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The cover image is a photo of a street in the city of Naples during the COVID-19 pandemic quarantine (April 2020)

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Accessibility Analysis for Healthcare Centers using Gravity Model and Geospatial Techniques

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Abstract

India's healthcare facilities continue to be limited and the current number of hospitals is not sufficient to meet the demands of the increasing population. In this study the multi-specialty hospitals handling sudden trauma such as cardiac arrests, strokes, burns, accidents, and major illnesses that were considered and analyzed for the ease of access within the city. The spatial accessibility index is measured using the Modified Three-step Floating Catchment Area which incorporates emergency factors in addition to travel time in travel impedance function. The findings show that all hospitals are currently found to be collectively located near to the city center and wards located in the periphery of the city having very low spatial access to healthcare facilities. The index also aids in delineating the healthcare deprived areas and over-served areas within the city. This identification is essential for the future planning of new healthcare services, to improve the capacity and ease of access to the existing healthcare facilities. The model of this investigative study can be extended further to all cities to assist in the pre-planning for provision of adequate healthcare facilities. Such information will be advantageous, to public health officials and policy/decision makers involved in urban expansion planning, for ensuring better and quicker access to health services with minimum delay in the event of emergencies.

Keywords

Spatial Accessibility; Modified Three-step floating catchment area; Healthcare; Geospatial techniques.

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1. Introduction

Easy access to public service facilities continues to pose a major challenge in growing urban habitats. Among various basic public amenities, the availability of proper healthcare facilities is the prime facility that is essential for promoting a healthy community and maintaining the well-being of society. However, ensuring quick accessibility to available healthcare facilities, especially to rural and remote communities, is found to be a difficult and challenging task, particularly in developing countries such as India. The potential of a healthcare facility can be defined based on the following dimensions, namely availability, accessibility, affordability, acceptability and accommodation (Aday & Andersen, 1974). It also depends on various other limiting factors such as spatial location of healthcare, its social importance and financial situation of an individual. Addressing the challenges of geographical disparity and improving access to healthcare facilities will greatly help reduce high mortality rates, prevent epidemics and lower the risk of spreading infectious diseases (Ahmad, 2012). The availability of quality healthcare facilities alone does not ensure a healthy community, easy access to such facilities does.

According to the report of World Health Organization (Andrulis, 1998), a high segment of the world's population who fall under the poverty line are unable to access healthcare services as they simply cannot afford it. It is the duty of the government to guarantee ease of access to high-quality, low-cost healthcare services to all sectors of people from varying socio-economic categories (Apparicio et al., 2008; Bai, 2013; Zali et al., 2016). To ensure equal healthcare access, it is therefore necessary to identify the particular areas deprived of these services and then, study the influencing variables that affect the access to healthcare such as location of healthcare service site, population density, healthcare capacity, demand and geographical impedances (Baru et al., 2010; Chand et al., 2013; Ye & Kim, 2014) and then finally, adopt these significant factors into the design to measure certain indexes, which will designate a region as overserved or underserved. In general, the prime factors of access to healthcare services are supply of healthcare, demand of the urban habitat and travel impedance. Supply of healthcare denotes the capacity provided for the population to meet the demand of healthcare services. It can be measured and interrelated by the number of physicians, beds or specific outpatient facilities. Healthcare demand can be measured by the population density that can be potentially benefitted by the offered healthcare services. Geographical impedance indicates the distance between the supply (healthcare) site and demand (habitat) site (ESRI, 2014; Dejen et al., 2019), which is defined by usual criteria such as terrain complexity, transportation mode, road network, traffic volume, time of incidence and any other factors that may represent 'friction surface'. Currently, the prominent dimensions of accessibility are main component in Amart City planning which is assessed by Geospatial techniques (Geurs & Van, 2004; Guagliardo, 2004; Gu et al., 2018; Gargiulo et al., 2018; Gaglione et al., 2019). This paper attempts to focus on the potential of using Geospatial techniques in the development of an accessibility model in the healthcare field (Higgs, 2004). Numerous published models are used to measure accessibility (Liu & Zhu, 2004; Lu, 2011; Horton & Das, 2011; Lagu et al., 2014) such as: Opportunity-based, Ratio-based, Travel-impedance based, Utility-based, Space-time based, Gravity-based, etc. each having its own advantages and disadvantages. Amongst all, the Opportunity-based model is the simplest and is defined by the available number of facilities within a threshold distance. It deals with only the supply, whereas the ratio-based model considers both supply and demand, i.e. provider-to-population. Travel-impedance based model takes into account only the travel cost and travel time and is suitable only for rural areas having insufficient healthcare facilities (Luo, 2004).

Utility-based models need sophisticated data which may not be readily available and is thus a more complex model and is not preferred for practical applications. Space-time based model tries to study the accessibility pattern of each person, thereby, making the model more comprehensive as the data required for development of the model needs to be accurate and reliable. The Gravity-based model promotes an effective theoretical framework, combining all indicators of accessibility and delivers the most effective measure of spatial accessibility for both urban and rural areas (Luo & Qi, 2009).

In spite of steady economic progress and social reforms, health problems continue to be high indicating the functioning of a less than efficient healthcare system in India (Radke & Mu, 2000). Bhore committee, 1943 was formulated before Independence with the intention of focusing on providing healthcare access to every single citizen of the country (Rang & Panda, 2014). The healthcare facilities which were intended to provide high-quality services to improve community health failed to do so due to the absence of sufficient number of healthcare experts and adequate workforce (Ray & Biswas, 2009). India has one doctor for 921 people which is less than the WHO standard. Hence, to effectively address the health concerns of the urban population, the National Urban Health Mission (NUHM 2014) was launched. According to the surveys conducted by NUHM (2014), only 29% of people in the country are served by Government hospitals and the remaining visit private hospitals. It is observed that the location of many of the hospitals in Indian states are not spatially distributed considering the demand of the urban habitant in terms of distance, time, cost, availability of physicians, emergencies, importance of hospitals, population served, etc. It is therefore necessary to consider a methodology that will take into consideration all of these factors and thereby comprehensively analyze the spatial distribution of existing healthcare centers, provide recommendations for improving the system and also identify human habitats that are deprived of these essential healthcare facilities. This research paper focuses on the analysis of the healthcare system existing in Tiruchirappalli, a medium sized city in Tamil Nadu, India because City has one doctor for 4,974 people according to the District statistical Handbook (Ravi & Ias, 2014). The research includes an extensive survey of 16 existing multi-specialty Healthcare Centers and an estimation of their accessibility index. The principal focus of this research is to suggest a modified three-step floating catchment area (M3SFCA) method that obtains the emergency factors along with travel time for computing the travel impedance function. This would include counting spatial factors, non-spatial factors in estimating the travel impedance which would give precise accessibility index value and this enhanced method would measure the accessibility more effectively and identify the healthcare deprived regions in Tiruchirappalli city.

2. Measuring Accessibility Using Gravity Model

Gravity model derived from the Newton's Law of Gravitation used in integrated planning of land use and transport. The first gravity model attempts to denote the accessibility by a simple ratio of healthcare supply to population demand, but the limitation of the model is that it fails to take into account the border-crossing patients, thereby resulting in the use of floating catchment area method (Luo & Wang, 2003). This floating catchment area (FCA) method is way better than previous model by considering boundary but it also doesn't interpret. Again, the FCA method is developed into two-step floating catchment area (2SFCA), considering a distance-decay function (McLafferty, 2003; Mahesa et al., 2019). Later, the 2SFCA was eventually modified into Enhanced two-step floating catchment area (E2SFCA) by incorporating distance weights to overcome its limitation (Meshur, 2016). This introduction of distant weights is primarily to differentiate accessibility within the catchment area, and it is done by dividing the catchment area into three sub-zones with travel time intervals of 0-10 min, 10-20 min and 20-30 min between any population point and any service site. Lately, the E2SFCA (Penchansky & Thomas, 1981; Qadeer, 2011) undergone modification by incorporating the Gaussian weights and the new model is proposed, namely Three-step floating catchment area (3SFCA) (Wan et al., 2012; Rekha et al., 2020). This Gaussian weight is given discretely based on the travel time for accounting the other competitive healthcare services within catchment time, the discretized weights is assigned for the each trips between healthcare service and census tracts and vice versa. This method is adopted for Thiruverembur block of Tiruchirappali city as preliminary study (Rekha et al., 2017).

2.1 Modified Three-step Floating Catchment Area Method

To improve the scope of gravity models, the M3SFCA utilized for the area of study was modified to include other non-spatial factors instead of distance weights alone in travel impedance function. This modified model will be more suitable to identify areas deprived of healthcare services. Essentially, the travel impedance weights will be assigned for each pair of demand-supply sites (residence-healthcare) considering both spatial and non-spatial factors as an additional step to 3SFCA for improving the index value. The method was executed in four steps for Tiruchirappalli city.

Step 1: Formulating a travel impedance matrix

Travel Impedance weights have to be incorporated in M3SFCA and were computed by developing a modified model based on the scores obtained from the questionnaire survey for each variable considered. The coefficients a_1, a_2, a_3, a_4, a_5 in the model takes the score given for each variable by the user and by the normalization technique the coefficients values are given. Thus, the final model generated for computation of travel impedance weights was obtained as:

$$f(d_{ij}) = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 \quad (1)$$

where x_1 is the infrastructure of the hospital, i.e., number of physicians, x_2 is the availability of intensive care unit in a hospital, x_3 is the ease of access to the hospital, which will include distance to the hospital from arterial road, x_4 is the number of ambulance in each hospital, x_5 is the travel time from each ward centroid to the hospital. The 'i' represents the number of wards, i.e., 65 and 'j' stands for total number of hospitals taken for the study, which in this case is taken as 16 multi-specialty hospitals.

Step 2: Selecting a Catchment size

The model first requires fixation of the catchment area size for further analysis. This catchment size was selected based on cumulative trip frequency statistics, obtained from questionnaire survey. The travel time taken by 75% of the trips was selected for establishing the catchment size, and this was applied for both the ward centroids as well as the healthcare services.

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

Where G_{ij} is the competition weight between the location i and service site j, Dist(i,k) is the travel time from i census tract to any healthcare site k within the catchment, and d_0 is the catchment size.

Step 3: Computing the supply and demand ratio (Rj) of each healthcare center

For each of the 16 hospitals, Physician to Population ratio was computed using the formula:

$$R_j = \frac{S_j}{\sum_i P_i f(d_{ij}) G_{kj}} \quad (3)$$

Where, S_j is the infrastructure of the hospital which is no. of beds, P_i is the population of ward i, G_{kj} is the completion weight between healthcare site i and habitat site k, and $f(d_{ij})$ is the travel impedance matrix developed.

Step 4: Computing Accessibility Index (AI) of each ward

Once all the necessary parameters for defining the importance of hospitals such as $f(d_{ij})$ and R_j are computed, the next step would be finding the accessibility index for each ward. For each ward, accessibility index (AI) for the hospitals lying within the catchment area of 30 mins was calculated using the following equation:

$$AI = \sum_i R_j f(d_{ij}) G_{ij} \quad (4)$$

Where R_j is the Physician to population ratio estimated, G_{ij} is the completion weight between i and j, and $f(d_{ij})$ is the estimated travel impedance matrix of each ward to healthcare facilities.

3. Accessibility analysis to Healthcare Centres

3.1 Study Area

Tiruchirappalli, also known as Trichy, is the fourth largest city in Tamil Nadu state and is situated on the banks of River Kaveri, which flows through the length of the district and is the principal source of irrigation and water supply. The topology of Trichy is flat with an altitude of 78m above sea level. The city covers an area of 167.23 sq. Km while the urban agglomeration spread is over an area of 129.84 sq. Km. The study area selected for this research comes under the Tiruchirappalli Municipal Corporation area, consisting of four zones, namely, Srirangam, Ariyamangalam, Abisekapuram and Golden Rock. These zones are further classified into a total of 65 wards, as given in Table 1 and Figure 1. The total population of the city is 911,980 as per census 2011, and the population distribution in each of the wards is considered as one of the factors in estimating accessibility. Health care services are provided by both government and private hospitals. The CSI Mission Hospital is one of the oldest situated in Uraiyur and Mahatma Gandhi Government Hospital offer facilities at a subsidized cost. Private Hospitals like Kavery Medical Center and Hospital, Chennai Medical College Hospital and Apollo Specialty hospital are some of the well-known multi-specialty hospitals of the city. In the year 2011, an estimate showed that there were 133 hospitals in the city including 10 maternity homes and two urban family welfare centers maintained by the Municipal Corporation.

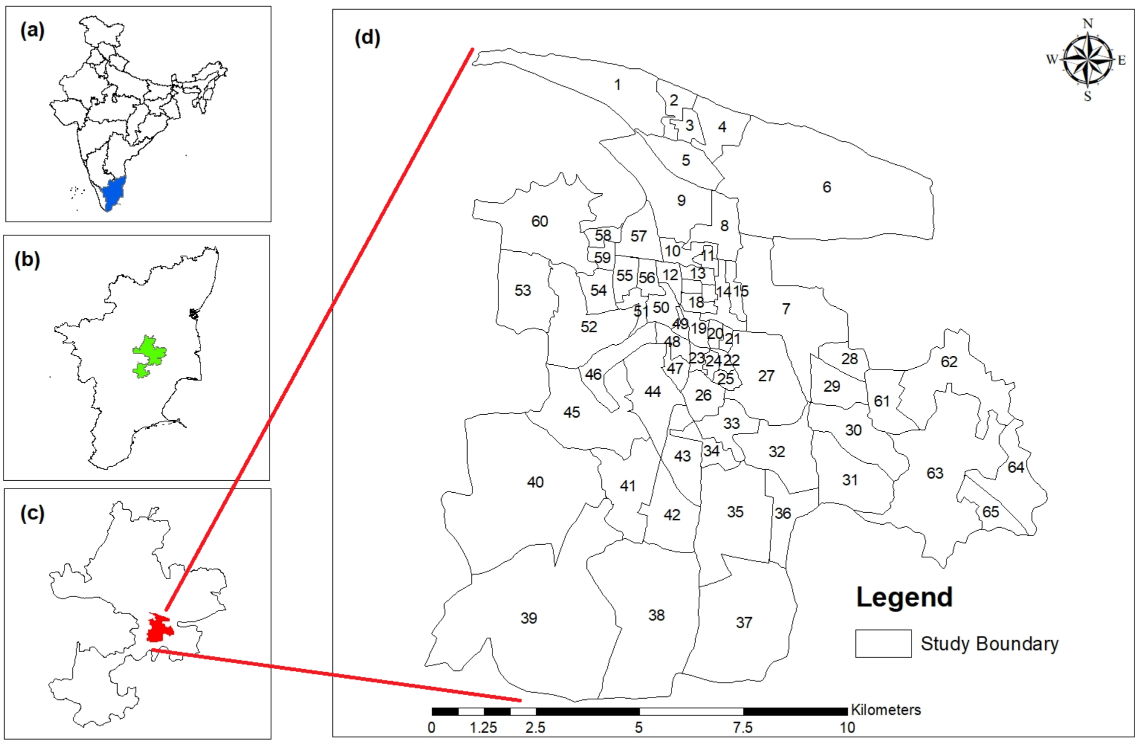

Fig. 1 Location Map of the study area: (a) location of Tamil Nadu in India (b) location of Tiruchirappalli District in Tamil Nadu (c) location of ward boundaries in Tiruchirappalli District (d) Location of 65 Wards of Tiruchirappalli city

S. No.	Zones	Wards	Total Number of Wards
1	Srirangam	1-6, 8-13, 16-18	15
2	Ariyamangalam	7, 14, 15, 19-29, 33, 61, 62, 64	18
3	Abisekapuram	40, 41, 45, 49-60	15
4	Golden Rock	30-32, 34-39, 42-44, 46, 48, 63, 65	17
		Total	65

Tab. 1 Classification of 4 Zones and 65 Wards in Tiruchirappalli City

3.2 Methodology

The following methodology was adopted for estimating the accessibility of hospitals in the city (Figure 2). The first step to any analysis involves thorough data collection. For the analysis of accessibility index, the collection of data was done two-fold, i.e. Non-Spatial data and Spatial Data.

The study of access to healthcare needs non-spatial data such as population, details of healthcare within the study area and suitable questionnaire survey. Since the database of private healthcare was not available with any particular organization, manual workplace survey was conducted. For the current research, the data for all multi-specialty hospitals of the study area was collected during September - October 2016. The workplace survey included information on infrastructure details of each healthcare facility in terms of name of the healthcare, address, healthcare specialty, number of doctors and beds, availability of Intensive Care Unit, Ambulance service and Pharmacy, distance to the main road and bus stop and time of operation. Similarly, a detailed survey of patients was also conducted to obtain information such as patient's residence, number of hospital visits, travel time and distance from home to healthcare center, starting time from home, mode of travel, household income, education qualification and their assessment of each of the factors affecting the accessibility (Schuurman et al., 2010; Sengupta, 2013).

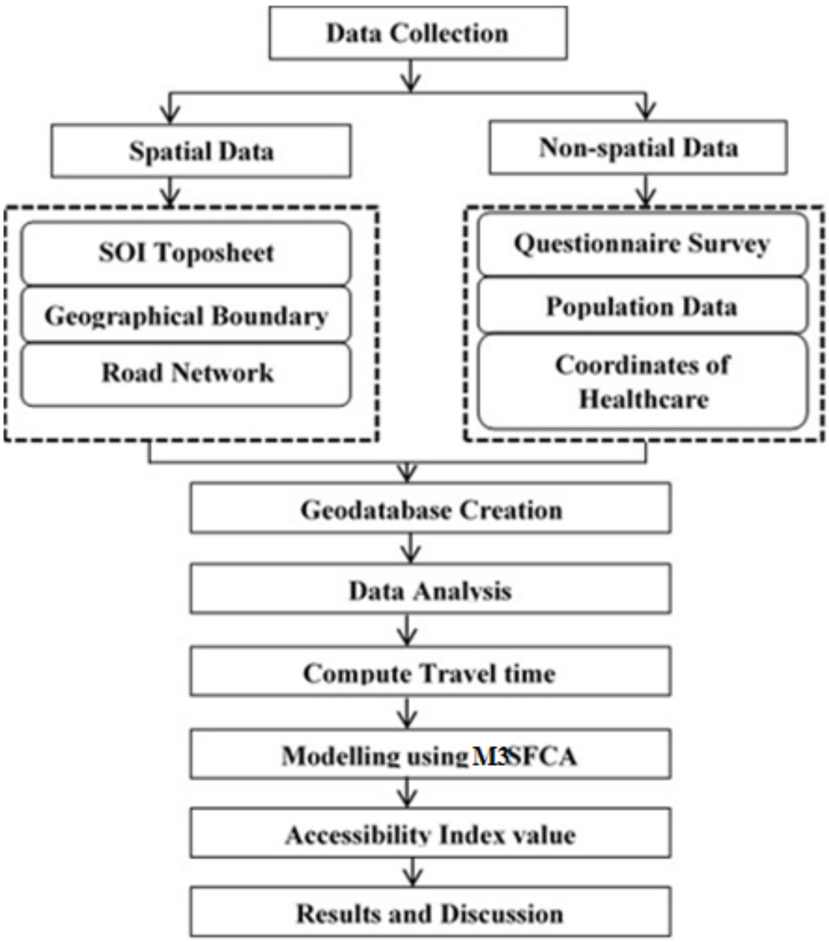

Fig. 2 Methodology of Accessibility Index

The gathered details were then used to confer weights for each factor to be considered for accessibility estimation. For collecting the data, quota sampling method was used to gather information from a particular group of people utilizing the healthcare services. A sample size of 5% of the total population size of people who visited a particular hospital on the previous day was taken. This sample size was then taken as a representation of the entire population of the study area.

Population is considered as a prime demand factor that influences the supply and demand ratio in accessibility analysis. The ward level population data for the study area for a time span of three decades, from 1991 to 2011 was collected from the Department of Statistics, Tiruchirappalli.

The spatial data for accessibility of healthcare facilities includes the ward map of the study area, the location of habitat, the location of healthcare facilities and spatial layout of the transportation system, i.e. the road network. These data are collected using satellite images, GPS and SOI toposheets. Incorporating these required data into modified three-step floating catchment area method for computing the accessibility index of the city.

4. Result and Discussion

4.1 Forecasting Population

The questionnaire survey was conducted for the year 2016, further analysis to determine accessibility requires the population data for that year. The available population data for three decades collected from the statistics department was thus used for forecasting the population for the year 2016. Fig. 4 shows the population data for the three decades (1991, 2001 and 2011) in a graphical map created from the data collected. The Incremental Increase method is used for forecasting (Radhakrishnan et al., 2014) the population for the year 2016 is shown in Fig. 3.

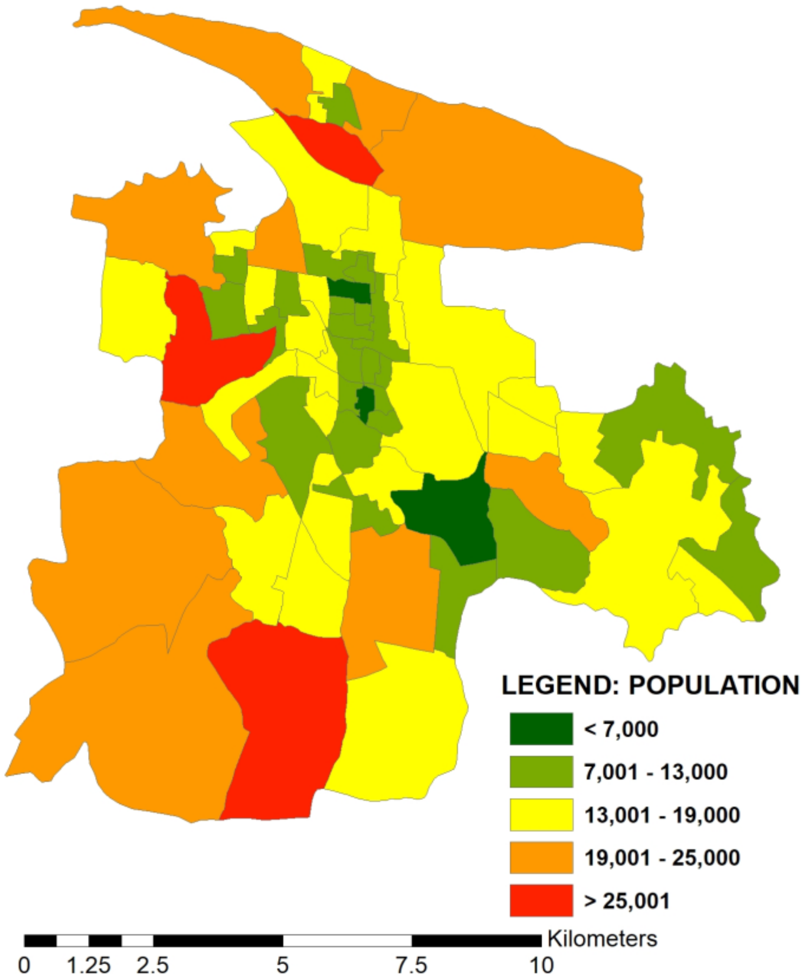

Fig. 3 Forecasted 2016 Population

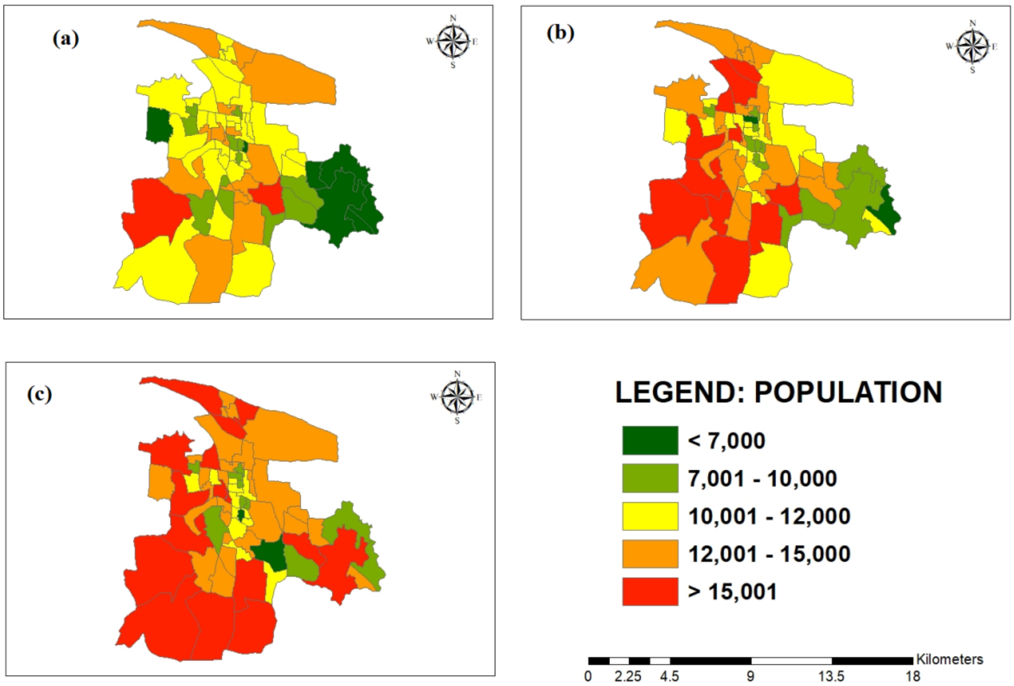

Fig. 4 Spatial distribution of the population for three decades of (a) 1991 (b) 2001 and (c)2011

4.2 Thematic Layers

The boundary of the ward map of study area was geo-referenced and ground control points were selected, the coordinates of which were taken using handheld GPS or Survey of India Toposheets. These 65 wards were digitized and from this, the location of habitat was established, which was taken as the centroid of the ward as shown in Fig. 5. The locations of healthcare centers on the digitized map were established by estimating their coordinates by ground survey using GPS as shown in Fig. 6. The road network including highways, arterial and sub-arterial roads were extracted as shown in Fig. 7 from high resolution image - Quick Bird Satellite image (0.61 m resolution), using ArcGIS 10.4 software. Origin-Destination network travel time was computed using network analysis tool available in ArcGIS software (ESRI, 2014).

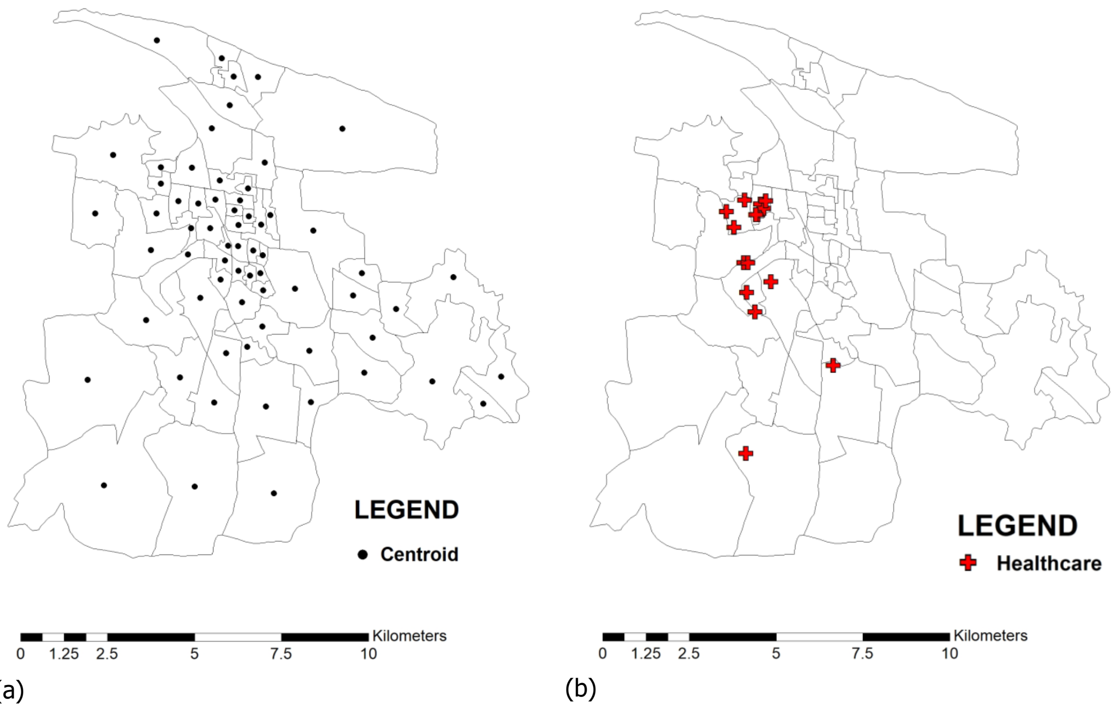

Fig. 5 (a) Origin Location Map (Centroid of Wards) and (b) Destination Location Map (Healthcare Centres)

The travel time data was obtained by using the OD cost matrix tool with input such as network dataset, origin point data, destination point data, nodes, turning parameter and speed of each network link in GIS environment. On applying the tool, two outputs were obtained, one with distance as the impedance and the other with travel time as the impedance. When impedance was taken as distance, then the matrix obtained was called Distance OD matrix and with Travel time as impedance, Travel Time OD matrix was obtained. For this study, only the travel time impedance was considered for accessibility analysis. For obtaining the travel time OD matrix, different speed limits from 30 to 60 km/h were assigned for different routes. This travel time OD matrix was taken into consideration along with the M3SFCA for estimating accessibility index.

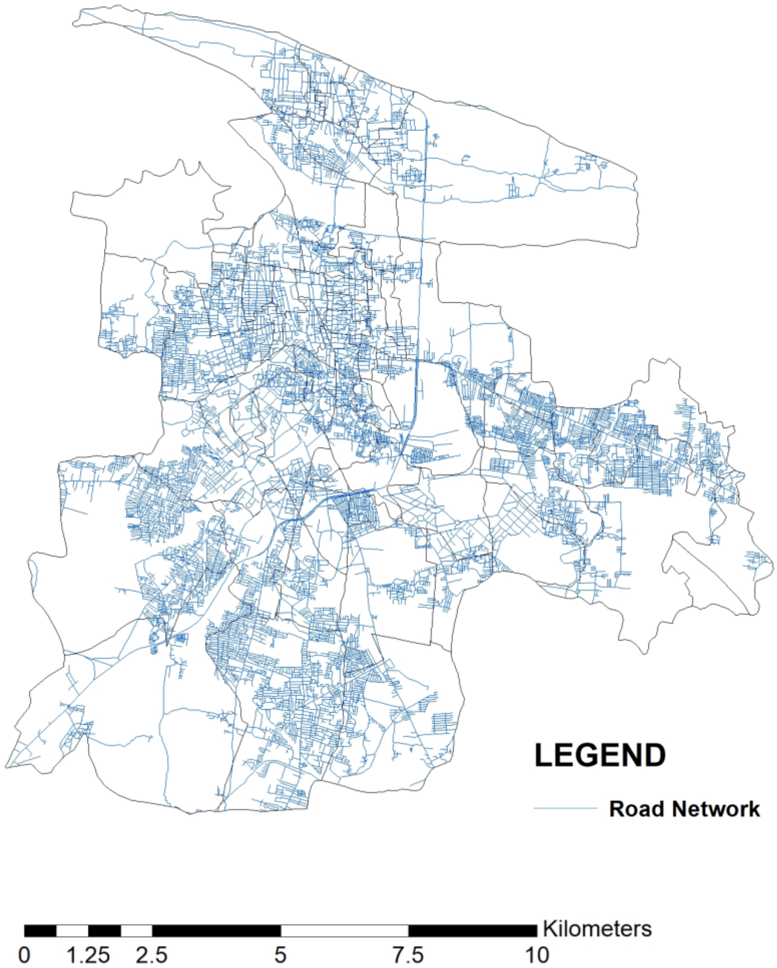

Fig. 7 Road Network Map of Trichy city

4.3 Reliability Analysis

The data collected through questionnaire survey has to be analyzed to determine its reliability. The data was passed through a reliability test. The questionnaire data collected was analyzed thoroughly with respect to the factors selected for accessibility analysis and the internal consistency of factors was examined by reliability analysis using statistical software. This test gives a measure of how well the items are inter-correlated as a group. In reliability analysis, Cronbach's alpha test was used to measure the reliability.

The reliability analysis was carried out in SPSS 10 with six selected variables to analyze the internal consistency of the data collected, namely infrastructure of the hospital, emergency services within the hospitals, ease of access, number of physicians in the hospital, distance from each ward centroid to hospital and household income. This analysis was performed on 358 samples collected and the Cronbach's alpha index was estimated. The analysis having Cronbach's alpha index less than 0.5 was considered unsuitable. From the analysis of data collected from survey conducted, a value of 0.601 was obtained for Cronbach's alpha index as shown in Table 2, which was observed to fall within the range of 0.6 to 0.8, making the data collected fit for the study.

Case Processing Summary

Cases	Valid	358	100
	Excluded	0	0
	Total	358	100
Reliability Statistics			
Cronbach's Alpha		N° of items	
0.601		6	

Tab. 2 Reliability statistics of data

4.4 Accessibility Analysis using M3SFCA method

The accessibility index is computed by four steps as described in section 2.1. In step 1, formulating travel impedance matrix: Coefficient value for each factor were derived from the survey conducted in 16 healthcare centers and incorporated to derive a model to estimate a travel impedance weights for each healthcare center to census tracts centroid, as given in Eq. 5.

$$f(d_{ij}) = 0.205x_1 + 0.183x_2 + 0.184x_3 + 0.205x_4 + 0.223x_5 \tag{5}$$

Hence, the impedance score is allotted for each trip between census tracts and healthcare facilities.
In step 2, selecting catchment size: From the trip statistics (Fig. 8), it was observed that as the travel time increased, the number of medical trips decreased exponentially. This implies that people prefer to go to the nearest medical facility rather than that located far away. From the data collected by the survey, the average travel time for the medical trips in Trichy city was obtained as 21 minutes. From the cumulative trip frequency versus travel time (obtained from questionnaire survey) (Fig. 9), it was noted that 75% of the trips took less than 30 minutes. Therefore, based on the total data collected, the trip statistics and the cumulative frequency results, the catchment area was taken as 30 minutes for computation of M3SFCA. The travel impedance of the trips having travel time more than 30 min considered to be zero, trips falling within 10 min assigned one as score, and rest of the trips falling between 10 min and 30 min computed by the inverse power function.

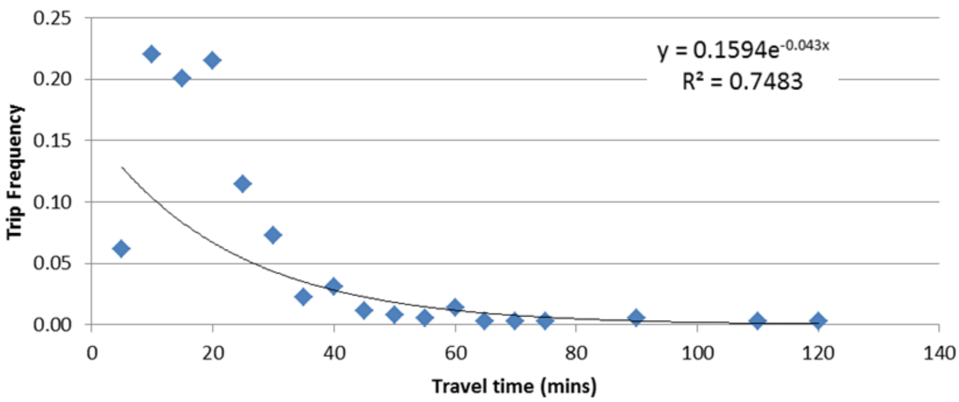

Fig. 8 Travel time versus Trip Frequency

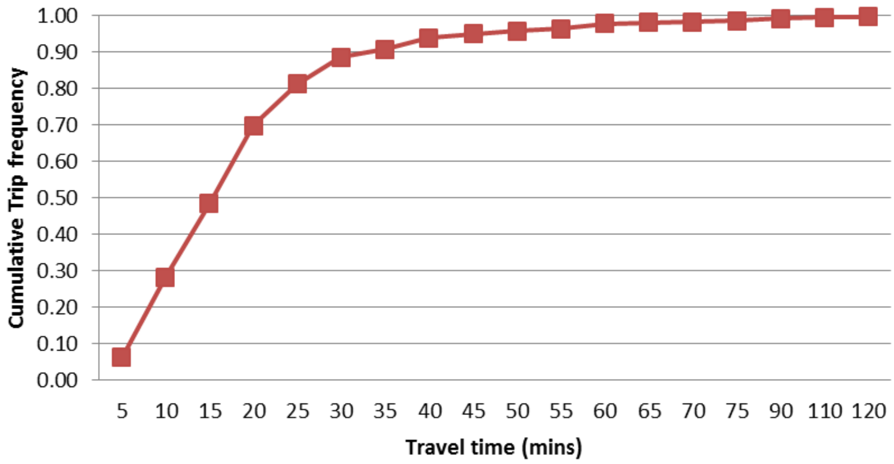

Fig. 9 Cumulative Trip Frequency versus Travel Time

In step 3, computing supply and demand ratio (R_j): This is computed using Eq. 3 gives a provider to population ratio in which the numerator describes healthcare service capacity and the denominator is the summation of the product of population of the census tracts, travel impedance of the corresponding census tracts covered within threshold distance and the competition weight. The R_j value of each healthcare center is shown in Tab. 3. This value defines each healthcare center's capacity to serve the population. The maximum value of R_j suggests that a particular hospital has more capacity to accommodate the patients within the threshold distance whereas a minimum value indicates a higher demand and the need to improve the healthcare facilities to meet the demand of the patients within the threshold distance.

Si. No.	Hospital	Score	Si. No.	Hospital	Score
1	KMCH (cant)	53.742	9	Royal Pearl	16.312
2	Wellcare	15.014	10	SVH	3.807
3	Arul	15.875	11	Tilak	2.462
4	Child Jesus	50.501	12	CSI	36.209
5	Geetanjali	5.034	13	Cethar	21.835
6	GVN	51.525	14	Apollo	60.722
7	Maruti	37.556	15	Vijaya	3.714
8	Nalam	10.677	16	Ananthagiri	9.291

Tab. 3 Physician to population ratio (Rj)

In step 4, computing Accessibility Index: It was estimated for all the wards and this is graphically represented in Fig. 10. The areas closer to the hospitals having higher accessibility are denoted by red whereas the ones distant from the hospitals with lesser accessibility are denoted by pink.

The spatial variation of accessibility shows that hospitals were more concentrated towards the center of the city and the most important variable affecting accessibility was the distance. It was observed that healthcare centers were collectively located in the K. Abishekapuram north and Srirangam zones in the city center where the traffic was more congested, due to which a patient took more time to reach the healthcare site.

The main issue therefore was the lack of quick access to healthcare centers in case of emergency situations. The other zones, namely Ariyamangalam and Ponnmalai were observed to be served less with healthcare services. Wards located in the outskirts of the city were observed to have minimal access to healthcare services. Accessibility could also be low because of poor infrastructure of hospital, location of hospital in the city or due to longer distance. Based on accessibility values, all the wards in Tiruchirappalli were ranked, to reliably identify the over served and underserved regions in the city.

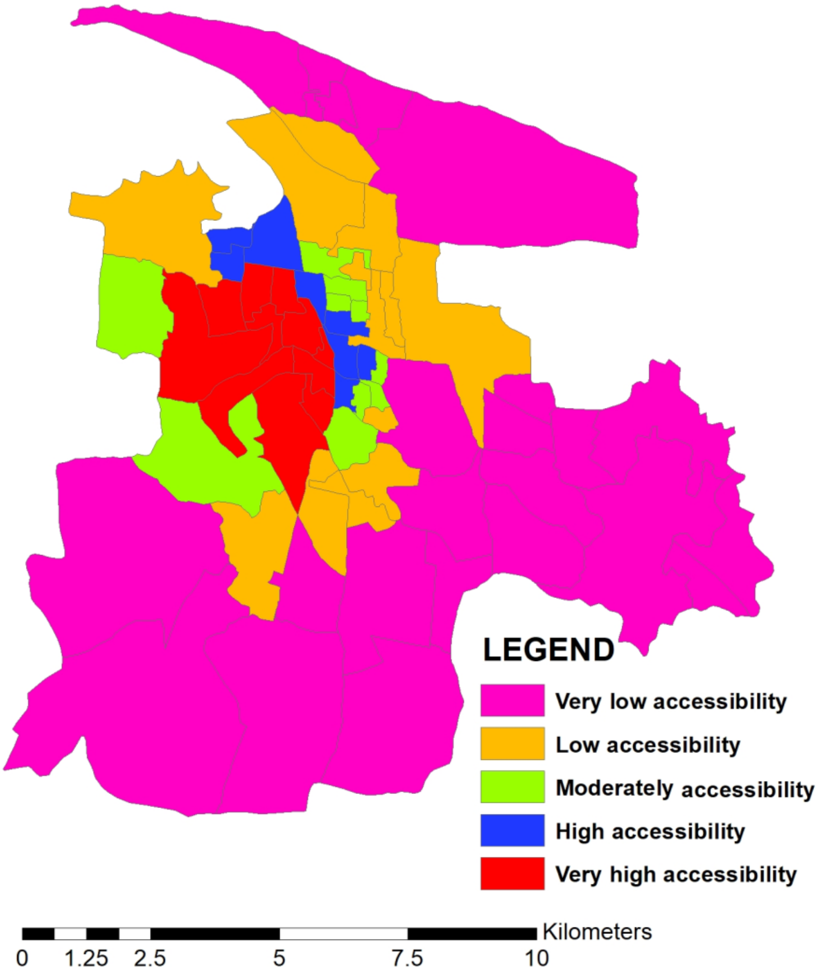

Fig. 10 Accessibility Index map

5. Conclusion

An attempt has been made to define the measure of the accessibility of urban residents to the existing multi-specialist hospitals in Tiruchirappalli, a medium-sized city. The study tries to integrate geospatial techniques and a modified gravity model approach to identify the capacity of a hospital to meet the demand of the increasing population based on many connected factors; it also identifies deprived census tracts for healthcare access in terms of accessibility index. The analysis of the study shows that within the city, there are spatial disparities in the distribution of population, related demographic and socio-economic characteristics. The existing healthcare facilities are also not evenly spread spatially across the study area but concentrated in a few wards of the city with almost all of them located near the city center, where maximum population density is also seen. In the event of an emergency or need for immediate specialized care, more than half the population of the city will have to travel for almost 60 minutes to reach best and quality healthcare services. The regions with low accessibility index and high percentage of population face similar difficulties as those of areas lacking healthcare facilities.

Through this study, an attempt has been made to define the potential of this new Modified Three-step floating catchment area in computing the measure of ease of access to healthcare facilities from each census tracts. The improvement of this model is that it takes into account several factors such as infrastructure, emergency services, ease of access and number of physicians in addition to the other usual factors like distance between the healthcare service site and population site. The disadvantage of this method is that it fails to address the overestimation problem, i.e. demand for one service site is always lowered by the other service site located near to it. Research studies in future overestimation issues to obtain a more efficient model. The proposed model has to be validated with the previous model for the performance analysis and reported in next phase of the research. This will be very helpful in planning for future development or further expansion of the healthcare facilities in the localities and to improve the ease of access for residential areas. In reality, complete equal access is not always possible, but it is necessary to plan and construct a scheme of healthcare and wellness facilities in such a manner that it permits the maximum accessibility for a maximum number of people at any given point of time. It is important to look at not only the distribution of healthcare facilities and population but also the socio-economic conditions of the residents of the surrounding areas.

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References

Aday, L. A., & Andersen, R. (1974), A Framework for the Study of Access to Medical Care, *Health Services Research*, 9(3), 208–220. https://doi.org/10.3205/psm000089

Ahmad, S. (2012), A GIS based investigation of spatial accessibility to health care facilities by local communities within an urban fringe area of Melbourne, *Research Repository*, Thesis. Retrieved from https://researchbank.rmit.edu.au /view/rmit:160354

Andrulis, D.P., 1998, Access to care is the centerpiece in the elimination of socioeconomic disparities in health, *Annals of Internal Medicine*, 129, 412–416.

Apparicio, P., Abdelmajid, M., Riva, M., & Shearmur, R. (2008), Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues, *International Journal of Health Geographics*, 7, 1–14. https://doi.org/10.1186/1476-072X-7-7

Bai, J. (2013), Accessibility to essential services and facilities by aged population in the local government area of Monash: a GIS-based case study, *RMIT University*, Thesis. Retrieved from https://researchbank.rmit.edu.au/eserv/ rmit:161177/Bai.pdf

Baru, R. V, Acharya, A., Acharya, S., Shiva Kumar, A., & Nagaraj, K. (2010), Inequities in Access to Health Services in India, *Economic & Political Weekly*, xlv (38), 49–58. https://doi.org/10.2307/25742094

Chand, R., Das, B., Awasthi, D. P., & Bisht, R. (2013), Heath and Family Welfare Statistics in India, 2013, *Statistic Divisions, Ministry of Health and Family Welfare*. Retrieved from: file:///C:/Users/Administrator/Downloads/Preface%20and%20Table%20of%20Contents.pdf

Dejen, A., Soni, S., & Semaw, F. (2019), Spatial accessibility analysis of healthcare service centers in Gamo Gofa Zone, Ethiopia through Geospatial technique, *Remote Sensing Applications: Society and Environment*, 13(January), 466–473. https://doi.org/10.1016/j.rsase.2019.01.004

Environmental Systems Research Institute (ESRI), 2014. Make OD cost matrix layer (Network Analyst) [online]. Retrieved from: http://desktop.arcgis.com/en/arcmap/10.4/extensions/network-analyst/od-cost-matrix.htm

Gaglione, F., Gargiulo, C. & Zucaro, F. (2019). Elders' quality of life. A method to optimize pedestrian accessibility to urban services. *Tema. Journal of Land Use, Mobility and Environment*, 12(3), 295-312. http://dx.doi.org/10.6092/1970-9870/6272

Gargiulo, C., Zucaro, F. & Gaglione, F. (2018). A Set of Variables for Elderly Accessibility in Urban Areas. *Tema. Journal of Land Use, Mobility and Environment*, 53-66. http://dx.doi.org/10.6092/1970-9870/5738

Geurs, K. T., & van Wee, B. (2004), Accessibility evaluation of land-use and transport strategies: Review and research directions, *Journal of Transport Geography,* 12(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Gu, T., Li, L., & Li, D. (2018), A two-stage spatial allocation model for elderly healthcare facilities in large-scale affordable housing communities: A case study in Nanjing City*, International Journal for Equity in Health,* 17(1), 1–13. https://doi.org/10.1186/s12939-018-0898-6

Guagliardo, M., 2004, Spatial accessibility of primary care: concepts, methods and challenges, *International Journal of Health Geographics,* 3, 1–13.

Higgs, G. (2004), A Literature Review of the Use of GIS-Based Measures of Access to Health Care Services, *Health Services & Outcomes Research Methodology*, 5, 119–139. https://doi.org/10.1007/s10742-005-4304-7

Horton, R., & Das, P. (2011), Indian health: The path from crisis to progress*, The Lancet*, 377(9761), 181–183. https://doi.org/10.1016/S0140-6736(10)62179-4

Lagu, T., Iezzoni, L. I., & Lindenauer, P. K. (2014), The Axes of Access -- Improving Care for Patients with Disabilities, *The New England Journal of Medicine*, 370(19), 1847–1851. https://doi.org/doi:10.1056/NEJMsb1315940

Liu, S., & Zhu, X. (2004), Accessibility Analyst: An integrated GIS tool for accessibility analysis in urban transportation planning, *Environment and Planning B: Planning and Design*, 31(1), 105–124. https://doi.org/10.1068/b305

Lu Wang. (2011), Analysing spatial accessibility to health care : a case study of access by different immigrant groups to primary care physicians in Toronto, *Annals of GIS* 5683(April 2013), 37–41.

Luo, W. (2004), Using a GIS-based floating catchment method to assess areas with shortage of physicians*, Health and Place,* 10(1), 1–11. https://doi.org/10.1016/S1353-8292(02)00067-9

Luo, W., & Qi, Y. (2009), An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians*, Health and Place*, 15(4), 1100–1107. https://doi.org/10.1016/j.healthplace.2009.06.002

Luo, W., & Wang, F. (2003), Measures of spatial accessibility to health care in a GIS environment: Synthesis and a case study in the Chicago region*, Environment and Planning B: Planning and Design*, 30(6), 865–884. https://doi.org/10.1068/b29120

Mahesa, R., Yudoko, G., & Anggoro, Y. (2019), Dataset on the sustainable smart city development in Indonesia. *Data in Brief*, *25*, 104098. https://doi.org/10.1016/j.dib.2019.104098

McLafferty, S. L. (2003), GIS and Health Care*, Annual Review of Public Health*, 24(1), 25–42. https://doi.org/10.1146/annurev.publhealth.24.012902.141012

Meşhur, H., F., A. (2016). Evaluation of Urban Spaces from the Perspective of Universal Design Principles: The Case of Konya/Turkey. *Tema. Journal of Land Use, Mobility and Environment,* 9 (2), 191-208. doi: http://10.6092/1970-9870/3786

Penchansky, R. and J. W. Thomas (1981). The concept of access. Definition and relationship to consumer satisfaction. *Medical Care*. 19(2). 127-140.

Qadeer, I. (2011), The challenge of building rural health services*, Indian Journal of Medical Research*, 134(11), 591–593. https://doi.org/10.4103/0971-5916.90982

Radhakrishnan, N., Eerni, S. K., & Kumar, S. (2014*),* Analysis of Urban Sprawl Pattern in Tiruchirappalli City Using Applications of Remote Sensing and GIS, *Arabian Journal for Science and Engineering,* 39(7), 5555–5563. https://doi.org/10.1007/s13369-014-1099-2

Radke, J., & Mu, L. (2000), Spatial decompositions, modelling and mapping service regions to predict access to social programs*, Geographic Information Sciences*. https://doi.org/10.1080/10824000009480538

Ranga, V., & Panda, P. (2014), Spatial access to in-patient health care in northern rural India*, Geospatial Health*, 8(2), 545–556. https://doi.org/10.4081/gh.2014.44

Ravi, S. M., & Ias, K. (2014), District statistical Handbook, *Deputy Director of Statistics*. Retrieved from: https://cdn.s3waas.gov.in/s3f73b76ce8949fe29bf2a537cfa420e8f/uploads/2018/06/2018061440.pdf

Ray, P., & Biswas, B. (2009), Role of service sector information for micro-planning: a case study*, Annals of Library and Information Studies (ALIS)*, 56(4), 267–272.

Rekha, R. S., Radhakrishnan, N., & Mathew, S. (2020), Spatial Accessibility Analysis of Schools using Geospatial Techniques*, Spatial Information Research, 27*, 1163–1170. https://doi.org/10.1007/s41324-020-00326-w

Rekha, R. S., Wajid, S., Radhakrishnan, N., & Mathew, S. (2017), Accessibility Analysis of Health care facility using Geospatial Techniques*, Transportation Research Procedia*, *27*, 1163–1170. https://doi.org/10.1016/j.trpro.2017.12.078

Schuurman, N., Bérubé, M., & Crooks, V. A. (2010), Measuring potential spatial access to primary health care physicians using a modified gravity model*, Canadian Geographer*, 54(1), 29–45. https://doi.org/10.1111/j.1541-0064.2009.00301.x

Sengupta, A. (2013), Universal health care in India: Making it public, making it a reality, (19), 23. Retrieved from http://www.municipalservicesproject.org/sites/municipalservicesproject.org/files/publications/Sengupta_Universal_Health_Care_in_India_Making_it_Public_May2013.pdf

Wan, N., Zou, B., & Sternberg, T. (2012), A three-step floating catchment area method for analyzing spatial access to health services, *International Journal of Geographical Information Science*, 26(6), 1073–1089. https://doi.org/10.1080/13658816.2011.624987

Ye, H., & Kim, H. (2014), Measuring Spatial Health Disparity Using a Network-Based Accessibility Index Method in a GIS Environment : A Case Study of Hillsborough Measuring Spatial Health Disparity Using a Network-Based Accessibility, *International Journal of Geospatial and Environmental Research*, 1(1), Retrieved from http://dc.uwm.edu/ijger/vol1/iss1/2

Zali, N., Rahimpoor, M., Saed Benab, S., Molavi, M., Mohammadpour, S. (2016). The distribution of public services from the perspective of spatial equality. *Tema. Journal of Land Use, Mobility and Environment,* 9 (3), 287-304. http://dx.doi.org/10.6092/1970-9870/3976

Image Sources

Fig. 1: Location Map of the study area: (a) location of Tamil Nadu in India (b) location of Tiruchirappalli District in Tamil Nadu (c) location of ward boundaries in Tiruchirappalli District (d) Location of 65 Wards of Tiruchirappalli city;

Fig. 2: Methodology of Accessibility Index;

Fig. 3: Spatial distribution of the population for three decades of (a) 1991 (b) 2001 and (c)2011;

Fig. 4: Forecasted 2016 Population;

Fig. 5: Origin Location Map (Centroid of Wards);

Fig. 6: Destination Location Map (Healthcare Centres);

Fig. 7: Road Network Map of Trichy city;

Fig. 8: Travel time versus Trip Frequency;

Fig. 9: Cumulative Trip Frequency versus Travel Time;

Fig. 10: Accessibility Index map.

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