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Road network accessibility analysis using graph theory and GIS technology: a study of the villages of English Bazar Block, India

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Abstract English Bazar municipality serves quality educational, health, marketing, recreational, administrative, and other urban facilities to the people of urban areas as well as rural areas of its surrounding. Over the last few decades, the study area experiences rapid population growth and positive economic changes. As a result, on a daily basis a huge quantity of goods and population flow within and outside the municipality. It creates high transportation demand for accessing the urban facilities. The roads and railway line radiate from the centre of the municipality towards the villages of this block and other adjacent blocks of the district. The aim of this paper is to analyze the road connectivity and network accessibility of the study villages using graph theory. Moreover, connectivity index, shimbel index, associated number, and average shortest path length have also been used for categorically understanding the magnitude of network accessibility. The result shows regional imbalances in terms of connectivity and network accessibility. Villages are located in the central position and adjacent to the English Bazar municipality (EBM) are most accessible. However, the distant villages which are far from the EBM having poor accessibility and poor road network efficiency. Therefore it would suggest that there is a need to improve the connectivity and accessibility of those distant villages for future growth and development of the study region.

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1 Introduction

Rural economic development is stimulated by the improved rural transportation and communication infrastructure [1]. Besides endogenous and exogenous development, diverse forms of rural development can be understood by network analysis [2]. The network is a set of nodes or vertices joined together by edges where vertices occupy particular positions in space and edges in these networks are real physical constructs, such as roads or railway lines in transportation networks [3]. Social and economic development largely influenced by road networks and it is a crucial component of public infrastructure [4]. When new roads are constructed or previous existing roads widened repairs, it would lead to decreases travel coast which also increases the accessibility of the zones. Thus increasing accessibility leads to change in the population and employment distribution [5]. For working at different places, the transport network is an important medium for human society [6]. The developed transport infrastructure has direct positive implications on spatial accessibility at both the national and international levels [7]. Assessing the accessibility in a particular region is one of the important aspects as it defines the road network performance [8]. Though accessibility is a very important aspect for understanding the transport issues but is difficult and hard to define accessibility [9]. Many kinds of literatures try to define network accessibility, such as "accessibility is the extent to which spatial separation can be overcome". Accessibility controls the spatial distribution of economic activities and the development of any region [10]. A simple definition of accessibility was given by Al-Sahili and Aboul-Ella [11] where "accessibility indicates the spatial relation between one location and others, or the degree of connection between that location and all others in a region". The concept of accessibility occupies the central position in transportation and regional research [12]. Accessibility is an essential measure to determine the level of connectivity and evaluating travel opportunities. Accessibility is the multidimensional concept that includes different measures such as network connectivity and node accessibility. Various measures have been used to identify the level of connectivity and nodal accessibility [13]. Garrison [14] introduces several measures of connectivity (i.e., beta index, association number, alpha index, gamma index) and accessibility indices (Shimbel index and nodal degree). Not only big cities but rural areas also experienced growth in economic activities which stimulate or expand the markets and as a consequence new road transportation system has been developed. The road is considered as blood of human civilization which has a positive impact on social interaction and economic prosperity in space [15]. Regional road development leads to the overall economic growth of the region and thus rural poverty reduced [16].

Graph theory model has been frequently used by the researchers for studding transport networks of any region [17]. For example, Chen et al. [14] analyzed the connectivity and accessibility of the Guangzhou metropolitan network of China using the Spatio-temporal modelling approach. Alpha index, beta index, cyclomatic number, and gamma index are used to showing the growth of the metro network. Tini and Shah [18] conducted a Geographical Information System (GIS) technology and Grid Tree Pattern (GTP) metrics to based study for understanding the topological formation of network in Abuja Municipality, Nigeria. Freiria et al. [19] identified the most important road network, the pattern of the road network of Spain based on its structural properties. Ford et al. [20] analyzed transport accessibility by various transport modes using GIS technology in London. Handy and Niemeier [21] in San Francisco (USA), study the network accessibility on local and regional scales using different measures of accessibility such as gravity-based measures, utility-based measures etc. Kim and Song [22] assess the performance of the network and vulnerability of the Seoul metro network using an integrated measure such as Integrated Accessibility and Reliability indicators (ACCREL). Koenig [23] explore relationship between the network accessibility and the trip rate in French cities and suggest that the trip rate is strongly determined by the accessibility of these cities. Liu and Zhu [24] focused on an integrated GIS approach for accessibility analysis for transportation planning in the Choa Chu Kang-Bukit panjang area, Singapore. The integrated GIS approach can integrate the functionality of GIS, formulation of Origin Destination (OD) matrix, and measures of accessibility of any region. Reggiani et al. [25] mapping the transport accessibility in Germany using exponential decay function, exponential-square root decay function, log-normal decay function, and power-decay function. Spence and Linneker [26] review the impact of motorway construction on changes of accessibility within the urban system in Great Britain using standard market potential accessibility measures. Xie and Levinson [27] measure the structure of road networks by assessing entropy, ringness, webness, beltness, circuitness, and treeness. Dill [28] examines the connectivity of Oregon regional network by using Street Network Density (miles per square mile), Connected Node Ratio, Intersection Density, and Link-Node Ratio methods. Abbas and Hashidu [29] inspected the network connectivity and accessibility in North-East Nigeria by using Shortest Path Matrix, the Associated Number Index, and the Shimbel index beside these, gamma, beta, and alpha indices are also calculated. Porta et al. [30] introduce Multiple Centrality Assessment (MCA) to probe the network of four 1-square-mile samples of urban street systems [(1) Ahmedabad, (2) Venice, (3) Richmond, and (4) Walnut Creek]. Olawale and Adesina [31] analyzed the relationship between connectivity of road network and tourist of Patronage in Lokoja Metropolis using Shimbel index, Gamma index, Percentages, graphs and Pearson Moment Correlation. Mavoa et al. [32] try to explain the accessibility via public transit in Auckland, New Zealand using public transit and walking accessibility index (PTWAI). Linneker and Spence [33] compare the Market-potential accessibility measure and the Access-cost accessibility measures for measuring the impact of M25 London Orbital Motorway on Britain. Murayama [34] using a time distance matrix and shimbel index to identify the impact of railways on accessibility in the Japanese urban system. Kofi [35] prioritize the location of an urban transport connection of Istanbul by using the measure of Alpha, beta, gamma, pi, theta, and detour index. Black and Conroy [36] used graphical measures of physical accessibility, physical accessibility indices, and resident's accessibility weighted for showing the transport availability and understanding the relationship between accessibility and travel behaviour in Sydney, Australia.

Curtailment to the topological properties of the transport network is the major disadvantages of using these indices. The on-field characteristic, nature of topography, mode of transportation and construction cost are excluding in this indices as these are important properties of measuring connectivity and network accessibility.

The main objective of this paper is to analyze the road network accessibility of the villages of English Bazar Block of Malda district. In this paper it is trying to demarcate the well accessible and worse accessible villages in the study area for future planning purposes. For identifying these, several maps were prepared based on shimbel index, average shortest path length and associated number, connectivity index. For determining the overall connectivity of the villages several network indices such as alpha, beta, gamma, pi, theta, degree of connectivity, grid tree pattern index, and cyclomatic number have also been used in this present study.

2 Study area

The English Bazar Block is bounded by 24° 50′ N to 25° 05′ N latitude and 88° 0′ E to 88° 10′ E longitude (Fig. 1). Villages in this block are connected with fertile alluvial land of Manikchak, Kaliachak I, and II in the West and North West by metalled roads and railway lines, and the villages are also connected with English Bazar and Old Malda a urban agglomerated area by road and railway line (Fig. 2). The rural area covering 235.79 km^2 and the total rural population of this block is 242,797 according to the 2011 census. Large villages (with 4000 + population) in English Bazar Block were Utter Chandipur, Bhabanipur, Atgama, Niamatpur, Khaskol, Sattari, Phulbaria, Nagharia, Lakshmighat, Jot Basanta, Anandipur, Madapur, Utter Jadupur, Dakshin Jadupur, Bara Phulbari, Tiakati and Mahadipur. Census towns of this block were Milki, Sonatala, and Bagbari. This block consists of 135 villages and 1 municipal area. English Bazar Municipality (EBM) is situated on the right bank of the Mahananda River and it is the district headquarter. The average density of the population of villages is 1030 people per km^2. The decadal growth rate of this block is 21.39% from 2001 to 2011. Malda district has a good trading relationship with neighbouring country Bangladesh through Mahadipur. Mango, silk, and jute are the main products that Malda export to Bangladesh. To access better education, marketing, banking, health, and other facilities, people are migrating from the villages to the municipal area. Malda Town railway station is located in the English Bazar municipality and it serves as a connecting point with adjoining district and other states in India. The villages and Municipality served by NH 34 and State Highway 10. These roads are connecting the production areas and there are so many metalled and non-metalled roadways that connect this block with other districts in West Bengal. The recent study is mainly focusing on the level of accessibility of the villages of English Bazar Block.

3 Data source and methodology

The movement of goods and services largely depends on the transport system and thus it stimulates the development of the economic and social sector. As a result, the transport system is essential for any region of the world. Improved road systems enhance the accessibility and mobility and thus travel time and travel costs both reduce significantly [37]. Socio-economic developments like access to education, health facilities, employment opportunities, household income, and reduction of poverty are associated with the improvement of the road network [38]. Nodes or vertices and edges are important elements which show the degree of accessibility [29]. Malda district situated in the central part and connects both north and south Bengal of West Bengal, as a result, the road network plays a vital role in the development process. To fulfil the objective of this paper, the recent study used some secondary data sources like village level map of English Bazar Block from Census of India, 2011 and validation of map done through Google earth image and data regarding population, the density of population, decadal growth rate, area are also collected from Census of India, 2011.

Firstly, the location map was collected from the Census of India, 2011. From this map, all villages of English Bazar Block were manually digitized after geo-referencing the map in Arc GIS v.10.5 software. The World Geodetic System (WGS) 1984 along Universal Transverse Mercator (UTM) zone was used for georeferencing the map. The roads were manually digitized from Google Earth images. Then a network dataset prepared by creating nodes and arcs in the study villages. For calculating different indices, the nodes and arcs were carefully counted. For identifying the accessibility and connectivity of 135 villages' different measures such as the Connectivity index, Shimbel index, Associated number, and Average Shortest Path Length were computed in Microsoft Excel v.2007. For better understanding, maps are produced by using Inverse Distance Weighted (IDW) method in the ArcGIS platform and these maps are very efficient for identifying the most accessible and most efficient network zones in the study area [39]. Figure 3 is showing the flowchart of the present study.

3.1 Application of network indices based on graph theory

Based on graph theory, various network indices are applied to evaluate the accessibility and performance of the

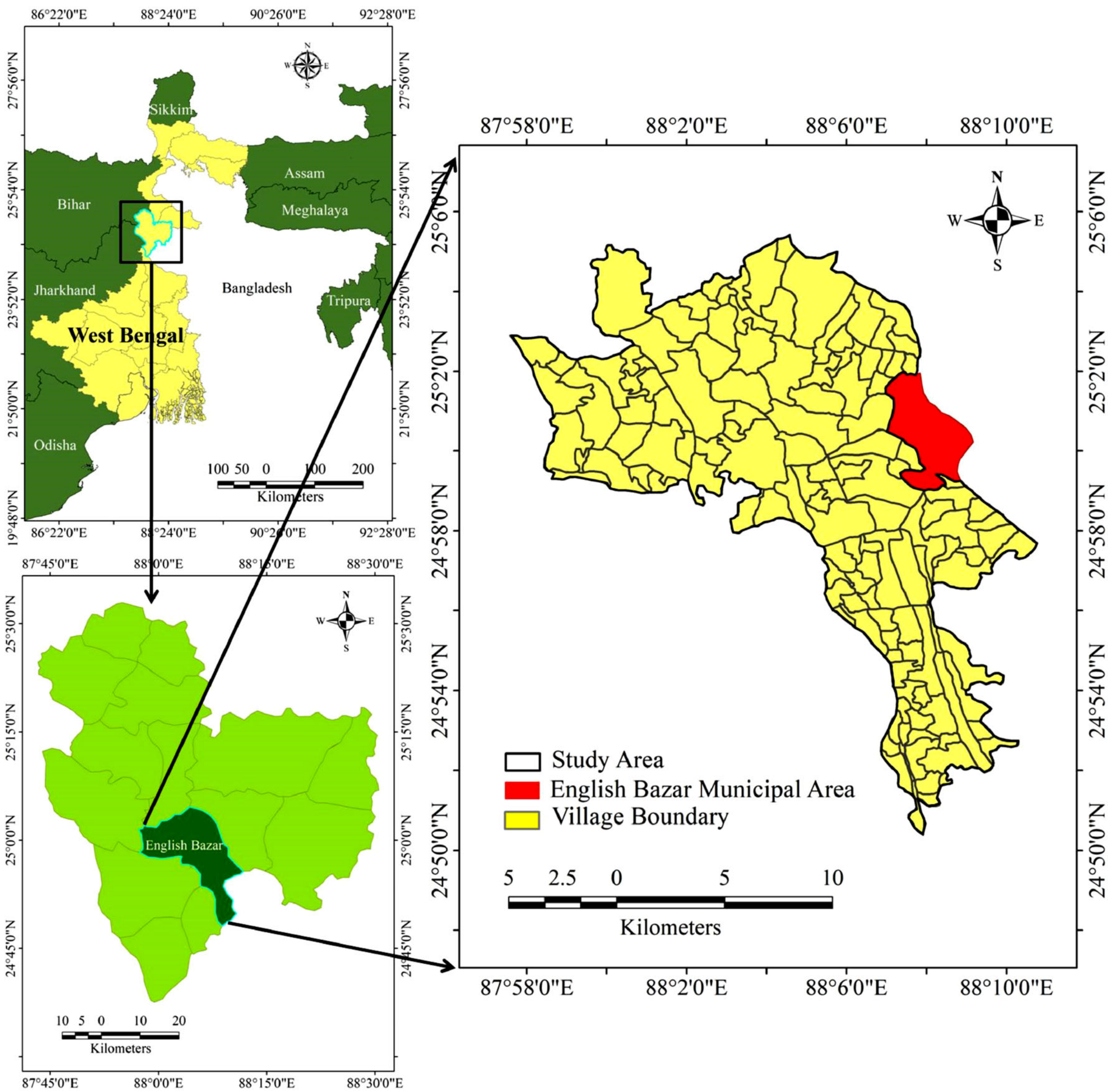

Fig. 1 Geographical location of the study area

network analysis [40]. A graph is a set of points called nodes or vertices which are interconnected by a set of lines called edges. The vertices are dots located at the junction of two or more edges and edges are lines that connecting two respective vertices [41]. Garrison and Marble (1962, 1964, 1965) contributed in this field by introducing Alpha (α), Beta (β), and Gamma (γ) Index [42]. Kansky enlists various measures such as Cyclomatic number, Network diameter and Alpha, Beta, and Gamma index, and tries to link between economic development and topology of the road network [43]. Many researchers are used different measures to evaluate the degree of connectivity, including Alpha Index, Beta Index, Gama Index, Network Density, Cyclomatic Number, Aggregate Transportation Score [44, 45]. The present study is based on some selected measures of graph theory. Total of 354 arcs and 135 nodes are shown in (Fig. 4) which is a base map for calculating network indices.

Alpha Index (α) is one of the important measures of network connectivity. The value of Alpha index varies within 0 to 1. The value 0 indicates minimum connectivity and the value 1 means maximum connectivity. This index is also expressed in percentile. Alpha Index (α) is calculated by using Eq. 1.

$$\mathit{Alpha\,Index}(\alpha) = (e - v + p)/(2v - 5)$$

Beta Index (β) is another simple measurement of network connectivity. It is the ratio between the number of links and nodes. The value of this index varies within 0 to 1. Where 0 indicates minimum connectivity and 1 means maximum connectivity. Beta index value exceeds 1 when the graph is complex. Beta Index (β) is calculated as:

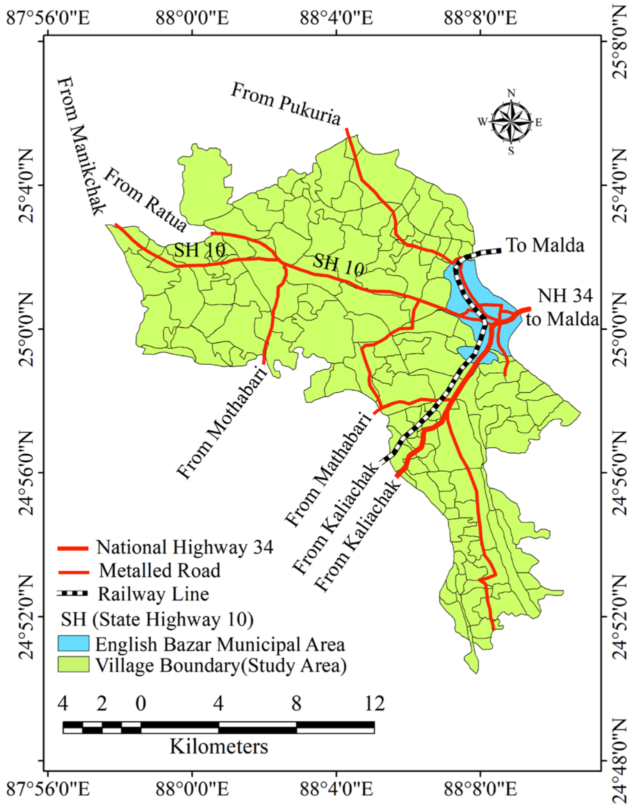

Fig. 2 Regional linkage of roads and railways in English Bazar Block

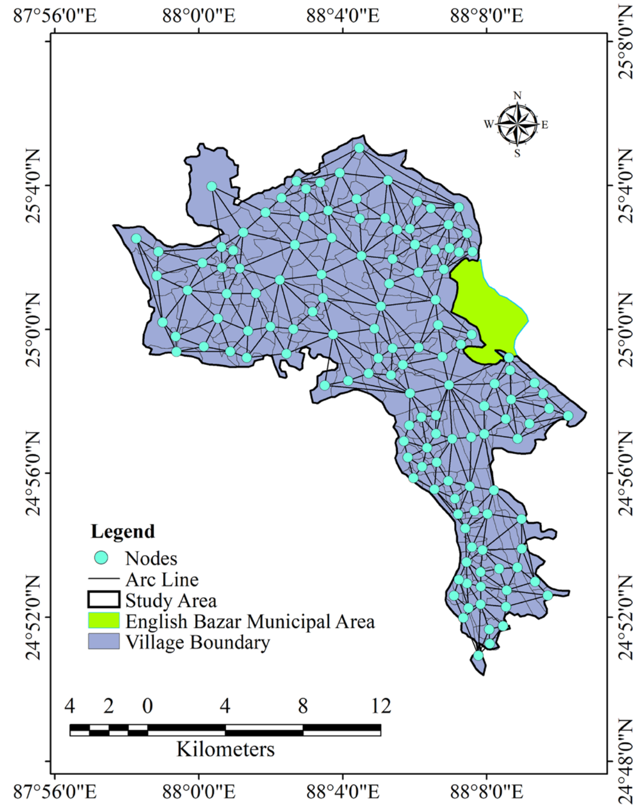

Fig. 4 Road network presented as graph of the study area

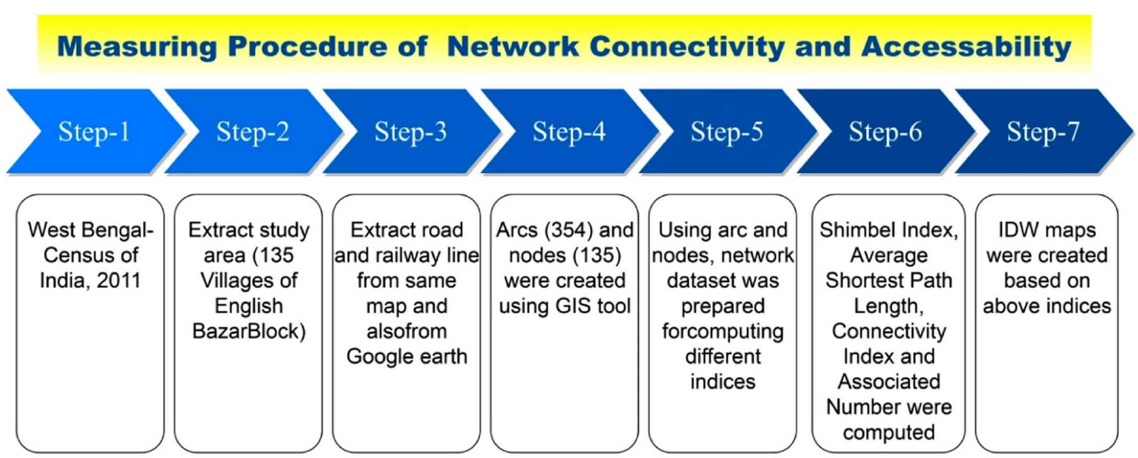

Fig. 3 Flow chart of the present study showing the methodological hierarchy of road network accessibility

$$\textit{Beta Index}(\beta) = e/v$$

Gamma Index (γ) is the relationship between the number of observed links and the number of possible links of a graph. The value of gamma index also varies within 0 to 1. Where higher the value grater the connectivity and vice versa. Gamma Index (γ) is computed as follows:

$$\textit{Gamma Index}(\gamma) = e/3(v-2)$$

Pi Index (π) is a ratio between the total distance of network to the total distance of diameter. Higher the value of Pi index means higher the connectivity and vice versa which is computed as:

$$\textit{Pi Index}(\pi) = \frac{\text{total distance of network}}{\text{distance of diameter}}$$

Grid tree pattern (GTP) index is used to showing the pattern of the network. In this index, 0–0.5 indicates tree pattern, 0.5–1 indicates grid pattern, and 1–2 indicates the delta pattern which is calculated as follows:

$$\text{GTP Index} = \frac{e - v + p}{(\sqrt{v} - 1)^2}$$

Eta Index (η) is the average length of an arc. Low eta value indicates a complex network. Eta value decreases when adding new nodes. Sparsely populated areas may experience high eta value which is express as:

$$\textit{Eta Index}\,(\eta) = \frac{\textit{total network distance}}{\textit{number of arcs}}$$

The degree of Connectivity (DC) is a suitable measure of network connectivity. Higher the value of the degree of connectivity means a higher level of connectivity. The degree of connectivity index is computed as:

$$\textit{Degree of Connectivity}\,(\text{DC}) = \frac{v(v-1)}{2/e}$$

Cyclomatic number (μ) is also an important measure of network connectivity. Higher the value of it indicates a higher degree of connectivity. The Cyclomatic number of the study area is calculated as:

$$\textit{Cyclomatic number}\,(\mu) = e - v + p$$

Note: e is the number of edges, v is the number of nodes, p is the number of non-connected graphs.

3.2 Measures of accessibility

Accessibility is determined by the structure of the transport network. Network connectivity is the basic measures of accessibility [13]. Therefore connectivity matrix is computed for showing the level of accessibility. Places with high connectivity regarded the best location as they are highly connected. Lower the value of connectivity index indicates lower the connectivity and vice versa. Connectivity matrix represented by the connectivity of node (*i*) with adjacent nodes (*j*). If two nodes are directly connected by an edge, the value 1 is given and if two nodes are not directly connected by an edge, the value of 0 is given. The Connectivity Matrix is represented as:

$$CI = \sum_{j}^{n} Cij$$

where *CI* is the connectivity index, *Cij* indicates the direct connection between *i* and *j* nodes (either 1 or 0) and *n* represents the number of nodes.

Shimbel index is used to determine the accessibility of the network, which represents the summation of the length of all the shortest path distances among all points (Vertex and node) in a circuit. Lower the value of simbel index indicates higher the accessibility and vice versa. Shimbel index is expressed as:

$$\text{SI} = \sum_{(i=1)}^{n} dij$$

where *SI* is the Shimbel index, *Dij* indicates the shortest distance between *i* and *j* nodes and *n* represents the number of nodes.

Associated number is another measure of network accessibility. It was first suggested by Koning in 1936 [46]. It may be defined as the maximum distance from one place to all other places. Associated number is the number of arcs needed to connect the most distant node from it. The associated number is the highest number for each row. Higher the value of the associated number indicates lower accessibility and vice versa. An associated number is also known as the Centrality index.

The Average Shortest Path Length (ASPL) is the measure of the efficiency of the road network. Computation of ASPL is very time-consuming. It is defined as the average number of steps along the shortest paths for all possible pairs of networks of nodes [47]. Higher the value of ASPL indicates lower efficiency and vice versa which is computed as:

$$\text{ASPL} = \frac{\sum_{ij}^{N} dist(vivj)}{\sum_{ij}^{N} has_{\_path}(vivj)}$$

where dist (vivj) represents all the pairs shortest path length of the graph, has path (vivj) represents the number of paths that exist in the graph. For a connected undirected graph, $\sum_{ij}^{N} has_{\_path}(vivj)$ = N (N − 1) and N indicates number of nodes.

4 Result and discussion

For measuring the connectivity and accessibility of any region the network analysis is very important as it evaluate the transportation network and also analyzing the interrelationship between nodes and lines [25]. The graph theory concept is taken into consideration for analyzing the network structure of the study area. The adjoining villages of the English Bazar town received and enjoy high, developed multi-modal transportation facilities for within the district as well as within the state. The National Highway 34 (NH-34) is passed over the block which connects the south Bengal with the north Bengal. For the development of this study area, improving the living standard construction of new roads, expansion and optimal use of the existing transport networks is very essential. The network analysis is frequently used to understanding the network facilities of a given region [48]. The network analysis is highly complex in nature. The network term is used for investigating the transport facilities in a given spatial extent [37]. A micro-level transportation system is the mixture of numerous sets of movement from one point (origin) to another (destination). When nodes are connected with one another it forms a branch or network system. By transporting the goods, people and other accessories these systems create a regional transportation network [49].

4.1 Connectivity analysis of the villages of English Bazar Block

Network indices are the most fundamental properties for analyzing the transportation network [44]. Based on of Alpha index there is 82.3% of connectivity in the study villages of English Bazar Block. The value of beta index is 2.62 which indicate a complex transport network. The value of gamma index (88.7%) is also high which depicts the villages are well connected. For the study villages, the Pi index value is 16.908. It is quite high that means a complicated and well-connected network exists over the study area. The GTP index value indicates the delta network pattern run of English Bazar Block. There is a high level of connectivity as the value of the degree of connectivity is 25.55 in the villages. The value of cyclomatic number indicates higher level connectivity exists in the villages of English Bazar Block.

4.2 Network accessibility analysis of the villages of English Bazar Block

The accessibility of local or regional aspects and connectivity within are the main topics in network analysis [49, 50]. The structure and complexity of a transport network are determined by the addition of new linkages and expansion of the existing routes. Consequently, on the basis of graph theory, the nodal accessibility procedure is used to assess the changes. An area adjacent to the nodal point or roads is highly accessible and with increasing distance between area and routes, the accessibility decreases accordingly [51]. In the study area, the accessibly is measured by the following methods: (1) Connectivity Matrix, (2) Shimbel index, (3) Associated number, (4) Average Shortest Path Length.

Accessibility analysis is very important for analyzing the transport network of any region. For a detailed analysis of the transport network of the villages of English Bazar Block, several indices such as Connectivity index, Shimbel index, Associated number or Centrality index and Average shortest path length are computed for the study of the nature of accessibility of the villages. The connectivity index is calculated for showing the nature of accessibility of the region because the accessibility of any region is also determined by a good connectivity of that region.

Connectivity index also calculated for showing how one node connected with other nodes (Fig. 5). Almost 33.33% of the regions having very good connectivity as the connectivity index values (6 to more than 10) are comparatively high. The villages which have very good connectivity are Shyampur, Madapur, Sadullapur, Dakshin Jadupur, Lakshmipur, Bagbari, Sonatala, Bilbari Niamatpur, Basudebpur, Balupur, Gangarampur, Jot Basanta, Utter Nazirpur, Sahazalalpur, Central part of Jot Basanta, Nischintapur, Tantipara, Tiakati, Byaspur Arazi Inlis, Bholanathpur and Cauka para. Almost 58.52% area is having moderate connectivity (4–6), On the other hand, almost 8.15% of villages having poor connectivity as the value is less than 4.

Shimbel index is used to showing the nature of accessibility of this region (Fig. 6). The central and the adjacent villages of EBM having comparatively low shimbel index value (less than 757) compare to another region which means central and adjacent villages of EBM are the most accessible areas in this study block. Villages situated in the north-eastern, north-western, south-eastern, south-western,

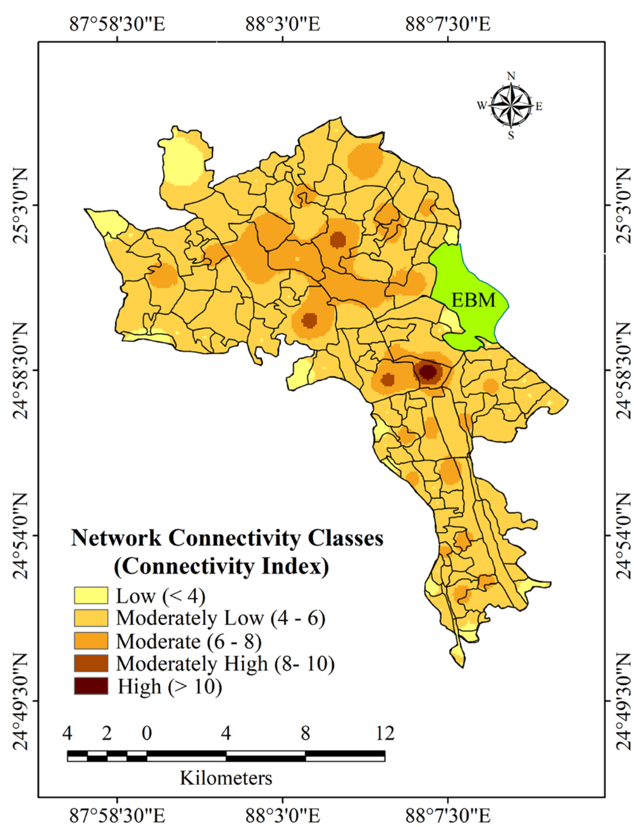

Fig. 5 Connectivity analysis of the study area using connectivity index

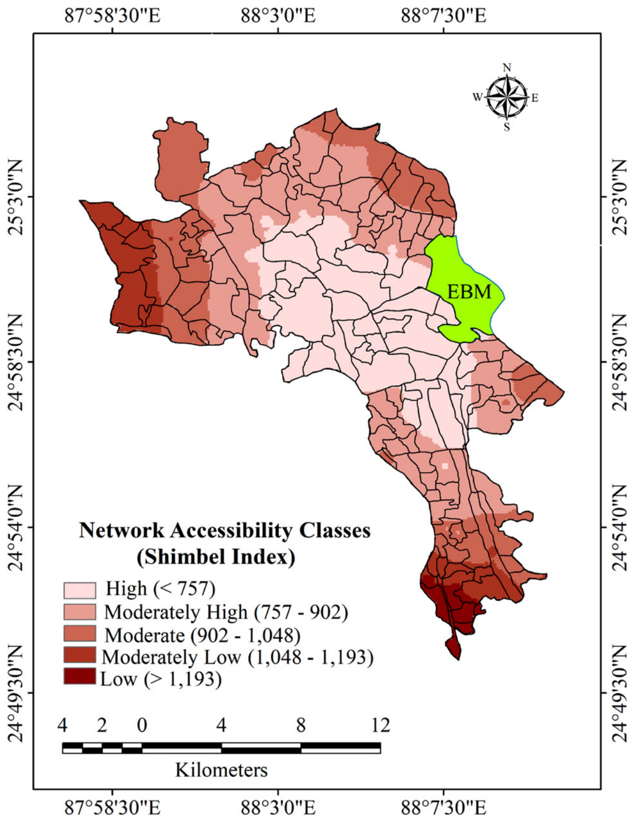

Fig. 6 Accessibility measurement of the study area using shimbel index

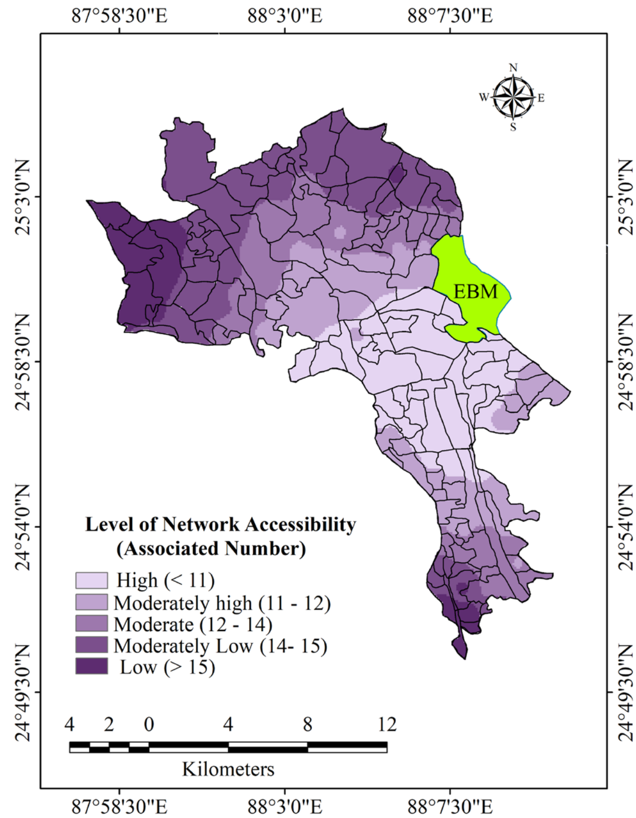

Fig. 7 Quantification of road network accessibility using associated number index

southern and northern of the central villages falls under comparatively moderately accessibility zone where Shimbel index value ranges from 757 to 902. Shimbel index value is moderate (902–1048) in the villages of Ramkeli, Bholanathpur, Badulyabari, Kanakpur, Ghurnimadia, Tentulia, Poramadia, Southern Jamalpur but the accessibility of these regions is not so flourished in comparison to the adjoining area of EBM as the Shimbel index value is moderate. It is evident from the shimbel index value that villages such as Ganga Gabindapur, Madia, Utter Chandipur, Utter Umarpur, Garmahali, Chauka Para, Parbatipur, Mahadipur, Khirkhi having moderately low level of accessibility as the value ranges from 1048 to 1193. The extreme southern most portion of the block having low level of accessibility as the value of shimbel index above 1193, which is comparatively high compare to remain areas. Jadupur is the most accessible village as the value of Shimbel index is low and it is 612. On the other hand, Utter Umarpur village is the most inaccessible village as the Shimbel index value is as high as 1338.

An associated number is used as a measure to show the level of accessibility (Fig. 7). According to calculated Associated numbers, the most accessible villages are located in the adjoining sites of the English Bazar municipality. But the villages far from the EBM area less and less inaccessible as the associated number are increasing towards the edges.

The Average Shortest Path Length (ASPL) is computed for analysing the most accessible region of the study area (Fig. 8). It is calculated that the network efficiency is very high in the villages near to the EBM as the ASPL value is very low (less than 0.074). The network efficiency is low in the villages located at the boundaries of the block because the ASPL values are high (0.102–0.116). The villages namely Utter Umarpur, Garmahali, Arazi Nazirkhani, Satgada, Utter Chandipur having very low network efficiency as the value of ASPL comparatively high (more than 0.116) as compared to remaining villages.

5 Conclusion

The Transport network is considered to be the main driving force for the growth and development of a region. Well connected and linked roadways provide a smooth linkage between places. Villages in the study area face increasing population pressure and their demands create an developed transportation networks. As their prevails positive relationship between road network connectivity and accessibility, different network indices based on Graph theory are

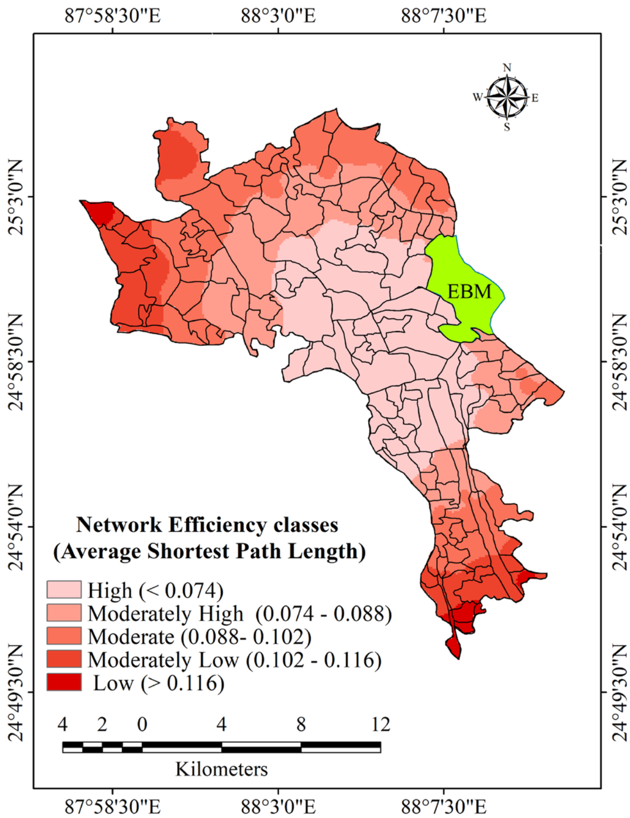

Fig. 8 Accessibility measurement of the study area using average shortest path length

implemented for understanding the overall connectivity of the study area. The graph theory is easy and sophisticated indices that improved our knowledge regarding network connectivity. The Alpha index value for the study villages is 82.3% which indicated high connectivity among the study villages. Alike all other indices like Beta index, Gamma index, Pie, Grid tree pattern, Eta, The degree of Connectivity and Cyclomatic number index values indicates a complex and well-connected transport network all throughout the region. This connectivity and network accessibility showing the flow of human, goods and resources from the study villages towards the English Bazar municipality. For evaluating the accessibility in a better way, more indices such as Connectivity index, Shimbel index, Associated number, and Average Shortest Path Length in a matrix form are calculated and the results showed centrality and efficiency of the road network of the villages are high which located in the core of the block or adjacent to the English Bazar municipality. The villages which are located far away from the core villages have experienced low network centrality and network efficiency therefore the network accessibility of those villages is minimal. Therefore, micro-level planning is very essential so it should develop new transport networks in the far distance villages with proper planning. Though the overall connectivity of these villages is quite good, but all villages do not experience smooth network connectivity and accessibility. Although Graph theory, Connectivity index, Shimbel index, Associated number, and Average shortest path length facilitated more information about the accessibility of the villages. Except for Graph theory which shows the overall connectivity of the villages, these indices needs more deep analysis of the transport network of these villages which is the subject of future research. The remote sensing, GIS, on-field observation and implementation of spatial tools may assist policymakers in connectivity and network accessibility measurements.

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Compliance with ethical standards

Conflict of interest The authors hereby declare that there is no conflict of interest and no human or animal involved or harmed in any way during this research work.

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