International Journal of Applied Research 2023; 9(4): 104-110

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 8.4
IJAR 2023; 9(4): 104-110
www.allresearchjournal.com
Received: 18-01-2023
Accepted: 20-02-2023

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Analysis of road network accessibility using graph theory and GIS technology: A study of Bhojpur district, Bihar

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DOI: https://doi.org/10.22271/allresearch.2023.v9.i4b.10731

Abstract
Analysis of accessibility is an important aspect in the study of transport geography. It generally develops the spatial relationship between one location to other locations and centres. The present study analyses the road network connectivity and accessibility of the study area using graph theory and geographical information system. Graph theory has been used to determine the level of connectivity whereas buffering method gives an idea to understand the physical accessibility in the study area. Shortest path matrix and Shimbel Index have been used for categorically understanding the magnitude of network accessibility. The GIS tool Inverse Distance weighted (IDW) has been used to show the efficiency of road network accessibility in the district. Along with main centre (district headquarter) high accessibility was found in the study region.

Keywords: Accessibility, graph theory, buffering, shortest path matrix, shimbel index, inverse distance weighted (IDW)

Introduction

The network is a collection of nodes or vertices connected by edges, where vertices occupy certain locations in space and edges in these networks are actual physical structures, such as roads or railroad lines in transportation networks. Al-Sahili and Aboul Ella's concise definition of accessibility is that "it indicates the spatial relation between one location and others, or the level of connectivity between that location and all others in an area" [1]. In regional and transportation studies, the idea of accessibility is at the centre [2]. Accessibility is an essential factor in determining connectivity and assessing travel opportunities. The multifaceted idea of accessibility covers several metrics including network connectivity and node accessibility. A new road transportation system has been built as a result of the expansion of economic activity not just in large cities but also in rural areas. The road network system is considered as the lifeblood of human civilization and contributes to both social cohesion and economic development in space. Regional road construction promotes regional economic expansion, which lowers rural poverty. Researchers commonly utilize the graph theory model to lay out transportation networks in any region [3]. Presents different kind of connectivity indices (beta index, association number, alpha index, gamma index) and accessibility indices (Shimbel index and nodal degree). GIS technology is used to determine the physical accessibility by using buffering method.

Review of Literature

The quantitative revolution had an impact on transportation studies by the middle of the 20th century, as well as many other fields of geography. The use of the gravity model was a significant advance to transportation research. A significant development in network analysis was the use of the Gravity model in transportation studies. Graph theory was used to analyse transportation networks in the 1960s. Later, theories like the systems approach were included in studies of transportation. There were attempts to conduct transportation-related empirical research over these decades. Statistical and mathematical methods were used in all of this research. W.L. Garrison (1958) made an effort to investigate the economics of highway maintenance and improvements and introduced the graph theory for analysing network studies with the help of different network indices such as, Alpha Beta, Gamma, Cyclomatic number, Eta, Theta, Pi indices [4]. By using graph theory, Burton (1962) examined the Northern Territory's highway network's accessibility patterns and projected that as the network's number of links increased, accessibility would also grow [5]. Kansky for the first time used geographical application of different network indices which were introduced by Garrison [6]. R.J. Johnston (1966) made an effort to analyse the accessibility index and its application to the study of bus services and settlement patterns [7]. He assessed the correlation between settlement type and accessibility. The concept of accessibility in the context of network connection and usability was novel. Kansky (1963) examined the correlation between transportation and development. Haggett (1969) presented the comparative study of different network indices which was a new approach to study transport geography [8]. Bhaduri, Sukla (1992) presented "Transport and Regional Development- A Case Study of Road Transport of West Bengal," makes an attempt to present a comprehensive picture of West Bengal's transportation geography with a focus on roads [9]. This was an effort to illustrate the road transport and development opportunities on the basis of transport accessibility and network efficiency.

In the field of accessibility many studies and researches have been done by scholars. Mayer (1954) presented 'accessibility as a measure of the extent of urban nodality In the Chicago region' [10]. Hansen (1959) described that how accessibility shapes land use. Forbes (1965) presented mapping accessibility [11]. Halden *et al*. (2005) presented Scottish household survey analytical topic report; accessibility and transport [12]. In which they have tried to described accessibility as to explain the ease of obtaining opportunities or of being obtained at a more basic and micro level. Sammer (1981) presented a paper on Transport accessibility and regional economic strength [13]. Giuliano *et al*. (2010) have been tried to explained accessibility and its significant effects on land values [14]. Geneidy *et al*. (2006) described that accessibility is a useful tool for monitoring land use and transport system in a space [15].

Statement of the Problem

The district has the ability to develop itself with the aid of accessible resources like water, rich soil, and primarily plain terrain since it is located in a historically significant location in the western part of Bihar. The district is very near to state capital but failed to reach its level of development. The availability of transportation infrastructure is less developed both inside and across regions, which is the major cause. Only certain areas are developed such the district headquarter or the area near by the district headquarter. Areas far from the central business district (CBD) show less developed transportation facility in terms of connectivity and accessibility as well. The Bhojpur occupies a significant position in the state because two major rivers The Ganga and river Sone are sharing its boundary and district shares the state boundary with Uttar Pradesh. The district experienced minimal industrial and commercial business at intra and inter- regional level due to lack of transformational facilities. The ratio of agriculture, industry, and urban level is not uniform and equal. The development of the transportation facility is necessary for the overall development of tehsils. It helps reduce regional imbalance and penetrate the transition from highly developed to less developed regions.

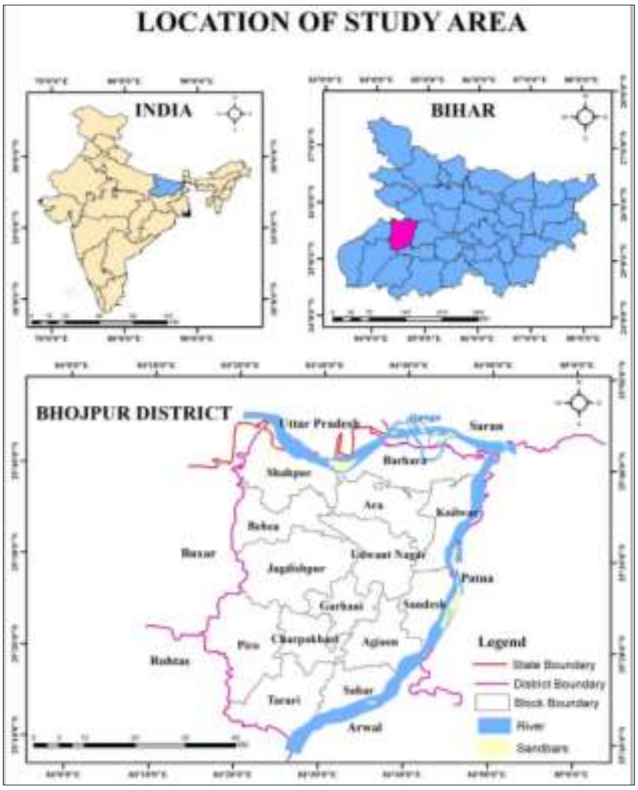
Objectives

1. To evaluate the accessibility of the road network in the Bhojpur district.
2. To determine the level of accessibility in the district.

Methodology

Present study is based on secondary sources of data. Data has been collected from district census handbook 2011, District road construction department, Bhojpur. Graph theory has been used to determine the overall connectivity in the district. Connectivity index, Shortest path matrix and Shimbel index have been used to analyse the accessibility of road network. Buffering method of ArcGIS 10.7.1 has been used to show the physical accessibility of road network. For better understanding Spatial Interpolation maps are prepared using Inverse Distance Weighted (IDW) method of GIS (Geographical Information System) technology. Software ArcGIS 10.7.1 has been used to create coropleth map through geo- referencing and digitisation.

Study Area



Source: Census of India, 2011

Fig 1: Location of Bhojpur District

Bhojpur district has been selected as the study area for the present research. According to district census handbook 2011, the district is situated in Bihar's former Shahabad district, in its north-eastern region. In 1991, it separated from the Buxar district. The district's geographic extent is between 25º10′ and 25º40′ N lattitude and 83º45′ and 84º45′ E longitude (Figure 1). The district encompasses 2395 km2 area in total. According to the 2011 Census, the district has a total population of 2728407 people and a population density of 1139 people per km2. There are 14 blocks in the district, 997 populated settlements, and 6 statutory towns. The State of Uttar Pradesh and district of Saran are situated in the north of the district, whereas Rohtas and Buxar District to the west, district Arwal to the south and Patna district is situated to the east of the study area. Transportation facilities serve 64.79% of the district's population. Pucca Road is beneficial to 81.81% of the population. The district roads are maintained by RCD, PWD, RED, REO, Zila Parishad, and the municipality. The district as a whole has considerably less railroad expansion. The sole rail line is the 37 kilometre Eastern Railway.

Analysis and Interpretation

Application of Graph Theory

Since Eular and Konig in 1936, several research have sought to apply graph theory to the analysis of transportation networks [16]. A graph is made up of a collection of nodes, also known as vertices, which are connected by a group of lines, also known as edges. The edges are the lines linking two individual vertices, and the vertices are the dots at the intersection of two or more edges. A traditional set of connectivity metrics are provided by transportation geography [18]. With the help of graph theory we calculate Alpha, Beta, Gamma, Pi, Eta indices, Cyclomatic number and Aggregate transport score to determine the level connectivity and accessibility. For the first time Garrison and Marble in 1962 introduced these (alpha, beta and gamma) indices. The present study is based on some of these measures of graph theory [49].

Alpha Index (α)

The ratio of the number of observed circuits to the number of possible circuits is known as the alpha index [20]. Alpha index is between 0 and 1. Greater connectivity is indicated by a high index number. The alpha index may be expressed using Equation 1.

$$\text{Alpha Index } (\alpha) = \frac{e-v+1}{2v-5} \qquad (1)$$

Where,
e = Number of edges
V = Number of nodes (vertices)

Beta Index (β)

It is the ratio of the nodes (vertices) in the network to its edges. A high beta index value denotes excellent connectivity, while a number that exceeds 1 indicates a very complicated network [20]. The beta index may be expressed and defined using Equation 2.

$$\text{Beta Index } (\beta) = \frac{e}{v} \qquad (2)$$

Where
e = Number of Edges
V = Number of Nodes (Vertices)

Gamma Index (γ)

According to Gauthier and Taffe, the gamma index calculates the gap between the observed number of edges and the optimum number of edges that might possibly exist in the network [21]. Its range of values is 0 to 1. Where 1 means the network is completed. The gamma index may be determined using the formula below (equation, 3).

$$\text{Gamma Index } (\gamma) = \frac{e}{3\,(v-2)} \qquad (3)$$

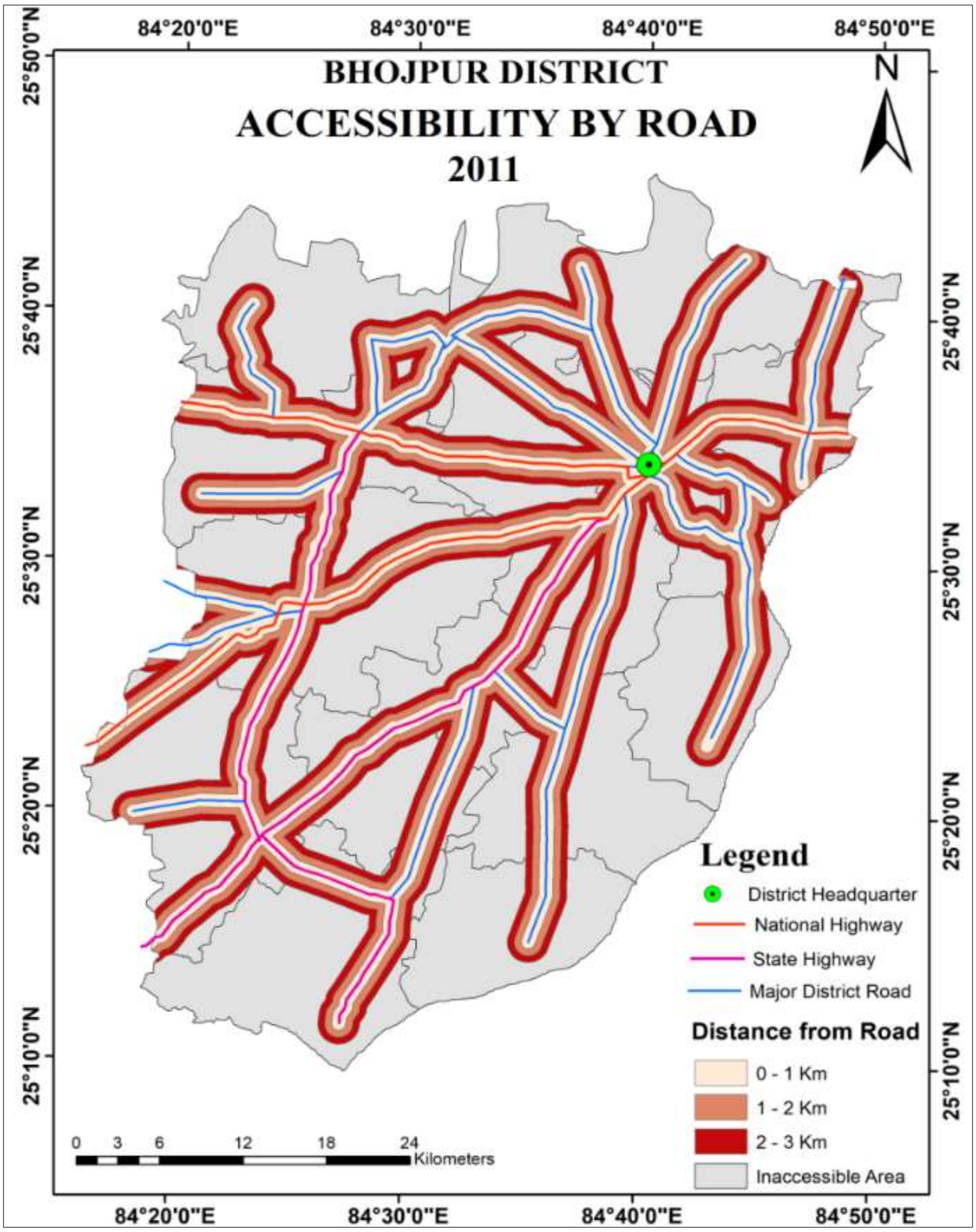
Where
e = Number of Edges
V = Number of Nodes (Vertices)

The present study is based on 392 nodes and 910 edges in the district of Bhojpur for the year 2011. After applying above formulas the value of Alpha index is 66.62% in the district. Beta index value is 2.32 which indicate the complex transport network in the district. Value of Gamma index is 77.77% which also indicate the good connectivity in the district.

Road Network Accessibility

Hansen deserves credit for providing the first definition of accessibility in the planning sector. He defines accessibility as "a measure of possible prospects for interaction" (Hansen, 1959). The word accessibility is mainly composed of the keywords "access" and "ability," which together signify "ability to access" [22]. The term accessibility is used in United Kingdom as to explain the ease of obtaining opportunities or of being obtained at a more basic and micro level [12]. Chorley and Haggett illuminate that, Accessibility is closely related with the concept of movement minimization [23]. According to Pandy (1986) Accessibility denotes the importance of a place and more particularly the ease with which one can travel from one place to another [24]. According to Sammer, the economic viability of the road system is influenced by the accessibility of transportation [13]. According to Giuliano, "accessibility" is the ease of moving between different locations [14]. Accessibility to roads, especially surfaced ones, is crucial as it links to the major commercial centres and aids in maximizing the benefits of economic activity and other social development initiatives.

Figure 2 is showing the map of the accessibility of surfaced roads which has been created using the "Buffering" tool of ArcGIS 10.7.1. To obtain a comprehensive image of the district's accessibility to surfaced roads, accessibility to surfaced roads is computed within a distance of three kilometres. Concurrently table 1 is showing that only 1129.80 sq. km of the total area of 2395 sq. km are accessible within 3 km of a surfaced road. This makes up 47.18 percent of the entire region. This demonstrates the district's backwardness by showing that residents in the remaining 52.80 percent of the land area must travel at least three kilometres to access surfaced roads.



Source: Created by Researcher using Buffering Tool (GIS).

Fig 2: Surfaced Road accessibility of Bhojpur District, 2011

Table 1: Accessible Area to Surfaced Road (Within 3 Km)

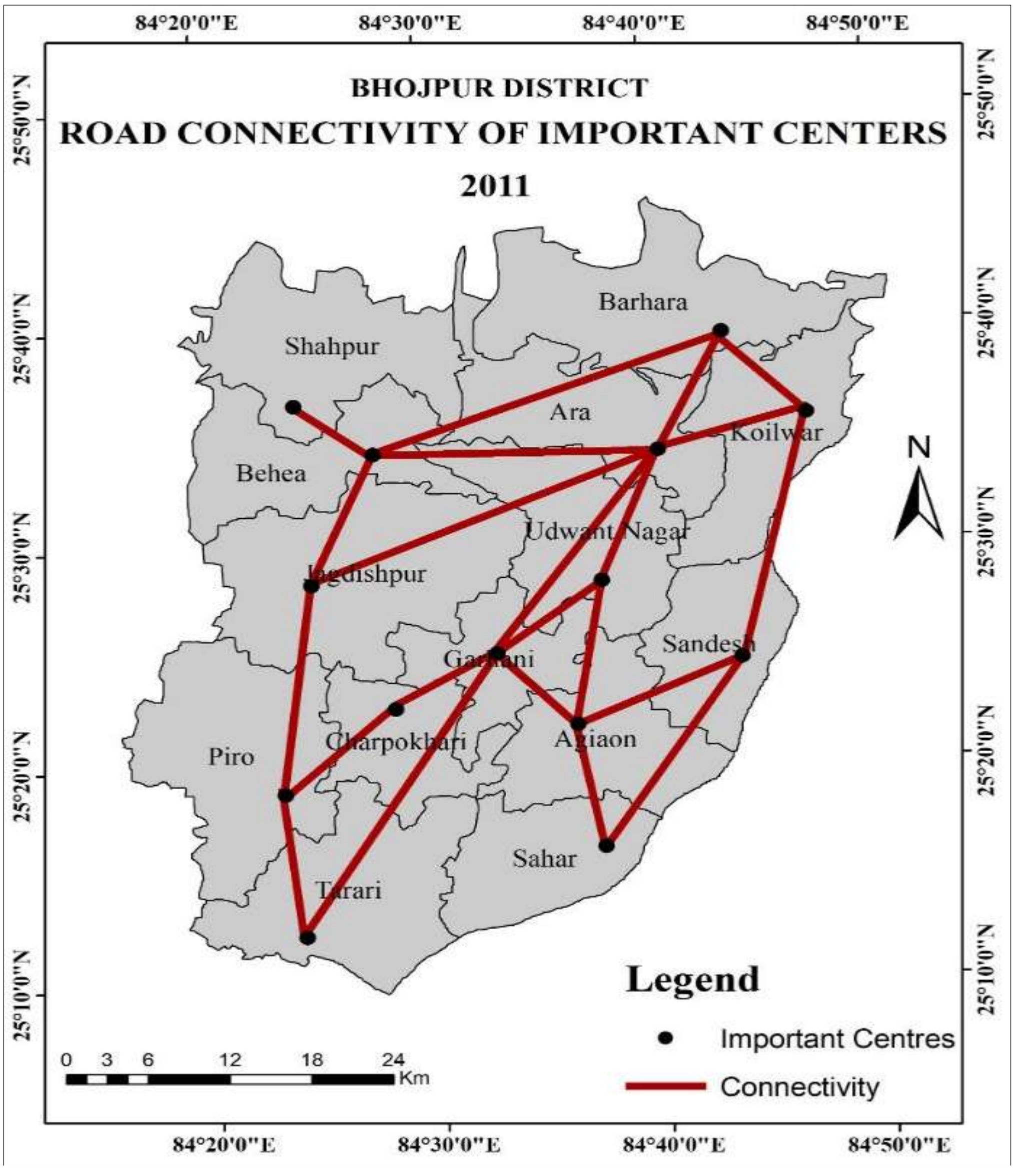
Sr. No.	Blocks	Total Area (in sq. km)	Buffered Area (in sq. Km)	Accessible Area (In %)
1	Agiaon	156	37.76	24.20
2	Ara	185	123.48	66.74
3	Barhara	208.1	95.51	45.89
4	Behea	134.92	90.39	64.51
5	Charpokhari	109.3	46.43	42.47
6	Garhani	112	63.58	56.76
7	Jagdishpur	257.8	127.19	49.33
8	Koilwar	168.5	98.51	58.46
9	Piro	218.4	126.93	58.11
10	Sahar	127	23.39	18.41
11	Sandesh	132.1	40.04	30.31
12	Shahpur	151.4	75.18	49.65
13	Tarari	201	64.61	32.14
14	Udwant Nagar	170.5	116.8	68.50

Source: Compiled by Researcher

Accessibility in Important Centres (Shortest Path Matrix)

As mentioned earlier that there is different method for find out the accessibility i.e. Shortest Path matrix, Shimbel index and Associated Number. For present study shortest path matrix and shimbel index methods have been used. There are 14 important centres have been taken into consideration for the study (Figure 3). In a real-world situation, the researcher is more interested in the length of the shortest path between any two nodes than in the total number of pathways between any two nodes.[25] Shimbel has proposed a method utilising the computing of a matrix D to find the shortest pathways in networks. Get a vector column by adding the rows of matrix D together. Higher accessibility to the network is considered for nodes with lower numerical values. Shimbel provided the following formula as shown in equation 4.

$$Ai = \sum_{j=1}^{n} dij \qquad (4)$$



Source: Census of India 2011

Fig 3: Road Connectivity of Important Centres, 2011

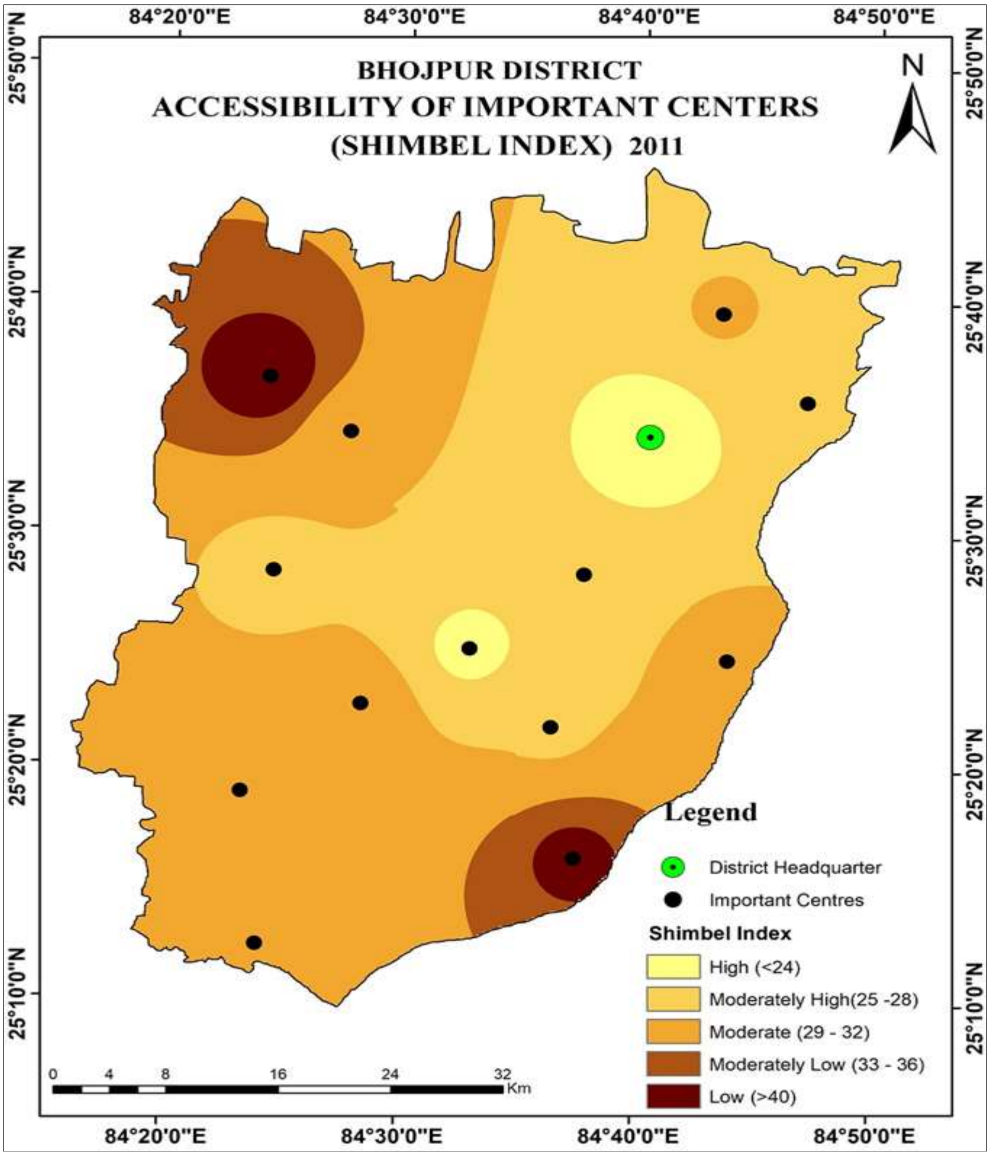
Table 2: Shortest Path Matrix (Important Centres 2011)

Important Centres	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	Shimbel Index
Agiaon (V1)	0	2	3	3	2	1	3	2	3	1	1	4	2	1	28
Ara (V2)	2	0	1	1	2	1	1	1	2	3	2	2	2	1	21
Barhara (V3)	3	1	0	1	3	2	2	1	3	4	2	2	3	2	29
Behea (V4)	3	1	1	0	3	3	1	2	2	4	3	1	3	2	29
Charpokhari (V5)	2	2	3	3	0	1	2	3	1	3	3	4	2	2	31
Garhani (V6)	1	1	2	3	1	0	2	2	2	2	2	3	1	1	23
Jagdishpur (V7)	3	1	2	1	2	2	0	2	1	4	3	2	2	2	27
Koilwar (V8)	2	1	1	2	3	2	2	0	3	2	1	3	3	2	27
Piro (V9)	3	2	3	2	1	2	1	3	0	4	4	3	1	3	32
Sahar (V10)	1	3	4	4	3	2	4	2	4	0	1	5	3	2	38
Sandesh (V11)	1	2	2	3	3	2	3	1	4	1	0	4	3	2	31
Shahpur (V12)	4	2	2	1	4	3	2	3	3	5	4	0	4	3	40
Tarari (V13)	2	2	3	3	2	1	2	3	1	3	3	4	0	2	31
Udwant Nagar (V14)	1	1	2	2	2	1	2	2	3	2	2	3	2	0	25

Source: Compiled by Researcher

According to Table 2 the centre Ara ranked first as it is having the lowest value of shimbel index i.e. 21. It is clear that Ara is most accessible centre within network as per the data of 2011. It denotes the primacy over the entire region. Since this centre is served by two national highways and also it is district headquarter.so that it is showing the highest accessibility in the district.

The centre Garhani ranked second with shimbel index value 23. This centre is benefitted by the state highway 12 other major district roads so that showing good accessibility. The centre Udwant Nagar is lying in the third rank as it is having shimbel index value 25. It is situated near to the centre Ara. The various centres were tied with it by shortest path. Centres namely Jagdishpur and Koilwar ranked fourth with shimbel index value 27. Jagdishpur gets advantage of national highway as well as state highway and major district road. This is the sub divisional headquarter of district so that is has good connectivity with other centres. Whereas Koilwar is situated near the district head quarter and small scale industries are located over here. Barhara and Behea are lying in the fifth rank with shimbel index value 29. They are situated at the extreme north and western part of the district. Charpokhari and Sandesh ranked sixth with shimbel index 31 whereas centre Piro ranked seventh with shimbel index value 32. These centres are far away from district headquarter and practices less accessibility with other centres. Centres namely Sahar and Shahpur ranked eighth and ninth with shimbel index value 38 and 40 respectively. These centres are situated at the extreme corner of the district i.e. Sandesh at the south-east and Shahpur at the north-west part and they practices less road network availability.



Source: Created by Researcher on the basis of Table 2

Fig 4: Shimbel Index Showing Network Accessibility, 2011

Figure 4 is showing road network accessibility of important centres of the study area using shimbel index value. This map has been prepared with the help of Inverse Distance Weighted (IDW) technique of geographical information system which is showing the efficiency of network accessibility of all 14 important centres in the study area. Centres having lower shimbel index value show high accessibility. Similarly centres with higher shimbel index value express low accessibility. It is clear that centres situated near the district headquarter are enjoying high accessibility as they have lowest value of shimbel index. As we go far from headquarter the accessibility is going to lower because the shimbel index value becomes higher. Shimbel index value and network accessibility is inversely proportioned. Centres situated at the middle part of the study area moderately high accessible. Similarly centres located at the south – west and north - eastern path of the district are showing moderate accessibility. Whereas centres lying in the north - west and south - eastern part are showing moderately low and low accessibility as they have highest shimbel index value.

Discussion and Conclusion

A region's growth and development are generally attributed to the transportation system. Roadways that are well connected and interconnected enable a good connectivity between different places. There is a positive relation between network connectivity and accessibility. Graph theory gives a clear idea about connectivity that the study area has good road network connectivity. By using buffering method physical accessibility has been analysed which shows that the district has accessible area within 3 km of main surfaced and major district roads. Total accessible area within 3 km of artery road accounts for 47.20 percent of the total area and rest 52.80 percent area is inaccessible to main artery road. Shortest path matrix and shimbel index showed the centrality and efficiency of road network among different important centres of the district. It was found that centres which are situated near the district head quarter have high accessibility. The centres which are located far from the headquarter experienced poor accessibility due to the low network centrality and network efficiency. Although the district has overall good network connectivity, but not all villages and centres have smooth network connectivity and accessibility. As a result, micro-level planning is very important, and with careful planning, new transportation networks should be built in the remote settlements so that they can get equal opportunity to growth and development.

Acknowledgement

The Vice Chancellor, Veer Kunwar Singh University, Ara, Bihar, and Head of the P.G. Department of Geography, Veer Kunwar Singh University, Ara, Bihar, are to be thanked for providing the author with all the required resources. For supplying crucial data and information, the author additionally acknowledges the Road Construction Department, Bhojpur District, Government of Bihar and Rural Work Department, Bhojpur District.

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