility thirst areas. Yan-Yan *et al.* (2016) suggested a concept of Area Public Transport Accessibility (APTA) in GIS environment based on passenger travel behaviour, travel psychology hypothesis and service range of transit and road network which provides quantitative information for location analysis and public transport optimization. Although researchers have developed accessibility index from various perspectives, there is still a need for integration of accurate determination of accessibility measure. This calls for the use of Geographic Information System (GIS) in determining the accessibility index as a graphical and descriptive measure of accessibility rather than quantitative one.

STUDY AREA

The study area is Trivandrum, the capital of Indian state Kerala and is an emerging metropolitan city in the southernmost part of India. As per Census 2011, Trivandrum Municipal Corporation has a population of 957730 with an average population density of 4454 persons/sq. km and an area of 214.86 km2, about 56% are for the residential purpose (Census, 2011). At present, the city has an estimated population of about 1.08 million considering a growth rate of 2.1% (Census 2011). The regional planning department has divided the study area into 100 Traffic Analysis Zones (TAZ) which is same as that of census tract and it is used as the local subdivision in this study. The land use data collected from Department of Town Planning indicate that land use for residential purpose is found to be 56%, followed by agricultural (22%), public and semi-public land use (13%) while the transportation area is 3%. Water bodies account for 3% and industrial and commercial area comprises 1% each. Using ArcGIS, a popular Geographic Information System (GIS) software package for mapping and analytics, the layout of the city demarcating the 100 TAZs used in the study was created as shown in **Fig. 1.**

METHODOLOGY

The availability of the data as the data-sharing tradition is absent and the accuracy and reliability of the available data are a serious issue in the case of most of the developing countries. Therefore, it is often challenging to study the land use-transportation scenario and measure the accessibility in developing countries by the researchers or academicians. Moreover, the data collection is a tedious, time and resource consuming process which hinders the study. In light of this, there is a need to develop an alternative methodology for examining the transport scenario and measure the accessibility using the available data. The proposed public transport accessibility index is a less data-intensive method incorporating the network-based distance to the bus stops, population, travel time and opportunities. The methodology used in the study is based on the factor that the index should measure the accessibility which comes from proximity to bus stops and land use destinations and the proportion of the population served. The accessibility index proposed in the study uses few basic calculations and fundamental commands of GIS. The methodology for acquiring and compiling the data are:

(a) Collecting the available maps of the study area like local subdivision map, existing land use map and road network map. The local subdivision may be the Traffic Analysis Zones (TAZ) used by the transportation planners or census tract.

(b) The creation of the geographic database (.kml file format) of the bus stops or fare stages and Points of Interests (POI) as per the need of the study in Google Earth platform. The POIs include educational institutions, administrative centers, commercial centers, hospitals, banks and places of worship.
(c) Collection of other secondary data like population and travel time.

Network Development

ArcGIS 10.4 was used to create the public transport network. Travel time was taken as the network impedance for the public transport network; the speed and delay data for which were obtained from National Transportation Planning and Research Centre (NATPAC), Trivandrum. NATPAC has carried out speed and delay study using moving car observer method on nearly 125 km of road stretch in Trivandrum city. The transit data, including bus stops, routes and schedules were collected from Kerala State Road Transport Corporation (KSRTC), which is the state road transport undertaking (SRTU) of Kerala. A walking speed of 1.2 m/s (IRC-93, 1985) was used to calculate the walking time. To calculate the walking distance, the city was divided into grids of 30m x 30m which is the approximate area per household. In GIS, the average distance from the centroids of the 30m x 30m grids within 500m search radius (Huang *et al.*, 2009) is calculated which gives the walking distance to bus stop. The 500m is considered to be the influence zone of transit stations (MOHUA, 2017) and hence it is taken as the walking distance to the bus stop. The network was constructed in view of both spatial and temporal aspects of accessibility. The spatial details include the bus stops and land use destinations to accurately capture the accessibility to and from the bus system. The temporal attribute of accessibility included in the study is the travel time impedance.

Access to Nearest Bus Stop

Access to the nearest bus stop is the service coverage of the stop and hence known as the stop access coverage. Access to bus stops measures the walking accessibility of the population. Usually, the spatial coverage or the walking accessibility is determined by using buffer analysis with a threshold radius around the bus stop. In this study, the walking accessibility is calculated, using the GIS buffering approach, as the proportion of the population within 500m buffer for each bus stop. A buffer area of fixed radius, i.e., 500 m, is firstly created around the bus stops in ArcGIS and then this area is overlaid over the transportation analysis zones and population data. The population served by bus service is calculated as the population having direct access to the public transit stops or network which is the population in the buffer area. The population in the buffer area is taken as the population served and the proportion of the population is calculated as the buffer population divided by the total population of the zones under the influence area of the buffer. **Fig. 2** shows the bus stops with 500m buffer overlaid on the population density map. It can be seen that only a portion of the urban area is covered in the 500m buffer. The area with low population density is devoid of public transport access.

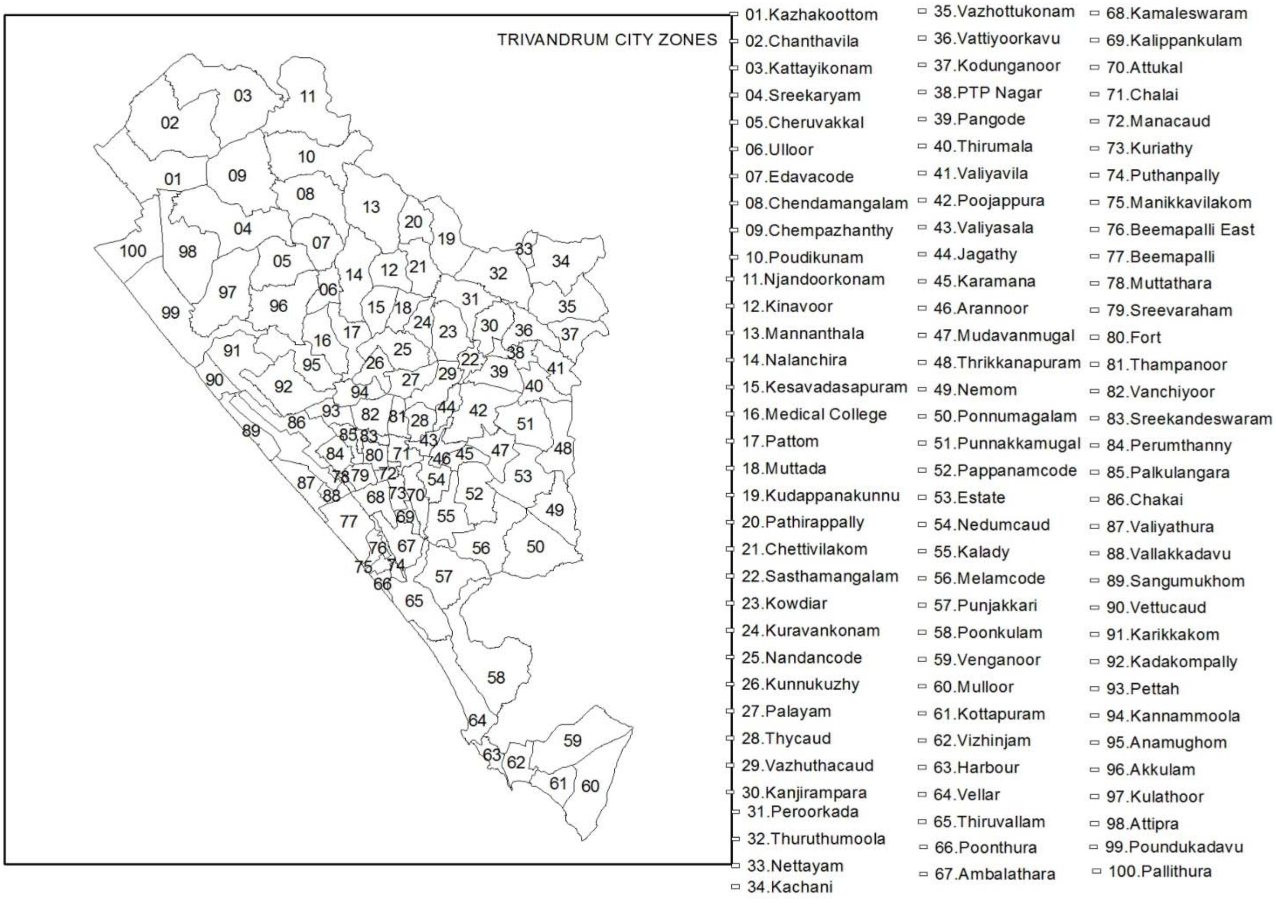

Fig. 1 Layout of Study Area.

Access from Bus Stops to Point of Interests (POIs)

This is a measure of service coverage from each bus stop that gives the area covered in a given time interval and the number of POIs accessible in these areas. Data for Point of Interests (alternatively known as land use destinations) were obtained from various readily available sources as these are the common daily destinations in the study area. The POIs include educational institutions, administrative centers, commercial centers, hospitals, banks and places of worship. **Fig. 3** shows the distribution of POIs in the city and it can be seen that POIs are concentrated in the central area of the city.

The POI shapefile is overlaid on the transportation analysis zones and the walking distance from the bus stop to nearest POI is calculated in ArcGIS. The service area for each time interval is created using Network Analyst Tool. The service area is created as ring polygons corresponding to the time intervals of 15, 30, 45 and 60 minutes respectively. The number of POIs that are accessible at each service time interval are obtained by the spatial joining of layers of polygons and the layer of POIs. **Fig. 4** shows the service area for a bus stop.

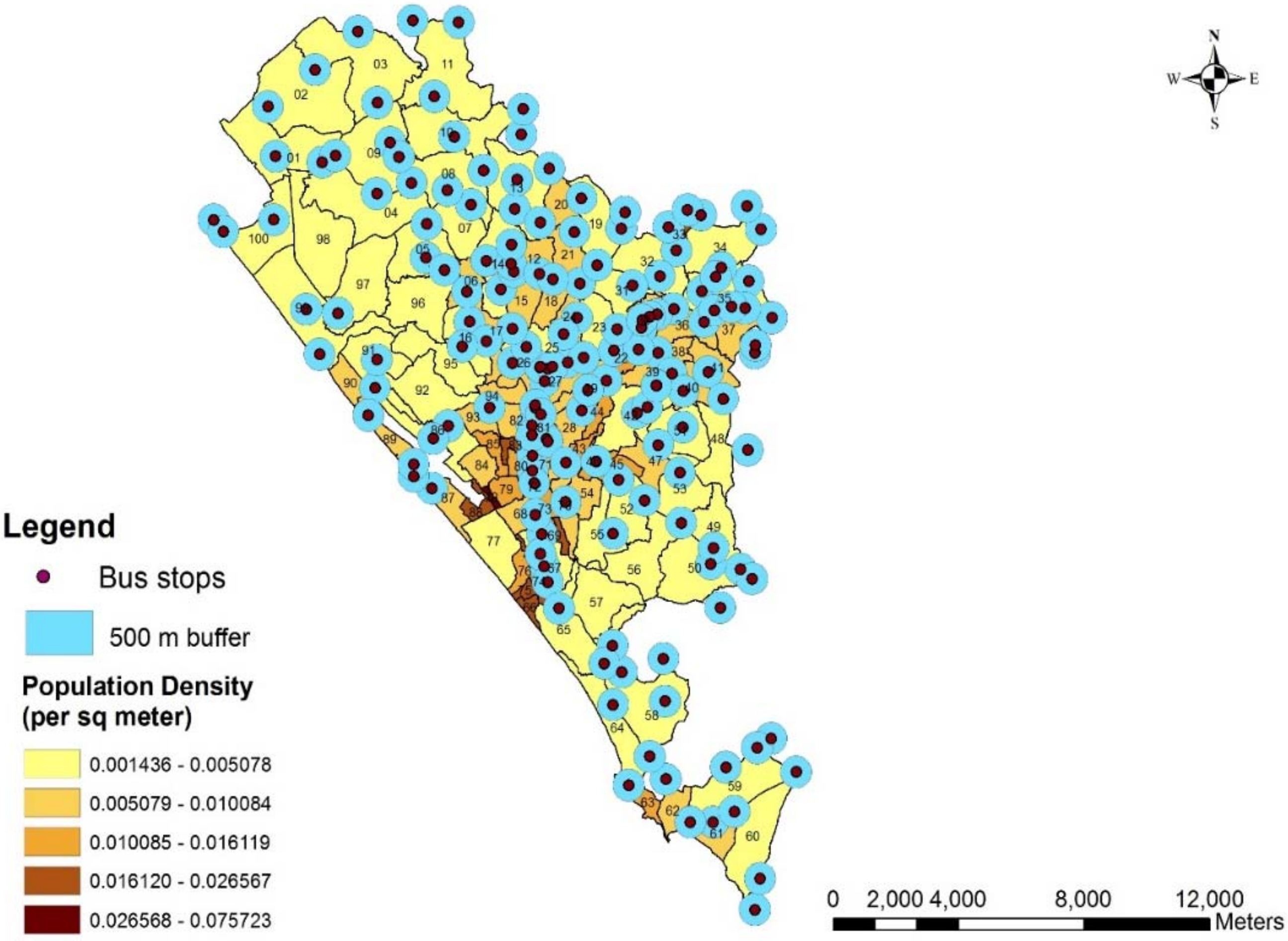

Fig. 2 Bus stops with 500m buffer overlaid on the population density map.

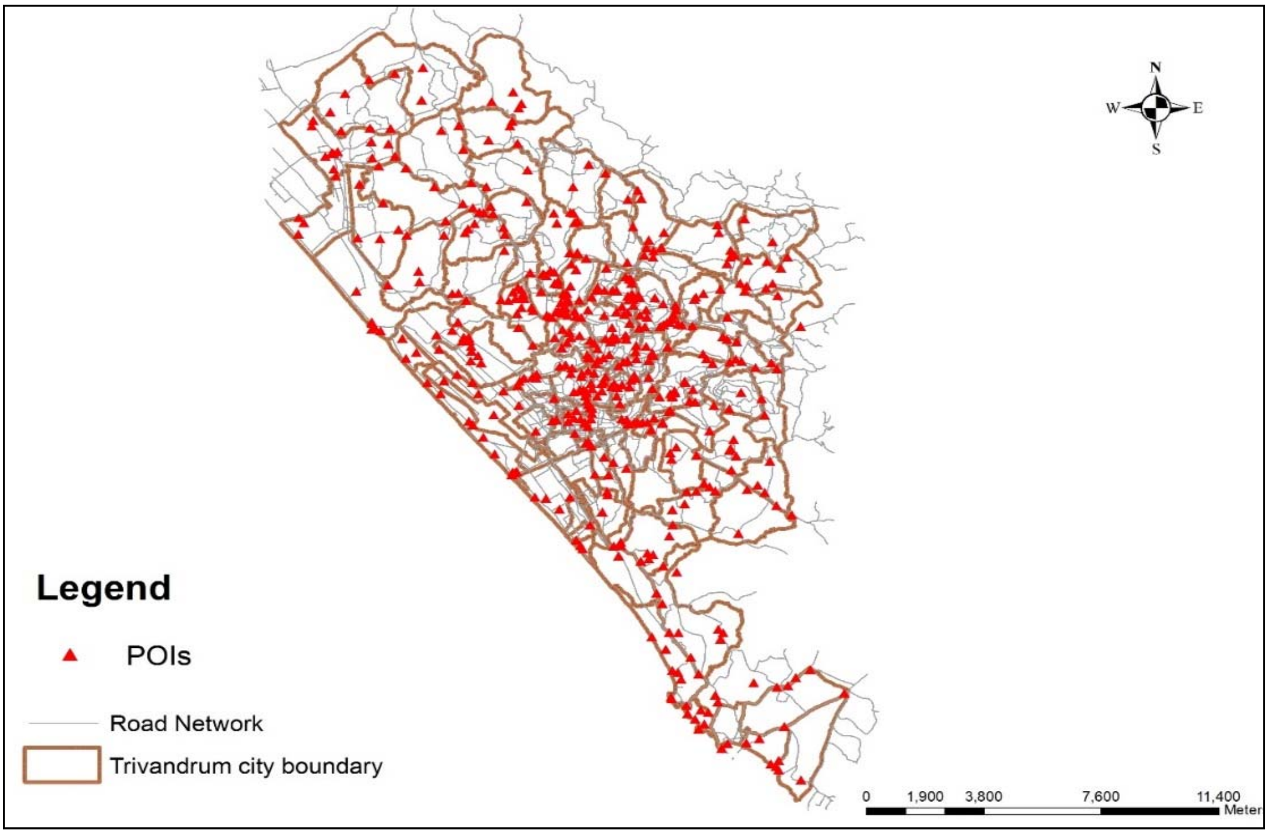

Fig. 3 Distribution of Point of Interests in the City.

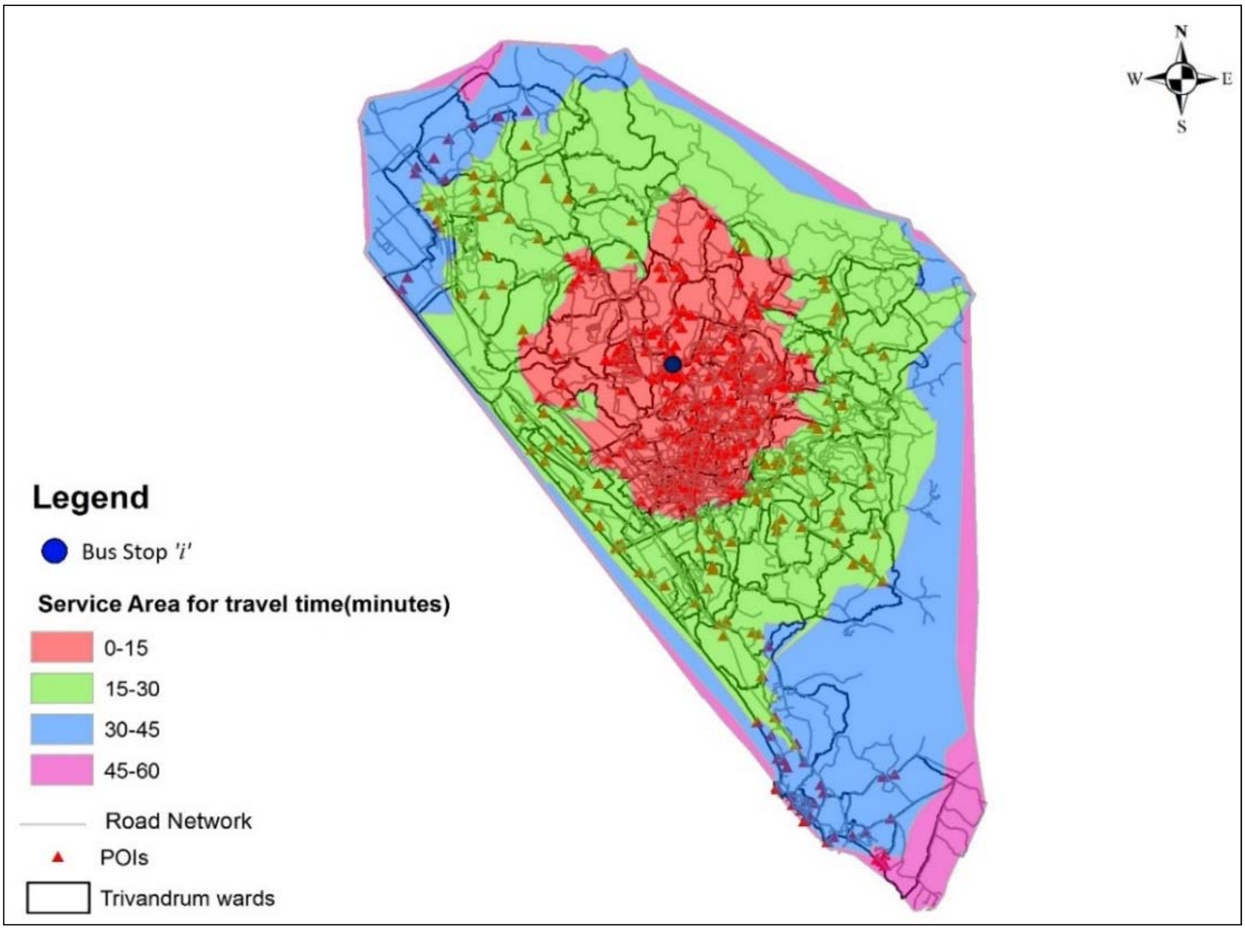

Fig. 4 Service Area for The Bus Stop ‘*i*’.

Table 1. POIs Accessible from the Bus Stop '*i*' for a Given Time Interval and the Proportion to Total POIs in the City

Time Interval	Number of POIs accessible for the time interval from the bus stop (in min)				Total number of POIs in the city
	0-15	15-30	30-45	45-60	
Number of POI	254	175	45	6	485
Proportion	0.524	0.36	0.0927	0.0124	

Table 1 gives the POIs accessible from the bus stop 'i' in various time intervals, say, 0-15 min, 15-30 min, 30-45 min, and 45-60 min, and its proportion to the total POIs in the city.

The service area is assigned a weight based on the time interval. This is done for accounting the distance to the services as the key element in determining the accessibility. The rationale is that the accessibility of a bus stop is affected by its proximity to services. The distance to the services increases the accessibility from the bus stop decreases. Therefore, the service area having minimum time is given maximum weightage. According to Barron and Barret (1996), the weights derived by Rank Order Centroid (ROC) method results in high performance as the process involves more systematic analysis of information embedded in the ranks. The ROC weights are given in **Eq. (1)**:

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{1}{j}, \quad j = 1,2,\ldots,n. \tag{1}$$

where, w_i is the ROC weight of i^{th} rank, where, $w_1 \geq w_2 \geq \ldots \geq w_n$ restricted to $\sum_{i=1}^{n} w_i = 1$.

The weightage calculation formula and the weightage values based on the ROC method for a given bus stop is given in **Table 2** and **3** respectively.

The access measure for the bus stop is calculated using the weightage factor for the service area and percentage of POIs served. Access measure for bus stop '*i*' is given by the **Eq. (2)**.

$$A_i = \sum_{j=1}^{n} w_j \times p_j \tag{2}$$

where, w_j is the weights assigned to the service area j and p_j is the proportion of POIs in the corresponding service area.

This gives the accessibility from the bus stop as shown in **Table 4.** The final stage in creating accessibility index involves combining the two access measures: access to bus stops and access from bus stops. The total accessibility measure for a bus stop $A_{i(t)}$ given by the **Eq. (3)**, is thus obtained by the summation of population proportion served which gives the accessibility to the bus stop and the access measure from service coverage which provides accessibility from the bus stop.

$$A_{i(t)} = A_i + P_{i(500)} \tag{3}$$

where, $A_{i(t)}$ is the total accessibility measure for bus stop '*i*', A_i gives the access measure for bus stop '*i*' and $P_{i\,(500)}$ is the proportion of the population served by bus service calculated as the 500m buffer population divided by the total population of the zones under the influence area of the buffer. Total accessibility measure for the bus stop '*i*' is given in **Table 5**.

RESULTS AND DISCUSSION

Table 6 presents the ranges and categories of the accessibility index. The index was grouped into 5 categories including very poor, poor, moderate, good and very good. The accessibility of about 6.55% bus stops is very poor, which serves about 2.36% of the population. 1.19% bus stops serving 1.47% population have very good accessibility. Overall, around 45% of the population has moderate accessibility.

Figure 5 illustrates the bus stop wise accessibility index of the Trivandrum Municipal Corporation. As demonstrated in Fig. 5, it can be observed that the areas with very poor and poor accessibility lie in the periphery of the study area while moderate and good accessible areas are the central area of the city. In other words, bus stops located in the central area of the city have high accessible values, the accessibility values decrease as the distance from city centre increases. This is mainly because of the fact that the number of bus stops in the city outskirts are less in number, are scattered and widely spaced. Therefore, the catchment area of a bus stop, i.e., 500m buffer serves only about 24% of the population. It must also be considered that the population density in the outskirts of the city is approximately 3257 persons per square km as against 51145 persons per square km in the city centre.

Correlation analysis was used to investigate whether the there is any relation between developed accessibility index and the trips performed using public transport. The fare transaction of ticket sales using Electronic Ticketing Machine provided the number of passengers boarding and alighting each bus stops. This was used to determine the trips (in precise, the number of passengers) performed using public transport. The value of correlation coefficient ranges between -1 to 1 representing negative to a positive relationship between the variables under consideration. The results show that the accessibility index developed in the study and the trips performed using public transport is having a positive correlation with a value of 0.67. This is in association with the literature (Morris *et al.*, 1979) that accessibility to public transport is one of the determining factors of ridership and hence it can be justified that the accessibility index developed in this study has an acceptable level of performance. The findings indicate that the transit planners can utilise this method to find the accessibility to bus stops and land use destinations.

Table 2. Weightage calculation formula

Rank	1	2	3	4
Weights	$\frac{(1+1/2+1/3+1/4)}{4}$	$\frac{(1/2+1/3+1/4)}{4}$	$\frac{(1/3+1/4)}{4}$	$\frac{(1/4)}{4}$

Table 3. Weightage Values based on Rank Order Centroid Method

Service Area	0-15	15-30	30-45	45-60
Weightage	0.52	0.27	0.15	0.06

Table 5 Total Accessibility Measure for the Bus Stop '*i*'

For Bus Stop '*i*'	
Access measure (A_i)	0.385
Population proportion served ($P_{i(500)}$)	0.124
Total Accessibility measure ($A_{i(t)}$)	0.51

Table 6 Accessibility Index Ranges and Categories

Range	Accessibility Index Category	Bus Stops (%)	Population (%)
0.1- 0.26	Very Poor	6.55	2.36
0.26- 0.41	Poor	36.90	20.91
0.41- 0.57	Moderate	36.31	44.38
0.57-0.72	Good	19.05	30.88
0.72-0.88	Very Good	1.19	1.47

Table 4. Access Measure Calculation based on Service Area

	Number of POIs accessible for the time interval from the bus stop '*i*' (in min)				
	0-15	15-30	30-45	45-60	Access measure
Weight	0.52	0.27	0.15	0.06	=0.273+0.0975+ 0.0135+0.000775 = 0.384775
Proportion of POI	0.524	0.36	0.0927	0.0124	
Proportion × Weightage	0.273	0.0975	0.0135	0.000775	

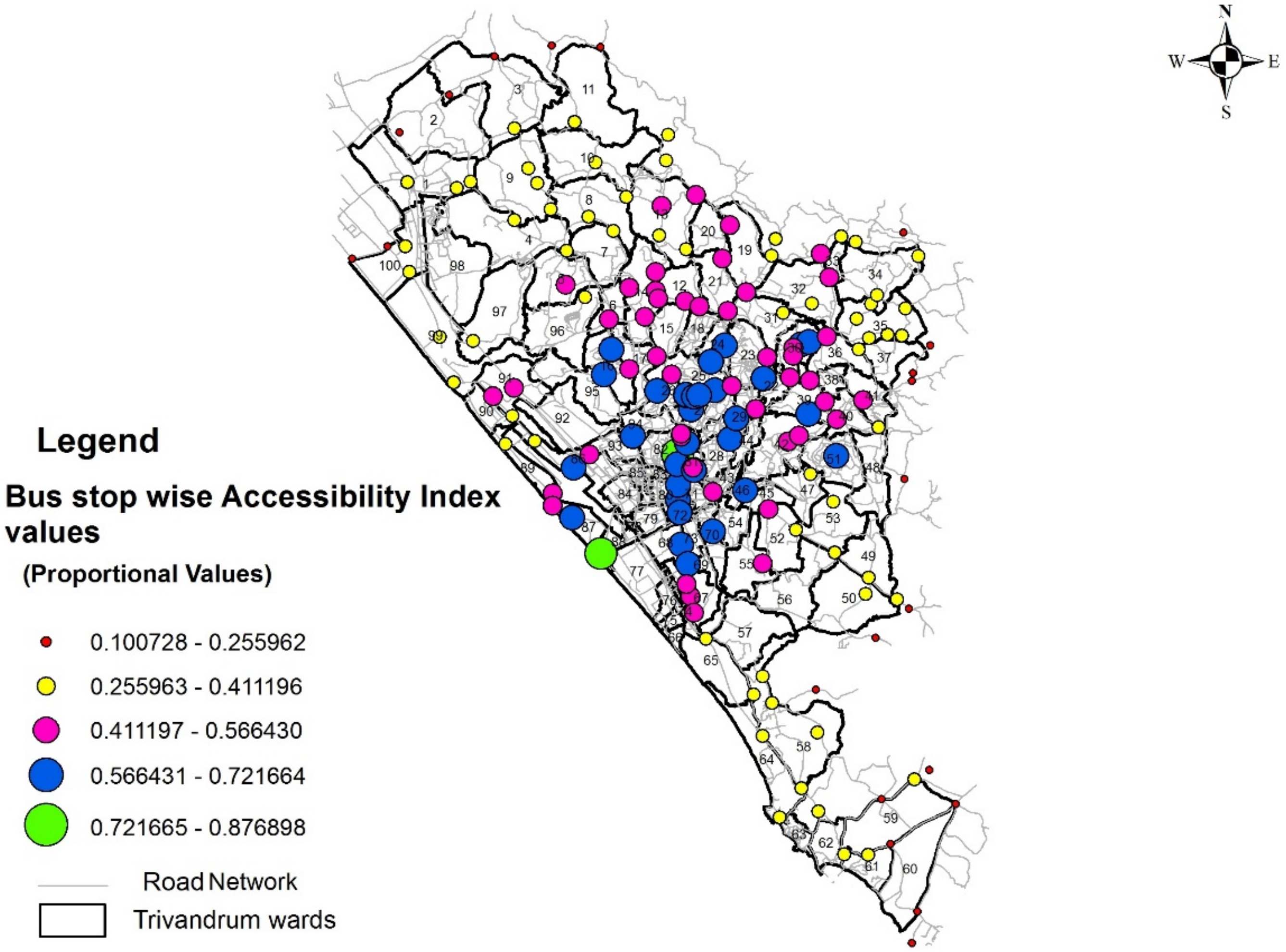

Fig. 5 Accessibility Index Map of Trivandrum Municipal Corporation

CONCLUSION

The methodology used in the study was based on the factor that the index should measure the accessibility which comes from proximity to bus stops and land use destinations. This study proposed the development of a GIS-based composite public transport accessibility index as a case study of Trivandrum city. This accessibility index helps in identifying the extent of remoteness in the city of Trivandrum.

(a) The proposed public transport accessibility index takes into account the network-based distance to the bus stops, population, travel time and opportunities or the land use destinations.

(b) It was observed that the accessibility index in the central area has a higher value and the accessibility values decrease to the periphery of the city. It can be interpreted that the availability of opportunities is higher in the central area while the number of opportunities is less in the other areas. Moreover, the density of the road network is more towards the city centre which contributes to higher accessibility values. Also, given that the concentration of population is high in the city centre and higher number of bus stops; the accessibility index tends to be more in these areas.

(c) This method is relatively cost-effective and fast to use and can be used for transport and land use planning exercises, giving emphasis on public transport. Moreover, the accessibility index proposed in the study uses few basic calculations and fundamental commands of GIS.

(d) The visual representation of the composite public transport accessibility helps in identifying the extend remoteness in Trivandrum city. Thus, it is useful in the route planning by introducing new buses in the high density zones, add missing links in the network and to increase the accessibility in the city outskirts.

The GIS-based public transport accessibility index gives the accessibility of a single point (i.e., the bus stop) by considering access to the point, access from the point to various land use destinations and network impedance. Since Trivandrum city has a predominant share of public transportation system, it is required for the planners to evaluate the public transport accessibility and ensure a moderate accessibility. Given the ease of calculating and updating the accessibility index and its operationalization, overall this methodology has the potential to become a useful decision support tool for transit operators and planners.

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