



Spatial accessibility analysis of schools using geospatial techniques

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Abstract The main objective of the present study is to enhance the accessibility facilities for local public to educational centers in Tiruchirappalli City. For this approach, the existing K-12 schools, Census tracts and road network were spatially plotted using the techniques of geospatial system. Spatial accessibility index is computed using Three-step floating catchment area (3SFCA) method. The findings indicate (39%) of catchment area has been shortage of education facilities. The index of 3SFCA and its spatial pattern has been compared, validated using enhanced two-step floating catchment area (E2SFCA) method. The incorporated Gaussian weight of 3SFCA clearly reduces the high estimate of demand problem of the study area. Through 3SFCA and E2SFCA, the number of wards observed to be shortage is 14 and 26 respectively. Overall, the analysis concludes that 3SFCA is an effective method in spatial planning of educational facilities. In future, this study enables the urban planners and decision makers to maximize spatial accessibility by establishing a new facility and improve the existing facilities in shortage region.

Keywords Tiruchirappalli City · Education facility · Geospatial system · Spatial accessibility · 3SFCA · E2SFCA · Shortage region

1 Introduction

One of the critical problems in developing countries like India is the spatial accessibility to educational facilities. Guaranteeing the provision of fair and equal access to educational opportunities is a fundamental right for all citizens [1–3]. Spatial, social, political and economical are the different dimensions that affect the accessibility to educational centers [4, 5]. Formerly in India, the elite people who are high in economic and political used education as a tool to dominate the other community people and suppress their growth. The different socio-income group exist will result in selection of different types of education system based on their affordability. The social, political and economic are the complicated dimensions of accessibility for which the data collection is more extensive and not readily available. Hence, the spatial dimension of accessibility to education services is assessed in this study using gravity model [6, 7]. The spatial planning and resource allocation of the education services depends upon the several criteria like distance, land use patterns and available road networks in urban areas [8–11]. The measures of accessibility to educational facilities can be classified into four categories: provider-to-population ratio, distance to nearest provider, average distance to providers, and gravitational models of provider influence. Provider-to-population ratios referred as supply to demand within the catchment such as states, census tracts or education services [12, 13].

Distance to nearest provider [14] and average distance to providers [15] were measured using travel distance alone without accounting the population size. This travel distance estimated by either the straight line distance, Euclidean distance and network distance. Finally, the gravity models, it assume that the spatial accessibility depends on the

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population access to education decreases with increase in distance to education services based on the law of gravitation. This model is more comprehensive and flexible to execute than the other models. Geospatial techniques play a vital role in defining methodologies used to measure accessibility with precision and reliability [16–19]. As a preliminary study, this is carried out for interpreting the spatial accessibility to primary healthcare center in Thiruvembur block, Tiruchirappalli [20].

In India, the total number of school-going students was 256.9 million in 2015 which is 20 percentage of the India's population [21]. K-12 education in India covers literacy programmes from kindergarten to 12th grade and is offered by both Government and the private sector. The public sector has an enrolment of 142.7 million. About 25% is taken up by private schools having 40% share of student enrolment of 114.2 million, 54% of the schools are run by the central/state government while 21% of schools fall under the purview of the Municipal Corporation [22]. The student–teacher ratio of most schools in India for primary school is 35:1 and secondary school is 30:1 but in some states it even exceeds 60:1 ratio [23]. By UNESCO [24] it states that Georgia (8.93:1), San Marino (6.93:1) and Kuwait (8.88:1) are the top most country having student teacher ratio where as India's overall student–teacher ratio 24.09:1 [24]. The statistics clearly show the disparity between supply and demand in the education system. The average world youth literacy rate is 91%, whereas India's is only 74.04% by UNESCO report, [25]. The literacy rate for the age group of 7 and above is 73% and 69.3% for the 15 and above age group. These statistics show that India has to substantially improve its education system in terms of proper spatial planning and ensuring improved access to all people.

The current study aims to develop a GIS-based approach for the characterisation of accessibility to educational facilities by local communities residing within Tiruchirappalli city, in the state of Tamil Nadu, India. For the study, it is assumed that there exists spatial variation in the distribution of educational centres and transportation infrastructure that together impact the overall accessibility to educational centres. It is also assumed that there exist localities in the case study area where accessibility to educational centres is relatively poor. To address these actual problems, the following objectives are framed for this study: (i) To map the existing locations of educational facilities, so as to understand the spatial distribution of the facilities, (ii) To compute travel time and travel distance between the educational centres and centroids of the census tracts, (iii) To compute spatial accessibility index using gravity model and (iv) To examine the variation in results for accessibility to educational facilities by different gravity models in Tiruchirappalli city

2 Gravity methods for measuring accessibility

A modified version of Newton's Law of Gravitation [26], they were initially developed to predict retail travel and help with land use planning. They can provide the most valid measures of spatial accessibility, irrespective of whether the setting is urban or rural. Gravity models attempt to represent the potential interaction between any population point and all service points within a reasonable distance, discounting the potential with increasing distance or travel impedance [27]. The gravity-based model gives a significant theoretical framework, associating all factors of accessibility and provides the most effective extent of spatial accessibility for both urban and rural areas. At first, gravity model computes accessibility by simple ratio of supply to demand i.e. the healthcare supply to population demand within the catchment, but the constrain of the model is that it fails to take into account the border-crossing patients, thus give rise to use of Floating Catchment Area (FCA) method [26]. This floating catchment area method is way better than previous model but it is not intuitive to interpret.

Successively, the improved version of FCA method is two-step floating catchment area (2SFCA), considering a distance-decay function. Subsequently, the 2SFCA was again upgraded into Enhanced two-step floating catchment area (E2SFCA) by including distance weights to overcome its limitations [14]. This newly added distance weights is the prime component to categorize the accessibility within the catchment area, and it is done by classifying the boundary into three sub-zones with travel time intervals of 0–10 min, 11–20 min and 21–30 min between any demand site and any supply site. Further, this method is modified and developed into Three-step floating catchment area (3SFCA) by incorporating Gaussian weights [20, 29]. The Gaussian weights introduced in the demand segment of the investigation are to minimize the demand overvaluation problem. Thus this method is superior to all gravity models and hence adopted in the study to analyze the spatial accessibility to urban services in Tiruchirappalli city.

2.1 Three-step floating catchment area method

In this study, the spatial accessibility to the considered education centres, i.e. K-12 Schools in Tiruchirappalli, Tamil Nadu is measured using the modified gravity model, i.e. Three-step Floating Catchment Area method proposed by [28, 29]. First, the travel time is used instead of travel distance to divide the catchment area based on the travel time. Second, although a continuous function is normally used for measuring distance impedance, in this study, a

segmented inverse-power function is used, as shown in Eq. (1).

$$f(t_{ij}) = \begin{cases} 1, & t_{ij} < 10 \\ 10/t_{ij}, & 10 < t_{ij} < 30 \\ 0, & t_{ij} > 30 \end{cases} \quad (1)$$

where t_{ij} is the travel time between the census tracts (i) and the education centre (j). Third, to reduce the overestimation of demand in supply and demand ratio the concept Gaussian weights is introduced, which distributes the demand to the available facilities within the catchment area. Theoretically, the assumption is that the other available proximity service sites have impacts on-demand service sites. Theoretically, the assumption is that the availability and proximity of other alternate service sites have an impact on the demand for a particular service site. Essentially, the Gaussian weights are consigned for each pair of demand–supply sites as an additional step. The method for estimation of spatial accessibility is executed in three steps:

Step 1: A catchment size is fixed and then competition weights are assigned to each educational service based on travel impedance Firstly, a catchment size is selected based on cumulative trip frequency statistics. The travel time taken by 75% of the trips is selected for the catchment size and it is applied for both the census tracts centroid as well as the educational services. Then, the selected catchment size is divided into three sub-zones with the interims at 10, 20 and 30 min. Later, existing education services within the catchment area are located and the Gaussian weights between each educational service site j and census tract i is computed by Eq. (2).

$$G_{ij} = \frac{T_{ij}}{\sum_{k \in \{Dist(i,k) < d_0\}} T_{ik}} \quad (2)$$

where G_{ij} is the Gaussian weight between the centroid of the census tract i and education site j, $Dist(i,k)$ is the travel time from i to any habitant site k within the catchment area, and d_0 is the catchment size of 30 min. T_{ij} and T_{ik} are the assigned Gaussian weights for j and k, respectively. The Gaussian weight G_{ij} equals 1 when there is only one educational site available for a population site i but decreases with an increasing number of alternative education sites.

Step 2: Estimating the supply and demand ratio (R_j) of each educational centre The catchment area of 30 min is defined for all the education sites j and the catchment area is split into three sub-zones by following the same procedure mentioned in Step 1. All the population sites within the catchment area served by the education site are examined and located to compute the supply and demand R_j ratio of each education site. The numerator and denominator give the supply and demand of the education site j, respectively.

$$R_j = \frac{S_j}{\sum_{r=1,2,3,4} \sum_{k \in D_r} G_{kj} P_k W_r} = \frac{S_j}{\sum_{k \in D_1} G_{kj} P_k W_1 + \sum_{k \in D_2} G_{kj} P_k W_2 + \sum_{k \in D_3} G_{kj} P_k W_3 + \sum_{k \in D_4} G_{kj} P_k W_4} \quad (3)$$

where S_j is the education site capacity of j which is determined by the infrastructure of the school, number of teachers, ease of access (i.e., proximity to the bus stop and distance to the main road), and network distance. W_r is the impedance of the rth sub-zone D_r . G_{kj} is the competition weight between the education site j and the habitant site k; P_k is the population size of the habitant k.

Step 3: Computing the spatial accessibility to education facilities of each census tract

$$A_i^F = \sum_{r=1,2,3,4} \sum_{k \in D_r} G_{kj} P_k W_r = \sum_{j \in D_1} G_{ij} R_j W_1 + \sum_{j \in D_2} G_{ij} R_j W_2 + \sum_{j \in D_3} G_{ij} R_j W_3 + \sum_{j \in D_4} G_{ij} R_j W_4 \quad (4)$$

where R_j is the supply and demand ratio of the education site j, W_r is the impedance of the rth sub-zone D_r , G_{ij} is the Gaussian weight between the ward centroid i and the education site j.

The catchment size for analysing spatial access to educational centres has been suggested as 60 min by Luo and Wang [30]. However, in this study, the catchment is fixed as 30 min based on Survey conducted 75% of trips frequently made in the study area. The 3SFCA assumes that an educational centre located near the habitat is influenced by the habitant’s travel cost/distance to that education site and the travel cost/distance to the other available adjacent education sites. Quite naturally, the habitant’s demand for educational centres decreases with the increase in the number of other educational sites nearby. Thus, the Gaussian weight G_{ij} is adopted in this model to overcome the overestimation of demand and maximise the accurate estimation of SPAI. Hence, the study carried out using 3SFCA model to compute SPAI for Tiruchirappalli city.

3 Accessibility to higher secondary education centres: a case study of Tiruchirappalli City

3.1 Study area

Tiruchirappalli is a culturally rich city, situated in the central part of the southern state of Tamil Nadu. Also known as rock city, it has a mixed topography of flat and undulated terrain, and is at an altitude of 78 m above mean sea level. The river Cauvery flows through the length of the study area, crossing from west to east [31]. According to

the census report of 2011, the total population was recorded as over 1 million. The city belongs to the Tier II category. The complete aerial coverage of the district is 4404 km² while the corporation area covers 129.84 km², which is selected as the study region for the present work. The spatial extent of the region lies in-between the latitude of 10° 44' to 10° 52' N and longitude of 78° 39' to 78° 44' E. In recent years, the study area has enjoyed rapid developments in educational, commercial, residential, recreational and transportation infrastructure [32]. The area consists of 65 municipal wards which are shown in Fig. 1.

3.2 Methodology

The spatial accessibility analysis of educational centres is attempted by the integration of geospatial techniques with gravity model and it involves processes such as data collection, creation of GIS database, modelling and analysis of the results.

The study boundary of Tiruchirappalli City Corporation extracted from the Survey of India Toposheets (No), Ward boundary is updated using Municipal Corporation Map and with high resolution satellite images. The prepared boundary map has the 65 census tract information for the

data collection process. The geographical data collection comprises of two types: (i) spatial and (ii) non-spatial datasets. The satellite dataset of QuickBird imagery of the year 2011, procured from National Remote Sensing Centre, Hyderabad with the spatial resolution of 0.61 m is used to extract road network data in the study area which is one of the layers required for accessibility analysis.

The non-spatial datasets such as Population data, number of household data, number of bus stop in each ward of the study area are collected from various government organisations such as Tiruchirappalli Municipal Corporation and Tiruchirappalli Statistics Department as well as other open source data [33]. Thus, the perceived data such as location of education facilities, bus stops and other major facilities in each of the census tracts are point-based entities which are acquired from Global Positioning System (GPS). There are nearly sixty-one schools of different categories such as Playschool, Nursery, Primary, Secondary and Higher Secondary Schools, present within the limits of the City Corporation. For the current research work, the number of K-12 schools present in the city which is about twenty-eight schools, is selected for the analysis.

A questionnaire survey [34] is conducted to gather varied information such as number of students, number of

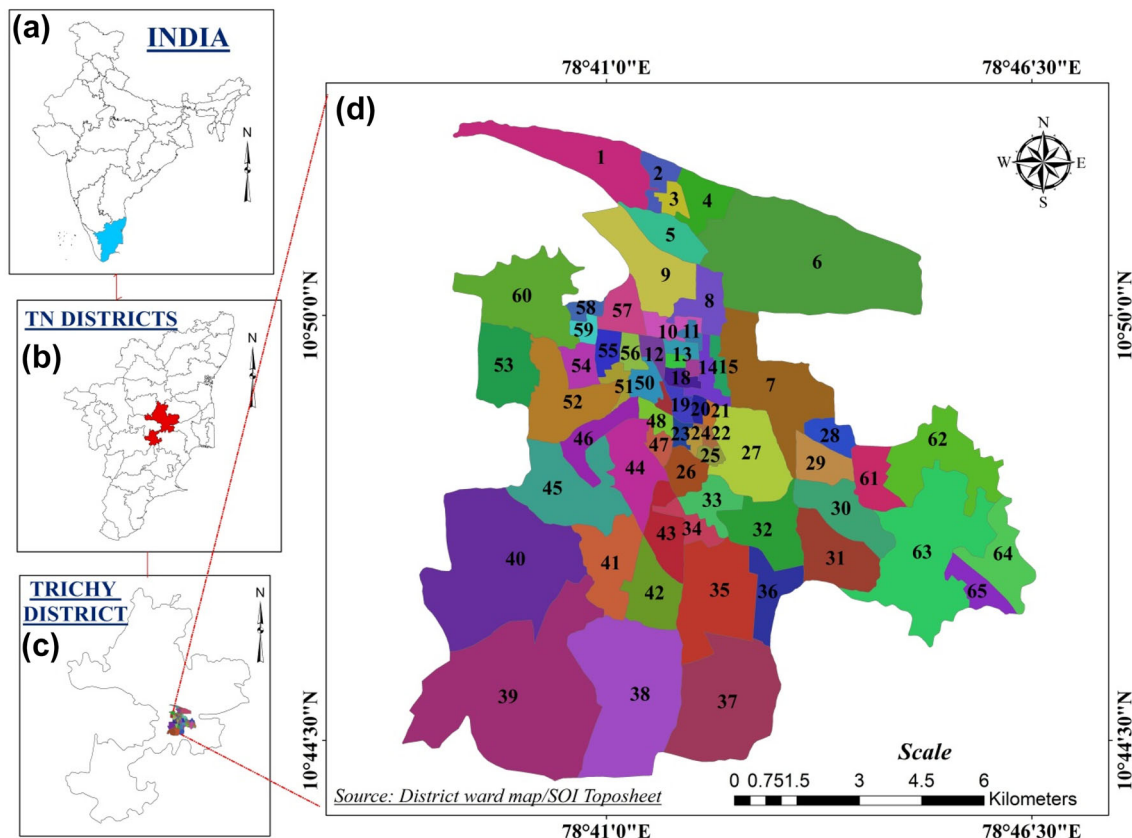


Fig. 1 Location Map of the study area: **a** location of Tamil Nadu in India, **b** location of Tiruchirappalli in Tamil Nadu, **c** location of Ward boundaries in Tiruchirappalli **d** location of 65 wards

teachers, school timings, availability of school vehicle, medium of instruction, the educational system (board) opted for by the school management, distance to transport facilities like the bus stop besides interviews with the school administration, interviews with parents to determine the factors that made them to choose a particular school, with the primary aim of understanding the major factors influencing accessibility from the user's point of view. A comprehensive survey of the educational institutes in the study area is conducted to obtain information about the number of teachers in the schools, the number of students enrolled in the schools, availability of transport facilities such as school buses or vans and distance from the school to a main arterial road. All of the above collected data can be incorporated into modelling of impedance function, which can then be used in the computation of the accessibility index of the study area.

The estimation of accessibility to education is evaluated by following step by step procedure. First, the data collected for the study is investigated for its reliability to incorporate for the analysis. Then, the thematic layers are created for the analysis with the data collected. Then the Origin and destination is fixed to obtain the travel time matrix. Integrating all the above outcome for the computation of spatial accessibility index using three-step floating catchment area. Then the spatial access ratio (SPAR) is computed for 3SFCA and E2SFCA. The SPAR results of 3SFCA and E2SFCA were compared. The spatial patterns are also mapped and scrutinise the deprived area identified by both the methods.

4 Result and discussion

4.1 Preparation of thematic layers

4.1.1 Road network

The road network of the study area is extracted from QuickBird satellite imagery using ArcGIS 10.2.1. The census tract consists of a robust transport system connected with significant locations of the city and also linked to adjacent cities like Thanjavur, Pudukkottai, Perambalur, Namakkal and Madurai. The extracted road network is used to measure travel time or travel cost by using the Network Analyst tool in a GIS environment. The straight line distance is one of the better indication measures for educational facilities and centroid of census tracts. The extracted road network is shown in Fig. 2.

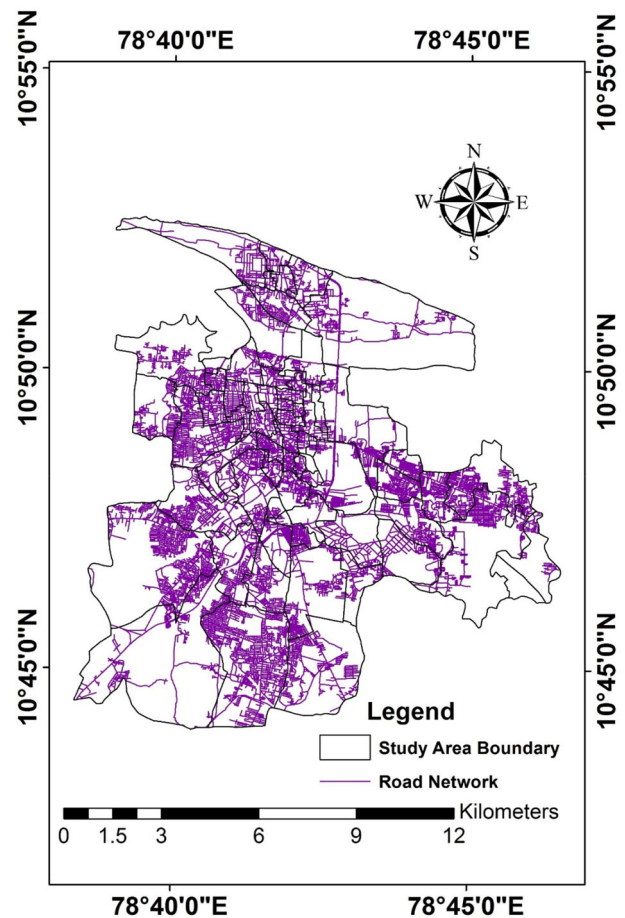


Fig. 2 Road network of the study area

4.1.2 Computation of centroid

The collected locations of the schools are converted as XY coordinates (Latitudes and Longitudes) using GIS tool. The Universal Transverse Mercator (UTM) 44 N Projection is fixed as the projection system for the datasets. For the analysis, two different types of schools are considered, i.e., Government and Private Schools, as shown in Figs. 3 and 4, respectively.

The road network is used as an essential variable to measure the centroid of habitation to the schools. The Origin-Destination (OD) cost function is attempted through the Arc GIS 10.4 version. The centroid of the census tracts is considered as the origin, and schools are taken as the destination for this study. Based on this observation, the OD travel time matrix is computed. The speed limit of each road network, and whether the road is one way or two way is considered in computing the travel time between OD. The centroid of ward habitation is shown in Fig. 5.

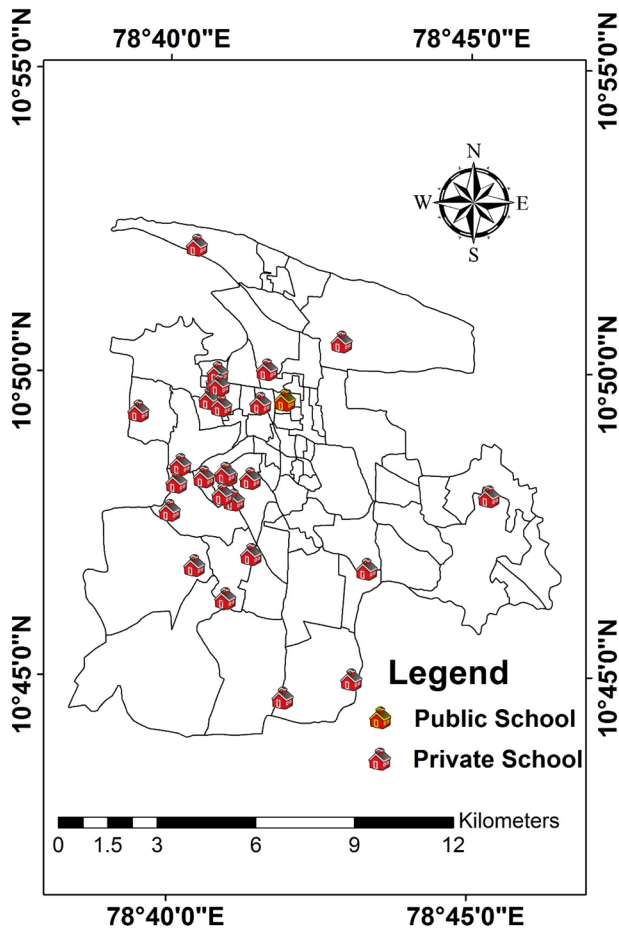


Fig. 3 Spatial entities of public and Private School

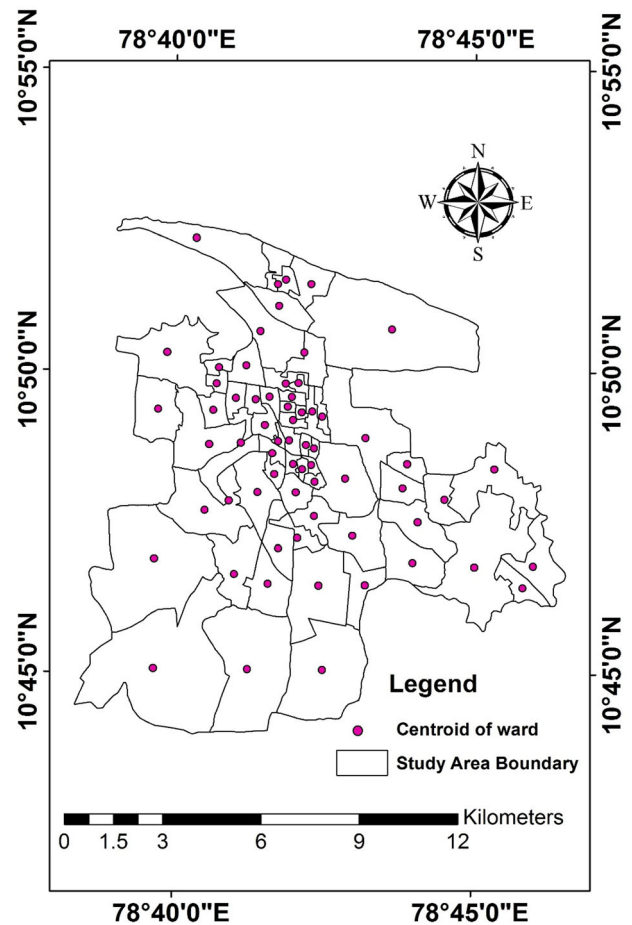


Fig. 4 Centroid of wards as a habitation

4.2 Questionnaire data analysis

The questionnaire survey is conducted to gain a better understanding of opinions from the public in response to a query regarding the positive and negative factors in the selection of schools. A total of 300 people are selected, including parents and school going students and they are individually questioned. The questionnaire data of responses from the public are considered for the analyses. The collected data from the questionnaire survey is initially checked for internal consistency for ensuring the reliability of the analysis. The internal consistency is defined by Cronbach’s alpha value [35] and usually, data having a Cronbach’s alpha value of more than 0.5 is considered to be most suitable for the study area. In the present study, the estimated Cronbach’s alpha value is 0.734, which is deemed acceptable. The results reveal that nearly half of the people in the study area use two-wheelers for their school trips. The remaining 6% of the population are observed to use public transit for their school trips. The geographical representation of public travel mode is shown

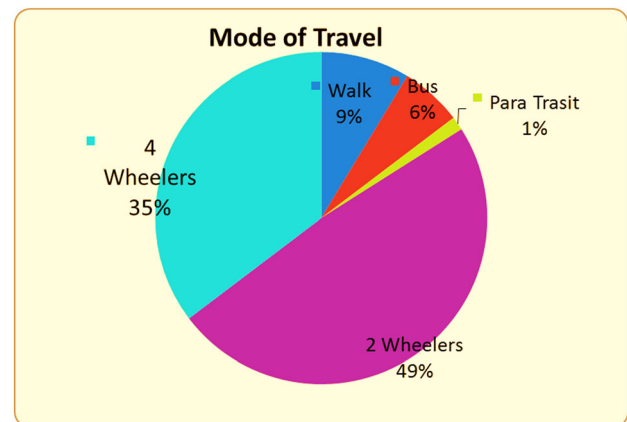


Fig. 5 Choice of travel mode of the public in the study area

in Fig. 6. The estimation and analysis of travel distance indicates that 39% of people travel 0–2 km, 25% travel 2–5 km, 33% travel 5–10 km and 3% travel 10–20 km for school trips, the graphical representation is shown in Fig. 7.

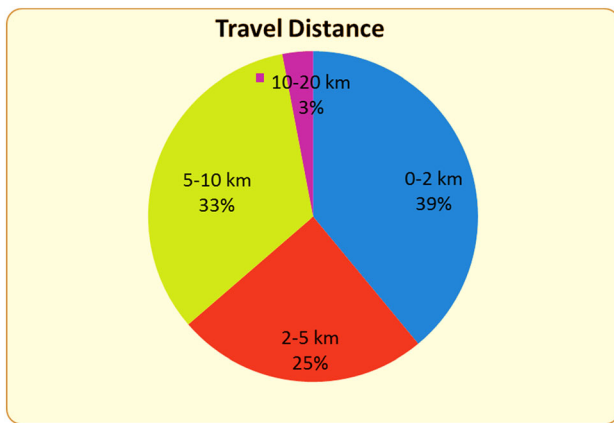


Fig. 6 Travel distance to education centers

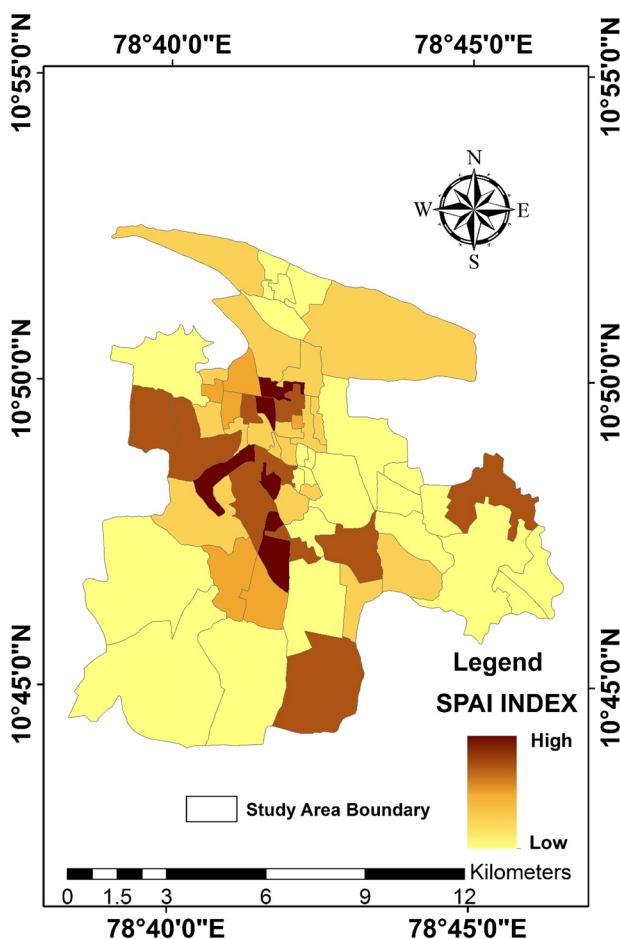


Fig. 7 Computation and result of Accessibility Index Map of 3SFCA

4.3 Computation of spatial accessibility index

The spatial Accessibility Index is computed by the three-step floating catchment area method which, as explained earlier in Sect. 3.2, ranks the ward with a level of accessibility to education centres considering the spatial travel

time and the demand for the education centres. According to the Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines, one primary school from standard 1–5th for every 5000 population and one senior secondary school from standard 6th–12th for every 7500 population should be considered as the prescribed standard. The existing education facilities in the city are 51 primary schools and 43 senior secondary schools for a population of 1.33 million. The existing schools are accessed by a maximum number of students residing within 5 km and the spatial distribution of the schools is satisfied for the northern and western part of the city. Students are observed to travel more than 5 km and 10 km according priority to quality of education, medium of instruction and the board the school follows.

As per the guidelines, the number of schools required for this population are 267 primary schools and 178 secondary schools. It is therefore necessary for 173 more primary schools and 130 senior secondary schools to be further provided. The spatial accessibility index of census tracts having zero or very low spatial accessibility index with less access to the education centres is shown in a light shade of green colour and census tracts with high access are shown in a darker shade, in (Fig. 8). The census tracts located in the southern and eastern part of Tiruchirappalli city have much less access when compared to the northern and western parts. The result indicates that (39%) of the study area has been shortage of education facilities.

Most of the schools providing higher secondary educations are located near the centre of the city (nearer to Chatram and Central Bus Stand) with higher population density. In these locations, facilities like transportation,

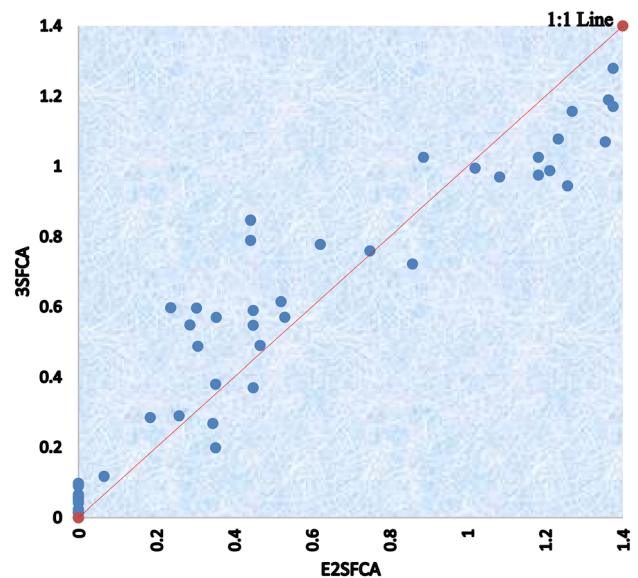


Fig. 8 A comparison of spatial access ratio between E2SFCA and 3SFCA

socio-economic conditions, etc., are beneficial for the population density. A vice versa effect is also seen in the study. In reality, the absolute equal spatial accessibility is not always achievable, but it is possible to plan and build a system of educational centres in such a way that it allows the highest spatial accessibility for a maximum number of people. It is essential to first determine the priority for low accessibility region shown in light shade of green colour (Fig. 9) and accurately measure ease of access to educational centres before any future development or further expansion of the localities and residential areas is considered.

4.4 Comparison between 3SFCA and E2SFCA

To present the results of 3SFCA and E2SFCA the Spatial Access Ratio (SPAR) is used instead of Spatial Accessibility Index (SPAI), because the SPAI values of two methods are at different extent which is not appropriate to compare the results. The SPAR is the ratio between a particular wards' SPAI to the mean SPAI of all wards. The SPAR values of both methods are plotted in 1:1 graph to observe the trend as shown in Fig. 8. The trend observed from the graph reveals that the 3SFCA has increased accessibility than E2SFCA for lower values and inverse trend is followed for higher SPAR values. It is evident that

3SFCA has a moderating effect in the urban city where there is high population density and education center exists.

The spatial pattern of accessibility to education center using SPAR of E2SFCA and 3SFCA are shown in Fig. 9. Lowering the demand of education site, results in minimizing the overestimation of demand problem. This change leads to more spatial access to education facilities in the city and locates potentially education deprived area. In other words, the shortage areas shown in 3SFCA are lesser and balanced than the E2SFCA. The education shortage area identified in E2SFCA is 26 wards and 3SFCA is 14 wards in which the shortage threshold value is taken as 30:1 recommended by Ministry of Human Resource Development, Government of India. From the Fig. 9, it is clearly evident that, wards in the outskirts of the city have no accessibility to education facilities. These are the places to be considered in future while planning the new establishment of education facilities by the urban planners and private sectors.

4.5 Key achievements for 3SFCA

Three-step floating catchment area is developed from Enhanced two step floating catchment area to overcome the overestimation of demand problem. The model also has logical assumption that the other available education sites

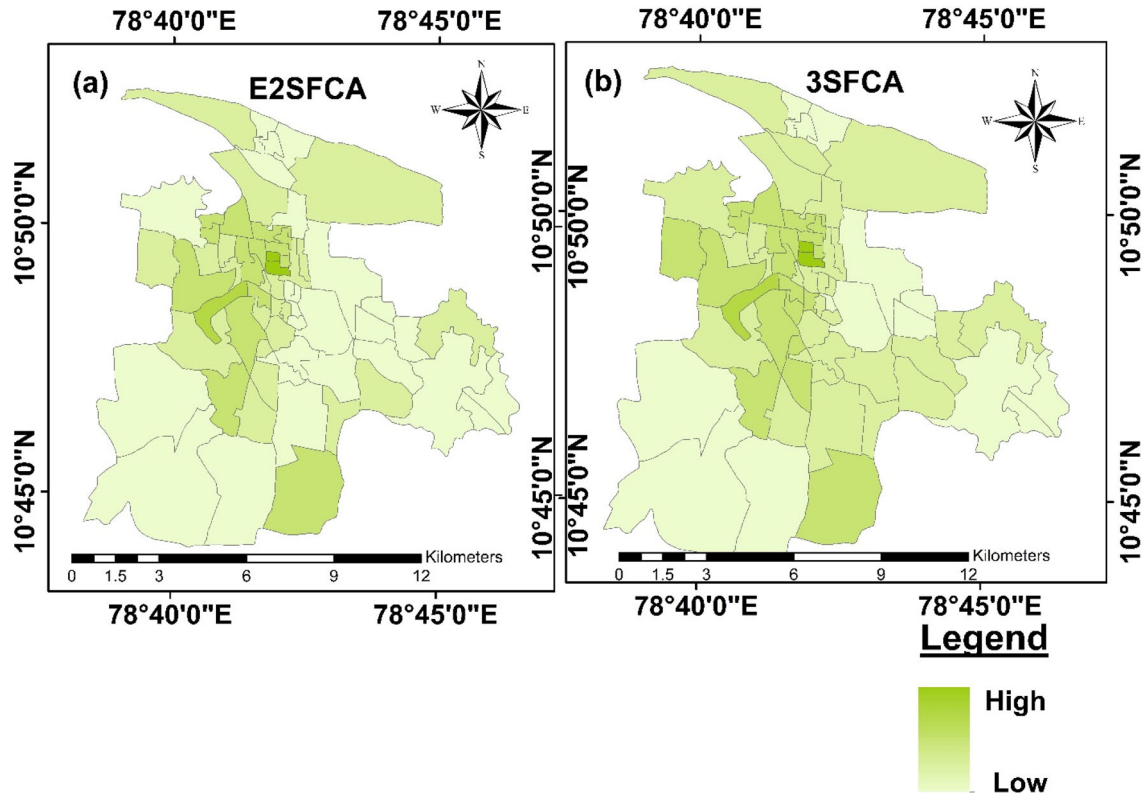


Fig. 9 Spatial pattern of spatial access ration measured by the a E2SFCA method and b 3SFCA method

nearby have influence on the education demand site. Hence the competition weight included in the E2SFCA is also adopted in 3SFCA model. The spatial accessibility measured by 3SFCA gives more reasonable shortage ward than E2SFCA. It is more essential to focus on rigorously demanding wards while planning new facilities. By this spatial planning, it improves equal accessibility to education facilities from all wards in the city.

5 Conclusion

The current study attempts to investigate the ease of accessibility to educational centres by the local public communities of Tiruchirappalli city. The GIS-based approach helps in the precise identification of demanded census tracts in terms of spatial accessibility to educational facilities. Hence, the study establishes the spatial variations of population distribution, which are associated with demographic and socio-economic characteristics of Tiruchirappalli city. The K-12 schools are not evenly distributed in the city, 23 wards portray the Accessibility Index (AI) value as zero, which indicates no accessibility to higher secondary schools. The study indicates 39% of region has been shortage of education facilities. So, this study will be useful to locate suitable sites for the construction of higher secondary schools in future. A combination of low spatial accessibility to educational centres and a higher proportion of dependent population results in a rather difficult situation for the residents in disadvantaged locations or under-developed areas. To effectively meet the educational demands of all the people, ways and means to maximize access to these regions should be considered by city planners. In future, the establishment of new schools by the government as well as the private sector should consider this regional disparity and ensure that schools are located in regions that are easily accessible by people from all areas. Such planned distribution not only improves access to facilities but also reduces the traffic congestion and facilitates easy mobility of the city.

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Compliance with ethical standards

Conflict of interest Authors state that there is no conflict of interest.

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