ROLE OF ROAD TRANSPORT NETWORK ON SOCIO-ECONOMIC DEVELOPMENT OF AIZAWL DISTRICT, MIZORAM

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ROLE OF ROAD TRANSPORT NETWORK ON SOCIO-ECONOMIC DEVELOPMENT OF AIZAWL DISTRICT, MIZORAM

BY

ZORAMKHUMA

DEPARTMENT OF GEOGRAPHY AND RESOURCE MANAGEMENT

Under the Supervision of

Prof. Benjamin L. Saitluanga

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Geography of Mizoram University, Aizawl.

DEPARTMENT OF GEOGRAPHY AND RESOURCE MANAGEMENT

Post Box No. 190
Gram: MZU

www.mzu.edu.in

Phone: 0389-2331604 (O)
: 0389-2331613 (O)
Mobile: 9856537375
Email: bena.sailo@gmail.com

Prof. Benjamin L. Saitluanga

CERTIFICATE

This is to certify that Zoramkhuma, registered under: MZU/Ph.D./1030 of 31.05.2017 is a research scholar working under my supervision on a thesis entitled 'Role of Road Transport Network on Socio-Economic Development of Aizawl District, Mizoram'.

All through his research pursuance, I found Zoramkhuma very serious, hardworking and dedicated. He could challenge his tasks with quality of scholarship and was able to carry out his assignment successfully.

I further certified that the thesis is this form is the report of the research scholar's original work. Certain extracts and quotes are duly referred to in an appropriate manner.

I recommend the thesis for due evaluation and recommendation.

Date:

(PROF. BENJAMIN L. SAITLUANGA)
Supervisor

DECLARATION

MIZORAM UNIVERSITY, AIZAWL

August, 2023

I, Zoramkhuma, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Geography.

(ZORAMKHUMA)
Research Scholar

(PROF. CH. UDAYA BHASKARA RAO)
Head

(PROF. BENJAMIN L. SAITLUANGA)
Supervisor

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CHAPTER I

Introduction

Transport network is a vital component of human society. Transportation facilitates the movement of people, goods, and information across geographical spaces. It plays a crucial role in shaping societies throughout history by influencing social interactions and thereby socio-economic development. Since mobility is one of the fundamental goals of transportation, it can only serve this function when people, goods, freight, and information are transported through a variety of modes of transportation. In recent times, development of science and technologies brings rapid development on automobiles, railways, and aviation industries by creating more options for modes of transportation. The improvement of transport technology has multiple consequences for the growth of transport demand, the reduction of transport costs, and the expansion and improvement of infrastructure. These technologies also enhance essential qualities of effective transportation; speed, safety, flexibility, regularity, cost effective and adaptability. These are significant for the mobility of people, goods, and information and have led to the complexity and diversity of transportation systems and networks.

The role of road transport networks in promoting socio-economic development cannot be overlooked. Roads serve as lifelines of space, connecting people, businesses, and communities and enabling the efficient movement of goods and services (Mieczkowski, 1978). In modern times, transport networks form the backbone of the transportation infrastructure, playing a crucial role in driving economic growth, fostering regional integration, and improving the quality of life of individuals across societies (Francois, 2002). Likewise, road transport networks serve as catalysts for connectivity and accessibility, bridging the gap between remote/isolated areas and more accessible areas (Sharma and Sewa, 2022). Road transportation provides isolated regions with improved access to essential services such as education, healthcare, and markets, and road networks improve connectivity, accessibility, and other development needs that promote social experience in positive ways (Simon, 1996). Furthermore, well-developed road networks enhance connectivity within and between regions, facilitating the movement of goods and services and enabling socio-economic growth to reach significant conditions. This connectivity drives mobility, trade, and commerce, which stimulate socio-economic growth and create employment opportunities, ultimately leading to poverty reduction and improved living standards.

Road systems enhance rural agricultural marketing and food security. Efficient road connectivity allows farmers to transport their produce to markets on time, reducing post-harvest losses and ensuring fair prices for their goods. It also facilitates the access of farmers to essential inputs, such as fertilizers, seeds, and tools, thereby enhancing agricultural productivity. The integration of rural areas with urban centers through road networks encourages the adoption of demand based farming techniques, for supplying urban requirement. That contributes to the overall growth and development of the agricultural sector in rural-urnban fringe and well connected rural settlements. Thus, an efficient transport network is essential for maintaining and improving the socio-economic conditions of a village and ensuring sustainable socio-development (Sreelekha*et al.*, 2016).

In this research work, the role of road transport networks on socio-economic development is considered as the topic of attention for two main reasons. First, road transport networks and their components - the network, junctions, infrastructure, and equipment–are considered important determinants of spatial interaction and controlling the flow of resources, consequently form the basis of a complex spatial system. Second, since geography is considered as the study of spatial relationships, the analysis of road transport networks is of specific interest because they are the major inducers of these interactions. Similarly, this study presumes that road transport networks are the primary means of connecting local resources, infrastructure, and people to distant locations and population centers. Thus, transport networks have a strong spatial component that is significant for economic activities. It has a significant impact on spatial variation in socio-economic development (White and Senior, 1983). Road transport networks and their systems of interaction can be a marker for the socio-economic development of an area, as they provide the basic infrastructure for any kind of investment and bolster its economic potential

(Lampe, 1983). Likewise, it is fair to argue that road transport networks are a major contributor to the socio-economic development of the region in general, and specific areas in particular.

Transport networks create patterns of linkages and spatial interactions that shape the movement of people, goods, and information. These networks serve as the backbone of social and economic activities, facilitating the flow of population, commodities, and information across different spaces. Traditionally, transport network has been studied from various disciplines such as engineering, economics, planning and geography. Each discipline offers a distinct perspective and focuses on different aspects of transport networks. Geographers examine the location, accessibility, and spatial organization of transportation nodes, such as ports, terminals, and transport hubs. Geography tries to understand the link between transport networks and the surrounding environment, such as physical and social environments to understand the transport network and its multifaceted effects on human society. Further, transport studies also seek to understand the connectivity and spatial linkages between various geographic regions.

The transport network overcomes the spaces that are brought on by both human and physical constraints and includes distance, time, administrative divisions and topography (Rodrigue, 2013). It transforms space across different dimensions and having significant impact on the transformation of the space over which relationships and interactions occur. Interaction of one point with another through a network creates connectivity of one point with another, and forms a spatial network and a spatial interaction system which then becomes the central medium of the mobility of information, population, freight, and flow of commodity etc. The location and position of the node in the network reflect the efficiency and intensity of the interaction. According to the intensity and efficiency of the interaction of a particular node (village) in relation to other nodes in the network the level of node accessibility varies. Accessibility varies according to one’s own location within the network system. Basically, all the locations (node) in the network have different levels of accessibility, but some are more accessible than others in the network (considered as locational advantage of a node). Thus, in transport network some mode of transportations is perceived as more significant than others due to its geographical hindrance of the region. The geographical situation in any mountainous area impedes the building up of modern transport and communication infrastructures - railways, waterways, airways, and ropeways etc. These elements are almost non-existent, absent or barely operational in the study area. It is worth reiterating that road transport networks are valuable links between places, regions, economic activities, and the rest of the world. It provides infrastructural facilities and facilitates social transformation (Gerald, 1986). Also, road transports networks help introduce new infrastructure, new economic activities, establishments, methods, and ideas to modify traditional practices. Its existence facilitates wider exposure of the local resources, capability, and specialisation of a region or a place to others. Therefore, a road network is recognised as a felt need in order for benefits to drop down to local inhabitants (Singh and Chauhan, 1984; Werner and Lucius 1992). Road transport networks also assist in promoting the advancement of technology and modern innovation. The development of a road transport network therefore paves the way for socio-economic transformation by establishing links with developed societies and making advanced regions accessible from even the remotest mountains (Rawat and Sharma, 1997). Thus, the study carefully attempts to unveil the relationship between road transport network and socio-economic development with the help of quantitative techniques and graphical representation.

1.1 Transport Geography

Geography is a synthesizing discipline that focuses on the relationship between natural and social phenomena over time and place in the context of a particular region. The quantitative revolution in geography led to the development of transport geography as a sub-field of economic geography in the 1960s. Thus, Ullman (1954) stated that "Transportation is a measure of the relation between areas and is therefore an essential part of geography" (Ullman, 1954). Transport geography frequently investigates the relationship between locations in terms of spatial interaction and association. It seeks to explain spatial linkages, with an emphasis on networks as the primary underlying for these interactions (Hoyle and Knowles, 1998). Consequently, the major scopes of transport geography include spatial connections between areas, transport patterns, resource exchange, demand, and the influence of transport networks on socio-economic progress.

Transport geography mainly focuses on the spatial interaction of different verticies and edges and their interaction in geographical space. The spatial interaction between places, the pattern of transport, exchange of resources and the demand created for movement of population of an area are critical factors affecting the social and economic progress. In broader sense the development of transportation leads to changes of spatial structure and socio-economy of the region. Economically, it increased the service zone of producer and thereby to fetch a better price for production. Transportation is movement of persons or goods for one place to another for some particular purposes. Transport geography has long history in the subject of geography and is an important branch of economic geography.

In transport geography transportation network can be studied descriptively and analytically. The traditional study of transport geography mainly concerned on the description of transport network by dealing with accessibility, connectivity, mobility, traffic density, transport model, compactness level of services and density of transport. The second approache involves analysis of network structure by seeking to explain the observed data or behavior. It attempts to explain the causes and interrelationships of underlying geographical factors in the surroundings. Simply, transport geography is a field of study that explores the spatial patterns, structure, processes, and impacts of transportation systems on the physical and social environment. Recently, application of remote sensing and GIS techniques revived the techniques of network analysis and become more interesting in the field of model base analysis and evaluation in the field of geography.

1.1.1 Spatial Patterns and Networks

Transport geography investigates the spatial patterns and configurations of transport networks that are influenced by terrain, population distribution, economic activities, and political considerations. It examines the location of transport infrastructure, the density of nodes (such as ports, airports, and terminals), and the connectivity between them. It helps us understand the relationship between transport infrastructure and spatial development, such as the growth of settlements along transportation corridors.

1.1.2 Structural Analysis

Structural analysis of transport networks involves studying the characteristics and properties of transportation systems. This theme focuses on the analysis of network topology, connectivity, and accessibility to understand the efficiency, connectivity, and resilience of transportation systems. It employs a variety of methodologies, including graph theory, geographical analysis, statistical modelling, and simulation, to assist planners, engineers, geographers, and policymakers in making decisions.

1.1.3 Accessibility and Connectivity

The study of transportation geography focuses on the concept of accessibility and its impacts on various aspects of society, including social equity, socio-economic development, quality of life, and geographical accessibility. It also investigates how transport networks improve regional connectivity by promoting trade, cultural interaction, and regional integration.

1.1.4 Transport and Regional Development

Transport geography examined the role of transportation in regional development. This theme investigates how transportation systems facilitate regional economic-activities, trade, and economic growth. It also examines the impacts of transportation infrastructure investments on regional disparities, accessibility, and the location choices of businesses and industries.

1.1.5 Transport and Urban Development

The study of transportation geography focuses on the reciprocal relationship between transportation and urban growth. This theme explores how transportation infrastructure and services shape the spatial organisation of cities, influencing land use patterns, urban sprawl, and the formation of central business district (CBD). It also focuses on the impact of urban form on travel behavior and the design of sustainable and livable cities.

1.1.6 Environmental Impacts

Transport geography investigates the environmental impacts of various forms of transportation and infrastructural initiatives. It explores solutions for minimising negative impacts and promoting sustainable forms of transportation. This study attempted to highlight the environmental dimensions of transport, which are essential for achieving a sustainable and resilient transport system.

1.1.7 Transport and Globalization

This analysis attempted to explore the role of transportation in global connectivity, trade, and the flow of people, goods, and information across borders. It explores the dynamics of international transportation, logistics, and supply chains, as well as the impacts of globalization on transportation patterns, infrastructure investments, and regional disparities.

1.1.8 Transport and Social Equity

The impact transports systems on society though the distribution of accessibility across different social classes is increasingly significant. This theme investigates issues of transportation equity, including differential access to transportation services, the affordability of transportation, and the impacts of transportation infrastructure projects on marginalized communities.

The above discussion indicates the broad range of topics and approaches involved in the study of transport networks. The field is constantly evolving, driven by technological advancements, demand and the need for efficient and sustainable transportation systems. Thus, transportation has an important role to play in the conditions that affect global, national and regional economic entities. It is a strategic infrastructure that is so embedded in the socio-economic life of individuals, institutions and corporations that it is often invisible to the consumer, but always part of all economic and social functions (Rodrigue *et al*., 2006). The main intention of transportation is thus to transform the geographical attributes (freight, people or information and others) to deliver from an origin to a destination. This interaction system formed a network in the geographical space. Due to the peripheral location, sensitive terrain condition, industrial backwardness and long continued negligence of the centre have together given near-static condition for socio-economic development in Mizoram. Even, the geographical hindrances of the region plays an infer role in the roadway, railway and airway connectivity in Mizoram. Thus, the road transport network is the only means of communication available to the population for spatial conectivity, acting as the primary mode of communication in Mizoram. It is one of the most affordable means of transportation in the state. Similarly, in Aizawl district, road transportation is the only possible means of transportation exist.

The present study examines the link between structure of road transport network (including topology, connectivity and accessibility) and socio-economic development in Aizawl District, Mizoram.

1.2 Concepts

In order to analyse road network structure and model, the study incorporates centrality measures. In order to analyse road network structure and network model, the study incorporates centrality measures to show node (settlement) characteristics in the network.

1.2.1 Network Structure

Transport network comprise links and nodes. Networks can exist in tangible or intangible forms. In transportation, a link typically refers to a travel route connecting two points, such as a road segment between intersections. Nodes often connect to multiple links, meaning an intersection node can be connected to multiple road segments (Boyles *et.al*, 2019). Structural analysis of transport networks involves examining the physical and topological characteristics of transportation infrastructure to understand their connectivity, accessibility, efficiency, and resilience (Barraza and Miquel, 2021). This analysis helps in evaluating network performance, identifying critical nodes or links, and exploring the overall structure of the transportation system. This involves analyzing the connectivity and arrangement of nodes (points of intersection or interaction) and links (transportation routes) within the network. It includes assessing the network hierarchical structure, the presence of hubs or central nodes, and the degree of connectivity between different parts of the network.

1.2.2 Centrality measures

Centrality measures are valuable tools for structural analysis of road transport network. Centrality measures are widely used in the analysis of road transport networks to assess the importance and influence of specific nodes (intersections or road segments) within the network (Ahmadza *et.al*, 2019). These measures provides node characteristics or indices base on number of connections, number of link needed to access furthest node from specific node, how easily a node can access all other nodes in the network, extent to which a node or link lies on the shortest paths between other nodes and level of influence by particular node in the network. Centrality measures help us to identify the most important nodes (settlements) or links within a transport network (Wang, 2017). Particularly, the results help to understand and analyze different characteristics of nodes in the network, such as accessibility, efficiency, resilience, robustness and visualization. In other words, these measures provide quantitative indicators that help identify critical locations, evaluate network efficiency, and guide decision-making in transportation planning and management.

1.2.3 Node Accessibility

Accessibility reveals ease of particular node from other nodes in the network. It also helps as to assess the spatial distribution of accessibility and the potential impact of transportation development (Wang *et al.*, 2020). The efficiency of a transport network is assessed based on metrics such as travel time, distance and cost. It involves evaluating the network ability to provide quick and direct connections between different nodes, minimizing travel distance, congestion and delays (Xie & Levinson, 2007). The resilience of a transport network refers to its ability to recover from disruptions and maintain its functionality. Resilience of a transport identifies critical nodes or links that exist in the network. While, robustness explore network capacity for maintain connectivity and functionality even under adverse conditions (Martín *et al.*, 2021).

1.3 Statement of the Problem

Since the advent of the human race, the means of transport have been evolving in accordance with the development in science and technology. Road transport network plays a critical role in regional socio-economic development with respect to space and time. Owing to physical and economic strains, road transport is the only vital means mobility in Mizoram. Hence, the road network structure and accessibility of the region or nodes play an important role in the socio-economic development of the region. The entire gamut of geographical, economic, social, and cultural interaction provided by road network has been significant for the region's socio-economic development.

Transport network not only provides mobility for people and their goods between fixed points over time and distance but also determines future growth and development of the region. The geographical location and opportunities may influence the entire development of the region. Also, the structure of the road network might give locational advantages than others for socio-economic development. The existing literatures argue that road network structure and accessibility are the product of the geographical characteristics of the area as well as its degree of socio-economic viability (Yang *et al.*, 2008; Kumar and Sen 2014; Jain and Dhiman, 2017; Li *et al.*, 2018). On the other hand, in a network, one must be located in a specific location that has significance for accessibility, interaction, and efficiency compared to the other nodes in the network. Especially in this proposed study area, the road transport network enables the topological structure of the network, which has implications for socio-economic development in relation to the levels of interaction and accessibility of various nodes in the network. To understand the levels of socio-economic development in a region, it is important to analyze the geographical location, topological structure of the network, accessibility, spatial interaction patterns and opportunities. By investigating the impact of spatial interaction and accessibility, we can identify areas for improvement to facilitate the growth and socio-economic development of the region.

In the present stage of development, the road network is a major channel for both inter and intra-village transportation of people and goods. On the other hand, spatial variations in road network structure and accessibility over space may lead to regional variations in socio-economic development in the proposed study. Meanwhile, the entire structure and accessibility of the road network may be determined by geographical phenomena. Keeping the above discussion in mind, the study would analyze the role of the road transport network on the socio-economic development of Aizawl district, Mizoram, which is expected to yield valuable conclusions.

1.4 Scope of the study

Transport networks play important roles in the development and changes of socio-economic and cultural spheres. Due to the existing transport planning, unequal geographical landforms, and rugged topography, the structure and accessibility of road network varied depending on the availability and locations of the vertex and edge in the proposed study area. The location of vertexes and edges varies depending on the geographical landforms in the proposed study area. The structure of road network determines various structural properties of transport network, such as connectivity, accessibility, and efficiency, which may be determined by geographical factors in the region. Thus, topological and structure analysis of road network is needed to address for investigating socio-economic development processes in the district.

It appears that the road network plays a determining role in regional characteristics and economic structure. The patial variations in connectivity, accessibility, and efficiency of vertexes and edges play a significant role in the development of a particular region. Network structure and accessibility of the region or an area does not only produce tangible produce and is also useful for satisfying some other need. The proposed study seeks to examine the spatial interaction of accessibility of road network and economic structure in the proposed study area. Understanding the relationship between nature of road network structure and accessibility of the road network and its mechanisms may provide the principle forces and variations in the proposed study area. The nature of the road network and accessibility may lead to the formation of specialisation in the region. Such findings may gather essential information for forecasting or predicting future road network growth and demand, policy formulation in the future, and planning action to achieve sustainable economic development in the proposed study area.

Both primary and secondary data sources are used in the proposed effort. This study utilizes appropriate statistical methods and tools for improved analysis, comprehension, and illustration. Remote sensing, geographic information systems (GIS), and network visualization and exploration software play an important role in this research, offering effective tools that have been extensively used for spatial data integration and data mining. The study also incorporated statistical approaches and suitable cartographic methods with the help of reliable network analysis software and GIS software. These tools assist in recognizing spatial patterns, connectivity connections, and potential congestion zones. It also helps us network visualization and handling complex network issues and data modelling.

1.5 Objectives

The objectives of the research are as follows:

1) To examine the characteristics of road transport network in the study area.
2) To analyze spatial variations of road network structure in the study area.
3) To analyze the spatial pattern of accessibility of the study area in terms of linkage relationship and efficiency.
4) To examine the socio-economic significance of road network in the study area.
5) To make appropriate suggestions on road transport network for spatial planning and development.

1.6 Study Area

Geographically, Mizoram lies between 21° 56' N - 24° 3' N latitudes and 92° 16' E - 93° 26' E longitudes (Pachuau, 1994). According to the 2011 census, the state consists of 8 districts with 26 Rural Development Blocks, 817 villages, and 22 statutory towns. The settlements are generally located on the hilltops, and the settlement types and patterns are almost the same everywhere—linear and compact. Mizoram is inhabited by several sub-tribal groups. Mara and Lai occupy the southern parts, while the central and northern regions are occupied by the Lusei, Paite, and Hmar communities. The Pawi occupy the eastern and northeastern parts of the state. Mizoram's total road length is 7592 kilometers, with surfaced roads accounting for 4728 kilometers and unsurfaced roads accounting for 2664 kilometers.

Aizawl district is located in the northeastern state of Mizoram, India. It is one of the eight districts of Mizoram and is the biggest and most populous district of the state. The district is home to several small towns and villages, including the capital city of Aizawl, which is the largest and most populous city in Mizoram. The proposed study area, Aizawl district, is one of the eight districts of Mizoram and is the biggest and most populous district of the state. Aizawl is the state capital and is located 3,715 feet above sea level. Mizoram is a mountainous state located in northeast India, with a predominantly tribal population accounting for 94.4 per cent of the total in the 2011 Census.

1.6.1 Location and Extent

Aizawl district shares borders with three other districts of Mizoram - Serchhip and Champhai districts to the east, Mamit to the west, and Kolasib to the north (Figure 1.1). The district occupies an area of 3576 km^2 in Mizoram and is situated between 23^o 18' N - 24^o 25' N latitudes and 92^o 37' E - 93^o 11' E longitudes. Survey of India Toposheet No. 83D/15, 83D/16, 84A/9, 84A/10, 84A/11, 84A/13, 84A/14, 84A/15, 84E/1, 84E/2, 83H/3 and 83H/4 covers the study area. Again, Aizawl district is sub divided into five Rural Development (RD) Blocks, such as Aibawk, Darlawn, Phullen, Thingsulthliah and Tlangnuam.

1.6.2 Relief features

Aizawl district covers an area of 3,577 km^2 and is mostly mountainous, with an average elevation of 1,000–1,300 meters above sea level. Elevation- and slope-based classifications were employed to understand the relief features of the area. The study area is predominantly mountainous and is characterized by mountain ranges and deep river valleys. The mountain ranges are aligned from north to south and run parallel to one another. The ranges are separated by narrow and deep river valleys, which contribute to the rugged terrain of the area (Pachuau, 2009). In Aizawl district, there is a noticeable relationship between elevation and slope. Aizawl district exhibits significant variations in elevation, with the lowest point being below 100 meters and the highest point reaching over 1,800 meters above mean sea level. The overall relief is higher, and the slopes are much steeper in the eastern half of the study area. The low-lying areas are mostly formed by river valleys, while the mountain ranges run parallel and aligned from north to south.

Hmuifang, Tawi, Chalfilh, and Mawmrang are and important and prominent in Aizawl district. The overall relief in this province is higher, and that in the eastern part is slightly higher than that in the western portion. The southern part of the district is constituted by the Hmuifang Range, which continues up to the Aizawl range. The middle part of the region comprises two conspicuous ranges: Tawi and Chalfilh. Tawi Range runs from the southeast of the area and descends in elevation towards the north, ending in Shifa village rising 1,889 meters. Chalfilh range extends abruptly to the extreme north and dominates the northern portion of and the highest point reaches 1,095 meters. Mawmrang range is situated in the northeastern part of the region, standing at an elevation of 1,812 meters (Pachuau, 2009).

The per centage of land surface cover varies depending on the altitude in Aizawl district. Very high elevations constitute only 6 per cent and 15 per cent is considered as high elevation. Low elevation areas cover 35 per cent and 32 per cent of Aizawl district is categorized as moderate elevation. Very low elevation area covers 12 per cent mainly found in river valleys. The gradient is particularly steep in very high above 1200 meter and gradually widened after an elevation of 900 meters until it reached a low elevation of 100 m (Figure 1.2B). There is also variation in elevation; the western and northern parts of the district have elevations as low as 200 meters, while in the middle and northeastern parts of the region, the elevation rises to 1000-1500 meters.

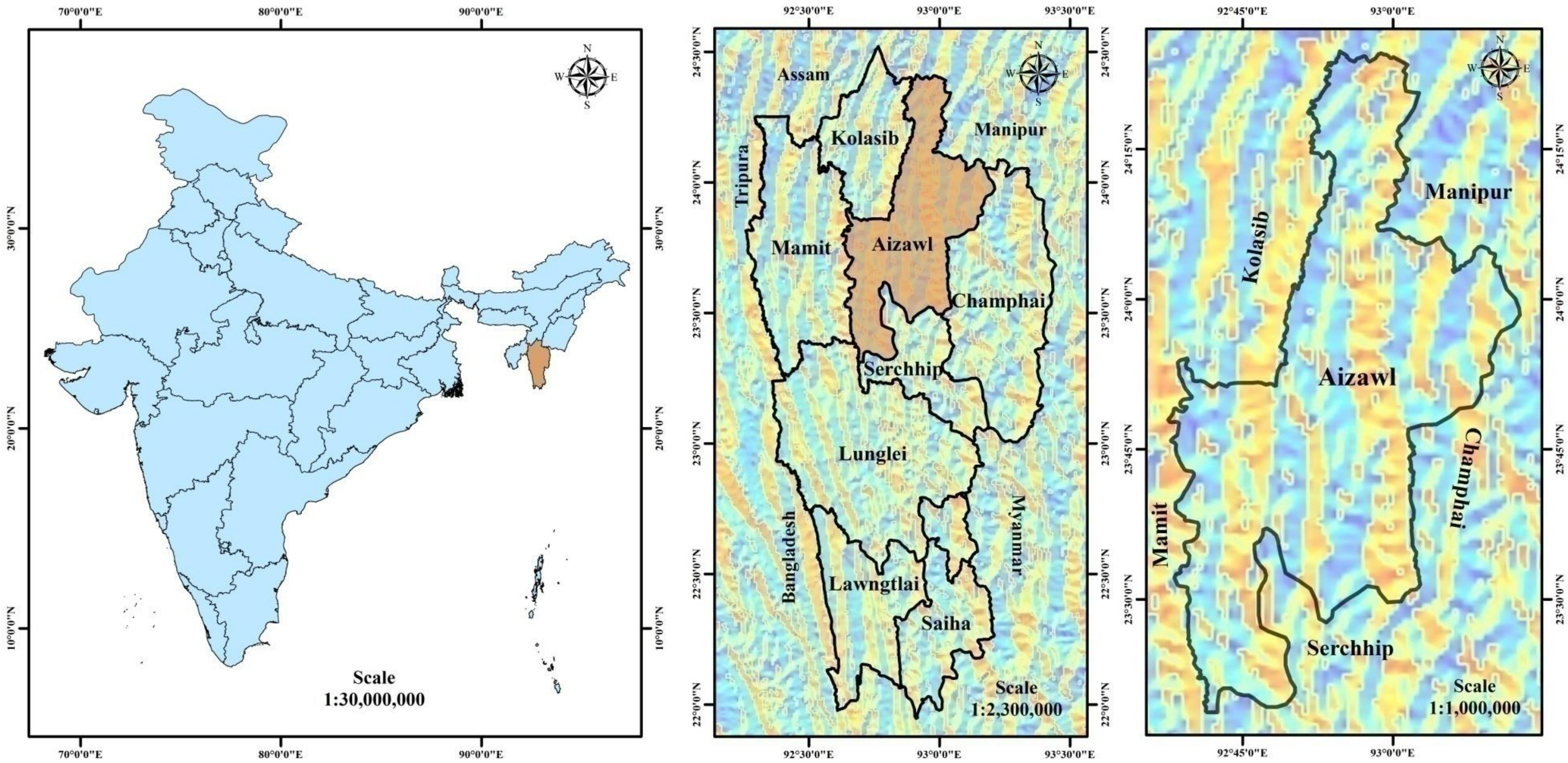

Figure 1.1: Map of Study Area

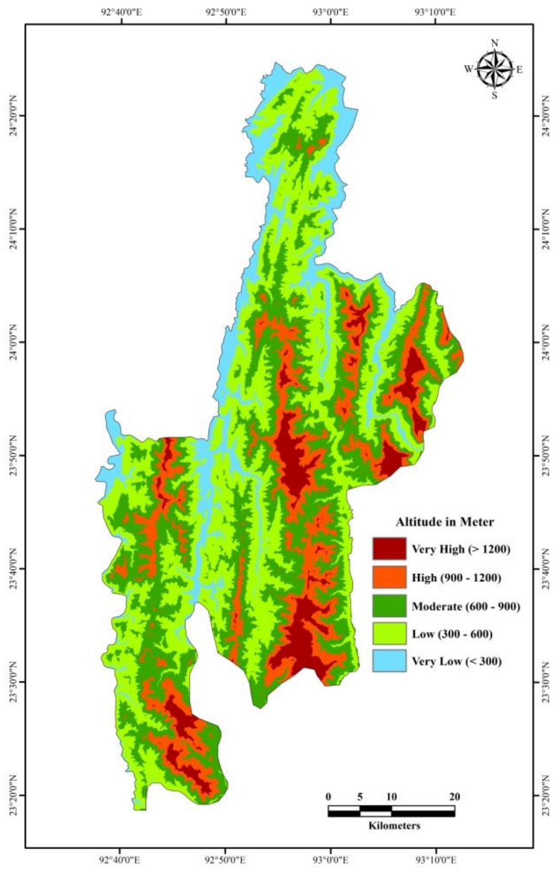

Figure 1.2A

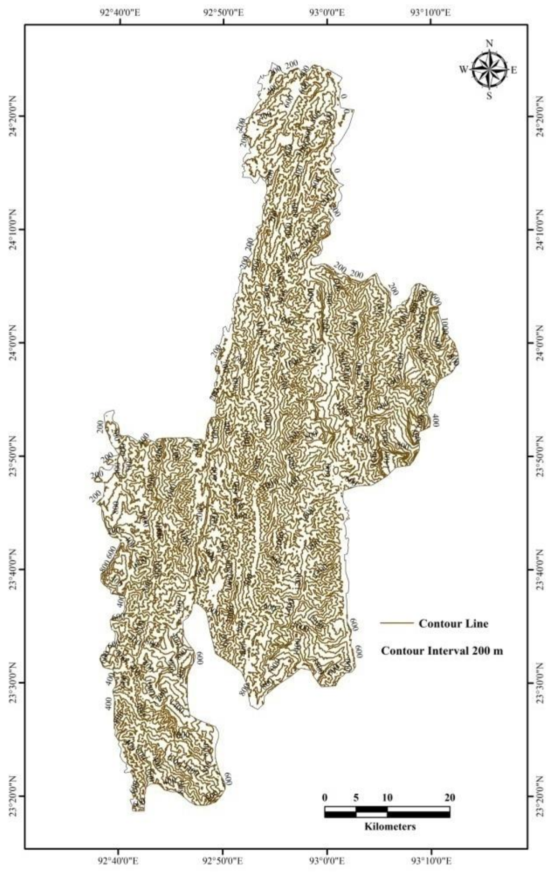

Figure 1.2B

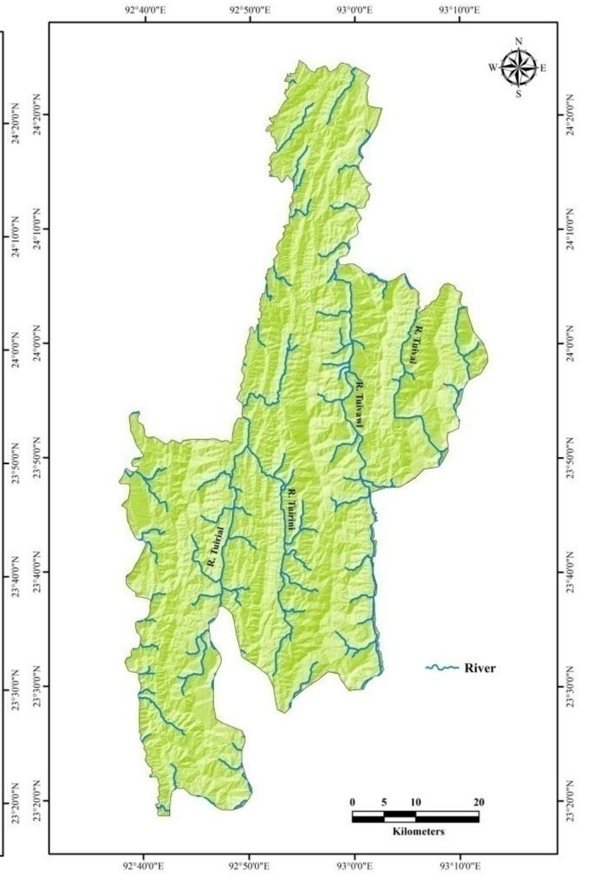

Figure 1.2C

Figure 1.2: (A) Relief Map of Aizawl District, (B) Contour Map of Aizawl District and (C)Drainange Map of Aizawl District

1.6.3 Drainage

The drainage systems in Aizawl district are the results of various geological factors, such as the direction of mountain ranges and slope inclination. The entire drainage system in the district is demarcated by a drainage divide that outlines a more or less rectangular-shaped drainage basin. The district is drained by two major river systems, Tuirial and Tuivawl, along with numerous streams and rivulets. These river systems rely heavily on monsoon rainfall, which serves as the major source of discharge. During the dry season, most of the streams and rivulets run dry and are considered ephemeral streams. Most of the rivers descend to Barrak river system. Generally, the drainage systems are originated from the central parts of the state and flow either towards the north or south direction along north-south trending ridges. These ridges act as the natural boundaries for the drainage system and determine the direction of the flow.

Navigable rivers are almost absent in this area, except for short stretches of Tuirial River, which are navigable only by small boats. Generally, the southern and central portions of the study area are dominated by the Tuirial River and its drainage system. Tuirial River rises north of Chawilung Village in the Aizawl district and flows north before meeting the Barak River in Assam. The right-bank river Tuirini is the only noticeable tributary of the Tuirial River, which flows parallel before joining the main river and originates from the western slopes of Tawi peak.

Another significant drainage system in the northeastern portion of the study area is the Tuivawl River and its tributaries. The river originates near Chhawrtui village in the Champhai district and flows approximately 63 kilometers north before joining the Tuivai River near the Manipur border. The river systems in Aizawl district are important sources of water for irrigation, agricultural purposes, and fishing. Especially, the Tuirial Hydroelectric Power Project, located on the Tuirial River, is a significant source of electricity and transportation for the region.

1.6.4 Soils

The major types of soils in Aizawl district are red and yellow soils. Red soil, which can be found on hill slopes and hilltops, is rich in organic matter and nitrogenous materials. These soils are also acidic, but have lesser amounts of phosphate and potash. The texture of red soil is generally fine, ranging from loam to clay, making it suitable for the production of rice and horticultural crops. Yellow soil is also found alongside red soil, varying in color from yellow to yellowish-brown, and is typically found on hill slopes.

Alluvial soils are also found in few pockets, especially in river valleys, where they are formed by depositional processes. Alluvial soils contain clay, sand, and silt and have a thin texture with a grey to pale brown color. They are fertile, contain a fair quantity of nitrogen and organic matter, and are less acidic in nature. Wet rice cultivation is practiced in small patches of alluvial soil suitable for agriculture.

1.6.5 Climate

Similar to other parts of Mizoram, Aizawl district has a humid tropical climate with a short winter and a long summer season characterized by heavy rainfall. The region is under the direct influence of the southwest monsoon, which brings a significant amount of rainfall within short period, typically between June and September.

In terms of temperature variations, the Aizawl District exhibits characteristics similar to those of the rest of Mizoram. The overall temperatures do not vary significantly throughout the year because they are influenced by seasonal changes and the physiography of the region. The elevated region experiences a moderate climate due to its high elevation and the significant amount of rainfall it receives during the summer season. The hottest months are observed from May to July, with maximum temperatures reaching about 31°C. The minimum temperature observed in the valley region, which is around 20°C. The onset of the monsoon reduces the daily temperature by 2°C to 3°C during the rainy season. During the autumn season, the diurnal temperature range was minimal, with temperatures ranging from 19.7°C to 27.3°C. The temperature continues to fall and declines further until the months of

December and January, which are considered the coldest months of the year. Winter average temperatures in Aizawl district can range from 13.2°C to 24.5°C, and higher altitudes may experience extremely cold and dry weather, with temperatures sometimes dropping below 5°C.

The average rainfall in the Aizawl district is about 203 cm per year. The rainy season, which typically lasts from June to August, the average rainfall exceeds 300 cm, and heavy rainfall is often accompanied by thunder and hailstorms. As a result, more than 54 per cent of the annual rainfall has been concentrated over the past few months. During the rainy season the temperature remained high and the relative humidity reached 85 per cent.

The driest season in Aizawl district is observed in winter, and January is the driest month of the year with less than 1 cm of precipitation. Winter season contributes to less than 2.5 per cent of the annual rainfall, which originates from the retreating monsoon. Specifically, places located on the windward slope (western slopes) receive more rainfall from the southwest monsoon winds, while those on the leeward slope (eastern slope) receive less rainfall.

1.6.6 Population

The district of Aizawl is populated by different sub-tribes of Mizo. The Lusei tribe became the dominant tribe in the district in terms of tradition and culture. However, a few pockets in the district were dominated by Hmar and Paite tribes. The middle region and urban areas of Aizawl district are characterized by a mix of various sub-tribes from the state. The southern area is mostly inhabited by the Lusei sub-tribe, while the Hmar sub-tribe dominates the northern part of the study area.

The total population in 1991 was 218,744, which increased to 325,676 by 2001, indicating a rapid growth rate of 48.9 per cent. However, in the 2011 census, the population growth rate declined to 23.66 per cent, with a total population of 400,309 persons. The study area experienced a significant increase in urban population growth from 2001 to 2011, an increase of approximately 26.8 per cent. In contrast, the rate of rural population growth was only 10.3 per cent.

Interestingly, the female population showed a greater increase than the male population from the 1991 to 2001 census, with growth rates of 52.5 per cent and 45.6 per cent, respectively. Similarly, in the 2011 census, the growth rate of the female population exceeded that of the male population, with increases of 26.6 per cent and 19.4 per cent, respectively.

In terms of rural-urban population, the proportion of the urban population in Aizawl District is notably higher than that in the other districts of the state. In 1991, the urban population constituted 45.7 per cent of the total population, which increased to 76.2 per cent in 2001 and to 78.6 per cent in 2011, significantly surpassing the state average of 52.1 per cent. Between 2001 and 2011, the urban population grew at a rate of 26.8 per cent, whereas the rural population grew by only 10.3 per cent. Unlike in other parts of the country, the proportion of the urban female population was higher than that of the urban male population, accounting for 50.56 per cent of the total population in 2011. The growth rate of the female population in urban areas during 2001–2011 was 31 per cent, while that of the male population was 22.9 per cent. The growth rate of the female population was higher than that of the male population at 12.3 per cent and 8.5 per cent, respectively.

In terms of population distribution, the study area has a significantly high population density of 113 persons per square kilometer, which is significantly higher than the state average density of 52 persons per square kilometer in the 2011 census. High population concentration was seen in the middle part of the district, especially along National Highway number 54, as well as along the main arterial roads. The concentration pattern becomes more intense near to an urban area, mainly because of urbanization processes.

1.6.7 Composition of Population

The ethnic population of Aizawl district is predominantly Scheduled Tribes, with 93.3 per cent of the population falling under this category. Scheduled Castes, on the other hand, make up only 0.16 per cent of the total population. Linguistically, Aizawl district is a mono-lingual area, with Mizo or Lusei being the lingua franca of the state. More than 93 per cent of the population spoke Mizo as their native tongue.

Small number of people in Aizawl district also speaks Hindi and Bengali. In some urban areas, Telugu-speaking populations also exist.

According to census reports, the total literacy rate in Aizawl district increased from 82.8 per cent in 2001 to 86.91 per cent in 2011. The rural literacy rate was 81.56 per cent, whereas the urban literacy rate was 86.04 per cent in 2011.

A unique feature of the study area is that the female population exceeds the male population. According to 2011 female population accounted 51.2 per cent of the total population in Aizawl district. As a result, sex ratio increased from 952 to 1009 in the 2001 and 2011 censuses, respectively. In terms of absolute figures, the sex ratio in urban areas was more ideal than that in rural areas. The sex ratio in rural areas is 954 females per thousand males, while in urban areas 1024 females per thousand males. This indicates that the female population has improved drastically in urban areas compared to that in rural areas.

Christianity is the dominant religion in Aizawl district, census 2011 records 94.7 per cent of the population identified as Christians. Hinduism is the second largest religious group, with 3.3 per cent of the population, and the majority of Hindus in the state reside in Aizawl district. Islam accounts for 1.3 per cent of the total population, while other minority religions, such as Sikhism, Buddhism, and Jainism, are also present in small numbers.

1.6.8 Occupational Pattern

According to the 2011 census, the occupational pattern of Aizawl district is dominated by primary economic activities. In rural areas, 77.71 per cent of the total working population is employed in agriculture and allied activities. The proportion of the agricultural population to the total working population varies in both rural and urban areas. Based on the 2011 census, more than 80 per cent of the rural main working population is engaged in the agriculture sector, primarily in shifting cultivation and horticulture-based activities. Conversely, in urban areas, only 10.6 per cent of the total primary workers are employed in the agricultural sector. Due to limited development in the secondary sector, the manufacturing sector employs only

1.6 per cent of the total workforce in the study area. Meanwhile, government jobs and business sectors are considered higher-income groups. In urban areas, small-scale industries contribute only 2 per cent of the total main workers, which is significantly lower than the national average. Particularly those in rural areas Agriculture is the primary source of livelihood and white-collar jobs dominate in urban areas.

1.6.9 Settlement Pattern

Out of 83 settlements in Aizawl district, 79 settlements are considered as rural settlements and the remaining four settlements are town/urban, such as Aizawl, Saitual, Sairang, and Darlawn. Aizawl is the largest and capital city of Mizoram with a population of more than 228,442 peoples.

In earlier days, settlements are strategically built on hilltops for easy defense, whereas factors such as arable land, water sources, and hygiene are secondary considerations for village site selection. The typical settlements were primarily small-scale, usually consisting of two lanes and regular house arrangements, with each side facing the other and divided by a village street (Pachuau, 2009). In rural areas, settlement patterns depend on topographical factors and administrative arrangement. While, urban settlement patterns are characterized by the arrangement of the transport network and the location of administrative centers, educational institutes, and medical facilities. Recently, the spatial organization of settlements and the establishment of new settlements were closely related to transport facilities. The administrative functions and transport facilities impact the natural and physical growth of any settlement.

1.6.10 Land Use and Land Cover

The terms “land use” and “land cover” are frequently used to define the characteristics and utilization of land, which is an essential resource for humans. The 2022 land use and land cover report for Aizawl district identified nine categories of land use covering a total area of 357.63 thousand hectares. Forest area constituted the largest portion, accounting for 76.38 per cent of the district. Land not available for cultivation comprised 4.7 per cent of the district, whereas barren and uncultivable land accounted for only 0.31 per cent. The remaining uncultivated land covered 15.98 thousand hectares, 6.4 per cent of which was classified as cultivable waste land. Fallow land was the second-highest land use type, constituting approximately 9.07 per cent of the total. Slope lands are typically used for shifting cultivation because of the hilly and undulating topography, resulting in a longer fallow period.

The net sown area only contributed 5.85 per cent to the total reporting area. Furthermore, only 3.2 per cent of the gross crop area was used more than once, and only 1.4 per cent of the net sown area was irrigated, with the remainder relying on the rainfall. The data suggest that agricultural development in Aizawl district lags behind due to geographical limitations and a shortage of technology in the agriculture sector.

Table 1.1: Land Use and Land Cover Aizawl District, Mizoram (2018 – 2019)

Sl. No	Categories	Area ('000 ha)
1	Reporting Area	357.631
2	Forest Area	273.158
3	Not available for cultivation	
(a)	Land put to non-agricultural use	15.627
(b)	Barren and Uncultivable land	1.2
4	Total (a+b)	16.827
5	Other uncultivated land excluding fallow land	
(a)	Permanent Pastures and Other Grazing Lands	1.02
(b)	Land Under miscellaneous tree crops and groves not included	13.938
(c)	Cultivable waste land	1.023
6	Total (a+b+c)	15.981
7	Fallow Land	
8	Fallow land other than current fallows	26.269
(a)	Current fallow	6.169
(b)	Total (a+b)	32.438
9	Net sown area	20.266
10	Area sown more than once	0.667
11	Gross Crop Area	20.933
12	Net irrigated area	0.3
13	Gross irrigated area	0.3
14	Rain-fed	19.97

Source: Directorate of Agriculture (Crop Husbandry), Govt. of Mizoram

1.6.11 Agriculture Production and Productivity

In Aizawl district agricultural practices range from the primitive shifting type (jhumming) in the hills to permanent wet rice cultivation in valley areas. Their agricultural produced is primarily used for home consumption and subsistence needs. Agricultural productivity is very low and farming is conducted on a small scale using traditional techniques. In recent years, some changes have been observed in the agricultural system towards horticulture-based and semi-commercial farming practices in the study region. Also in certain areas, farmers have modernized their agriculture by applying irrigation systems, insecticides, pesticides, and high-yielding varieties of seeds. Owing to the demand in urban areas, farming systems and productivity patterns are more diverse in close proximity to urban areas. Therefore, in villages such as Sairang, Seling, Saitual, and Muallungthu, agricultural productivity varies depending on the proximity of metropolitan areas and accessibility of roads.

According to existing records, six primary crops are regularly cultivated in Aizawl district: rice, maize, pulses, oilseeds, tobacco, and sugarcane are dominant crops. Rice is the staple food and is extensively grown on hill slopes and valley areas. Over the years, there have been fluctuations in the yield of various crops in the district. Since 2017–18, there has been a noticeable increase in the yield of several crops. For instance, the yield of rice increased from 1574 kg/ha in 2017–18 to 1716 kg/ha in 2020–21. The pulse yield has also significantly increased from 3001 kg/ha in 2017–18 to 4680 kg/ha in 2020–21. Other crops like maize and oilseeds have also recorded increase in yield. However, there has also been a decline in the yields of some crops like sugarcane and tobacco. Sugarcane has witnessed a decline of over 15 per cent from 2017 -18 to 2020–21 and the yield of tobacco is also decreased from 889 kg/ha to 633 kg/ha between 2018–19 and 2020–21 (Table 1.2). Such fluctuations in yield can be attributed to several factors, including climatic conditions, availability of technological inputs, changes in demand and market conditions.

A reduction in shifting cultivation is evident in the study area, leading to a significant decrease in the production of crops such as rice, maize, and tobacco.

However, horticultural crops such as oranges, pineapples, and bananas are grown on hilly slopes across different parts of the district. Vegetable production is another major agricultural product, particularly in the proximity of urban areas and in areas with good road connections. Rural roads play a vital role in connecting farmers to market centers, enabling them to sell their produce and increase their income.

Table 1.2: Yield of Corps in Aizawl District, Mizoram (2017 - 2021)

Year	Kilogram per Hectare					
	Rice	Maize	Pulses	Oilseeds	Tobacco	Sugarcane
2017-18	1574	1749	3001	1328	500	36540
2018-19	1620	1817	3097	1234	889	37646
2019-20	1580	1840	1659	314	861	30499
2020-21	1716	1884	4680	1356	633	30803

Source: Agriculture Department, Govt. of Mizoram

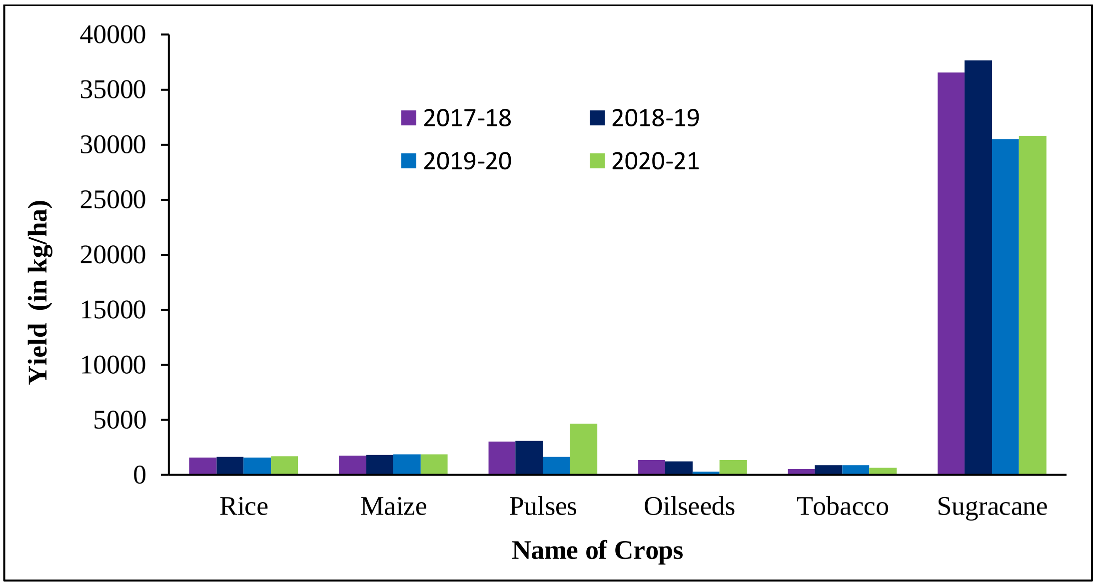

Figure 1.3: Yield of Corps in Aizawl District, Mizoram (2017 - 2021)

1.7 Significance of the study

The impact of transportation networks on socio-economic development has been widely discussed across various academic fields. However, the geographical aspects and perspectives of this subject have received insufficient attention. Given that the field of transport geography is relatively new, there is a vast area to explore in understanding the connection between transportation networks and socio-economic development. Therefore, this study plays a crucial role in addressing the knowledge gaps concerning the correlation between road networks and socio-economic development from a geographical standpoint.

The insufficiency of research hampers researchers, policymakers, planners, and decision-makers in comprehending the underlying fundamental issues and challenges related to socio-economic development in relation to road transport systems. However, research can provide valuable insights that can be used to identify problems, determine their causes, and develop effective solutions for establishing an efficient transport network. The results of this study can signify decisions regarding infrastructure investments, transportation policies, and sustainability initiatives.

The road network is indispensable for socio-economic growth as it enables physical connectivity between different locations, facilitating the transportation of goods, services, and people. It serves as a vital connection between locations and acts as the principal catalyst for socio-economic growth. As a crucial component of the interaction system, road networks are associated with various aspects of socio-economic development. Consequently, this study is significance for investigating the spatial interaction systems and its impact on socio-economic development in a specific study area.

The geographical limitations of the study area have resulted in a lack of diverse transportation options, which poses significant challenges for transportation in Aizawl district. Consequently, road transportation has become the sole means of transportation available to the masses. Therefore, investigating the effectiveness of the road transport network is necessary to understand its role in supporting socio-economic development in mountainous area. This investigation will serve as a basis for policymakers, planners, and stakeholders and further studies in Mizoram as a whole and Aizawl in particular.

The incorporation of network theory to assess the effects of road networks on accessibility and spatial interaction is rare, but the results are significant for understanding the causes of socio-economic development. The use of network theory for strategic planning and solving site suitability problems is more appropriate. It reflects the relationship between entities and the information flow through the network, which are important parameters for explaining heterogeneity (entropy), importance (centrality), and the connection pattern of the road networks. The study also demonstrates the significance of spatial modeling and analysis tools for road transport network analysis. This emphasizes the relevance of geographical aspects in transport analysis.

1.8 Limitation of the Study

Extraction of road network from remotely-sensed imagery is rather difficult as the appearance of a road varies according to satellite sensor types, spectral and spatial resolution, ground and weather conditions. Even the appearance of roads in the same image is also different due to the materials used for road construction. Moreover, spectral characteristic appears differently with differing physical conditions such as roads in deserts, vegetation fields, hills and valleys, village roads, city roads, cycle tracks (Ahmad and Deore, 2014). Several problems related to road data extraction from remotely sensed data can result in geographical and technical errors. Geographic features like the topography and vegetation cover that are characteristics of the study area also result in radiometric and atmospheric errors which too can be considered as technical errors. These errors create tricky and confusing issues in the extraction of road data network and point features from satellite images. Therefore the process of data extraction becomes a complicated and problematic task.

The limitation of local centrality measure lies in the fact that the degree of centrality value is influenced by local measures since the value of a vertex is determined by the euclidean distance, number of neighbors, and failed to depict its position in geographical distance in the entire network.

1.9 Organization of Chapter

The present study is orderly arranged into seven chapters.

Chapter I: The first chapter deals with the introduction of the research, which consists; general introduction of the topic, a statement of problems, the scope of the study, geographical perspectives of the study area, relevance of the study and chapterization.

Chapter II: The second chapter is devoted to a literature review that elaborates the earlier contributions of the present study so as to establish a strong foundation for the research.

Chapter III: The third chapter highlights the methodology adopted in this study. It also discusses the concept and principles of the methods adopted for road network analysis (centrality measures), socio-economic attributes, and data integration techniques.

Chapter IV: This chapter is devoted to analyzing the topological structure of road networks in the Aizawl district. First, it analyzed the spatial distributions of node accessibility using centrality parameters, such as degree of centrality, degree of Centrality, degree of Eccentricity, Closeness Centrality, Betweenness Centrality and Eigenvector Centrality. The chapter ends with a description of the characteristics and relationships of the parameters.

Chapter V: Spatial variations in socio-economic development and its consequences are described in detail in this chapter. The chapter also analyzed the spatio-temporal variations in population growth, sex ratio, crude literacy rate, dependency ratio, and agricultural working population.

Chapter VI: Chapter six describes the role of the road transport network and socio-economic development in Aizawl district. The study analyzed the accessibility of nodes (settlements) and levels of socio-economic development by calculating the Mean Accessibility Index (A_I) and Mean Socio-Economic Development Index (D_I).

Later in the chapter, the relationship between the accessibility index (A_I) and socio-economic indicators (D_I) is discussed.

Chapter VII: The last chapter provides a summary of all six chapters, drawing synthesized concluding remarks. It traces the major conclusions and summarizes the findings of the study.

CHAPTER II

Review of Literature

2.1 Introduction

The study of transport networks is one of the interests of geographers, as these networks play a significant role in spatial interaction systems. Transport networks have been extensively studied as a distinct discipline, spanning across various areas of human and mathematical sciences. Literature on this topic can be found in diverse subjects, including geography, economics, regional science, urban planning, engineering, and computer science. Therefore, conducting a literature review is crucial, as it provides an overview of previous studies on transport networks and their associated issues.

The proposed study combines various aspects and adopts a multi-disciplinary and multi-dimensional approach. The literature associated with this study encompasses a broad spectrum, spanning from modeling to analysis, transport network planning, and the cause-and-effect analysis of transport. Thus, it includes fundamental concepts of transport networks, network analysis from different dimensions, network attributes, and the relationship between road transport networks and socio-economy within the geographical context.

2.2 Classical Works on Transport Geography and Transport Network

The earlier attempt in transport geography was mainly based on a theoretical rather than empirical approach. Thünen (1914) work 'The Isolated State', made an attempt to address the limitations of transportation and its impact on the intensity of agricultural production around the market center during the classical period. Thünen also hypothesized the influence of transport costs on agricultural production and its dependence on accessibility characteristics. His classical work on agriculture land use model understands the influence of transport network on the dynamics of agricultural land use and agricultural production with respect to distance from the '*isolate estate'*.

In 1909, Alfred Weber's works on 'Least Cost Location Theory attempted to address the significance of the transport networks in the selection of industrial locations. A similar approached was presented by Lösch (1940) in different perspective in his theory of 'Profit Maximization', which focused on the hierarchical arrangement of settlements in association with transport network patterns.

Until the 1950s, most works on transport geography were produced by European geographers, although North American geographers also made significant contributions during this period. These pioneering works exhibited two distinctive characteristics. Earlier European geographers such as Robert (1946), Sealy (1955), and Morgan (1958) primarily focused on transportation modes and commodities. In contrast, American geographers like Jefferson (1928), Ullman (1949), and Ullman and Mayer (1954) primarily dealt with route classification, mapping, and flows. It is important to note that both of these classical works were carried out using a descriptive approach. However, these contributions led to a shift in transport geography towards a more dynamic approach, incorporating theoretical and quantitative studies.

A bit later, the works of transport geographers shifted towards a broader and more theoretical approach, with a particular emphasis on spatial interaction and interregional linkages. The pioneering works of Ullman (1954) outlined the nature and scope of this new branch of geography and demonstrated its various economic aspects related to transport network entities. These aspects include traffic volume, origin and distribution, as well as the structure and infrastructure of the networks.

Significant changes were observed in the works of North American geographers, with a focus on quantitative approaches, the introduction of location theory, spatial analysis, regional science, and the implications of various mathematical techniques. Garrison (1956) Berry and Garrison (1958) performed a modified version of the central place theory to study intra-city and inter-city linkages. This work by Berry and Garrison also led to another innovative concept known as the *'gravity model'*. The gravity model, to a certain extent, drew inspiration from Ullman's earlier approach to transport analysis. The model has become widely used in transport planning, regional science and urban transport network studies. The works of Garrison (1959) gained attention in geographical world due to the incorporation of newly developed techniques that encompassed an interdisciplinary approach and location analysis within the subject. These new techniques provided fresh impetus for geographers to further investigate flow data embedded within the economic landscape. Additionally, Garrison *et al.* (1959) introduced another dimension of studies, concentrating on the impact of highway changes. These contributions have broader implications for the socio-economic and socio-political milieu, leading to the recognition of transport planning as an essential tool for resolving socio-economic and socio-political issues.

This gravity model encouraged scholars to visualize macro units to understand the potential interaction between humans and served as a basis for postulating the attractive force of interaction between two areas (Carrothers, 1956; Warntz, 1957; Isard, 1960). Since then, the dimensions of transport studies have become multifaceted and deviated into many folds, focusing on the interests of scholars and the objectives of the studies.

Much of the work that followed contemporary spatial analysis methods derived from the broader cluster of general location theory, which is evident in Christaller's central place theory. Christaller (1966) settlement development models treated transport networks as primary economic indicators, influencing the range and function of settlements within both upper and lower limits. The theory also conceptualized the idea of centrality in terms of functions and services. Accordingly, Christaller’s theory also aimed to explain settlement development, functions, and centrality based on the flow of goods and services through transport networks, with a particular focus on urban locations.

2.3 Structure and Topology of Road Network

The structure of road networks interplays different aspects of the networks or network properties. The notable development in 1950s was marked by changes in dimensions within transport geography, transitioning from a descriptive to a quantitative approach. Ullman's works (1956 and 1957) laid the foundation for understanding interaction through quantitative approaches, emphasizing three key attributes of spatial interaction - complementarity, transferability, and intervening opportunity. These concepts of spatial interaction create spatial relationships across geographical space, resulting in varying degrees of connectivity and interaction.

This new approach promoted experimentation and the innovation of new techniques within the subject. The outcomes consolidated new approaches to studies in the 1960s, including the application of graph theory in transport network analysis. The analysis of transport network systems based on graph theory was developed by Kansky (1963) in transport geography. This foundational work solely relied on graph theory to investigate the structural properties of network systems and utilized statistical techniques such as correlation and regression analysis to analyze the spatial structure of these systems. Graph theory approach has had significant development in spatial structural analysis, road development prediction (probability of route development), and travel behaviour analysis. Garrison and Marbel (1965) discussed transportation and commodity flows by examining the structure of transport networks. They employed graph theory as an interpretive framework and developed a simulation model to depict the morphological characteristics of transport networks while comparing inter- and intra-national network structures.

The categorization of complex network systems using statistical and computational techniques has attracted considerable attention in scientific literature, as evidenced by the works of Mohring (1961) and Gauthier (1966). Basically, these works explore the subsequent effects of network topology and structure on the efficiency of node accessibility, movement patterns, direction, flow patterns, and other factors within a given environment. Garrison (1960) also placed emphasis on topological and structural measures, employing graph-theoretic network analysis and modeling techniques.

Similarly, significant attempts have been made to apply topological and graph theory techniques to analyze transport networks within broader conceptual frameworks (Nystuen and Dacey, 1961; Burton 1962, 1963). The landmark work of

Kansky (1963), titled "Structure of Transportation Networks: Relationships Between Network Geometry and Regional Characteristics", introduced graph theory in a resilient and dynamic way for transport network analysis. His analytical method incorporated extensive empirical analysis and a more systematic approach to studying transport networks. Kansky's study primarily focused on the structural analysis of networks, emphasizing how the networks structure influences the geographical identity of a region. He argued that the structure of a transport network in any area cannot be examined in isolation without considering the geographical characteristics of that area. Apart from this, Kansky introduced statistical techniques such as correlation and regression analysis to determine the strength of the relationship between transport measures, economic development, and geographic characteristics. Since then, the application of graph-theoretic and matrix measures has been widely used in the field of transportation geography. Furthermore, the concepts of travel behavior, route development, and planning aspects have also been highlighted using probabilistic approaches.

A similar approach to studies has been undertaken by Valsilvskiy (1963). His study attempted to investigate three components of transport geography. These components include the study of network by location (including structure and evolution), the analysis of network flows and their significance, and the examination of the impact of networks and flows on the economic and social system.

Since then, the works on transport geography have advocated wider perspectives, encompassing not only the structure and characteristics of transport networks but also their origins, evolutions, planning, and probability aspects. Chapin and Hingtower (1965) drew attention to the usefulness and potential feasibility of transport networks in shaping activity patterns and land use. The pioneering works of Haggett (1966 and 1967) also introduced the application of graph theory in the field of human geography, particularly in the analysis of urban transport networks.

In line with the concepts of graph theory, Marble (1967) and Nystuen (1967) presented theoretical concepts of travel behavior, which were further expanded by Rushton *et al.* (1967). Rushton and his colleagues attempted to validate network approaches as tools for analyzing central place function and the determining factors of consumer travel behavior in urban areas. The study also emphasized the attractiveness of different locations for consumers through the urban road network. Similarly, Hurst (1967) aimed to gain a macroscopic view of movement patterns and trip-makers responses to the transport system. Hurst argued that travel decisions and cognition are influenced by utility, perceived space, habit, and role. These studies also highlighted the weaknesses of the behavioral approach in empirical studies and encountered methodological problems in evaluating transportation systems and their elements.

Gauthier (1968) investigated the problems of transport development and economic change in São Paulo, Brazil. Gauthier primarily focused on the changing relationship between accessibility, the highway network, and the growth of urban centers, with a specific emphasis on the development of highway transportation and its impact on urban economy. Subsequently, the abstraction of human and physical phenomena into network structures has become a dominant area of study in human and economic geography.

The evolution of the concept of graph theory in the early 1970s marked a shift in approaches to transport network analysis in the field of geography. The studies primarily focused on three main approaches: (a) the structural approach, which analyzed the pattern of the network and the relationship between the networks topology and the real world, (b) the evolution approach, which highlighted the factors contributing to the progressive nature of the network, and (c) the nodal/accessibility approach, which investigated the centrality and functional importance of nodes in the network system. Thus, Taffe and Gauthier (1973) laid a strong foundation for the structural analysis of transport networks. To provide a better understanding of network compression, growth, evolution, and accessibility, they employed techniques for analyzing aggregate scores. It is evident from their studies that by using graph theory, all three approaches can be evaluated and interpreted in a systematic way. For instance, the determination of route development, size and pattern, spatial structure, centrality of nodes, accessibility of nodes, efficiency, and flow patterns of the network have been explained through various graph theoretic measures.

Transport network analysis in transport geography was also influenced by studies on urban transport, spatial processes and flows, farms and recreational locations, as well as continued research on individual models and historical studies. Hurst (1973) adopted a descriptive approach at the sub-regional, regional, and international scales. This approach is particularly beneficial for understanding the interdependent role of transport in our socio-economy and serves as a unifying link within and beyond the field of geography. The development of transport geography encompassed diverse approaches, but they can generally be classified under the categories of “descriptive approach” or “quantitative approach”. Furthermore, the diversity in approaches reflects the lack of a unified set of theories in transport geography for integrating the wide range of studies. However, Hurst argued that a significant number of studies in transport geography have meaningful generalizations and principles.

On the other hand, dimensions of policy-oriented transport studies have been carried out by Wheeler (1973). His paper aimed to investigate the individual elements of transportation as a subsystem and their interrelationships to understand the system as a whole. His approach integrated social and economic themes in transport geography to a greater extent. The paper also emphasizes the importance of integrating the transport system with the functions of an area in decision-making processes and the policy context.

The book “Network Analysis in Geography” by Haggett and Chorley (1979) focuses on three important stages of network analysis in geography. The first stage involves analyzing spatial structure, topological structure, and geometric measurements. The second stage addresses the evaluation of network structure in terms of efficiency by examining optimal locations within the network. The third stage explores the growth, transformations, and changes of the network over time. Haggett and Chorley work contributed to the broader implementation of transportation networks for explaining cultural and operational contexts.

The late work of Ullman (1980) assumed that transportation nodes and vertices are central figures and agents of interaction within geographical space. Thus, the concentration of interaction at these vertices determines the extent of the relationship between geographical spaces. Factors influencing interaction may be geographic, economic, social, or technological in nature. Moreover, the processes of interaction may change over time in response to attraction and repulsion factors, and they also vary depending on the characteristics of the space.

After the 1980s, research on transport networks became more dynamic and integrated with information technology and computer systems. This opened up new perspectives, shifting the focus not only to the topological and structural characteristics of networks but also to the role and identity of nodes and the distribution of centrality values among them. Crucitti and Porta (2006) implemented mathematical modeling techniques for road networks, utilizing primal graph theory and computer systems to represent real-world data and facilitate further analysis. The research highlights that the topological and structural analysis of road networks plays a significant role in determining the distribution of node centrality values and the identity of nodes. The study also emphasizes the importance of considering geographical factors when investigating the distribution of node characteristics.

The spatial variations in the structural attributes of a network have an inherent impact on the performance of the transport system, which is crucial for the flow of information and the patterns of commodity movement. Mathematically, the connectivity and arrangement of a network are known as topology. Therefore, road transport networks exhibit various specific topologies that signify their structures in terms of edges, vertices, paths, and cycles (Rodrigue *et al.*, 2006).

"Networks, which can be embodied as a set of nodes representing spatial locations and a set of links representing connections, possess many different structural properties, displaying both topological and geometric variations. The arrangement and connectivity of nodes and links of a network is referred to as its topology" (Xie and Levinsion, 2007; Demsar *et al.* 2008). Transport network topology represents the physical expressions of the network within and between spaces. The structural properties of transport networks have a cause and effect relationship with the movement, resulting in the integration and interaction of spaces.

Devkota (2015) graph theory is a tool to implicate topological analysis, which provides information on structural attributes such as accessibility, centrality, distance, orientation, density and geometric pattern. Kilicman and Abdu (2018) repeat the significance of graph theory in network analysis, suggesting that it enables the measurement of topological properties in complex network structures. A graph simplifies the representation of interactions and relationships between points, serving as a depiction of topological space. Conversely, topology is a powerful mathematical tool for understanding the interactions and relationships between vertices and edges in a graph.

2.4 Transport Network and Socio-Economic Development

Transport networks are agents of spatial interaction between spaces and have become an important subfield of study in geography. However, initially geographers paid little attention to understanding the significance of transport networks in the transformation of the space-economy. In the latter part of the 19^{th} century, systematic efforts were made, and the results were recognized as a causative branch of geography. Again, the notable works of Ullman (1954 and 1956) laid out three fundamental concepts of factor topology to explain the interaction or movement of two areas involving transportation networks: *complimentary*, in the sense of the economy, two locations can interact with each other through supply and demand, where one location acts as a supplier while the other becomes a consumer (demand); *intervening opportunity*, with respect to location, one must intervene to offer better opportunities as a point of origin or destination; *transferability*, exists the tendency to substitute one demand with another when the frictional effects of the distance between the two areas decrease the likelihood of interaction.

Ullman's economic understanding of demand, specifically in terms of opportunity and transferability, has been further refined by Mayer (1954). The study constructs theoretical frameworks for analyzing the spatial interaction between two locations, with a particular focus on the fractional effect of these areas. Their detailed examination of urban development and transportation patterns highlights the significance of nodal and hierarchical order within urban centers, along with the optimal positioning of these centers.

The works of Godlund (1956) trace the development of bus services in different time periods. The researcher employed statistical, mathematical, and graphical methods as tools to depict and evaluate nodal accessibility, referred to as the "centrality of place". The concept was utilized to examine the role of nodal points in the area, which holds significance for the surrounding community. His works deliberately address the dynamics of the economic landscape and regional centrality. The study provides key elements for predicting regional centrality or identifying suitable centers for the development of public institutions, commercial enterprises, or housing in Sweden. The fundamental approach of the works viewed the road transport network as a social and Economic Context, Which Functions as a catalyst for economic innovation and serves as the backbone of development.

It is worthwhile to argue that movement of goods and services are determined by the transport network system. Spatial difference in transport system has implications on freight rate structure in the region. The freight rate structures twist and bend concerning isobars (nodal region). The works of Alexander *et al.*, (1958) argue that the movement of goods and services is determined by the transport network system. But, spatial differences in the transport system have implications for freight rate structures in the region. The freight rate structures twist and bend concerning isobars (nodal region). Therefore, it can be asserted that the nodal region has a profound impact on changes in economic structure at the local and global scale. It appears that nodal regions are delimited in terms of the transport foci for to/from movements. When comparing the structure of road nodal regions and rail nodal regions (according to variations in the transport system), the road transport system is more efficient than rail in shorter areas that have a higher accumulation of loads in the hinterland. Therefore, the concept of nodal regions can be utilized as tools for understanding and analyzing the functional and factors influencing economic activities.

Berry (1959) article attempted to answer three primary questions regarding the role of transportation in the space economy, its influence on economic patterns, and the significance of roads in promoting economic improvement, drawing upon existing literature. Chronologically, traditional works emphasized descriptive analysis, focusing on specialized economies, circulation and traffic, as well as the transport system. In contrast, contemporary works are more empirical and theoretical, contributing to our understanding of the structure, processes, and theoretical frameworks through the use of statistical and mathematical techniques. This reviewed article strongly emphasizes the importance of both descriptive and empirical analysis in addressing the complexity of transport networks in the space economy, particularly in the transformation of producers and consumers and the specialized sources of supply in various dimensions. Further, the transport system has a mutual relationship with specialized economies, circulation, and traffic.

Subsequently, Brown (1959) and Garrison (1959 and 1960) applied graph theory to examine the interlink between highways and the spatial structure of the economy. These studies primarily relied on a graph theory approach to investigate the link between the structural properties of the transport network system, such as connectivity, accessibility, and efficiency, and their impact on the economy. The pioneering works on road network analysis from a geographical perspective were initially conducted by Kansky (1963). His introductory work was based solely on graph theory, focusing on investigating the structural properties of the network system and applying statistical techniques (correlation and regression analysis) to excavate the relationships between transport network structure and economic development.

Taffe *et al.*, (1963) compared transport development in developing countries, thereby extending the study of network system structures through the application of matrix and graph theory. The study aimed to integrate regional development and transportation networks within the broader framework of the national economy. Its objective was to consider population characteristics, land value, energy consumption, per capita income, and socio-economic factors in relation to road transport network of a particular region. Additionally, the application of mathematical and statistical tools opened up new dimensions in transport geography.

The transport network and commodity flow pattern in India was addressed by Berry (1968) in his work titled 'Essays on Commodity Flows and the Spatial Structure of the Indian Economy'. In this work, Berry emphasized the importance of ancient transport nodes in regional and spatial organization. The paper not only examined commodity flow but also discussed the relationship between commodity flow and regional economic structure, as well as the pattern of spatial interrelationships. The study also addressed the significance of the transport network and commodity flow for input-output analysis and consumption patterns.

Transport development planning involves two basic issues. Firstly, it should focus on areas where development is already in progress. Secondly, it should prioritize economic aid for relatively backward areas to ensure uniform development in the region. Considering the second option, Larsen (1968) investigated the needs of road transport planning for development in Denmark. The study found that road network development is a tool for regional development and facilitates interaction between different spaces. Road network development has a direct positive relationship with income, consequently leading to a higher chance of population growth. The study also examines the direct benefits accruing to road users from new facilities compared to existing ones, as well as the indirect effects these facilities will have on the areas they serve.

Eliot (1969) works explored the characteristics of land use, travel behavior, and the economic activity associated with traffic at different levels. Similarly, Forrest (1974) focused on investigating the changes in land use resulting from the influence of the transport network. The findings of the study unveiled that the development of transportation routes has a substantial impact on land use changes and the accessibility of specific regions, consequently influencing the behavior of commuters.

Similarly, Barber (1977) investigated the link between road transport and the dynamics of the economy. The study primarily focused on the impact of investment in the road transport network on spatial variations in the regional economic system, specifically in relation to supply and demand. The scholar utilized the 'Representative Network Investment Model' to determine the potential investment required for economic development. This model was also used to predict the optimum investment requirement for a single investment in a specific location. The paper highlights two possible ways of improving nodal performance within the road network: first, upgrading or rehabilitating existing links to reduce transport costs and expand capacity, and second, adding new links to the network.

In the initial developmental studies, McGranahan (1972), Kravis *et al.* (1979) and Isenman (1980) measured a country's development by focusing on the growth of income (Gross Domestic Product or Gross National Product) and its components. More and more scholars from various fields of study have criticized the inadequacy of growth output or income-based socio-economic development studies.

Nordhaus and Tobin (1973), Hicks and Streeten (1979) and Othick (1983) focus on the modified form of income based study called the 'Welfare Approach Development' become more popular for comparative studies between countries and over time. Another approach known as the 'Social Indicators Approach' is gaining credence as well as it is applicable for addressing the issues of contemporary socio-economic development (Bunge, 1981; Hsaio and Wong, 1983). The social indicators approach suggests that development is a multi-dimensional process built upon the premise of socio-economic development. It involves the transformation of the whole social system, and the appropriate measures for such a process should, therefore, incorporate a wide range of social and economic indicators that reflect various aspects of society (Khan, 1991).

Traditionally, scholars have sought to answer why settlement areas tend to move in certain directions. Boarnet (1994) provided empirical evidence that attempts to explain patterns of settlement decentralization. The study examines how population and employment are dispersed across the area due to transport development. The location of residences and firms determines the differential inter-urban population and employment changes. The study argues that the expansion of the transport network intervenes in the location decisions of both residences and firms. The study also emphasizes the implications of transport network development on population dynamics and employment changes, highlighting the growing significance of understanding urban development.

The scope of socio-economic development studies becomes wide and complex, and used as tools for addressing various concepts and issues such as 'quality of life', 'well-being', 'living conditions', 'happiness', and 'life situation' that are incorporated as its aspects. Recently, 'social security', 'political trust', and 'environmental well-being' have created their own niche in this subject matter. Despite some methodological problems and data constraints, in the recent past, socio-economic development researchers like Ram (1982), Zerby and Khan (1984), Milenkovic (2014), Raut (2015)and others have developed a number of 'Composite Indices' for measuring the levels of socio-economic development. These new 'Aggregate' or 'Composite Approaches' are rapidly gaining recognition as they are found to be a better approach for addressing the issues of development in general and socio-economic development in particular. Still, the problem continues to lie in choosing appropriate indicators for measuring the levels of socio-economic development. In order to overcome this issue, the researcher arbitrarily chooses the indicators of socio economic-development that fit their research objectives. In the present study five socio-economic indicators were identified and carefully selected for measuring the levels of development in the study area

On the other hand, the distributional patterns of road networks have yet to receive attention in terms of theoretical and empirical interpretation. To address this gap, Jacoby (2000) presented three theoretical models that explore the relationship between transportation and farmer behavior, transportation and wages, and the impact of road networks on farm profitability and the distribution of farm production. The empirical analysis conducted in the study highlights the significant implications of network accessibility on rural economic development and changes in the rural economic landscape, such as variations in wages and prices. The study concludes that access to markets provides substantial benefits, particularly for farmers, and that agricultural output and the use of modern inputs are dependent on the connectivity of rural roads. Furthermore, affordable and accessible transport facilitates better access to healthcare facilities, schools, and consumer goods.

The relationship between the transport network and development has been discussed from different dimensions. But, the underlying question that needs to be answered is that of co-development. The idea is that transport drives development, and in turn, development necessitates the development of transport infrastructure. In relation to this, Levinson (2008) examines the spatial co-development of the rail network and population distribution in London. The study finds that the rail network acts as a precursor to population growth, and as the population grows, there is an increased demand for the expansion of rail deployment. This feedback mechanism serves as an ideal force for socio-economic development in the region, contributing to the stabilized development in the core areas of the city. However, it is worth noting that the railway network also leads to sub-urbanization and an increased movement of labor from cities to suburban areas.

The works of Ivanova and Masarova (2013) examined the road transport networks impact on economic growth and competitiveness in Slovakia. The paper addressed the issue of how the road network generates advantageous geographical locations or regions, including various advantages derived from the road networks accessibility, job opportunities, infrastructure, and market. The advantage of the road network extends beyond the mobility of the population and the movement of goods from one point to another. The road network also affects the flexibility and mobility of the workforce, which is significant for employment density. Higher employment density is directly associated with socio-economic development and an improvement in the quality of life in the region, which has implications for competitiveness and investment location.

Scholars like Hartshorn and Alexander (2014) significance of transportation on the socio-economy of regions. They revisited the applicability of Weber's industrial location theory emphasizing the importance of road transport for industrial development. The discussion inhales the impact of road improvement on location attractiveness. As a result, the attractiveness of a location depends on the quantitative and qualitative growth of both local and national road networks.

The expansion of local road networks leads to an increase in residents who benefit from the new infrastructure. The growth of highway networks is linked to the growth of local employment. To investigate this concept further, Iacono and David (2016) conducted a test between the growth of the road network and changes in employment and population. The findings revealed a positive relationship between population change and the local network, but surprisingly little evidence of a relationship between the highway network and employment change. It appears that the limited development and maturity of highways weaken the connection between the road network and employment location.

Wang (2017) considered that spatial interactions have played a significant role in understanding development. The interaction between spaces within a particular area forms a networking system that is crucial for the flow of information and commodities. Addressing the influence of the transport network on socio-economic development, the study primarily focuses on the quantitative analysis of the robustness and resilience of the road network as the primary area of study.

Transportation provides connectivity between places and facilitates interaction among populations. The role and significance of transportation in daily activities cannot be overstated, whether in rural or urban areas. In the context of socio-economic development, the efficiency of road transport may vary in these two conditions. In rural areas, socio-economic development aims to improve the quality of life, well-being, economic activity, and agricultural productivity. Therefore, Olu *et al.* (2018) conducted an assessment of the impact of road transport networks on rural development. Particularly for rural areas, road transport is a primary necessity that goes beyond connecting populations. It enables access to market centers, enhancing rural productivity, and contributing to socio-economic growth, especially in terms of rural commodities and livelihoods.

2.5 Transport Network and Spatial Science

The recent advancements in geo-spatial technology have had a substantial impact on the academic and scientific community. The importance of remote sensing and GIS techniques has also increased significantly for network analysis. Naturally, geospatial technology possesses the flexibility to integrate mathematical and statistical tools, which play a crucial role in the study of transport networks. Geurs and van Wee (2004), Mavoa *et al.* (2012) have developed accessibility models by incorporating advanced graph theory approaches in diverse urban areas. Weiping and Chi (2014) have presented the theoretical foundation and the construction process of accessibility models using GIS techniques. By examining the spatial variations in transport cost and accessibility within London, Ford *et al.* (2015) made predictions regarding future investments in infrastructure and identified appropriate transport systems.

Quantitative techniques like graph theory offers a fundamental analysis of the network's topology and node accessibility. Likewise, topological indices such as the beta index, alpha index, gamma index, and cyclomatic number evaluate the network structural properties and measure its level of connectivity. Thus, Chen *et al.* (2014) conducted a study by integrating quantitative and GIS-based travel time analysis to investigate the spatio-temporal variation of node accessibility and examine the evolution of the network over time. The study argues that the network's topological structural and properties play a decisive role in determining the spatio-temporal accessibility of nodes, and they are considered vital determinants of growth, including factors such as settlements, households, occupations, and population distribution.

Wang *et al.* (2020) utilized GIS techniques to understand the association between road network structure and ride-sharing accessibility. This study utilized Open Street Map (OSM) to examine Uber services within different time windows. The study aligns with the concept of cities as sets of interactions across networks. It observed time-sensitive heterogeneous effects of road network structure on ride-sharing accessibility.

In another study, Martin *et al.* (2021) investigated the resilience of transportation networks in Mediterranean regions, specifically Sardinia in Italy and Valencia in Spain. The study employed a two-stage methodology. First, geo-database techniques were used to define and select mobility infrastructure in different sections. The second stage involved analyzing the resilience of these sections. The study argued that evaluating the criticality of road sections is important for decision-making to support transport planners and policymakers.

2.6 Indian Geographers on Transport Geography

In India, scholars have conducted studies on the regional analysis of transport systems in various dimensions. Majid (1950) attempted to establish a connection between market accessibility and the transport network in Bihar. Kayastha (1960) highlighted on the challenges related to constructing transport routes and communication infrastructure in mountainous areas. Dutta (1963) and Singh (1967) conducted research on road network accessibility, traffic flow, and traffic patterns. Sinha (1971) made notable contributions to the understanding of transport networks and their economic interlinkages. The study revealed that the transport network and economic development serve as landmarks of growth and productivity, particularly in agrarian societies. Kayastha and Singh (1972), and Mukheijee (1974) focused on studying urban transport systems and the associated issues. The analysis of transport problems and the role of transport in the development of various sectors of the economy at the regional level was conducted Ramachandra (1977) and Singh (1984). These studies primarily emphasized the transportation problems, accessibility concerns, and the functional aspects of urban transport networks.

The study of the relationship between market accessibility and the functionality of the transport network has been a subject of interest among scholars. Deka (1979) highlights the importance of the road network in the Brahmaputra valley. The study explores the nature of the road transport network and its significance in the processes of development and the potential of the Brahmaputra region as a whole, with a specific focus on the importance of the road network for intra-regional development.

Raza and Aggarwal (1986) edited the book "Transport Geography of India: Commodity Flows and the Regional Structure of the Indian Economy", which extensively assessed commodity flow and the regional structure in India using measurement techniques for the structure of the transport network. The book also evaluates the nodal hierarchical and regional organization of the economy, with a focus on the nature of urban-rural exchange of commodities.

Sharma (1989) conducted an investigation into the spatial variations of the transport system and development in Manipur. Sharma utilized graph theoretic measures to identify network elements and analyze the network structure of the transportation network. Additionally, he assessed the significance of spatial linkage within the transport network on socio-economic development and the establishment of new settlements.

Kumar (1991) conducted a comprehensive study that explored various dimensions of transport geography and the developmental profile of an advanced region in India. The study specifically focused on Meerat, analyzing its significance as a nodal center from both local and national perspectives. Kumar examined the spatial and temporal patterns of commodity flows and social interactions through a thorough investigation, providing valuable insights into regional transportation dynamics.

Naidu (1997) investigated the spatial structure of transportation networks in terms of topological and geometric elements in the Chittor district of Andhra Pradesh. The study employed traditional techniques such as Alpha, Beta, Gamma, Eta, Theta, and Pie indexing methods for network configuration and network efficiency measurement. The study observed that the road transport system has a tremendous impact on economic development and it facilitates resource accessibility from remote areas.

In the book 'Transport Geography of India', Raza and Aggarwal (1999) present a wealth of illustrations and diagrams that effectively supplement their discussion of methodologies and practical techniques within the field. These elements provide a comprehensive overview of the working processes specific to

India. Moreover, the book extensively evaluates the vital role that transportation plays in facilitating commodity flow and shaping the regional structure of the Indian economy.

Rao (2003) works highlight the essential significance of roads for rural development. His research examines various aspects of development, including small-scale businesses, trade, health, education, forestry, and fisheries. This comprehensive study provides valuable insights into the intricate relationship between transport infrastructure and overall economic development. Rao deliberately concludes that the establishment of a well-connected rural transportation network plays a crucial role in shaping the socio-economic development of villagers.

Studying the pattern and problems of transport, Sharma (2005) examined the issues associated with road transport in Guwahati city. The study revealed that improper transport planning leads to problems such as accidents, traffic congestion, and traffic management issues.

Jayasree (2009) outlined the importance of transport planning, design, and orientation in urban areas, with a focus on the road network. The study addressed network problems in urban areas through the analysis of network topology, urban form, and dynamic travel demand. By highlighting the role of the transport network in urbanization, the research described the nature of urban sprawl in plain areas. The study proposed that urban transport policies are a prerequisite for achieving objectives and implementing techniques at the field level.

In 2011, Lakshmanan conducted a systematic analysis to assess the magnitude and characteristics of the impact of transport infrastructure on broader economy. Critically examining recent theoretical advancements, Lakshmanan successfully identified a range of causal mechanisms that establish a strong correlation between transportation and economic growth. These mechanisms include market expansion, gains derived from trade activities, shifts in technology, processes of spatial agglomeration, and the promotion of innovation and commercialization of new knowledge within urban clusters.

The impact of roads on socio-economic development has been investigated by Kharkongor (2012) in Riboi District, Meghalaya. Kharkongor employed a spatio-temporal analysis method to examine the relationship between road network development and the region's socio-economy. The demand for extensive improvement of the road network to facilitate faster and more efficient services is high, given the regions growing and emerging economy. The study concluded that villages with high accessibility experience greater economic and social development compared to inaccessible or less accessible villages in the district. Therefore, road connectivity is a crucial infrastructure requirement for the betterment and upliftment of the local population, as well as to address regional imbalances.

Neethidevi (2013) investigated the implications of road transport development and the structure of the transport network on the spatial variation of resources and regional imbalances. The study employed graph theory matrix and non-graph theoretic measures to examine the structural properties of the network, including connectivity, accessibility, and efficiency. It also analyzed the spatial-temporal variation in the development pattern.

Raut (2015) conducted an examination of the connectivity of tehsil-level roads in Solapur District. The study utilized variables such as road density, alpha index, beta index, and gamma index to analyze the pattern of the road network and accessibility. A buffer analysis was performed to determine the number of locations that are accessible or inaccessible from main roadways, and the study explored the use of geo-information technologies to assess accessibility. The aggregate transportation score (ATS) was calculated to investigate the relationship between transportation and development. The results revealed a strong spatial correlation between socioeconomic development and transportation.

Sreelekha *et al.* (2015) conducted a detailed investigation into the road network connectivity and urban spatial structure in Calicut. The researchers recognized the significance of understanding the interconnections between the road network and the spatial layout of the city to gain insights into its transportation system and overall urban development. To achieve their research objectives, they employed a combination of statistical techniques and Geographic Information System (GIS) technology. The study identifies key areas of connectivity, potential bottlenecks, and spatial patterns of urban development in relation to the road network.

Daniel *et al.* (2021) focused on the city of Thiruvananthapuram, Kerala, as their study area. They investigated the spatial distribution of socio-demographic characteristics, including population density, employment density, and household density. This researcher explored the relationship between socio-demographic characteristics and road network centrality. Their findings revealed a strong correlation between socio-demographic diversity and the centrality measures of the road network. This suggests that the complexity of the urban space is significantly influenced by the transportation infrastructure. The study identified several prominent factors affecting land-use intensity. Notably, road centrality emerged as a key factor influencing the variation in land-use intensity.

Sharma and Ram (2023) conducted a research to explore the relationship between road network connectivity and accessibility in airport regions. The study employed graph theory and connectivity indices of road networks, considering geographical aspects. Utilizing QGIS tools, centrality indices were used to assess accessibility within the airport region. The study indicated that the connectivity of the airport significantly influences the surrounding area within the identified influence zone. The results emphasized the importance of identifying critical nodes and links in the road network. Such identification is crucial for comprehensive planning when developing new airport regions, as it facilitates improved accessibility and stimulates overall development in the surrounding areas.

The study of the transport network in Mizoram is still in its early stages of development. Pachuau (1994 and 2009) made significant contributions to shedding light on the overall landscape of the transport network and communication infrastructure in Mizoram. Their works, specifically the books titled ‘Geography of Mizoram’ and ‘Mizoram: A Study in Comprehensive Geography’, provided a comprehensive understanding of the spatio-temporal patterns and development of road density in the region. In these books, Pachuau delved into various aspects of the transport network, analyzing the challenges faced in establishing an efficient transportation system in Mizoram. These works not only provided a comprehensive overview of the existing infrastructure but also raised awareness of the challenges and opportunities for further research and analysis of the transport network in Mizoram.

CHAPTER III

Methodology

3.1 Introduction

The present work involves both qualitative and quantitative analyses of data collected from primary and secondary sources. This chapter discusses methodology of the study. It presents the extraction techniques that were employed for road network analysis. It also discusses both mathematical and theoretical frameworks of road network analysis.

The study addressed three methodological problems. Firstly, topological structure of road networks was measured on the basis of network centrality analysis techniques. The topological centrality analysis was used as tools for network modeling and examining the centrality of each node in the entire network. Secondly, this work measured socio-economic development of the study area. The socio-economic attributes were specified on the basis of road network and socio-economic development. Thirdly, the study integrated these two parameters (centrality measures and socio-economic development) into a quantitative unit of measure to answer the research questions.

3.2 Materials and Method of Data Collection

The study of road network and its components rely on both primary and secondary sources of data. Each of the data sources has a wide range of advantages and disadvantages, and different levels of application in obtaining significant results. This work has also attempted to establish a comprehensive integration of primary and secondary data in a systematic way in order to arrive at substantially precise results. Data collection for this research work fell into two main heads. One was extraction of geospatial data (point feature, line feature and polygon feature including physical characteristics of study area) which comprised of two sections - primary and secondary sources of data. Second, it involved collection of reliable socio-economic data which again constituted two different sources - primary and secondary sources of data.

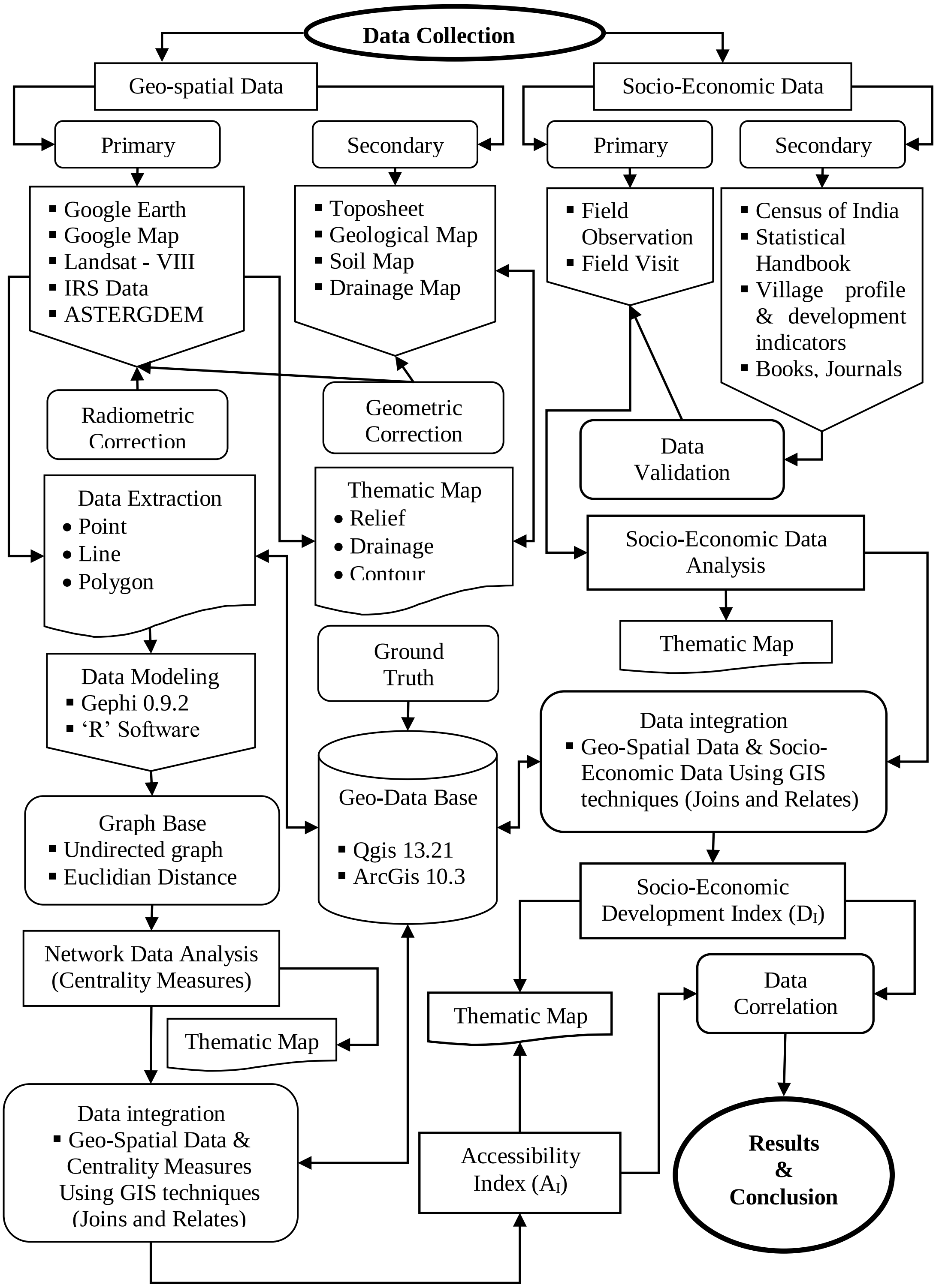

Figure 3.1: Flow Chart

3.2.1 Geo-Spatial Techniques

Geospatial data signifies objects, events, or phenomena that are located on the earth's surface. Geographic information system (GIS) allows us to manipulate, retrieve, store, input, analyse and represent geospatial data (Chang, 2017).

The spatial attributes including point and line features are the basic parameters of road network analysis. A line feature represents road network while a point signifies villages or nodes. Google Earth, United State Geological Survey (USGS), BHUVAN (Indian-Geo Platform of Indian Space Research Organization), and Open Street Map (OSM) were heavily utilized to obtain point and line features in this work.

Extraction of road networks from remotely-sensed imagery is challenging due to varying road appearances based on satellite sensor types, spectral and spatial resolution, ground and weather conditions, as well as spectral characteristics in different physical conditions, leading to geographical and technical errors during the extraction process (Amini *et al.*, 2002 and Agouri *et al.*, 2001). Due to these intricate matters the adoption of multiple methods is necessary to overcome both human and technical errors. As a wholesome solution to this problem the study has to incorporate the collection of both primary and secondary sources of data for the geospatial characteristics of the study area. The following sections point out the details of geo-spatial data collection.

3.2.1.1 Primary Data

At this stage, points (villages) and lines (roads) were extracted with the help of geo-spatial data platforms. The extracted data were then transformed and converted into readable and manageable formats in order to perform further manipulation and analysis. To facilitate further analysis the extracted data was first stored in the ArcGIS and QGIS database and other computable programming software. The following steps were involved in the collection of geo-spatial data.

3.2.1.1a Point Features and Road Network Data Extraction

Point features were generated according to two basic principles. One being road intersections representing nodes or villages and the other, the edge of a line which is considered as a node that represents 'dead-end connectivity' as well as 'dead-end-node'.

Extraction of accurate road network data was one of the main issues of the research since it is an essential step for achieving an accurate illustration, assessment, manipulation and analysis. The study incorporated road network data mining by using Manual[1], Semi-Automatic and Automatic techniques[2]. Reliable open source platforms were utilised for data collection that included satellite images, shape files and metadata. Data was manipulated with the help of widely accepted road network extraction techniques, such as Manual, Semi-Automatic and Automatic techniques. Each of these has their own degrees of significance and advantages.

Here, the manual data extraction method was extensively utilised as data extraction technique, which is more appropriate for overcoming technical error, mathematical algorithm, topographical and geographical challenges. But, image processing techniques and extraction techniques like Semi-Automatic and Automatic are also employed to achieve accuracy in data assessment and geometric progression.

The road network data was extracted from various sources of the reliable open source data bank, such as;

- Google Earth
- Landsat - 8 Image
- IRS data (LISS-III and LISS-IV)
- Digital Elevation Model

Google Earth platform was considered for the collection of primary sources of data (road network data and point data). Google Earth platform is an open source platform that allows us to explore and generate up-to-date and real world geo-spatial data. Google earth also provides time series images (temporal data), that allows us to explore and visualise changes of geo-spatial data across time in the study area, which is an efficient tool for the extraction of road network data. The Google Earth platform provided specific tools to extract geo-spatial data (points, lines and polygon) of different aspects. The data was stored in a folder with a specific extension format i.e. Keyhole Markup Language (*.kml*) and converted into the Shapefile format (*.shp*) with the help of a GIS software. Satellite images were employed as the base of accuracy assessment, geometric correction and alignment in doubtful areas. In general, the following procedures were followed for the extraction of *.kml* data from the Google earth domain;

(i) Identifications of points and line features.

(ii) Point and line extraction: Open Google Earth > My Place > Add Folder > Add Placemark/Add Path/Add Polygon > Digitize Target Feature > File Name > Extracted File > Save Place As > Save As *.kml* File.

(iii) The extracted '*.kml*' data (points and lines) was converted to the Shapefile (*.shp*) format/extension by the following procedure; Open ArcGis > Arc Toolbox > Conversion Tools > From *.kml* > *.kml* to Layer > Import *.kml* Layer > Select Output Folder > Run > Add Extracted File > Right Click on Layer > Data > Export Data > Select Output Folder > Save As *.shp* File.

(iv) Error Correction: Roads going through various geographical landforms, forest area were sometimes obscured by shadows and other objects. To overcome this situation, the researcher incorporated image analysis techniques like semi-automatic and automatic methods for the extraction of data. Further, the extracted data was also adjusted with the help of geometric correction and improvement of road segments in doubtful areas.

3.2.1.1b Thematic Layer

For the purpose of the study a set of different thematic layers were developed for the illustration of geo-spatial and non-spatial data for better understanding. These thematic layers provided the geographical aspects of the study area and utilised as the basis of interpretation of geographical profiles of the study area. Thematic layers like Relative Relief, Drainage and Contour were generated through remote sensing and

GIS platform. Thematic layers were actively involved for illustrating a real world road network map, village locations, and accessibility and socio-economic maps. Besides these, ground truthing holds an important role in this research. It primarily serves the purpose of rectifying data inaccuracies arising from geometric and radiometric errors in points, lines, polygonal features, and images.

3.2.2 Secondary Data

Secondary data were used to collect existing spatial data information. The spatial information mainly provided geographical profiles of the study area which was necessary for understanding the geographical dimensions of study area - Aizawl district. On the other hand, existing spatial data was utilised for data validation, accuracy assessment and understanding the pattern of road network development in the area. Relevant information was collected from the following sources:

- Toposheet No. 84 A/9, 84 A/10 and 84 A/14, issued by Survey of India 1990
- Drainage Map of Mizoram, Mizoram Remote Sensing Application Centre.
- Geomorphological Map, Mizoram Remote Sensing Application Centre.
- Geological Map, Mizoram Remote Sensing Application Centre.
- Soil Map, Mizoram Remote Sensing Application Centre.

Accordingly, the study prepared and interpreted maps to illustrate the geographical profiles of Aizawl district. Network data base was also developed and updated for computing network centrality measures and perform advanced manipulation processes in GIS software.

3.2.2.1 Socio-Economic Data

Suitable socio-economic data were also collected to examine the role of road networks on socio-economic development of Aizawl district. Socio-economic attributes like population growth, crude literacy, sex ratio, dependency ratio, agriculture workers and other necessary information was collected from both primary and secondary sources of data.

Primary data collection is limited to areas where doubts exist and is used to address concerns related to the accuracy and reliability of secondary data sources by focusing on specific areas or aspects where uncertainties exist. The advantage of this method is that it helps to provide an insightful and meaningful result for better understanding of the prevailing links between road transport network and socio-economic development in the area in general and village wise in particular. Therefore, the study was primarily based on secondary data that would help to analyse the degree of socio-economic development. Village level information mainly provided socio-economic profiles of the villages on a temporal basis, which is necessary for measuring, the various levels of socio-economic development.

3.2.2.1a Primary Data

The study was largely dependent on secondary data (especially socio-economic data). But there was a compelling need to collect primary data towards acquiring more reliable data. Primary data surveys were conducted only in instances where the available secondary data encountered challenges with reliability and inconsistencies in record-keeping. This means that primary data was utilised as a supplementary source in order to strength data and also limit errors in secondary data. Thus, village level survey was conducted with the help of open-ended questions. Accordingly, field visits were carried out in order to understand the current situation prevailing in the study area. Field observation also helped us to identify and fix the intermediate locations of nodes (including villages and junctions) and links. Mainly, the following attributes have been collected from primary sources.

- Actual Total Population Size
- Total numbers of Actual Male and Female Population
- Numbers of Actual Households
- Occupational Pattern.

3.2.2.1b Socio-Economic Data Secondary Data

In this work secondary data was a critical source of data especially for socio-economic indicators. Secondary data were collected from government publications on a temporal basis. Apart from this, additional data related to road network and historical information was collected from departmental records, books, NGO publications, etc. The socio-economic information were gathered from the following:-

- Census of India 2001, Primary Census Abstract, Mizoram.
- Census of India 2001, General Population Tables (A-Series), Mizoram.
- Census of India 2001, General Economics Table (B-Series), Mizoram.
- Census of India 2001, Social and Cultural Table (C-Series), Mizoram.
- Census of India 2011, Primary Census Abstract, Mizoram.
- Census of India 2011, General Population Tables (A-Series), Mizoram.
- Census of India 2011, General Economics Table (B-Series), Mizoram.
- Census of India 2011, Social and Cultural Table (C-Series), Mizoram.
- Village profile and development indicators (2017-2018) issued by Directorate of Economic and Statistics, Government of Mizoram.
- Statistical Handbook of Mizoram 2021, by Directorate of Economic and Statistics, Government of Mizoram.
- Annual Report 2017-18, 2018-19 and 2019-20, Public Works Department Government of Mizoram.
- Government data records, books and journals etc.

3.3 Method of the Study

This portion aims at providing an insightful explanation to the methods and techniques that were applied in the study. The following methods were adopted in the study.

3.3.1 Concept of Network Topology

The fundamental of the network analysis is based on network topology and the robustness and resilience of road network has been the primary focus of the study. Thus, graph theory offers an opportunity to perform topological measures of complex network structure. A graph is a simple interactions and relational combination of one point to another; it can be used to represent topological space. Topology is a powerful mathematical tool to explain the concept of interaction and relation of vertices and edges on the graph (Kilicman and Abdu, 2018). At the higher level, topological analysis provides information of structural attributes, such as accessibility, centrality, distance, orientation, density and geometric pattern etc. The characterisation of complex network systems using statistical and computational techniques has attracted considerable attention in scientific literature in recent years. Similarly, researchers from geography and transportation exclusively focus on topological and structural measures based on graph-theoretic network analysis and modeling techniques (Garrison, 1960; Kansky, 1963; Rodrigue *et al.*, 2006).

Graph theory is one of the most popular transport network modeling techniques that offers an efficient description of the topology and their dynamic processes (Black, 2003). Road networks are represented and modeled with two mathematical modeling techniques, such as *Primal Graph*[3] and *Dual Graph*[4] method (Crucitti & Porta 2006; Demsar *et al.* 2008). The study models road network according to the primal graph theory, which is regarded as representing real-world data representation to make way for further analysis. Mathematically, a Graph is a set of vertices (V) and edges (E), and $G = (V, E)$ which is made-up of a pair of vertices (nodes) V and a set of edges (links) E, assuming the number of V and E respectively equals to n and m. Figure 5.1 portrays an *Undirected Graph*[5] with n=7 and m=9. Now, $V(G) = \{v_1, v_2, v_3, v_4, v_5, v_6, v_7\}$, and $E(G) = \{e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8, e_9\}$. An edge is the function of $ek = (v_i, v_j)$ which means that the connection of node v_i to node vj, which is also known as *path*[6]. For example, the edge e_2 connects the nodes v_2 and v_3 (Lin, 2017). A Graph based representation of a network measures the topological possibilities or capacity of interaction of each node on the graph. But the number of topological interactions may range from *0* to ∞, thereby determining the structural attributes of vertices and edges on the network.

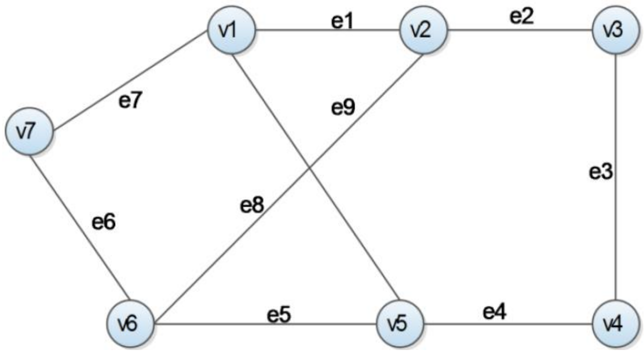

Figure 3.2: Simple Representation of Undirected Graph

Table 3.1: Adjacent Matrix for the Undirected Graph

Node	v_1	v_2	v_3	v_4	v_5	v_6	v_7
v_1	0	1	0	0	1	0	1
v_2	1	0	1	0	0	1	0
v_3	0	1	0	1	0	0	0
v_4	0	0	1	0	1	0	0
v_5	1	0	0	1	0	1	0
v_6	0	1	0	0	1	0	1
v_7	1	0	0	0	0	1	0

The study employs a computation environment for spatial analysis and further mathematical calculations; a network model is developed to transformed spatial world into digital or computer based transformation. Computable environment also provides an opportunity to integrate topological structural attributes with spatial analysis techniques, which is more applicable and significant for spatial science.

Normally, if the node between v_i and v_j is connected by an edge e_i, the corresponding adjacent value is equal to 1, otherwise the node between v_i and v_j is detached by an edge, and the corresponding *Adjacent*[7] value is equal to 0 which means the absence of interaction. For undirected graph, the value of both directions equal to 1 once there is an edge between two nodes. In this study the whole road network model was designed on the basis of *Connected Graph*[8]. Figure 3.2 and Table 3.1 represent the process of conversion of network model to a computable environment and explains the process of transformation of real world features to topological and structure of spatial network.

3.3.2 Concept of Network Centrality in Geography

The concept of "Centrality"[9] is discussed in different fields of study through a wide range of parameters. The concept of centrality is of fundamental importance in network analysis. Its goal is to provide a measure of the relative "importance" of a node in a network. In the larger picture, the concept of centrality exposes the role and identity of the node and edges in the network system, considering that the nodes existed in the network as common resources which are accessible from any point through the edges. In this context, the road network system represents the mode of communication, which represents the means of centrality, and the node is recognised as the center of diffusion formed by a complex network system in the area. Thus, transport networks facilitate the efficiency of movement of people and goods in various directions and also enhance the level of accessibility of each node in the chain of network. The study of road network implies the distribution of centrality and its attributes over space in different dimensions and maintains that some places are more important than others because they are more central. The study transport network primarily focuses on centrality measures for the analysis of nodes, their spatial distribution and arrangement which have a significant role for local and global attraction (Wilson, 2000).

The study primarily focuses on interacting systems of vertices and edges with the help of centrality measures. The spatial interaction systems, spatial distribution and arrangement of nodes have a significant role for local and global attraction. "Geographical centrality is an evolving concept that differs from one perspective to another at different stages. A spatial unit has strong centrality when its average distance to other spatial units is closer in the region, and such centrality is based on geographical proximity. On the other hand network may also determined geographical centrality. A spatial unit with one or more attributes is relatively stronger than other spatial units in the region may also be considered to possess strong centrality, and this centrality is based on scale attributes" (Li *et al.*, 2017).

3.4 Data Modeling

The research also included the analysis of the topological structure of the network which in turn deals with the relative positions of spatial features. Towards achieving this task the following steps were performed:

(i) To convert the real world road network into a computable environment for advanced manipulation and future analysis a network model was run on scripts and prepared with the '*R*' programming statistical software which allowed us to generate network data model with simple coding languages. Meaning each of the road network was turned into an undirected graph, valued as *G*, where intersections or villages were considered as nodes and road links as edges.

(ii) The obtained graphs was described with the help of Adjacency Matrix *A*, and by considering the entity of node a_{ij} as being equal to 1, there is an edge between node *i* and *j* or interaction between the nodes. On the other hand, the link between the nodes a_{ij} equaled to 0, so there is an absence of interaction or connection between nodes *i* and *j* in the adjacency matrix.

(iii) The connected nodes were identified and linked with the help of road network data that was extracted from geo-spatial data sources. The list of nodes was given and each was named in place of the 'unique id' (such as name of the village or node number).

(iv) The network data was exported to Coma Separated Values (.csv) file format.

(v) The exported data was uploaded in the Gephi[10] file for visualisation and further analysis. Here the Gephi 0.9.2 was employed to calculate topological properties of nodes in the network.

(vi) Accordingly, topological or structural properties of network were measured with the help of centrality measures. These included degree of centrality, closeness centrality, betweeness centrality, eigenvector centrality and eccentricity centrality are which considered as topological properties. The following section explains method adopted for topological measures.

(vii) The centrality values (structural attributes) of nodes were used to measure degree of accessibility of nodes of the network. Centrality values also measured the importance, influence and prominence of each nodes in the network. The following section explains the method adopted for topological measures.

3.5 Method of Topological Measures and Network Data Analysis

The concept of centrality plays a fundamental role in network analysis. The goal of Centrality Mmeasures[11] is to provide a measure of the relative "importance" of a node in a network, and thus different motivations lead to different centrality measures (Krnc, 2015).

3.5.1 Node Centrality Measures

Keeping this statement in mind the study has adopted centrality measures to analyse the local and global significance of each node in the network. In centrality measures every connected node has some degree of centrality, but the degree of centrality may vary with respect to position and location of node in the network. Also, one node may gain greater importance than others if it is linked with other important nodes.

Different measures of centrality have been adopted in this study as different levels of significance for depicting topological structures and identification of critical nodes and vertices. The centrality of each node was calculated based on the mathematical equations using the centrality measures - the Degree Centrality (being connected), Eccentricity (being straight), Closeness Centrality (being near), Betweenness Centrality (being in between), and Eigenvector Centrality (being influential).

(a) Degree of Centrality (C_D): The degree of centrality is a simple mathematical representation of the degree of point that is based on the concept of adjacency matrix (Niemiens, 1974 and Freeman, 1979). The C_D of a vertex *v* in an undirected network is the number of links connecting to a node. Degree of Centrality (C_D) represents adjacent link of vertex *v* in network, which is simply defined as the degree of $C_D(v)$ of a vertex *v* in an undirected graph (Figure 3.3). This measure is widely adopted by professionals and researchers in various capacities (Bolland 1988; Porta 2015 and Zhang 2017). Instead of a global influence, this measure is largely restricted to the local and neighborhood factors. It is also directly linked with the surrounding nodes.

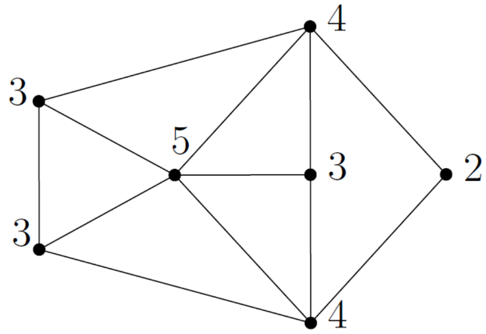

Figure 3.3: Graphical Representation of Degree of Centrality (C_D) of each Node

The Degree of Centrality (C_D) values is calculated using the following equation;

$$C_D(v) = x = \frac{\deg(v)}{\mathrm{n}-1} \dots\dots\dots\dots \; (i)$$

where, $|V| = N$ represents the number of vertices in the network, *i* the reference node, a_{ij} the number of the adjacent edges that originate from a node and *deg (i)* the degree of a node. When the graph is developed with undirected graph, the lower limit of C_D represents 2 (two) degree and the maximum degree can be infinite. The degree with 2 degree of centrality represents the lowest degree of confection/intersection, which has limited direct connection with surrounding nodes.

(b) Eccentricity: An Eccentricity centrality measure is one of the most direct and simplest methods of centrality measures in a network or graph. In a graph, the eccentricity of a node is defined as the length of a longest shortest path starting at any given node (Takes and Kosters, 2013). Mathematically, it is also defined as, the eccentricity *e(v)* of a vertex *v* in a connected graph *G* which is the distance between *v* and a vertex that are farthest from *v* in G, while the radius *rad (G)* is the smallest eccentricity among the vertices of *G* (Solima, 2018) In simple words, eccentricity is the minimum number of links required to reach the furthest nodes in the network (Figure 3.4). Therefore, eccentricity is considered as one of the global measures of the network analysis. It is applicable for detecting the strategic locations or spatial location of facilities that provide required facilities within a short period of time in the context of a road transportation network. According to Iwabuchi *et al.*(2018), Degree of Eccentricity (C_E) of *e (v)* of a vertex $v \in V$ can be denoted by the following equation;

$$e(v) = \max_{w \in V} \{d(v,w)\}. \dots \dots \dots \dots (v)$$

where, distance *d*(*v*,*w*) between two vertices *v*, $w \in V$ is defined as the length of the shortest path between *v* and *w*.

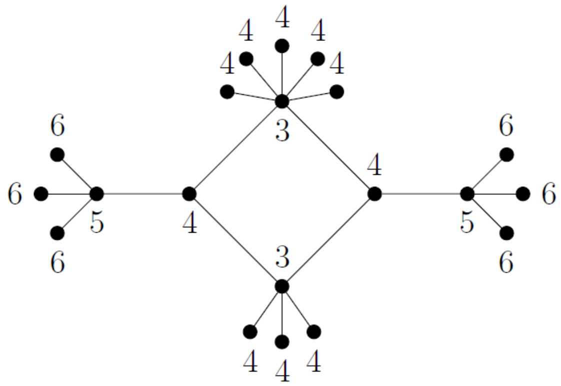

Figure 3.4: Graphical Representation of Eccentricity (C_E) of each Node

(c) Closeness Centrality (C_C): "Closeness is a rough measure of the overall position of an actor in the network, giving an idea about how long it will take to reach other nodes from a given starting node" (Oliveira and Gama, 2012). The centrality of a point is measured by summing the geodesic distances from one point to all other points in the graph and is called closeness centrality (Sabidussi, 1966). It is also recognised as a global technique of network centrality analysis. It examines the identity of a node to all connected nodes in the network. C_C measures as to what extent a node *(i)* is close to all other nodes along the shortest path in the network (Figure 3.5). C_C evaluates the degree of centrality through geodesic distance from a given vertex to all the other vertices. When the vertex *i is* close to all the other vertices in the network, the geodesic path or distance of the vertex *i is expected to score the* least closeness centrality than other vertices (Tisiotas and Polyzos 2013). Further, closeness centrality is applicable for strategic planning for locating emergency services, public distribution systems and public services infrastructure etc. This analysis also emphasises the distance of a prominent node (actor) to all others in the network by considering the space from each actor to the others. Then, the Closeness Centrality (C_C) is expressed as;

$$C_C(i) = \frac{N-1}{\sum_{\mathrm{j=i}}^{N} d_{ij}} \dots\dots\dots\dots (ii)$$

where, N is the total number of nodes in the network, d_{ij} is the shortest path length between node i and j. Simply, C_C measures the mean distance of vertex with other vertices through geodesic path. The calculated values are between 0 to1; with the higher value indicating that the node is more central.

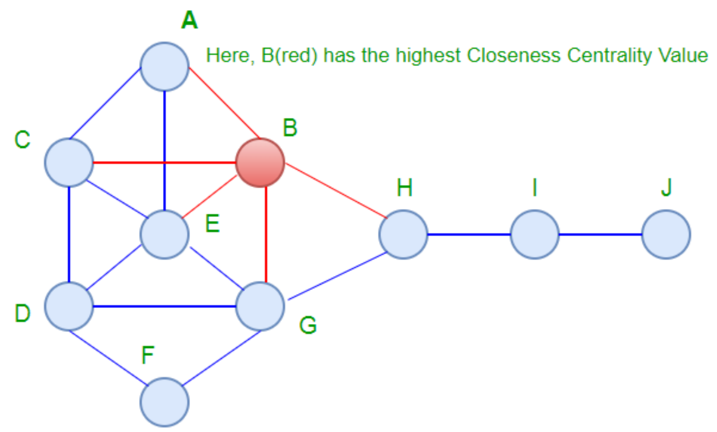

Figure 3.5: Graphical Representation of Closeness Centrality (C_C) of each Node

(d) Betweenness Centrality (C_B): In a network system, some of the nodes are more central than spatial distance due to their position/location in the network. Similarly, betweness centrality measured the shortest edge distances between all pairs of vertices in the network is considered in this equation (Batista and

Bazzan, 2015). This equation defines the significance of a node location in the network system, which corresponds to their influence on and control over the other. This measure calculates the potential significance of a particular node on the communication line between other nodes in a network. Betweenness centrality also attempts to evaluate the criticality of a node in the network, with reference to the number of times a node is needed to be crossed through the shortest path in the network. Consequently the critical node therefore plays a mediating role between other nodes of the network. It also explains the role of third-party nodes for controlling the flow of information in the network. But in a network, the number of intermediary values may range from *0* to ∞. To give an illustration, consider a vehicle called 'Z' that has to deliver products from node *'A'* (production center) to *'C'* (market) in order to satisfy a demand, but *'A'* does not have any direct access to *'C'*. Hence, *'A'* and *'C'* need an intermediary (third-part) for fulfilling this requirement. All the nodes lying between *'A'* and *'C'* (considered as node *'B'*) have significance or persuasive power to link *'A'* and *C* contact between *'A'* and *'B'*. On the other hand, if *'A'* has other channels to reach *'C'* (with respect to euclidean distance), then *'A'* becomes less dependent on node *'B'* and thus *other nodes* will gain more power while *'B'* will lose some significance with respect to *'A'* and *'C'*. The following equation defines Betweenness Centrality (C_B);

$$C_B = \sum_{s \neq v \neq t \epsilon V} \frac{d(s,t|v)}{d(s,t)} \dots\dots\dots\dots (iii)$$

where, *d(s,t|v)* is the number of shortest paths that are available between *s* and *t* passing through the node *v* and, *d(s,t)* is the total number of shortest paths that exist between *s* and *t*.

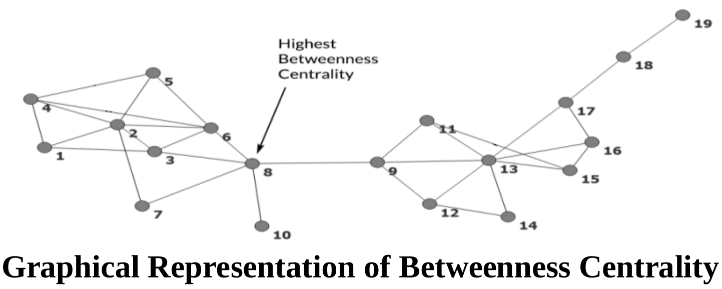

Figure 3.6: Graphical Representation of Betweenness Centrality (C_B) of each Node

(e) Eigenvector Centrality: Eigenvector centrality measures the centrality of a node in a network based on the weighted sum of centralities of its neighbors (Jayaweera *et al.*, 2017). Mathematically, considering the entire graph with an adjacency matrix, eigenvector centrality of a node *(aij)*, implies that *i* contributes to *j*'s status, and x_i denotes the status of an individual *i* in the network (Major, 2006). This means that eigenvector centrality takes into consideration the properties of neighborhoods (Rustam, 2006). It measures the importance of a node based on its links with other central nodes (Wen *et al.*, 2019). Thus, the measure of eigenvector centrality in the network considers two important determinants such as firstly, the number of links or number of adjacency nodes and, secondly, the centrality values of adjacent nodes (Figure 3.7). This study applies the eigenvector centrality measure to evaluate the degree of diffusion or dissemination of information, which then influences surrounding nodes. It is used as a good measure of the scale of spreading (the scale/degree of diffusion). The following equation describes Eigenvector Centrality (C_E);

$$\lambda x = \sum_{j=1}^{N} a_{ij} x_j \ldots\ldots\ldots\ldots (iv)$$

where, A is the adjacency matrix for this graph; a_{ij} =1if vertices i and j are connected by an edge and 0 if not, $Ax = \lambda x$, $i = 1,\ldots,n$. then, λ denotes the largest eigenvalue of A and n is the number of vertices (Bonacich, 2007).

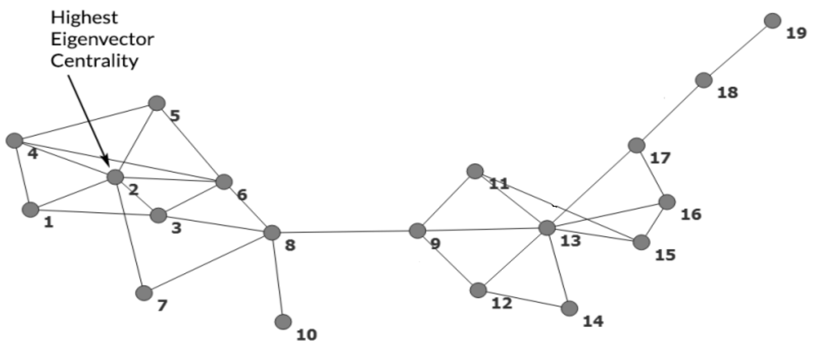

Figure 3.7: Graphical Representation of Eigenvector Centrality (C_V) of each Node

3.5.2 Analysis of Node Centrality Measures

Estimation of node centrality provides the significance of a node in terms of connectivity, relationship, and flow of information over the network. Also, the study aims to incorporate topological properties and real world network systems for exhibiting the critical nodes and changing patterns of centrality in the network, which in turn is very crucial for bringing out a logical explanation and perform decision making. To this end, the following steps were initiated:

(i) The calculated results (centrality measures) were exported in Comma-Separate Values files (.csv) and stored in Geo-data base (.gdb) in ArcGIS 10.3 platform.

(ii) The geo-data base was integrated with geo-spatial data (which was already extracted i.e. nodes/villages) with "Joins and Relates" technique. And GIS platforms allow us to store data, manipulate, retrieve, analyse and visualise the network.

(iii) GIS techniques were also adopted for the illustration of the spatial distribution of node centrality and also represent real world road network in map format. In general these techniques help us in visualizing and understanding the changing patterns of node centrality and the changes therein. Also it helps us to identify the important nodes over geographical space more specifically.

(iv) In addition, appropriate statistical diagrams were also utilised for data representation and analysis.

(v) Classificatory approaches were adopted for examining the changing patterns of node centrality and spatial centrality. Each of the centrality measures were logically classified into five centrality classes, such as Very High, High, Moderate, Low and Very Low level of centrality.

3.6 Method of Socio-Economic Data Analysis

In the process of accomplishing the stated research objectives, methods for socio-economic data analysis played a critical role. Socio-economic data analysis was performed to examine the socio-economic structure and the changes therein. The following methods were applied for the analysis of socio-economic attributes in order to show the levels of and changes in socio-economic indicators at the village-level.

(a) Population Growth: Population growth does not only mean a numerical increase in population; it also includes the decrease or decline in population of an area within a particular period of time. Broadly, population growth is categorised into two i.e. natural growth and actual growth of population. Natural growth of population considers only births and deaths whereas migration is taken into consideration for actual population growth. But the change in population, both in numbers and composition, bring in an identical effect on society (Prabhakar, 2001). Particularly, numbers of population growth have been taken as base of reference. Here, the study considers population growth as negative indicator that retards socio-economic development. Accordingly, population growth is calculated as;

$$Population\ Growth = \left(\frac{P_C - P_B}{P_B}\right) \times\ 100 \ldots \ldots \ldots \ldots (vi)$$

where, P_C is the total population of the current year (i.e. 2011 census) and P_B is the total population of the base year (i.e. 2001 census).

(b) Crude Literacy Rate: Literacy rate is one of the important indicators of socio-economic development. As it has positive impacts on ability to identify, understand, interpret, communicate and compute in the form of any language using printed and written materials associated with varying contexts. Typically, the definition of literacy is based on the skills-based conception and all definitions integrate social, economic and political empowerment. The Census of India has adopted a wider concept and based on the report of the Population Commission of the United Nations which states that a person with the "ability to both read and write simple massage with understanding in any language" is taken as a sufficient basis for classifying a person as literate. Thus, literacy does not only develop personal wellbeing or personal learning; it also has immense implications on the socio-economic development of an area. Crude literacy rate is calculated as follows;

$$Crude\ Literacy\ Rate = \frac{Numbers\ of\ Literate\ Persons}{Total\ Population} \times 100 \ldots\ldots\ldots\ldots (vii)$$

(c) Sex Ratio*:* According to the Census of India, Sex Ratio is defined as the number of females per 1000 males in the population at a given point of time. Simply put, sex ratio can be expressed as the total number of female population for every 1000 males within a specific area and period of time. The dynamics of the sexes has meaningful reflections on the underlying socio-economic and cultural conditions and patterns of an area in various ways. The changing pattern of the proportion of females against males affects social and economic relationships within an area or region. The pattern of change in sex ratio helps us to implement various types of planning and developmental programmes and provide a meaningful understanding of demographic indicators like fertility, mortality, migration and socio-economic structure. The percentage of change in sex ratio is computed as follows:

$$S_R = \frac{Number\ of\ Females}{Number\ of\ Males} \times 1000 \ldots\ldots\ldots\ldots (viii)$$

$$\Delta\ Sex\ Ratio = \left(\frac{S_{R_C} - S_{R_B}}{S_{R_B}}\right) \times\ 100 \ldots\ldots\ldots\ldots (ix)$$

where, S_{R_C} is sex ratio of current year (i.e. 2011 census) and $S_{R_B}$is sex ratio of base year (i.e. 2001 census).

(d) Change in Dependency Ratio: Dependency ratio is a measurement to assess the extent of economic dependency in a population (Srinivasan, 1998). The study considers total dependency ratio as one of the determinants of socio-economic development. Total dependency ratio is not only the elderly to active population, but also includes the elderly plus the younger population (0-14) years to active population. It is evident that the proportional change of dependency ratio is determined by of relatively increased of older population and rise younger populations and it is paramount important for socio-economic consequences. Thus, numerical increase in the younger population and aged population has direct implications on working population. Change of dependency ratio highlights the age structural pattern of the population that depend on working population, which is very crucial for addressing levels of demographic burden on the existing community of an area. Particularly so, a change in dependency ration could be related to the economic performance of an area and may be utilised as the basis for implementation of social policies. The following equation is employed for understanding change in dependency ratio;

$$D_R = \frac{Number\ of\ \text{Population} \ \leq\ 15 + \text{Population aged} \ \geq 60}{\text{Population between ages } 15\ - 64} \times 100 \ldots\ldots\ldots\ldots (x)$$

$$\Delta\ Dependency\ Ratio = \left(\frac{D_{R_C}\ -\ D_{R_B}}{D_{R_B}}\right) \times\ 100 \ldots\ldots\ldots\ldots (xi)$$

where, D_{R_C} is dependency ratio of current year (i.e. 2011 census) and $D_{R_B}$is dependency ratio of base year (i.e. 2001 census).

(e) Change in Agricultural Workforce: The importance of agriculture can neither be overstated nor overlooked. But the existence of a large agricultural workforce in the occupational structure posese limits to socio-economic development. A large scale agriculture working population also indicates a subsistence form of economy and further points to a limited diversification of the occupational structure in the region. The changing pattern of agricultural workforce highlights the level of diversification of occupation and movement of agricultural workers from low productivity agriculture to sectors with higher productivity. The current study presents the trends and pattern of agricultural workforces with respect to spatio-temporal variations within the study area. The following equations are used as measured of Change in Agricultural Workforce.

$$A_W = \frac{Agriculture\ Working\ Population}{Total\ Working\ Population} \times 100 \ldots\ldots\ldots\ldots (xii)$$

$$\Delta\ \text{Agricultural Workforce}\ = \left(\frac{A_{W_C}\ -\ A_{W_B}}{S_{W_B}}\right) \times\ 100 \ldots\ldots\ldots\ldots (xiii)$$

where, A_{W_C} is agricultural workforce of current year (i.e. 2011 census) and $A_{W_B}$is agricultural workforce of base year (i.e. 2001 census).

Appropriate figures and cartographic techniques were used to illustrate the results of various findings. Analysis of the figures, maps and other information helped in establishing findings and providing logical explanations of the results.

3.7 Measures of Level of Nodes Accessibility

The concept of accessibility measures changes over time. The implication of centrality measures for accessibility was advocated by Hansen (1959) who based it on his idea of accessibility. Watts and Strogatz (1998), Barabási and Albert (1999), Porta and Latora (2006), Rubulotta *et al.* (2013), Hellervik *et al.* (2019), and Sahitya and Prasad (2020) etc. discussed centrality measures as the key variables that are considered for the measurement of node accessibility. Accordingly, centrality measure allows for the simplification of the complex network system that is influenced by the topological structure of the network. Keeping the above discussions in mind, the study is an attempt to examine the impact of road transport network (through the principles of level of nodes accessibility using centrality measures) on socio-economic development. The study considered Aizawl district as the study area and road transport networks were extracted for analysing the topological structure of Aizawl district. Further, the study adopted the idea of synthesisation method to simplify the overall picture of node accessibility and node centrality in the network. For analysing the overall levels of node accessibility and centrality, the study implemented simple statistical techniques called *Mean Accessibility Index* (A_I), which can be expressed by the following formula:

$$A_I = \sum_{i\geq 1}^{n} \left(\frac{C_{Di} + C_{Ci} + C_{Bi} + C_{Ei} + C_{Vi}}{\bar{X}Deg}\right) \text{x}100$$

where, A_I is mean accessibility index of i node, C_{Di} the weighted rank of i node in Degree of centrality measure, C_{Ci} is the weighted rank of i node in Closeness centrality measure, C_{Bi} weighted rank of i node in Betweeness centrality measure, C_{Ei} weighted rank of i node in Eccentricity centrality measure, C_{Vi} weighted rank of i node in Eigenvector centrality measure and $\bar{X}Deg$ is the mean of Accessibility Index.

3.8 Levels of Socio-Economic Development

Despite some methodological problems and data constraints, in the recent past socio-economic development researchers like Ram (1982), Zerby and Khan (1984), Beuningen (2013), Milenkovic (2014) and others have developed a number of 'Composite Indices' for measuring the levels of socio-economic development. These new 'Aggregate' or 'Composite Approaches' are rapidly gaining recognition as they are found to be a better approach for addressing the issues of development in general and socio-economic development in particular. Still, the problem continues to lie in choosing appropriate indicators for measuring the levels of socio-economic development. In order to overcome this issue, the researcher arbitrarily chooses the indicators of socio economic-development that fit their research objectives. In the present study five socio-economic indicators were identified and carefully selected for measuring the levels of development in the study area.

For synthesising the selected socio-economic indicators, the study adopted the aggregate method to measure levels of socio-economic development. Socio-economic indicators like population growth, sex ratio, crude literacy rate, dependency ratio and agricultural working population are aggregated by using *Mean Socio-Economic Development Index* (D_I). The following equation explains the mean socio-economic index:

$$D_I = \sum_{i \geq 1}^{n} \left(\frac{P_{Gi} + S_{Ri} + L_{Ri} + D_{Ri} + A_{Wi}}{\bar{X}Soc} \right) \text{x}100$$

where, D_I is the mean socio-economic development index of *i* village/node, P_{Gi} weighted rank of *i* village in Population Growth, S_{Ri} weighted rank of *i* node in Sex Ratio, L_{Ri} weighted rank of *i* node in Crude Literacy Rate, D_{Ri} weighted rank of *i* node in Dependency Ratio, A_{Wi} weighted rank of *i* node in Agricultural Working Population and $\bar{X}Soc$ is the mean of Socio-economic Index.

3.9 Correlation Analysis

With the aim of finding the association between road transport network and socio-economic development in Aizawl district, the study adopts a multi-dimensional approach by selecting relevant socio-economic attributes and their calculations (centrality measures). In the recent past the multi-dimensional approach has gained applications in understanding the correlation between road network and socio-economic development (Naidu, 1997; Kharkongor, 2012; Raut 2015; LOBsang 2020). But, the application of multiple approaches and methodologies necessitates data integration and the problems that lie before it are evident in the fact that quantification of multiple indicators depend on a single parameter that is brought about by the absence of a well-defined data integration method. Therefore many researchers have utilised various techniques that are more often than not chosen arbitrarily (Milenkovic *et al.,* 2014). This means that different approaches and indicators are adopted to develop a multidimensional framework that are characterised by distinct stability and strength. In order to overcome this difficulty, the study carefully completed a survey of literature and adopted multi-dimensional concepts like ranking method, composite index (aggregate index) and correlation technique to achieve the objectives. The ranking method assesses the status of edges (villages) by considering road centrality metrics and socio-economic situations. The composite index is used to combine a set of indicators based on their scores. Afterwards a correlation technique is applied to merge road centrality measurements and socio economic data resulting in a link, between the independent and dependent variables.

In order to examine the correlation between road network and socio-economic development, the study adopted a multi-dimensional approache. These included network centrality measures that represent independent variables and socio-economic measures which are all based on dependent variables. The following steps were performed for data correlation:

(i) The whole work was categorised into two dimensions - independent variables (road network topology/centrality domain) and dependent variables (socio-economic domain).

(ii) The variables were separately measured with the help of appropriate methods in order to provide the basis of analysis and explore the impact of road network on socio-economic development (detail discussion in section 3.5 and 3.6).

(iii) As the network topology indicators and socio-economic indicators are measured in different units of measurement the study employed the ranking method to make the variable comparable. Also, this technique allowed us to achieve data aggregation and establish correlation between the variables. Thus, the study employed statistical normalization/transformation methods like ranking techniques for classifying calculated values by their rank. This method helped us to unify the parameters into a single/uniform unit of measurement or range of measurement.

(iv) Nodes/villages were assigned with different ranks and were weighted based on the desirability of the individual indicator's score in line with the underlying conceptual model. The weights represent the importance of nodes/villages in terms of centrality and their respective socio-economic scores. For example, the node with the least centrality value is assigned a lower rank.

(v) Both independent and dependent dimensions were aggregated and ranked by calculating the Mean Accessibility Index (A_I) and Mean Socio-Economic Index (D_I). The former provided the basis for the levels of road network accessibility and thereby reveal the significance of a node within the network. The later indicates the overall level of socio-economic development.

(vi) Transformed values were utilised as the basis of categorisation of villages in terms of accessibility and levels of socio-economic development.

(vii) Further, an understanding and observation of the relationship between the selected indicators and variables (composite indices) utilised statistical programs, such as coefficient of correlation, regression and appropriate statistical data representation techniques were implemented in this research.

(viii) The study also employed Geographic Information software, ArcGis 10.3 and QGIS-Madeira for geospatial analysis and cartography. GIS techniques represent stores and analyse data from the spatial perspective. GIS techniques were also utilised in three main categories; modeling spatial variations of road network accessibility and socio-economic development, analyzing and visualisation of spatial changes in accessibility and socio-economic development, and the identification of changing trends in both variables.

CHAPTER IV

Topological Structure of Road Network

4.1 Introduction

A spatial variation of structural attributes of road network has an inherent impact on the performance of transport system. This chapter deals with topological structure of road transport network in Aizawl district. Mathematically, the connectivity and arrangement of a network is known as topology. Topology and structure of a network affect the attributes of a node in particular and the edge in general (Mohring, 1961; Gauthier, 1966). Thus road transport networks have various specific topologies signifying their structures in terms of edges, vertices, paths, and cycles (Rodrigue *et al.*, 2006). Basically network topology and structure has subsequent effects on the efficiency of node accessibility and, controlling the movement pattern, direction and flow pattern within the entire networking system.

Road network is the life line of the study area as it is the only medium of physical link to access different points in the region. This chapter deals with spatial variations of topological characteristics, structural properties and dynamics of edges and vertexes with correspond to Centrality Measures.

4.2 Spatial Distribution of Node Centralities

In network science, every connected node or village and town has some degree of centrality. A particular node may be more important than others if it is linked with other important nodes. Attention is focused on analysing the spatial distribution of centrality of settlements and their graphical representation that helps visualise the changing patterns of centrality in the entire network system. Node distribution facilitates the understanding and identification of critical node and vertices in the network, which is important for the characterisation and visualisation of critical nodes and vertices inside the network (Kisgyorgy and Vasvari , 2014). It also measures and examined the magnitude of importance of a road or intersection (node) and at what level a network is centralised on certain roads (Zhang, 2011).

Identification of critical nodes is highly crucial for understanding the flow of information, commodities and movement of people in the whole network. Detecting such nodes has significant impacts on the network structure's optimisation and maximisation.

In this chapter, the analysis and illustration of the spatial distribution of nodes over space were performed in three steps - statistical, graphical and geographical representations. Statistical analysis is conducted to find out centrality values, variations and association of nodes in the network. Graphical representations highlight the arrangement of real world road network. Lastly, Geographic Information System (GIS) is used to represent the spatial distribution of nodes over space to examine node centrality patterns and the identification of crucial nodes in the entire network system.

Five different measure of centrality are employed in this chapter to examine the centrality of settlement. They are the degree of Centrality, degree of Eccentricity, Closeness Centrality, Betweenness Centrality and Eigenvector Centrality. Classificatory approach was adopted to describe the changing pattern of the topological structure. As discussed in the methodology section Jenks natural breaks classification method was employed to classify settlements into five groups.

4.2.1 Degree of Centrality (C_D)

Degree of centrality value shows the direct connectivity that a particular node or settlements has one another. It defines the connectivity on the basis of local and first neighborhood or adjacent perspectives (Niemiens, 1974).

It is found that the minimum and maximum degrees of centrality are 1 and 7 respectively. The entire settlements are classified into fivegroups- (a) Very High C_D (More than 4 C_D), (b) High C_D (3-4 C_D), (c) Medium C_D (2-3 C_D), (d) Low C_D (1-2 C_D) and (e) Very Low C_D (0-1 C_D), (Table 4.1; Figures 5.2 & 5.3).

(a) Very High C_D: In the entire study area, Very High C_D is only represented by Aizawl (Table 4.1). Aizawl, the capital city of Mizoram, is the administrative, financial and commercial centre of the state. The city is also a historical establishment and its location has afforded it the status of being a significant and critical node therefore making it the ‘centre of attraction’. The city accounts for only 0.49 percent of the total geographical area of the study area (Figure 4.2)

(b) High C_D: A High C_D values comprises settlements located along important and prominent routes running in a north-south direction in the district. They are Sialsuk, Seling and Dilkhan. Sialsuk is the only critical node in the southern portion of the study area. Seling and Dilkhan are found in the middle part of the study area. Both of them are critical junctions in the eastern and northern routes. Sialsuk is represented as the most important node in the south, while Seling is located in the central part, and Dilkhan has the status of being the critical node in the eastern section of the network. The vegetable market and eateries in Seling developed mainly due to occurrence of road transport network. The high degree of centrality, Sialsuk, Seling and Dilkhan constitutes only 3.61 per cent of the total nodes (Table 4.1). Very High C_D classes are also represented as major branching structures of the network.

(c) Medium C_D: Settlements with Moderate C_D are scattered in the study area and they account for only 8.43 per cent of the total nodes. Hmuifang and Sateek villages are found in the southern part of the district. Sairang is found in the western apart while; Saitual/Keifang and Phullen are located in the western section of the network. Khanpui and Sakawrdai junctions are situated in the northern parts of the network. In terms of geographical area, about 16.57 per cent of the study area comes under the Moderate C_D class and the middle and southern parts of the area fall in this class. Geographic features like mountain ranges and ridges have a big impact on how road networks are arranged and developed.

(d) Low C_D: A substantial number of settlements in the district have Low C_D values, with 48 villages (57.83 per cent) belong to the Low C_D class. Noticeably this category accounts for 56.71 per cent of the total area of the entire study area. It is observed that settlements under Low CD class align with the main routes in different directions and are sandwiched between High C_D and Moderate C_D (Figure 4.1).

(e) Very Low C_D: Settlements categorised as Very low category (≤1 degree of centrality value) represent dead-end connections that are mainly located on the periphery of the network close to the boundary with other districts and other states (Figure 4.1). This category includes 24 nodes, which accounts for 28.92 per cent of the total nodes and 23.90 per cent of the geographical area (Table 4.1). The 1 degree of centrality represents the lowest degree of connection, which has limited direct connection through the surrounding nodes or dead-ends (Appendix–I).

Settlements showing Very high degree of centrality like Aizawl, Sialsuk, Seling and Keifang/Saitual have significant potential to control the stability, flow of information and infrastructure which in turn has critical implications on the socio-economic development of the proximity nodes. Thus it can be argued that the Very High C_D and High C_D are more attractive and are significant for controlling the flow of commodities than those in the low scoring categories (Figure 4.1). The study identified that about 86.75 per cent of villages which fell under Very Low C_D and Low C_D classes are insignificant in this network. It is important to note that settlements are aligned linearly along the direction of network which is influenced by geographical factors like the direction of mountain ranges and topographic structure which inadvertently affects the orientation of the network. Similarly, the C_D values which are measured in this study clearly indicate the nature of the terrain of the district. Settlements with high C_D values are critical locations and historical important.

Table 4.1: Classification of Settlements on the Basis of Degree of Centrality (C_D)

Class	No. of Village	Percentage	Name of Village
Very High (≥4)	1	1.20	Aizawl
High (3-4)	3	3.61	Sialsuk, Selling, Dilkhan
Medium (2-3)	7	8.43	Sateek, Hmuifang, Sairang, Saitual/Keifang, Phullen, Khanpui, Sakawrdai
Low (1-2)	48	57.83	Hualngohmun, Melriat, Kelsih, Falkawn, Muallungthu, Tachhip, Aibawk, Maubuang, Thiak, Sumsuih, Chamring, Samlukhai, Lamchhip, Samtlang, Sihphir, Tuirial, Thingsultlangnuam, Thingsulthliah, Tlungvel, Phulmawi, Rulchawm, Ruallung, Mualpheng, Tawizo, North Lungpher, Sesawng, Mualmam, Thanglailung, Phuaibuang, Khawlian, NE. Tlangnuam, Zawngin, Suangpuilawn, Lamherh, Vanbawng, Khawruhlian, Hmunnghak, Pehlawn, East Phaileng, Kepran, Sawleng, Darlawn, Sailutar, Ratu, Lungsum, New Vervek, Vaitin, Zohmun
Very Low (0-1)	24	28.92	Sailam, Lungsei, Phulpui, Chawilung, North Lungleng, Muthi, Maite, Lenchim, Buhban, Tualbung, Sihfa, Luangpawn, Daido, North Khawlek, Lailak, North Serzawl, Sunhluchhip, Khawpuar, North Khawdungsei, Palsang, Mauchar, North Thinghmun, Chanchhuahnakhawpui, Thingsat
Coefficient of Variation			46.49

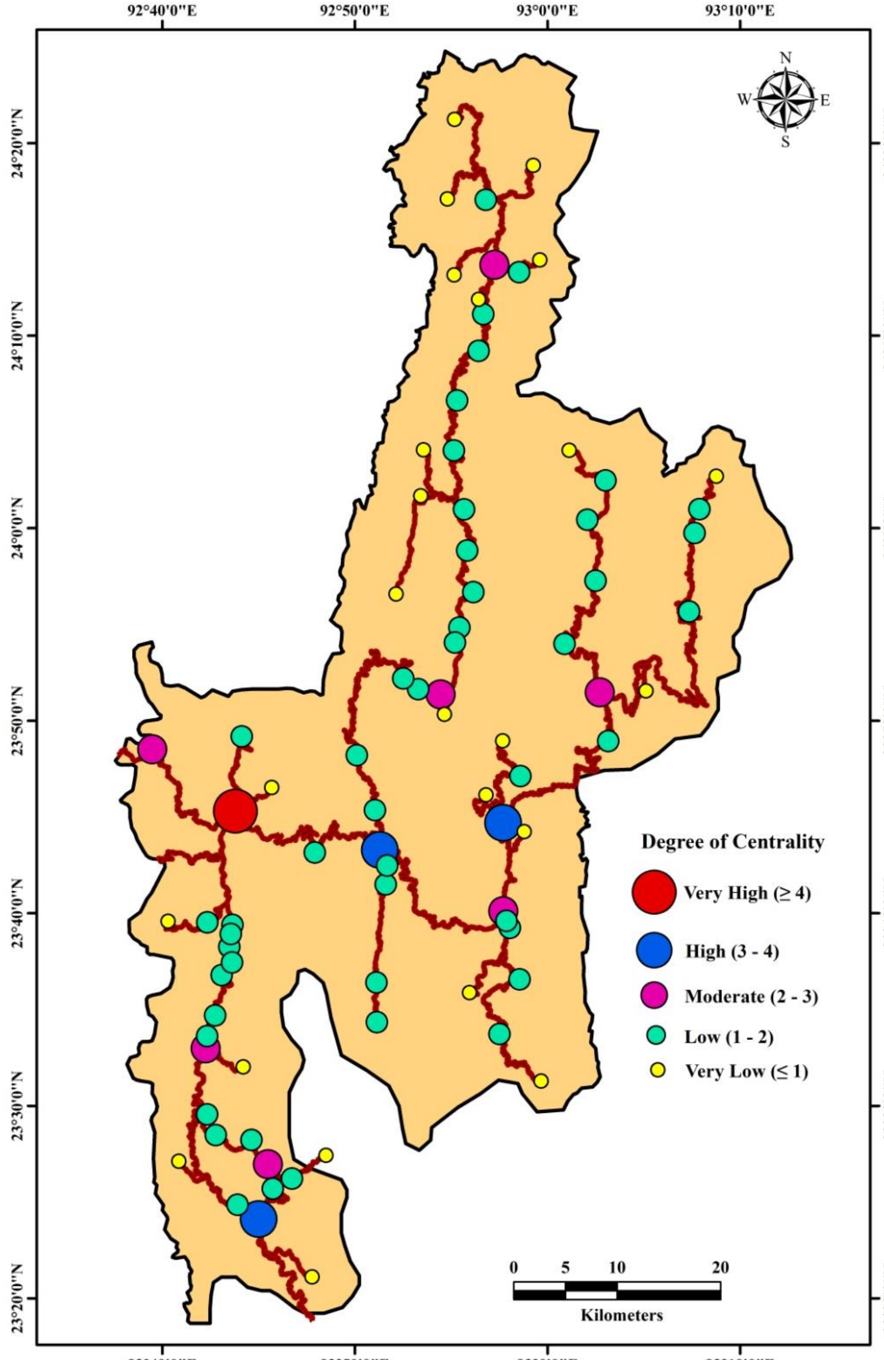

Figure 4.1: Spatial Location of Degree of Centrality (C_D) Class

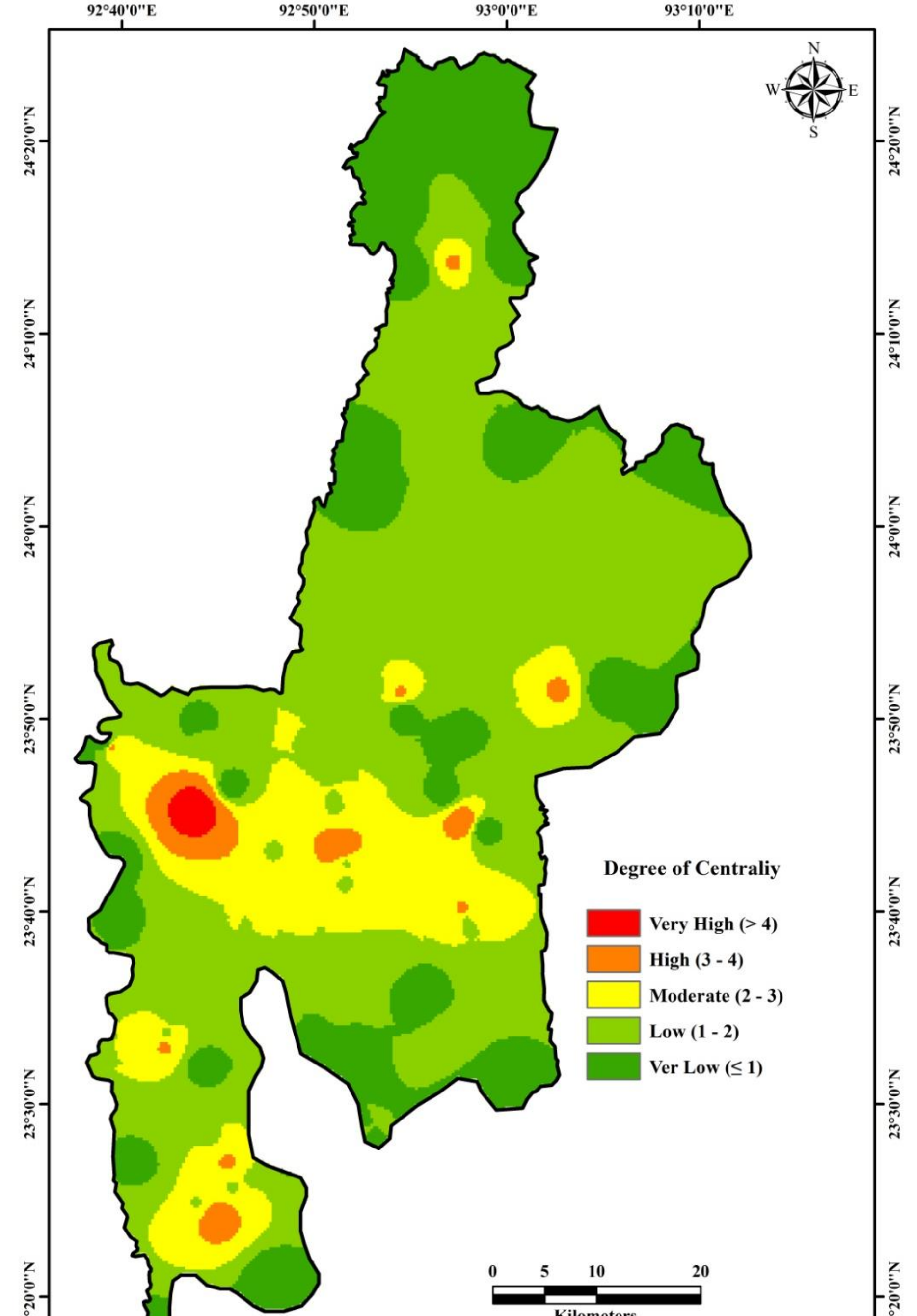

Figure 4.2: Geographical Area of Degree of Centrality (C_D) Class

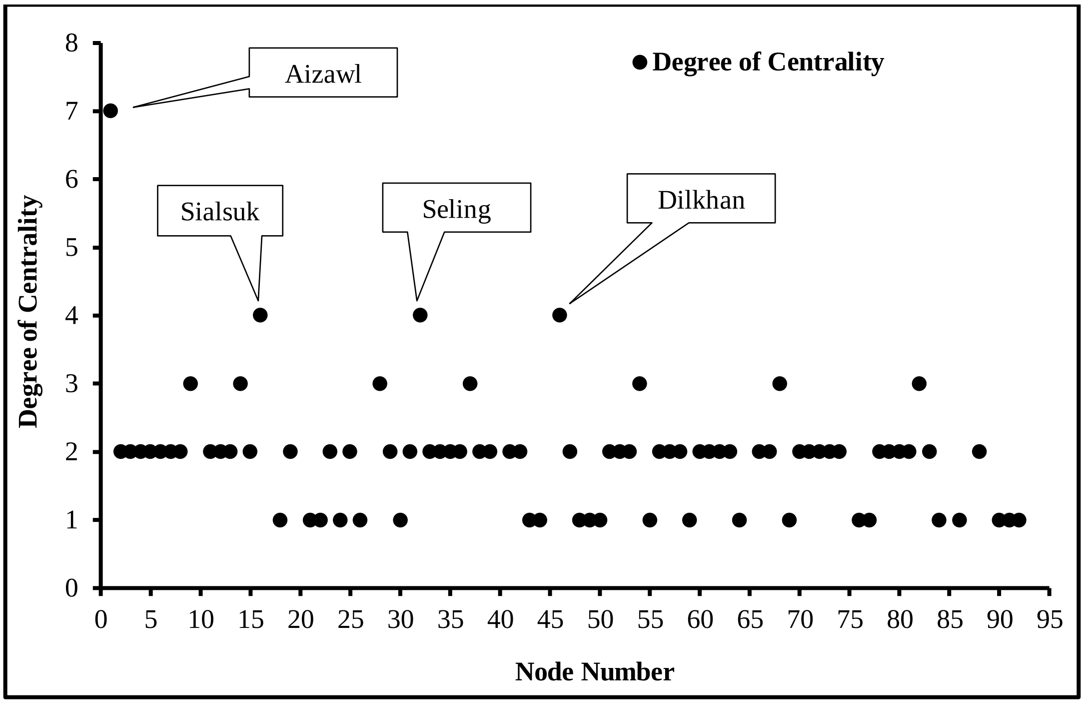

Figure 4.3: Grapical Representation of Degree of Centrality Model

4.2.2 Degree of Eccentricity (C_E)

Eccentricity centrality index is used to determine the shortest distance of a particular node from the furthest node in the network. Settlements with less eccentricity values are more accessible than those nodes showing high values. So, higher value of eccentricity indicates the node is farther away from other nodes in the network, and a node with lower eccentricity means the other nodes are actually quite close.

The degrees of eccentricity values are grouped into five classes; (a) Very High C_E (Less than 23 C_E), (b) High C_E (23 - 26 C_E), (c) Medium C_E (26 - 30 C_E), (d) Low C_E (30 - 34 C_E) and (e) Very Low C_D (More than 34 C_E), (Table 4.3; Figure 4.5 & 4.6). This classification applies the inverted method of classification for classifying nodes centrality; meaning the low scoring nodes are placed in high C_E class and so on.

(a) **Very High C_E**: About 16.87 per cent of the total settlements are found to be highly accessible. This category occupies an area of about 13.74 per cent of the area of Aizawl district, and a total of 22 nodes fall under it (i.e. High C_E value class).

The minimum C_E value is seen in Mualmam node (19 CE value) which is more accessible from the furthest nodes as can be seen in the graph (Figure 4.4). This means that reaching the furthest point from Mualmam requires 19 road segments Mauchar (Euclidean distance through shortest path). Other settlements with Very high value of C_E are Ruallung, Aizawl and Pehlawn in the eastern, western and northern sectors. The spatial arrangement of Very High C_E nodes indicates that the nodes lying in the center are more compact, as a result of which almost all the nodes lying in the central and middle parts of the network come under this category. The spatial distribution pattern of Very High C_E nodes reveals that the centrality value on eccentricity analysis is determined by the network topological structure.

(b) High C_E: High C_E occupies the highest percentage share of the total study (30.74 per cent) and is mostly confined to the East, West and in the vicinity of very high C_E regions of the districts (Figure 4.6). The class with the greatest proportion of eccentricity centrality is the High C_E class which accounts for 27.71 per cent (23 nodes) of the total settlements. Generally, the western portion and the eastern portion of the district have low eccentricity values. It is also evident that high scoring nodes are generally adjacent to the very high scoring nodes and serve as the cell of the centre. Sawleng is the northernmost critical node while Thanglailung occupies the easternmost section of the district (Figure 4.4).

(c) Medium C_E: Medium $_{CE}$ contributes about 22.89 per cent of the total settlements in the study area. Figure 4.4 shows that settlements with medium eccentricity values are mostly concentrated in the mid-north and mid-south parts of the study area. But the distribution over space is extremely diverse. Out of the total of 19 nodes, only six are in the southern part of the district while 13 nodes are found in the northern and north-eastern sections. The north-eastern sector alone contributed about 42 percent of the settlements of the class. The pattern of distribution of Medium C_E follows a longitudinal direction which can be attributed to the arrangement of the network.

(d) Low C_E: The percentage share of low scoring nodes constitutes 14.81 per cent of the total settlements. Similar to the moderate C_E class, the nodes are mostly associated with the preceding nodes. The node distribution is spotted in three regions such as north, north-east and south-west parts of the study area. Interestingly, only two villages are considered as the low C_E class from north-eastern and four villages are from northern section. The southern portion alone contributes 50 per cent of the settlements falling under this category. Concerning the compactness of the distribution pattern, the settlements with low C_E values of south-western portion are more compact than those in the north and north-east parts of the network due to the formation of a ring-type topology (Figure 4.4). The percentage of the medium C_E class area to the overall area is around 27.43 percent and, the coverage is irregular in shape and the western portion is mostly wider and tapers towards the east (Figure 4.5).

(e) Very Low C_E*:* A very low degree of eccentricity is found in the nodes that account for about 16 per cent of the total nodes. The very low CE villages are found in the extreme north and south portions of the network. In terms of eccentricity value, villages like Mauchar, Palsang and Chawilung are considered as least accessible settlements in the study area. These villages are dead-end villages that create least accessible. On the other than, very low category settlements in the southern portion are closer to one another, although accessibility has been restricted by the arrangement of the road network. Spatially, the distribution of nodes is more compact in the south than in the nodes lying in the north. About 16.54 per cent of the total area comes under this class and, they areconfined only to the northern and southern fringe of Aizawl district (Figure 4.4 and 4.5). The analysis and illustration of node distribution reveal that the nodes lying in the northern and southern regions of the network are insignificant.

The nodes with low scoring C_E values are centrally located and easily accessible from any point. On the other hand, the spatial distribution of eccentricity values highlights that node values progressively increase away from the center in all directions. Table 4.2 shows that almost 44.58 per cent (including very high and high category) of the nodes are critical nodes because the diameter of the node is minimum from the isolated node. The highest accessible settlements (least degree of eccentricity) mainly found in and around western part of the study area. On the other hand, the least accessible nodes showing the highest degree of eccentricity are found in eastern portion of the study area. This means that the nodes in the central and middle parts of the network are more critical and that the farthest nodes are less influential and less significant. In the study area, it is possible to argue that network compactness rather than diversity has a greater impact on the value of eccentricity. It indicated that the centre of network is also of paramount importance in identifying the problems of the location of a facility used for serving the network. These are significant for socio-economic development and strategic planning to monitor the entire networking system.

Table 4.2: Classification of Settlements on the Basis of Eccentricity (C_E)

Class	No. of Village	Percentage	Name of Village
Very High (≤ 23)	14	16.87	Mualmam, Khawruhlian, Sesawng, Hmunnghak, Seling, Khanpui, Saitual/Keifang, Thingsultlangnuam, Tuirial, Aizawl, Lailak, Pehlawn, Rulchawm, Thingsulthliah
High (24-26)	23	27.71	Dilkhan, East Phaileng, Hualngohmun, Muthi, Ruallung, Sairang, Samtlang, Sihfa, Sihphir, Tlungvel, Kepran, Melriat, North Lungleng, North Lungpher, Phulmawi, Thanglailung, Tualbung, Buhban, Kelsih, Lenchim, Mualpheng, Phullen, Sawleng
Moderate (27-30)	19	22.89	Darlawn, Falkawn, Tawizo, Zawngin, Luangpawn, Maite, Muallungthu, Phuaibuang, Suangpuilawn, Khawlian, Lamherh, Sailutar, Tachhip, Aibawk, North Serzawl, NE. Tlangnuam, Ratu, Sunhluchhip, Vanbawng
Low (30-34)	14	16.87	Daido, Lungsum, North Khawlek, Sateek, New Vervek, Phulpui, South Maubuang, Sakawrdai, Lungsei, Samlukhai, Thiak, Vaitin, Chhanchhuahnakhawpui, Thingsat
Very Low (>34)	13	15.66	Khawpuar, North Khawdungsei, Sialsuk, Sumsuih, Chamring, Hmuifang, North Thinghmun, Sailam, Zohmun, Lamchhip, Chawilung, Mauchar, Palsang
Coefficient of Variation			17.82

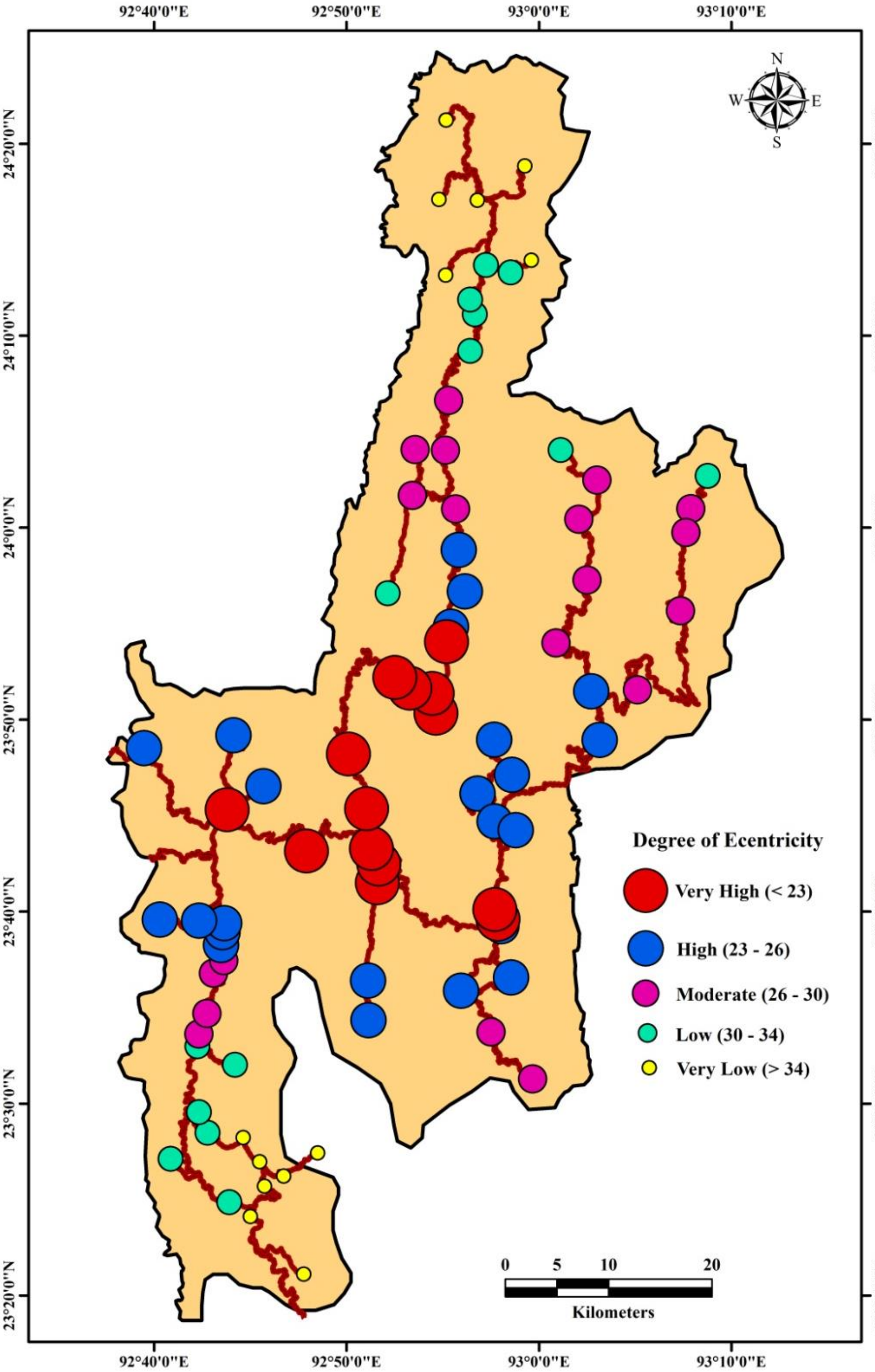

Figure 4.4: Spatial Location of Degree of Ecentricity (C_E) Class

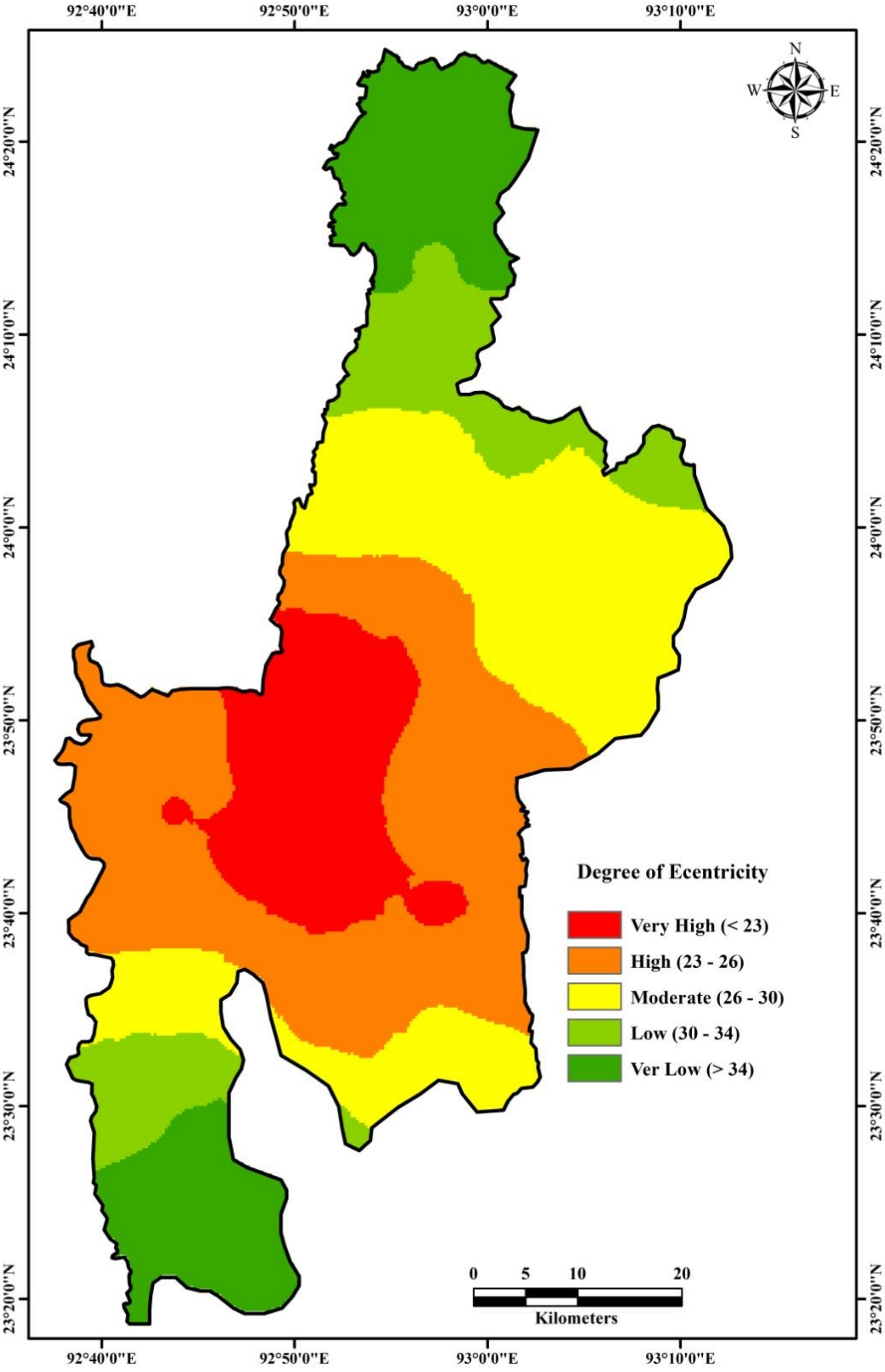

Figure 4.5: Geographical Area of Ecentricity (C_E) Class

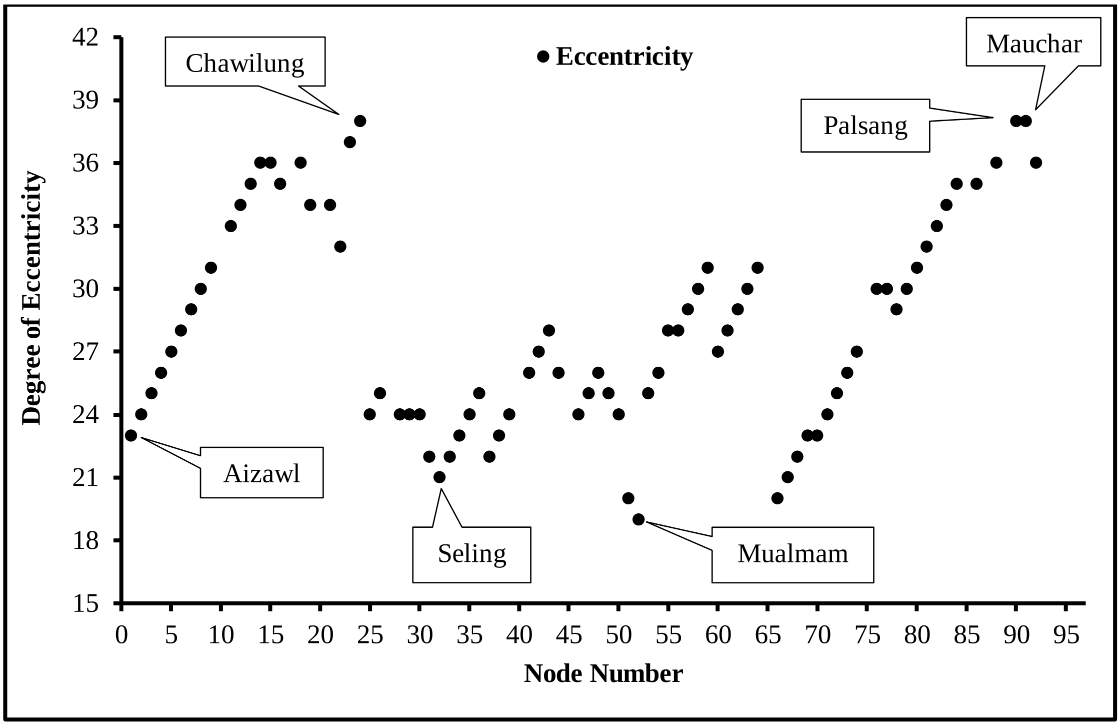

Figure 4.6: Grapical Representation of Degree of Eccentricity Model

4.2.3 Closeness Centrality (C_C)

Closeness centrality measures the shortest path of a particular node to other nodes in the network. It shows how fast a particular node can be reached from all other nodes in the network. It means that the prominent node has the maximum number of ties over the shortest distance with all other nodes in the graph. The analysis shows the distance of a prominent node (actor) to all others in the network by considering the space from each actor to the others. On the basis of their closeness centrality value, settlements are calssified into five classes; Very High C_C (> 0.0960), High C_C (0.0831 - 0.0960), Moderate C_C (0.0691 - 0.0830), Low C_C (0.0567 - 0.0690) and Very Low C_C ($\leq$ 0.0566), (Table 4.4; Figure 4.7, 4.8 and 4.9).

(a) Very High C_C: Settlements having the highest closeness centrality values constitutes 20.48 per cent of the total settlements in the network. In this network, Seling a critical junction in the network scores the highest closeness centrality value. Very high centrality villages are mainly found in the middle part of the network. The percentage share of very high C_C accounts for about 23.37 per cent of the total area (Figures 4.7 and 4.8).

(b) High C_C: The high centrality class comprises 15 villages of the study area and it accounts for 18.07 per cent of the total nodes (Table 4.3). The settlements are scattered around the middle and western parts of the network (Figure 4.7). It may be noticed that the nodes in the western section are lying closely to the very high nodes. On the other hand, the eastern portion has a different characteristic which is marked by the presence of direct link to the very high scoring nodes of the preceding class. So, the geographical distribution pattern demonstrates a direct and significant association between very high centrality and the high centrality class. Figure 5.8 illustrates that this class runs in a longitudinal direction; the northern section of which is wider as we go towards the south-east. Nodes like Sairang, Thingsulthiah, Tlungvel are critical nodes that supply agricultural products to the surrounding settlements. Therefore, in this area, market centers are agriculture-based and their main economies depend on a semi-commercial based agriculture system. The total area coverage constitutes 18.52 percent of Aizawl district, and the middle part of north and south fall under this category with a small pocket of the western part also falling in this category (Figure 4.8).

(c) Moderate C_C: The category of Moderate closeness centrality comprises 16 nodes which constitutes 19.28 per cent of the total number of nodes in the network (Table 4.3). In this class, Darlawn and Aibawk villages are important halting points in the northern and southern trunk of the network respectively. Sateek with a centrality value of 0.071 is the most isolated node in this category (Annexure-I). The spatial distribution of moderate centrality settlements is characterised by a linear one. Therefore, the arrangement of the road network may have a significant impact on the existence and development of settlements. This category occupies 20.82 per cent of the study area. The Moderate CC region is found in the middle of the northern and southern parts of the district (Figure 4.8).

(d) Low C_C: From total settlement in the study area about 26.51 per cent of the settlements are categorised as Low C_C. The arrangement of the nodes indicates a linear pattern of distribution (Figure 4.8). In terms of area, about 21.25 per cent of the area experience low closeness centrality. Low C_C regions are identified in the north and the south-western parts and there are small patches in the south-east portion of the study area (Figure 4.8). The northern region alone contributes about three-fifth of the nodes of this category, which is mainly due to the linear arrangement of nodes.

(e) Very Low C_C: In total this category constituted about 15.65 per cent of the village. The total number of nodes that come under this category is 16, with 8 of them being from the north and 5 others from the south. As shown in Figure 5.8, the nodes are confined to two pockets - the northern and southern tips of the study area. This isolated category occupies only 15.87 per cent of the total area of the district (Figure 4. 8). The northernmost node is represented by Mauchar and Sailam in the south and they represent the most isolated nodes amongst this class. This class is considered as being nearly insignificant in controlling the flow of both tangible and intangible elements in the network.

As shown by the relatively higher Closeness Centrality value Seling is the most centrally located node in the study area. About 38.55 per cent of the nodes (very high and high C_C class) are important in that they are centrally located in the network. Thus, settlements with very high and high C_C classes are critical for the establishment of strategic facilities such as emergency and community services (Table 4.3 and Figure 4.7). These settlements are treated as agents of transmission and vital links of the network. Geographically, settlements with very high and high degree of closeness centrality are generally located within the central regions of the network. Location in the central position results in the overall road network topology having better accessibility and higher degree of control compared to other settlements in the network. The settlements located in the isolated areas have poor accessibility and are difficult to reach from any other point, which means that the settlements have limited resources compared to the higher value settlements. The Figure 4.8 and Figure 4.9 illustrated that geographic centrality in the centre/middle region of the area is influenced by the network proximity. Interestingly, the high scoring nodes are surrounded by the succeeding values. It shows that the low scoring nodes are diverge in the north-south direction from the highest centrality values in this network. The spatial arrangement that emerges also reveals that nodes are arranged in varied patterns ranging from the compact to the dispersed type of distribution.

Table 4.3: Classification of Settlements on the Basis of Closeness Centrality (C_C)

Class	No. of Villages	Percentage	Name of Village
Very High (> 0.096)	17	20.48	Seling, Tuirial, Sesawng, Saitual/Keifang, Aizawl, Mualmam, Thingsultlangnuam, Hualngohmun, Khawruhlian, Rulchawm, Sairang, Samtlang, Sihphir, Muthi, Hmunnghak, Dilkhan, Melriat
High (0.0831 - 0.096)	15	18.07	Thingsulthliah, Sihfa, Khanpui, Ruallung, Kelsih, Thanglailung, North Lungleng, Pehlawn, North Lungpher, Tualbung, Tlungvel, Falkawn, Lailak, East Phaileng, Phullen
Moderate (0.069-0.083)	16	19.28	Muallungthu, Buhban, Kepran, Phulmawi, Mualpheng, Lenchim, Tachhip, Zawngin, Sawleng, Aibawk, Darlawn, Tawizo, Phuaibuang, Suangpuilawn, Luangpawn, Sateek
Low (0.0567-0.069)	22	26.51	Khawlian, Lamherh, Maite, Sailutar, Phulpui, Ratu, NE. Tlangnuam, Vanbawng, South Maubuang, North Serzawl, Sunhluchhip, Lungsum, Samlukhai, Thiak, Daido, Nnorth Khawlek, Chhanchhuahnakhawpui Lungsei, New Vervek, Sialsuk, Sumsuih, Thingsat
Very Low (≤ 0.0566)	13	15.66	Sakawrdai, Chamring, Hmuifang, Sailam, Vaitin, Lamchhip, North Khawdungsei, Khawpuar, Chawilung, Zohmun, North Thinghmun, Palsang, Mauchar
Coefficient of Variation			24.37

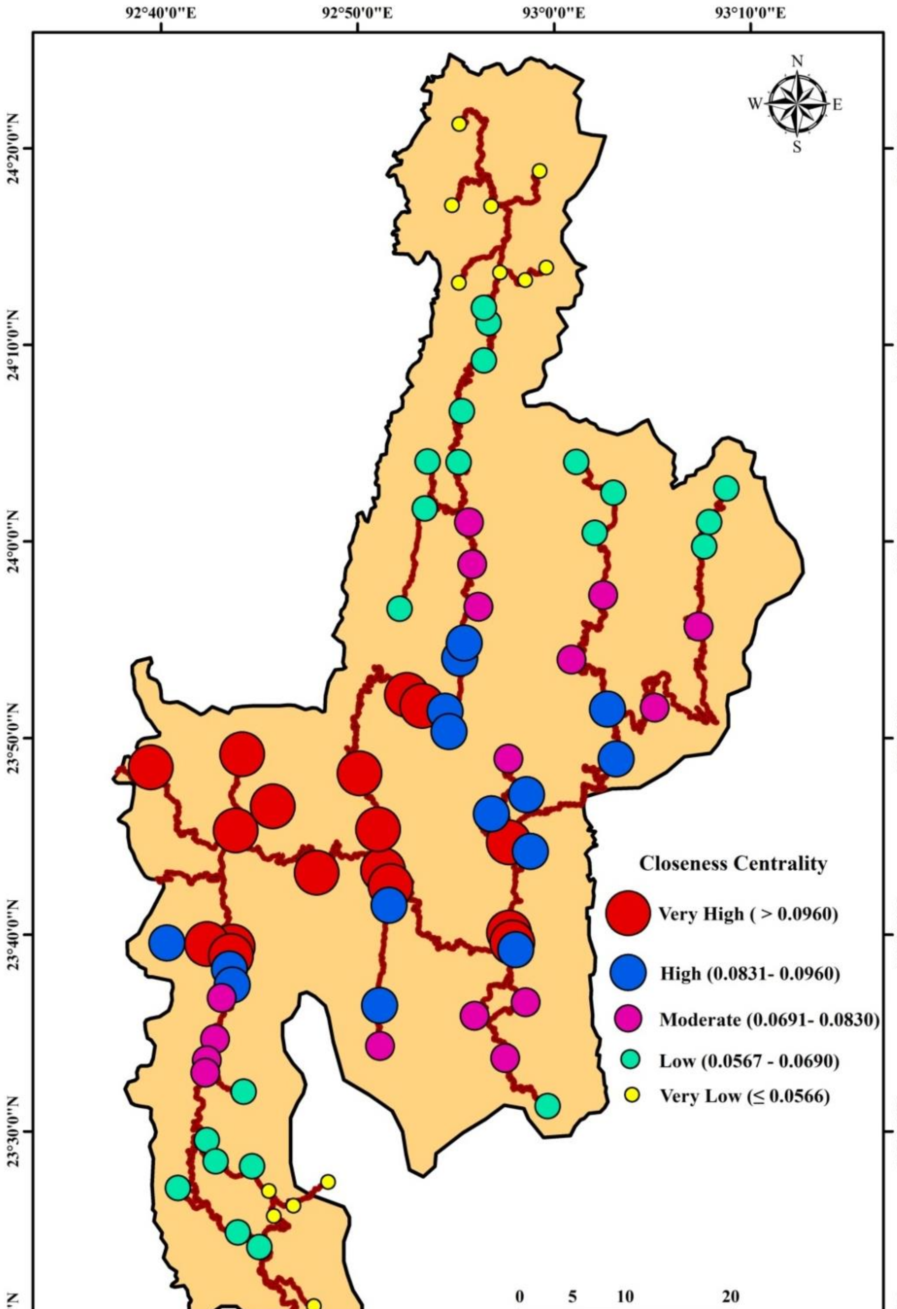

Figure 4.7: Spatial Location of Closeness Centrality (C_C) Class

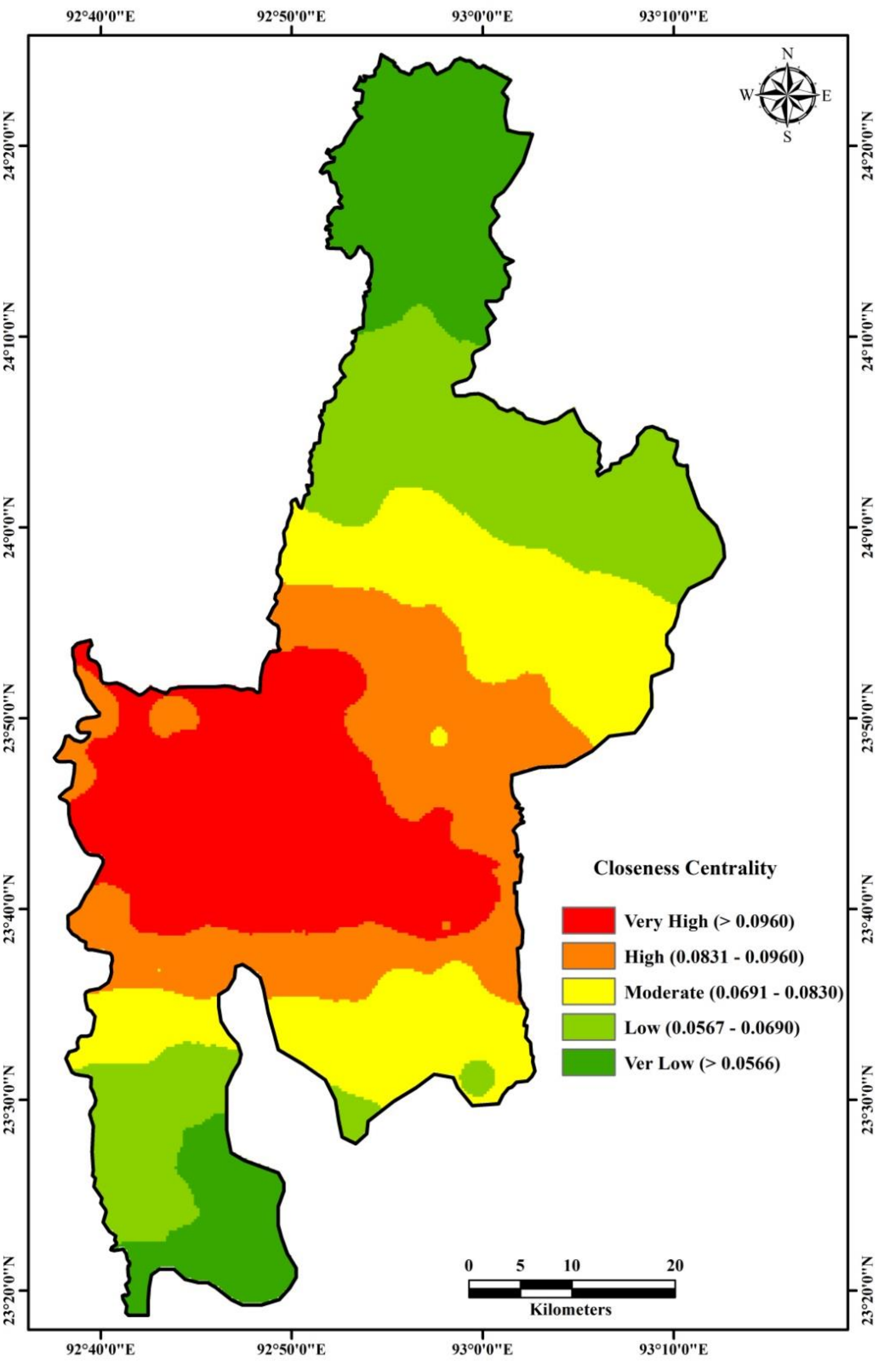

Figure 4.8: Geographical Area of Closeness Centrality (C_C) Class

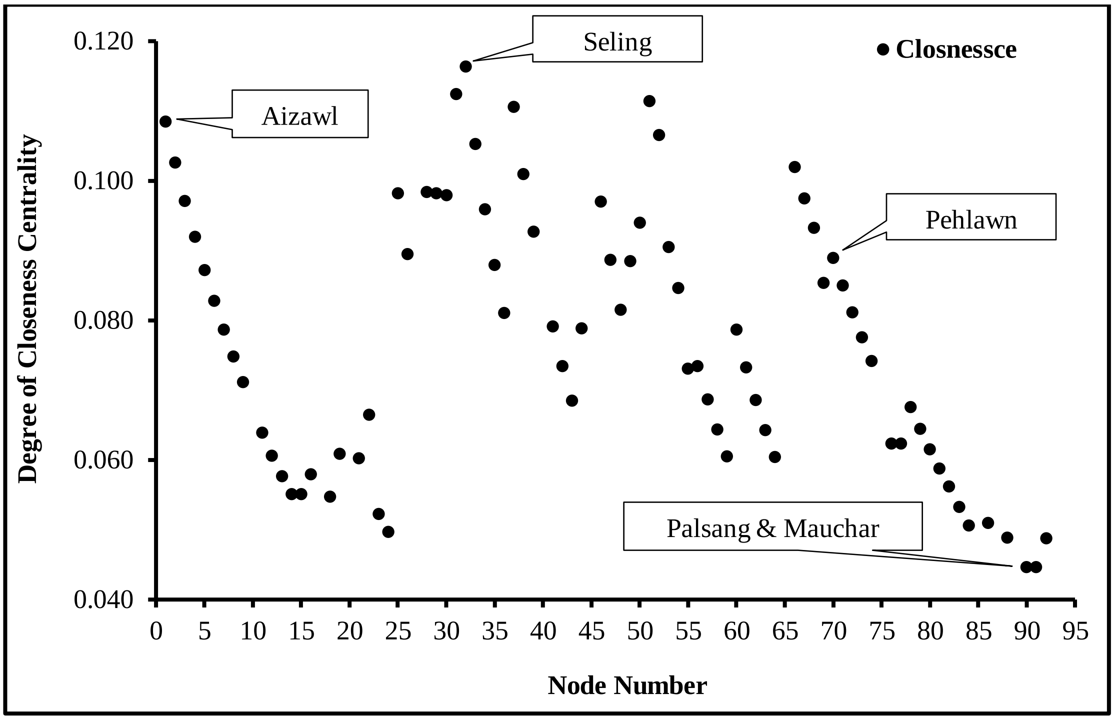

Figure 4.9: Grapical Representation of Closeness Centrality Model

4.2.4 Betweenness Centrality

Betweenness centrality measures the number of shortest paths the node is part of and passes through this node (Farhad & Ulfat 2019). It provides the information on how much control a node has over flows in the network or how often is this settlement on the path between other settlements. The measure highlighted the frequency of settlements that are needed to be passed through to reach one settlement from other settlements; it means that a node lies between other nodes in the network. The study interprets and analysis the calculated results by categorising the nodes into five classes; (a) Very High (More than 2040 C_B), (b) High (1405 – 2040 C_B), (c) Moderate (541 - 1404 C_B), (d) Low (96 - 540 C_B) and, (e) Very Low (Less than or equal to 95 C_B).

(a) Very High C_B: The computed betweenness centrality reveals that the very high centrality class is represented by only three settlements that comprises 3.61 per cent of the total nodes. The most critical sentiment in this network is Seling followed by Aizawl and Tuiral settlements (Table 4.4). The study revealed that the degree of betweenness centrality of a settlement (Δ) is significantly high between the settlements. Seling enjoys a persuasion advantage of 917 times compared to Aizawl. Consequently, the Seling node holds 917 additional effective or betweenness degrees in comparison to the Aizawl node. This disparity empowers Seling to govern the movement of information and commodities within the network more extensively. (Annexure-I). In order to control the others in the network, the highest value holds the most significant and dominant position. In general, the middle part of the has very high betweeness centrality. This arrangement of nodes also emphasises on critical edges in the network like Aizawl to Seling (via Tuirial). In terms of geographical area, this category occupies about 8.61 per cent of the proposed study area and this area can be labeled as an most accessible area. Geometrically this category forms an irregular shape and occupies the middle part of the region which thereon makes a bulge towards the north (Figure 4.11).

(b) **High C_B:** Nodes with 1405 to 2040 C_B values are categorised as high degree of centrality for this network. It contributes to about 18.07 per cent of the total nodes in the network. In this class Saitual/Keifang are the most central locations, while Falkawn and Darlawn are registered as the most isolated nodes of this category (Table 4.4). The nodes that are included in this category act as intermediate or transit points or halting points etc. The distribution pattern indicates a linear pattern of distribution along with the arrangement of edges. Out of the 15 nodes in this class, 9 nodes (60 per cent) are located on the northern trunk of the network. The eastern part of the network, Saitual/Keifang is the only settlement representing this category. The proportion of area coverage of the high C_B class nodes is about 13.17 of the total area. Figure 4.11 shows high C_B region and takes an asymmetrical shape which is found in the vicinity of very high C_B class.

(c) **Moderate C_B:** Moderate C_B class accounts for 14.46 per cent from the total number of settlements in the study area. Normally these nodes run along the ridges and are distributed along the three main trunks of the network. Somehow the nodes under this category represent the halting points and junctions between the edges etc. Some of the important junctions and halting points in this category are Sateek in the south, Dilkhan and Phullen in the eastern section and Sakawrdai in the northern section of the network (Figure 4.11). A moderate degree of betweenness centrality contributes to about 16.91 per cent of the total area of Aizawl district. The area coverage is narrower in the middle part of the region and northern area consists of smaller pockets. Comparing it with other parts of the area, the area coverage is broader in the northern section and south-eastern parts of the study area (Figure 4.11).

(d) Low C_B: In this network about 22.89 per cent of the total nodes are classified as low C_B (Table 4.4). Amongst those settlements Rulchawm scores the maximum betweensess value. The lowest degree of centrality is noticed in Tlungvel, Mualpheng, Khawlian, Lamherh (Figure 4.10). This class of node centrality implies limited connectivity with adjoining nodes due to lack of spread of the network and remote location of the nodes from the high scoring nodes. Regarding the limited area coverage of this category, the region falling under this category presents irregular distribution characterised by narrow patches in all directions. On the other hand, the maximum geographic extent of this category is found in the eastern portion of the district (Figure 4.11).

(e) Very Low C_B: Out of the 83 nodes, 34 nodes belong to this category which is about 40.96 per cent of the total nodes in the network (Table 4.4). From the total nodes in this class, more than 70 per cent of the nodes belong to 0 betweenness centrality, which means that those nodes have 0 levels of persuasive power and are considered dead-end nodes (Annexure-I). Very low C_B class nodes are scattered all over the network and this category constitutes the largest area coverage of all classes at 42.83 per cent. These are mostly located in the north, south, east and western edges of the study area (Figures 4.10 and 4.11).

The analysis shows that betweenness centrality measure is a straightforward method to investigate the structure of network topology. The study identified that almost 64 per cent of the total settlements that belongs to low and very low C_B classes. These settlements are therefore, considered insignificant (being between) for the flow of information. It means that lack of adjacency and immediate neighbour resulted in the insufficient linking of these settlements with arterial and sub-arterial roads in the road network (Table 4.4). Further, settlements having lower values in the network possess the least importance and are the least influential over other settlements. The distribution of low and very low C_B results called non-tree-edges (constant movement for crossing the nodes to and fro and cross edges) structure that yields minimum betweenness value. One the other hand, results is ideal for identification of the most influential road edges in the network. Thus, road segment between Seling and Aizawl (via Tuiral) is one of the important road segments in the whole network. Similarly, most of the highest betweenness values are observed along important road segments and ultimately these settlements are represented as major collection centres, dissemination centres, halting points and junctions, namely Seling, Tuirial, Aizawl, Keifang/Saitual and Darlawn etc. The study reveals that the betweenness centrality measure can be used as a helpful tool in the identification of road network topological structures, accessibility, functional hierarchy, bridgeness and resilience (Figure 4.10 and 4.11). This measure is a helpful tool in determining the critical road segment/major roads, such as arterial roads, sub-arterial roads, secondary roads etc. Also betweenness measure is useful in better identifying distribution centres, collection centres, halting points and junctions. Further the result is applicable in performing transport pattern analysis, transport development planning, infrastructure development, strategic planning and road network dynamics analysis. These are significant factors for determining the socio-economic conditions of the settlements that located in the network.

Table 4.4: Classification of Settlements on the Basis of Betweeness Centrality (C_B)

Class	No. of Villages	Percentage	Name of Village
Very High (> 2040)	3	3.61	Selling, Aizawl, Tuirial
High (1405 - 2040)	15	18.07	Saitual/Keifang, Sesawng, Mualmam, Khawruhlian, Hmunnghak, Khanpui, Pehlawn, Hualngohmun, East Phaileng, Melriat, Kepran, Kelsih, Sawleng, Falkawn, Darlawn
Moderate (541 - 1404)	12	14.46	Muallungthu, Tachhip, Dilkhan, Aibawk, Sateek, Sailutar, Ratu, Thanglailung, Lungsum, Phullen, New_Vervek, Sakawrdai
Low (96 - 540)	19	22.89	Rulchawm, Ruallung, South Maubuang, Thingsultlangnuam, Zawngin, Samlukhai, Thiak, Sialsuk, Thingsulthliah, Phuaibuang, Suangpuilawn, Zohmun, Sumsuih, Hmuifang, Sairang, Tlungvel, Mualpheng, Khawlian, Lamherh
Very Low (≤ 95)	34	40.96	Lamchhip, Samtlang, Sihphir, Phulmawi, Tawizo, North Lungpher, NE. Tlangnuam, Vanbawng, Vaitin, Chamring, Sailam, Lungsei, Phulpui, Chawilung, North Lungleng, Muthi, Maite, Lenchim, Buhban, Tualbung, Sihfa, Luangpawn, Daido, North Khawlek, Lailak, North Serzawl, Sunhluchhip, Khawpuar, North Khawdungsei, Palsang, Chhanchhuahnakhawpui, Mauchar, North Thinghmun, Thingsat
Coefficient of Variation			115.83

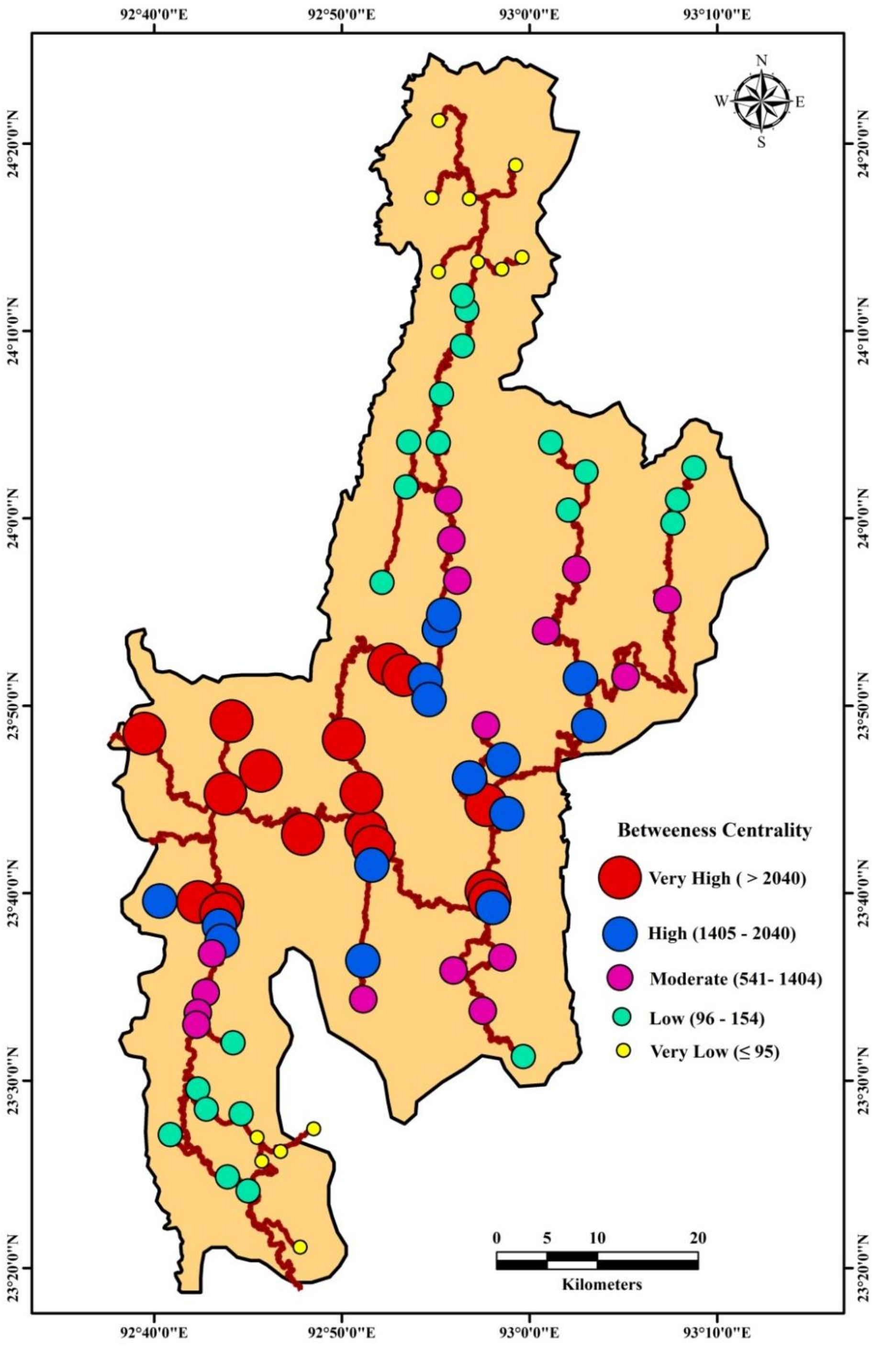

Figure 4.10: Spatial Distribution of Betweeness Centrality (C_B) Class

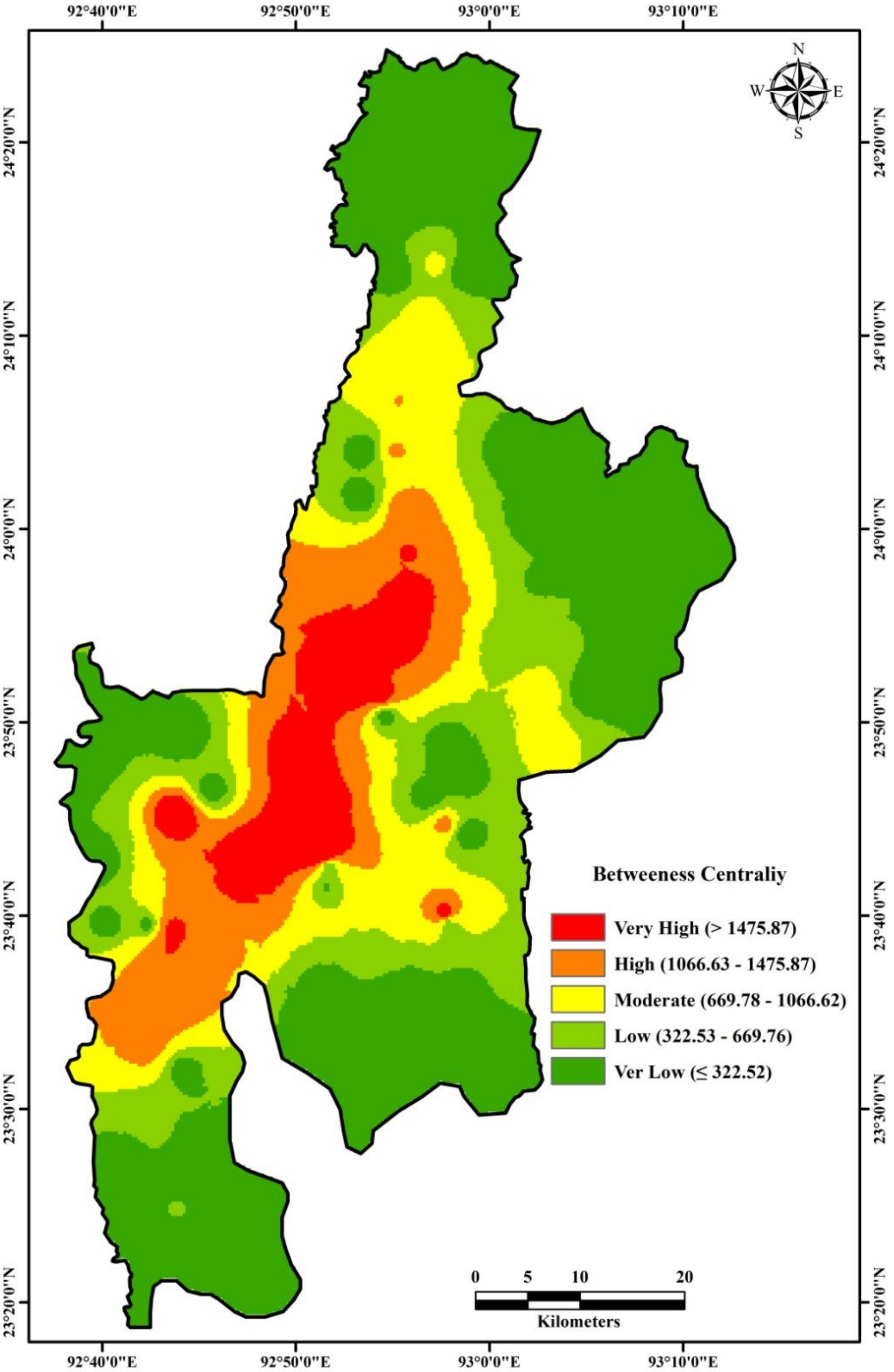

Figure 4.11: Geographical Area of Betweeness Centrality (C_B) Class

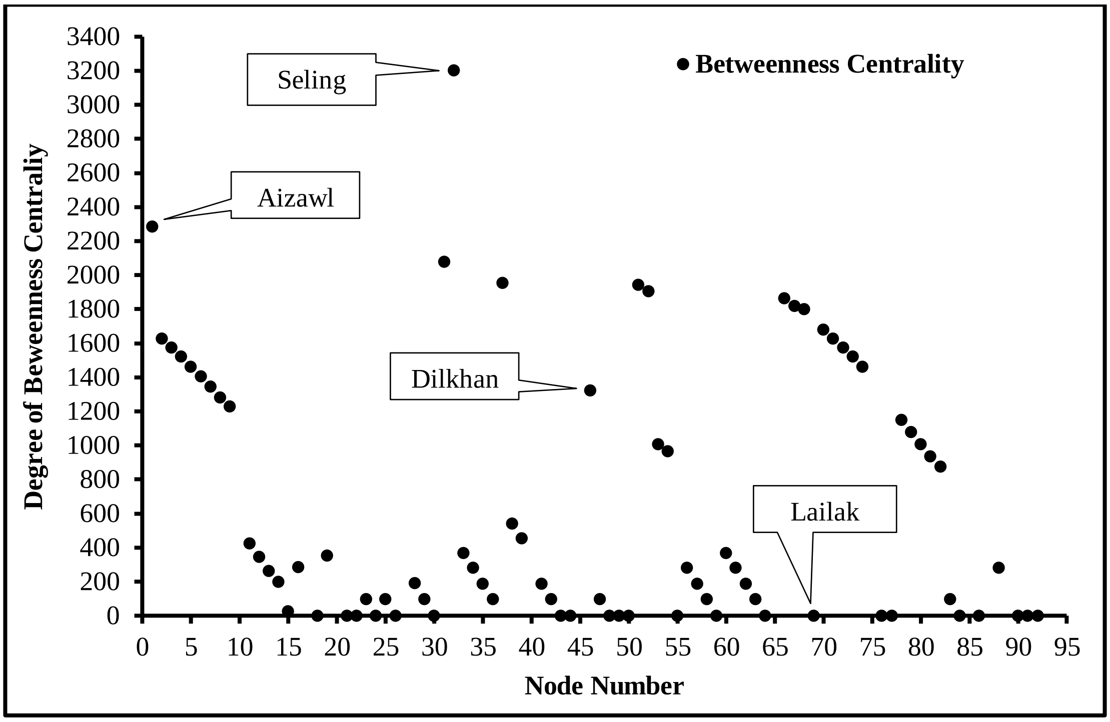

Figure 4.12: Grapical Representation of Betweeness Centrality Model

4.2.5 Eigenvector Centrality (C_V)

The final parameter adopted for topological structure analysis is eigenvector centrality. The principle of eigenvector centrality measure is different from other centrality measure, and the measure depends on its surrounding notes. Eigenvector centrality measure considers both the local/surrounding nodes values to determine its centrality value. Thus, the centrality of a vertex is proportional to the sum of the centralities of the vertices to which it is connected (Wen *et al.*, 2019). It defines the importance of a settlement through its connectivity to important settlements. In order with the above discussion, the study adopted a classification method to analyse eigenvector centrality values and categorised them into five major classes - (a) Very High (More than 0.500), (b) High (0.281 - 0.500), (c) Moderate (0.181- 0.280), (d) Low (0.1071 - 0.180) and, (e) Very Low (Less than or equal to 0.107).

(a) Very High C_V: Only three nodes are classed under very high eigenvector centrality. This constitutes 3.61 per cent of total settlements in the network (Table 4.5). In the entire network system, Aizawl has the highest eigenvector centrality or 'eigencentre'[12], Seling secures the second position and

Tuirial secured the third-highest eigenvector value in the network (Annexure - I). The high scoring nodes are distributed along the main arterial road in the network (i.e. National Highway 54) or that the nodes present a distribution pattern that forms main arterial edges between Aizawl to Seling (via Tuirial) in the network. Figures 4.14 reveal that the very high C_V nodes show a linear pattern. Interestingly, the edge between Aizawl to Seling crosses the valley region and links the two major subgraphs (subsets) including the northern and southern sub-graphs. Thus the settlements lied along NH-54 acting as the main trunk/transmitters of transportation flow in the entire network. The result of Figures 4.13 and 4.14 also shows that the location and position of nodes over the network ultimately affect the geographic centrality of the surrounding areas. But, the geographical extent of this category is minimal, accounting for only about 1.52 per cent of the study area. Again the area is confined to the western part of the study area forming a spherical shape. Further, the quantitative and qualitative presentation of C_V class depicts the topological structure of the network and is optimised by 3.70 per cent of nodes or that only 1.52 per cent of the area controls the entire geographical area of Aizawl district.

(b) **High C_V:** This category encompasses the high order nodes and their strategic position in the network affords them higher status. The proportion of these nodes is a mere 9.64 per cent (8 nodes) of the total nodes in the network. Generally, the settlements with the highest eigenvector centrality value are seen in and around very high C_V or directly adjacent to the eigencenre (Aizawl). It means that the Aizawl node has direct implication/control over the nodes surrounding it. The northern segment of the network experiences the absence of any node with high C_V value (Figure 4.13). Considering eigenvector centrality to real-time applications in the road network, Aizawl, Tuirial and Seling take up the role of main dissemination centres. Sialsuk and Sialsuk/Keifang settlements are the halting points and distribution centres and have strong positions in the ranking in the southern and eastern segments of the network respectively. In terms of geographic area, about 9.88 per cent of the area experiences high C_V category and their coverage is limited to the western and central parts of the study area (Figure 4.14).

(c) Moderate C_V: The third highest eigenvector centrality is categorised as moderate C_V, and in this 13 nodes (15.66 per cent) of the network experience moderate values. In contrast to nodes in the former classes, the nodes in this category are scattered all across the network. The moderate category occupies about 18.31 per cent of the total geographical areas of Aizawl district. Normally, moderate C_V areas are concentrated in three regions - the middle, eastern and southern portions of the study area. In the northern segment of the network moderate eigenvector centrality is observed only in Sakawrdai. Geometrically, the middle part of the region forms an irregular shape and is wider towards the east (Figure 4.14). This means that the eastern portion of the area is dominated by the moderate C_V category and serves as the main distribution centre or main junction of the area.

(d) Low C_V: From the total settlements, 40.96 per cent of the network belongs to the low C_V category (Table 4.5). The illustration of node distribution as can be seen in the Figures 4.13 indicates a dispersed pattern of distribution of the low C_V category in the network. It can be assumed that the disperse pattern of distribution in the network forms a linear arrangement of nodes and is necessarily influenced by geographical phenomena. Low eigenvector centrality class dominates the south central portions and a channel of low C_V regions also portrays a meandering pattern in the middle parts of the study area (Figure 4.14). The percentage share of low C_V nodes accounts for 40.96 per cent of the total nodes, while the area coverage of the low C_V category is only 14.62 per cent of the total area. To some extent the linear pattern of distribution of low C_V category has the least impact on the centrality value.

(e) Very Low C_V: The area of very low C_V category constitutes more than half of the geographical area of Aizawl district (53.82 per cent). The calculated eigenvector value, shows heterogeneous structure on the fringes of the networks and as the network structure is determined by network type, pattern and directions. The lowest eigenvector value in this network is found in the North Khawlek, which is located in the northern part of the network. Geographically, those of very low C_V nodes are found mostly in the north, north-east, south and south-east portions of the network. In terms of area coverage, the majority of the northern area is dominated by this category. The spatial distribution of nodes with very low eigenvector shows that the node distributions are influenced by geographical determinants like the direction of mountain range and ridge lines. In the case of the very low C_V category (Figure 4.13 and 4.14), it can be argued that the position and arrangement of nodes have a significant effect on the estimation (spatial interpolation) of geographical accessibility.

Figure 4.13 shows that there is a sharp declining trend of eigenvector centrality values between eigencentre and the next successive values indicate that the network is a centralised type of a network. The settlements with very high and high C_V are mainly confined in the middle part of the region, these towns and villages are strategically significant for the movement of information and the foundation of socio-economic development in Aizawl district. It is also crucial to understand the centre of trade routes and commodity flow which is crucial for stability to maintain long-term socio-economic development in the centre. The analysis also provides us to recognized which towns and villages serve as the hubs of networks that support the district long-term socio-economic sustainability. The coefficient of variation (78.87 per cent) or the difference between the upper (1 C_V value) and lower limit (0.042) helps us understand the variations of links from one node to other nodes, the importance of these nodes in the network. Further, the analysis claims that the proposed network experiences uncertainties associated with the eigenvector centrality measure for each of the nodes and the network is disrupted by complexities in the network and geographical factors.

Table 4.5: Classification of Settlements on the Basis of Eigenvector Centrality (C_V)

Class	No. of Village	Percentage	Name of Village
Very High (> 0.500)	3	3.61	Aizawl, Selling, Tuirial
High (0.281 - 0.500)	8	9.64	Sairang, Hualngohmun, Saitual/Keifang, Samtlang, Sihphir, Dilkhan, Muthi, Sialsuk
Moderate (0.181 - 0.280)	13	15.66	Phullen, Sesawng, Thanglailung, Thingsul Tlangnuam, Sakawrdai, Sateek, Rulchawm, Samlukhai, Hmuifang, Chamring, Melriat, North Lungpher, South Maubuang
Low (0.1071 - 0.180)	34	40.96	Zawngin, Ruallung, Khanpui, Zohmun, New Vervek, Sumsuih, Mualmam, Sailutar, Darlawn, Aibawk, Thingsulthliah, Phuaibuang, Tualbung, Thiak, Hmunnghak, North Lungleng, Sihfa, Kelsih, Pehlawn, Vaitin, Lungsum, Khawruhlian, Ratu, Sawleng, Suangpuilawn, Lamchhip, Tachhip, Mualpheng, Sailam, East Phaileng, Kepran, Falkawn, Muallungthu, Khawlian
Very Low (≤ 0.107)	25	30.12	Tlungvel, Lungsei, North Khawdungsei, Lamherh, Phulpui, North Thinghmun, Luangpawn, Tawizo, North Serzawl, Sunhluchhip, NE. Tlangnuam, Lenchim, Lailak, Phulmawi, Vanbawng, Buhban, Palsang, Mauchar, Khawpuar, Chhanchhuahnakhawpui, Chawilung, Maite, Daido, North Khawlek, Thingsat
Coefficient of Variation			78.87

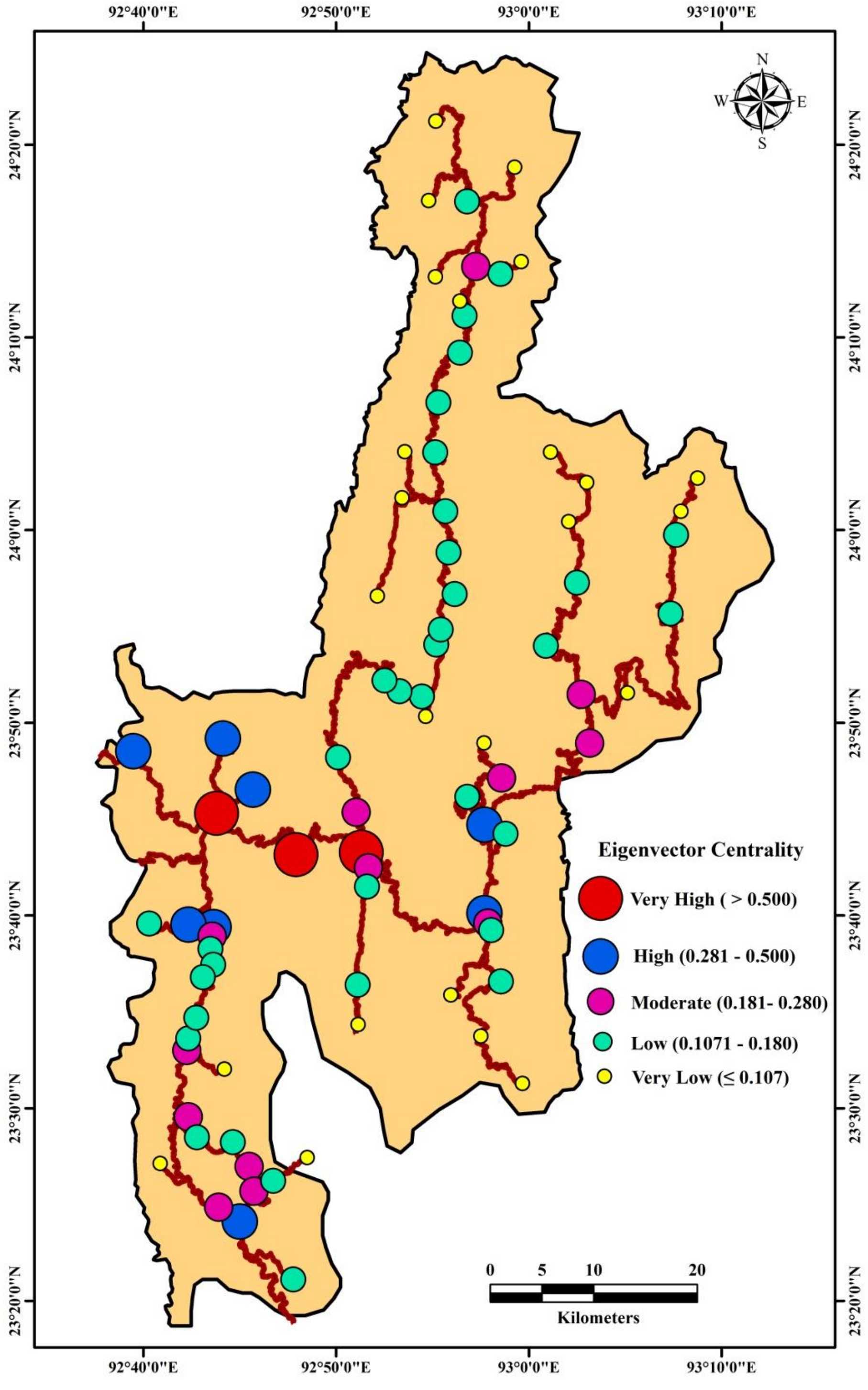

Figure 4.13: Spatial Location of Eigenvector Centrality (C_V) Class

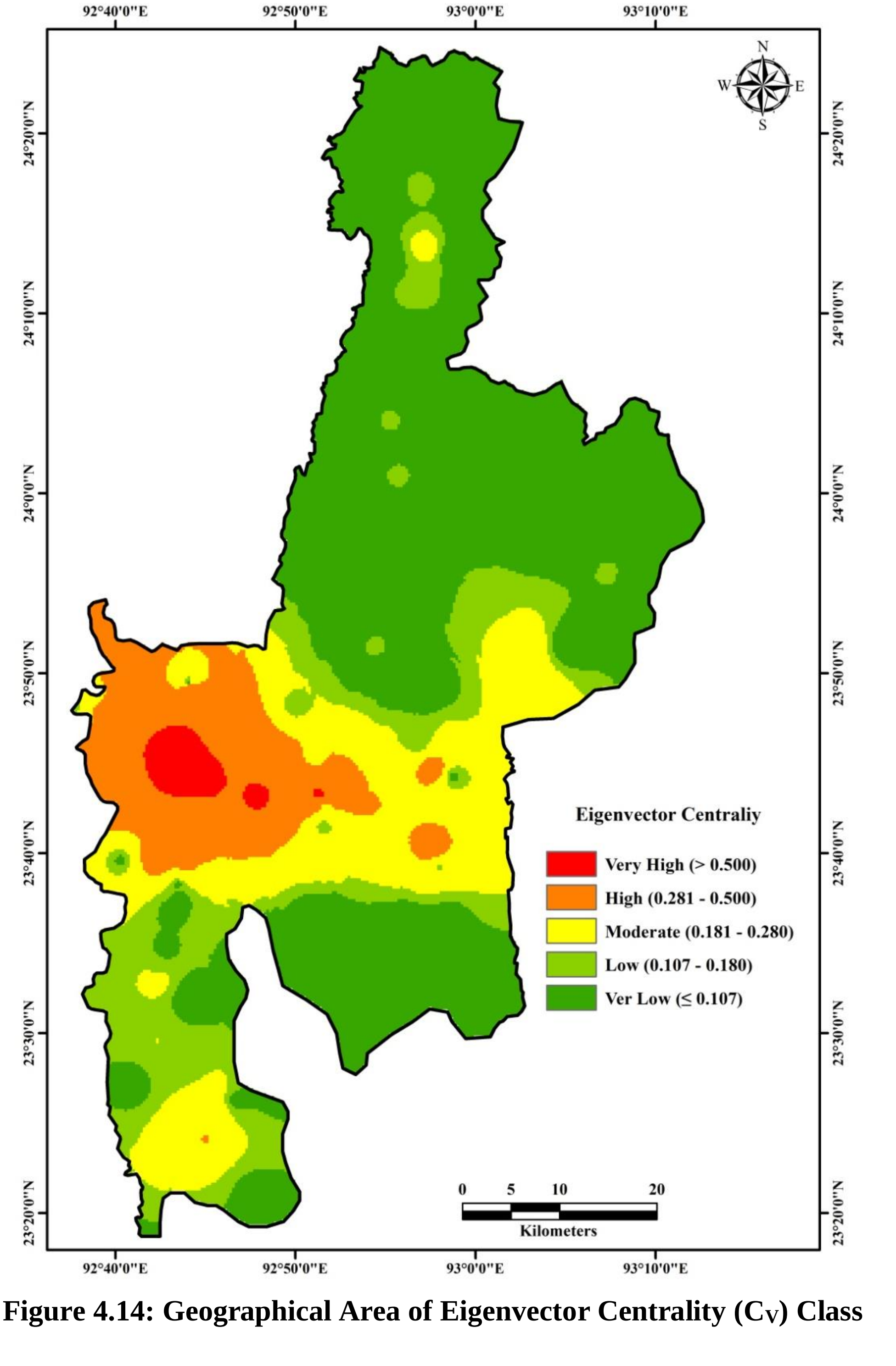

Figure 4.14: Geographical Area of Eigenvector Centrality (C_V) Class

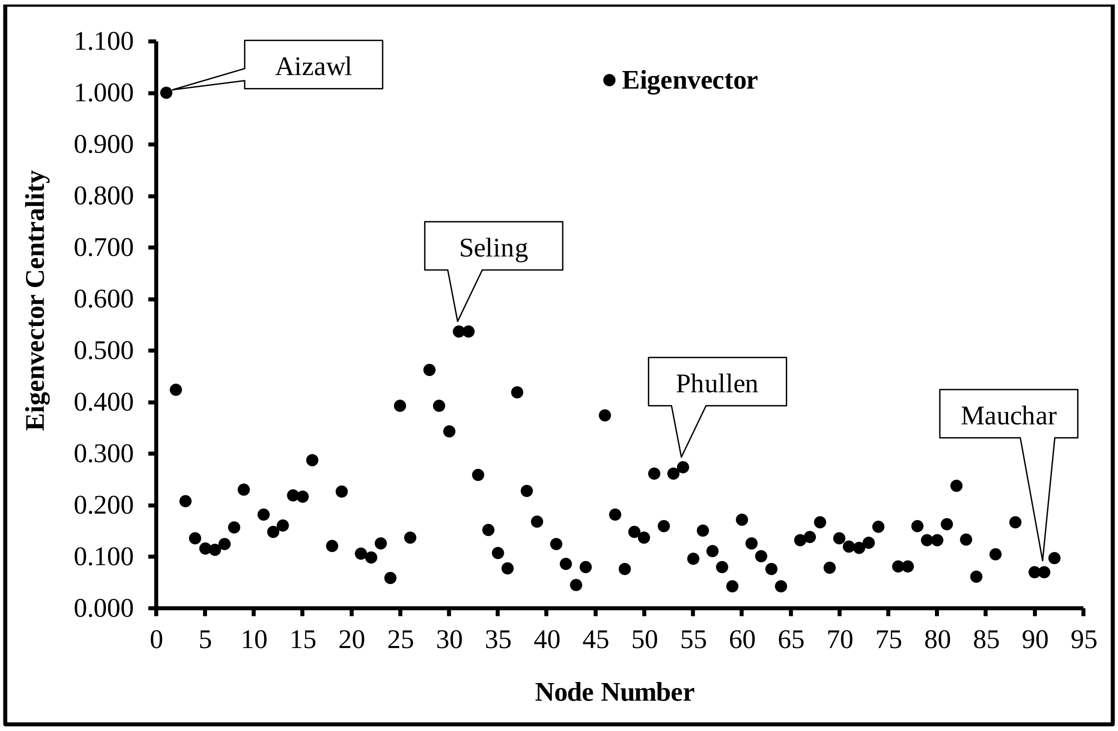

Figure 4.15: Grapical Representation of Eigenvector Centrality (C_V) Model

4.3 Spatial Variations of Node Centrality within Centrality Classes

In the network centrality analysis, each of the centrality measures has a variety of topological structures and centrality patterns. But, the classification technique adopted to determine different measures of centrality is unsatisfactory in addressing the issue of the 'sensitivity of the individual nodes'[13] of the *topological structure* of the network in the study area. Further, different classes offer different information or redundant information depending on the centrality measures employed for computing the measures of network centrality. Thus, it is important to examine the variations of settlement centrality within the various centrality classes. The variations of the centrality class reveal characteristics, pattern, sensitivity, and topological variability of the network.

According to the calculated values, it can be said that betweenness centrality measure has the highest degree of variation amongst the centrality measures. The level of dispersion around the mean of betweenness centrality measure is *r*=115.83 per cent, eigenvector is ranks second with a score of *r*=78.87 per cent, the degree of centrality third (*r*=46.49 per cent), closeness comes in the fourth position (*r*=24.37 per cent) and the least degree of variation is experienced in eccentricity (*r*=17.82 per cent). In the case of betweenness and eigenvector centrality measures the centrality between the settlements show a discrepancy in both the highest values and the minimum centrality values, which means that the distribution of centrality values are more inconsistent in these measurements. Comparing neighborhood-base and shortest path approaches (excluding betweenness), global-based centrality measures have a least degree of variation because all the nodes exist in the network are considered for the centrality of a particular node (Table 4.6).

The study observed that the degree of centrality has limited variation in the elements due to the absence of variations between the nodes, which is the result of the network topology and its complexity. As a result, the variation in centrality within the class is equal to *r* =0 per cent, which is due to the minimum range of adjacent nodes in the network or due to the restrictive nature of the network structure. This means that each of the centrality classes is categorised by a single element (Annexure-I).

Table 4.6 and Figure 4.16 illustrate the coefficient of variation within each of the centrality class. Generally, a very high degree of centrality class is associated with diversity within the class. For high and moderate classes in the network the centrality values are more compact and uniform, meaning that the coefficient of variation have declined in these two classes. On the other hand, the low centrality class has a higher degree of spatial variations of node centrality while some nodes falling under this category were very low due to the location and positional problems in the network. Normally very high degree of centrality class experience greater coefficient of variations than those high and moderate classes. It is also observed that the value of CV increases from the high to the very low class. For instance, in the betwenness centrality measure the spatial variation of centrality in the moderate class is *r*=15.78 per cent and increases to *r*=34.27 per cent. Again, in the very low degree class the increase is more than four times with r=156.81 per cent of spatial variation within the class. The shape of the figures also indicate that the diversity of centrality is more in the lower centrality classes with regard to closeness, betwenness and eigenvector centrality measures. On the other hand, in the eccentricity measure, the diversity of centrality is more in the higher degree classes than in the lower centrality classes. This means that high degree of centrality is confined to a few segments of the network and a larger portion of the nodes are least central in the network.

In the network centrality analysis, each of the centrality measures has a variety of topological structures and centrality patterns. Classification method generalises centrality values in single parameters or with some specific ranges. But, the problem is for addressing the levels of sensitivity of the class. For this reason, the study inculcated the statistical tools like coefficient of variation for observing the characteristics, pattern, sensitivity, and topological variability of the classes. Thus, the study exposed that the class with High, Moderate and Low class observed uniform characteristics in general. But the characteristics are being reversed on extreme class i.e. Very high and Very Low (Table 4.6 and Figure 4.1). On the whole, it can be said that an increasing trend of node centrality within the network leads to a diversified centrality pattern in general and a decline in node centrality leads to a diversified centrality pattern in particular. It can be said that the least degree of centrality results in an increase of spatial variability. In the hilly areas, the diversity pattern increases rapidly with an increase in the network connectivity pattern because of the nature of the hill topography which does not allow a uniform increase in the centrality levels.

Table 4.6: Coefficient of Variation on Centrality Classes Index

Class	**Centrality Measures (Coefficient of Variations in Per cent)**				
	Degree	Closeness	Betweeness	Eigenvector	Eccentricity
Very High	0	6.10	23.71	38.76	6.11
High	0	3.80	10.41	13.91	3.36
Moderate	0	4.77	15.78	12.66	4.07
Low	0	5.61	34.27	12.87	4.04
Very Low	0	7.43	156.81	25.00	3.22
All	46.49	24.37	115.83	78.87	17.82

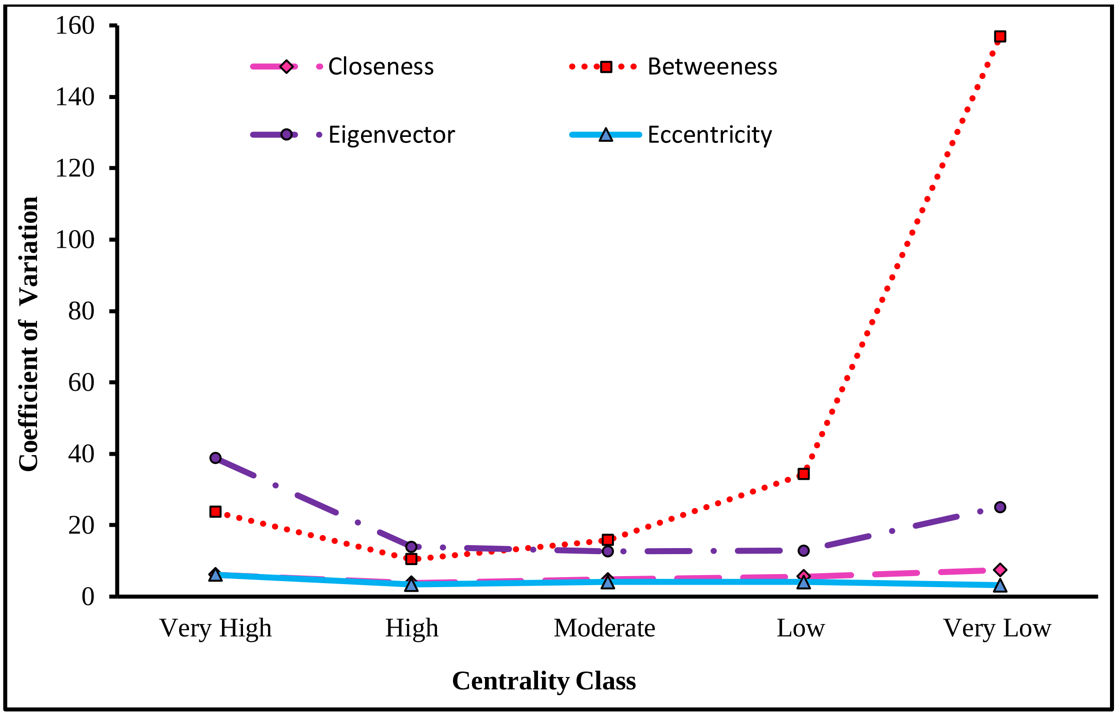

Figure 4.16: Correlation Coefficient of Centrality Class

4.4 Correlation of Centrality Measures

The study is also designed to investigate the correlation between the centrality measures. Here, the study found out that positive correlation exists between the centrality measures such as, degree of centrality, closeness centrality, betweeness centrality, eigenvector and eccentricity centrality measures. In the present network system some of the centrality measures were more associated than the other parameters. The strongest overall correlation among the centrality is experienced between C_C and C_E at r=0.95 followed by C_D and C_V correlation with r=0.77. On the other hand, the weakest positive correlation between centrality measures exists between C_D and C_E, and the correlation is also considered weak even though the correlation is positive (r=0.25). Since the relationship between the centrality measures have positive correlation (0 to +1) when the value of node centrality is increased by one centrality measure, ultimately it is expected to increase node centrality by using other centralities. But, the intensity of the coefficient of correlation differs with the calculated magnitude of '*r*' between the pair (Table 4.7).

Again, centrality measures were classified into two categories on the basis of their principles of centrality -neighborhood-based and shortest global/path-base. Degree of Centrality (C_D) and Eigenvector Centrality (C_V) are measures for neighborhood-based centrality, while Closeness Centrality (C_C), Betweenness centrality (D_B), and Eccentricity (C_E) are known as measures for shortest global/path-based centrality. Thus, the study also examines the degree of associations between these two categories. The lowest correlation was found between C_D (i.e. neighborhood-base/local centrality measure) and C_E (shortest path-base/global centrality measure). As for the correlation index, when the calculated value of global centrality measure increases the local centrality measures may increase with a limited value.

The road network layout within Aizawl district demonstrates varied characteristics amongst centrality measures. These characteristics provide valuable insights into the connections among these particular vertices. The parameters employed for distinct central measures reveal varying degrees of correlation among them.

Table 4.7: Correlation Coefficient of Centrality Measures Index

Degree of Measures	Degree (C_D)	Eccentricity (C_E)	Closeness (C_C)	Betweeness (C_B)	Eigenvector (C_V)
Degree (C_D)	1.00				
Eccentricity (C_E)	0.25	1.00			
Closeness (C_C)	0.36	0.95	1.00		
Betweeness (C_B)	0.56	0.53	0.59	1.00	
Eigenvector (C_V)	0.77	0.37	0.56	0.48	1.00

4.5 Conclusion

The study identified that the combination of geographical, historical, economic and social factors are important factors for the existence of road networks which in turn is very crucial for the location of node centrality. It is found that the topologicl structure of road network in the study area is centralised network type as indicated by the 'Hub and Spoke'[14] organization model which is a part of centralized network. The study found that Aizawl is the central hub of the network in the study area and offers a full array of services for the whole network. On the other hand, Sialsuk, Seling and Keifang/Saitual vertices are acting as secondary establishments or hubs, offering a limited range of services for the low scoring nodes. In terms of interaction, the hubs and spokes network system is a more efficient and facilitates optimum use of transport resources in the network. The networking system allows a maximum utilisation of hubs and spokes in a uniform way. So, the hub and spoke organisation is an efficient mechanism for administration, distribution planning, providing high-frequency services and monitoring etc.

The study revealed that spatial distribution of nodes centrality is significantly determined by geographic centrality. Node centrality explains the nature of geographical centrality namely, global, local, isolated unit of centrality. All the very high and high centrality value nodes are confined to the central and middle parts of the network. These centrally located settlements are more influential in the flow of information through the network system. The location and position of node centrality play different roles in the dissemination of information in road transport networks. The results demonstrate the significance of centrality measures for critical probability of nodes with respect to the location and position of the node in the network. The models also demonstrate the efficiency and velocity of nodes for information dissemination on the basis of Euclidian distance (not dependent on geographic distance). On the other hand, both the location and position of node centrality determine heterogeneity and diversity of spatial/geographical centrality. But, the problem of the study lies in the fact that the study only adopted matrix distance to obtain relatively general results and facilitate its application. At some point geographical constraints and its attributes form complex geographical factors to control the network system e.g., topography, population and economy etc.

In general, the vertices with high degree are more influential and have greater impact on the surrounding vertices. Aizawl is considered as an eigencentre which is surrounded by high value nodes like Sairang, Sihphir, Tuirial, Hualngohmun and Samtlang (Figure 4.13).

The nature of the topological structure is varied amongst the global and local centrality measures. Especially for global centrality measures like Closeness centrality, Betweeness centrality and Ecentricity (i.e. very high and high class) are distributed in a longitudinal fashion which is primarily influenced by the arrangement of the road segments. Geographical factors play a critical role in the segmentation of the road network and are associated with the spatial distribution of nodes or their alignment.

In the context of local centrality measures like C_D and C_V, the critical nodes are distributed in compact forms and confined to a limited segment of the network. They are quantified as hubs or distribution center of the networks. The analysis found out that the low and very low degree classes are distributed in an irregular fashion, which points to the fact that the low scoring nodes are diverse in nature due to the influence of local and global factors.

The correlation coefficient of centrality measures specifies the quality and quantity of relationship between the centrality measures. Between the centrality measures, local centrality measures are more associated than global centrality measures. Table 5.8 shows that all centrality measures have positive relationship. But some of the centrality measures are more associated than others. The highest correlation coefficient value is observed between closeness centrality and degree of eccentricity which indicates the two parameters are considered as global measures and almost identical relationship. On the other hand the lowest degree of correlation was observed between degree of centrality and degree of eccentricity.

Analysis of Coeeficient of variation (CV) shows that those nodes falling under low centrality categories experience greater diversity than those nodes under high centrality classes. This means that higher inequality exists within the lower classes, which is a consequence of the structural topology of the network.

The study identified that important nodes and spatial distribution of nodes in a systematic way. The study showed that the different concepts and measures of centrality are appropriate for identification and analysis of network centrality.

CHAPTER V

Spatial Variations of Socio-Economic Development

5.1 Introduction

Development is dynamic concept, and different people use it to mean different things. Literally, development refers to the process of change from a lower to a higher stage particularly considering some parameters some parameters. According to Drewnowski (1966), “development is a process of qualitative change and quantitative growth of the social and economic reality which we can call either society or economy. Because of the close inter-relationship of economic and social elements no ‘purely’ social or ‘purely’ economic development is possible. Consequently, it is better not to speak of social development separately and vice versa”. Development is a positive concept aimed at improving the quality of life by reducing regional imbalances, minimizing rural-urban differences, and meeting basic necessities for all people.

The process of socio-economic development is a complicated subject matter to be expressed in the form of a rigid theoretical framework. This implies that socio-economic development cannot be explained by mere speculations because it is not possible to determine the processes if there is no actual experience of the factors involved. These factors can only be recognised by exploring the real world knowledge of socio-economic conditions and processes (Pajestka, 1973). The improvement of socio-economic conditions involves some degree of structural changes.

The term socio-economic was an umbrella term that was often used to determine the current status of society or smaller units of population (UNCE, 2019). The term itself explains the relationship between society and the economy. The concept strictly points to the social, economic, cultural and political aspects necessary for society’s transformation at various developmental levels. It means that socio-economic is a dynamic concept and measurable, and reflects the status of the community, society, or nation. But, the attributes and parameters may vary according to the adopted objectives. It is also evident that the idea of socio-economic development is inextricably linked to the idea of social and economic advancement of the society (Filgueira and Filgueira 2001). Thus, the definition of socio-economic development encompasses any improvement of material for the wellbeing of the people that leads to an enhancement of the quality of life.

Socio-economic development can be traced through multiple approaches of study. The concept may change with the approach used and the objectives adopted. Primarily in the subject of geography, the idea of socio-economic development is mostly similar to other subjects. The only difference that is seen in geography is that the conceptions of socio-economic development are based on space and time. Geographically, socio-economic development can be examined from three sources. Firstly, the basic level of analysis simply suggests an understanding of the conditions and quality of life of people. Secondly, the analysis considers the distribution of socio-economic development with reference to time by understanding the changes within the area. The final analysis is less normative based, focusing on areal-differentiation and inherent complexities in socio-economic development, linked to associated factors. It also seeks to comprehend transformations in socio-economic development within specific time and space.

So a lucid examination of the factors of socio-economic development and its attributes is imperative in order to fulfill the research objectives. Both quantitative and qualitative approaches are adopted to examine the socio-economic processes and their spatial variations in Aizawl district. In view of the above argument, the study carefully chalked out the factors of socio-economic development and its attributes towards computing significant results in this study. In addition, the current chapter seeks to understand the spatio-temporal variations of socio-economic development.

5.2 Spatio-temporal variations of socio-economic development

Five important parameters of socio-economic development have been selected in this study. Population growth, sex ratio, crude literacy rate, dependency ratio and agricultural working population are the parameters of socio-economic development that have been considered in this study. The study utilized a classification method to analyze the levels of socio-economic development in the study area. Further, the study adopted statistical mapping and graphical techniques are employed to simplify the results.

5.2.1 Population Growth

The analysis of population change over a specific area has significance in that it helps us in understanding the demographic trends, dynamic character and associated factors of socio-economic as “Population variables are both determinants and consequence of the development processes” (Census, 2011). As far as development issues are concerned the dynamics of population plays crucial and centric roles (Mookherjee, 2009). The change in population, both in numbers and composition, bring in an identical effect on society (Prabhakar, 2001). Thus, population growth can be considered as one of the primary determinants of socio-economic development in a region.

The annual increase in population from 2001 to 2011 census in Aizawl district reached 2.4 per cent, which is slightly higher than 2.2 percent compared to the state’s annual increase in population. Aizawl district alone contributes to 36.68 per cent of the state’s population according to the 2011 census with 73.38 per cent of the district’s population residing within the Aizawl municipal area. The total population of Aizawl district in 2001 was 3,23,632 persons, which increased to 4,00,208 persons in the 2011 census. During 2002 – 2011, the grow rate of Aizawl district was 23.66 per cent as against 22.78 per cent for the state of Mizoram. During the decade the population growth rate ranged from 110.8 per cent in Mualmam (highest) to -33.9 per cent in Thingsat (lowest). For further analysis the calculated values were categorised into – Very High, High, Moderate, Low and Negative population growth.

(a) Very High Population Growth (>30 per cent): The entire study area includes 83 towns and villages of which about 19.28 per cent (16 villages) experienced high population growth. Interestingly, in Mualmam village the population grew exponentially from 2001 to 2011, securing the highest population growth of 110.98 per cent. This is followed by Lailak, North Khawdungsei, Tawizo and others (Table 5.1). The distribution pattern shows an uneven distribution of population growth, but the northern tips of the study area like Mauchar, Palsang, North Thinghmun, Khawpuar and Zohmun have also experienced very high population growth. They are found in the villages connected by the main road and border villages that exhibits a combination of road connectivity, location advantages (mainly on the bridge line), proximity to an urban area and developmental activity (Figure 5.1). For instance Falkawn is in close proximity to Aizawl and houses the Zoram Medical College (ZMC), while Tuirial and Mualmam are considered as having locational advantages in the network.

(b) High Population Growth (20 – 30 per cent): High population growth occured in 10.84 per cent of the total settlements. Aizawl city recorded a population growth with 28.55 per cent. Interestingly, despite the influx of population from rural areas, Aizawl falls under the high population growth category mainly because the base population was already high. The Aizawl municipal area exerts a significant degree of pull and has therefore resulted into a rise of population in the surrounding areas. As a result, a significant growth rate of population was observed in adjacent villages such as Mutthi and Samtlang. Sakawrdai village in the northern part of the study area has also withnessed high population growth due to its strategic location as a notable halting point and an important market centre in the north. In spite of their isolated location in terms of accessibility, villages like Chhanchhuahna Khawpui, Maite, North Lungpher, Daido, Luangpawn have all experienced high decadal growth of population between 2001 and 2011 (Figure 5.1).

(c) Moderate Population Growth (10 – 20 per cent): Out of the 83 settlements considered in the study, 26 towns and villages come under this category. They account for 31.33 per cent of the total number of settlements. In this class, the highest population growth was noticed in Thanglailung village, followed by Thingsul Tlangnuam, Vaitin and Melriat (Table 5.1 & Annexure-II). The notified towns of Sairang and Saitual also registered moderate population growth rate. Thingsul Tlangnuam, Dilkhan, Phullen, Khanpui villages are the important halting points in this category. The population growth pattern suggested that the population growth in the moderate class is characterised by the natural growth of population owing to an increase in life expectancy. The distribution pattern shows that settlements with moderate population growth are directly associated (linked by road connectivity) with settlements that are characterised by low and negative population growth (Figure 5.1).

(d) Low Population Growth (0.1 - 10 per cent)*:* There are 20 settlements having low population growth in Aizawl district accounting for 24.1 per cent of the total settlements. In this class, the least population growth was seen in Sateek with 0.47 per cent of decadal growth followed by Aibawk and Samlukhai. Interestingly, the southern region has shown lower population growth rate in comparison to the northern part. Figure 5.1 shows that low population growth is mostly confined to the southern, northern and central parts of the study area.

(e) Negative Population Growth (< 0 per cent): Negative population growth was observed in 12 settlements which constitute about 14.5 per cent of the total settlements. Over the decade Seling village witnessed the sharpest decline of population with a -20.31 per cent decrease during 2001 -2011, followed by Chawilung and Sialsuk which experienced more than -10 per cent of population decline. Significant negative population change was found in north and north eastern portions of the district. Half of the villages under negative population growth category is found in the northern part of the study area (Figure 5.1). It appears that the decline of population in the region is associated with three factors – economic, mobility and social. Lack of employment opportunities among the rural youth and the impediments of rural-economic development may have compelled rural youth to venture out of their hometowns to search for better job opportunities elsewhere, especially in urban areas. The second factor is related to mobility inferred by the development of road network. The third factor may include social determinants like birth control and family planning. Successful implementation of family planning programmes and wide adoption of birth control methods in rural areas have also led to a downturn in natural population growth over time.

In the study area, the high increase in population growth was observed in two geographical regions. The middle part of the region has experienced a high growth rate due to the urban population explosion and its associated factors. Secondly, the isolated villages of the northern region have witnessed high population growth due to the influx of population from neighbouring states, and better access to medical facilities has helped with natural growth by lowering the mortality rate and improving the longevity of life. The magnitude of population growth is higher in the middle region, which is triggered by urbanisation in Aizawl and its surrounding areas. Meanwhile, the southern and northeastern parts of the study area experienced the least population growth and negative population growth (Figure 5.1). Negative population growth in the region is mainly attributed to social and economic factors, especially severe out-migration and low natural population growth. Thus, the study identified that both natural and actual population growth have significant implications on population change in Aizawl district.

Table 5.1: Classification of Settlements on the Basis of Population Growth, Aizawl District, 2001-2011

Class (in Percent)	No. of Village	Percentage	Name of Village
Very High (>30)	16	19.28	Mualmam, Lailak, North Khawdungsei, Tawizo, Mauchar, Palsang, Tuirial, North Thinghmun, Khawpuar, Zohmun, Muthi, North Lungleng, Sunhluchhip, Falkawn, Chamring, Lamherh
High (20 – 30)	9	10.84	Aizawl, Chhanchhuahnakhawpui, Maite, Hmuifang, North Lungpher, Sakawrdai, Daido, Luangpawn, Samtlang
Moderate (10 – 20)	26	31.33	Thanglailung, Thingsultlangnuam, Vaitin, Melriat, Zawngin, NE. Tlangnuam, Muallungthu, Dilkhan, Thingsat, North Serzawl, Sailutar, Sesawng, Sumsuih, Khanpui, Hualngohmun, Mualpheng, Pehlawn, Phullen, South Maubuang, New Vervek, Sairang, Saitual_Keifang, North Khawlek, Tualbung, Lenchim, Tachhip
Low (0 – 10)	20	24.1	Lungsum, Kelsih, Sihphir, Phulpui, Khawlian, Rulchawm, Phulmawi, Tlungvel, Sailam, East Phaileng, Ruallung, Thiak, Lamchhip, Buhban, Lungsei, Sawleng, Khawruhlian, Samlukhai, Aibawk, Sateek
Negative (< 0)	12	14.46	Suangpuilawn, Phuaibuang, Sihfa, Thingsulthliah, Vanbawng, Darlawn, Ratu, Hmunnghak, Kepran, Sialsuk, Chawilung, Seling

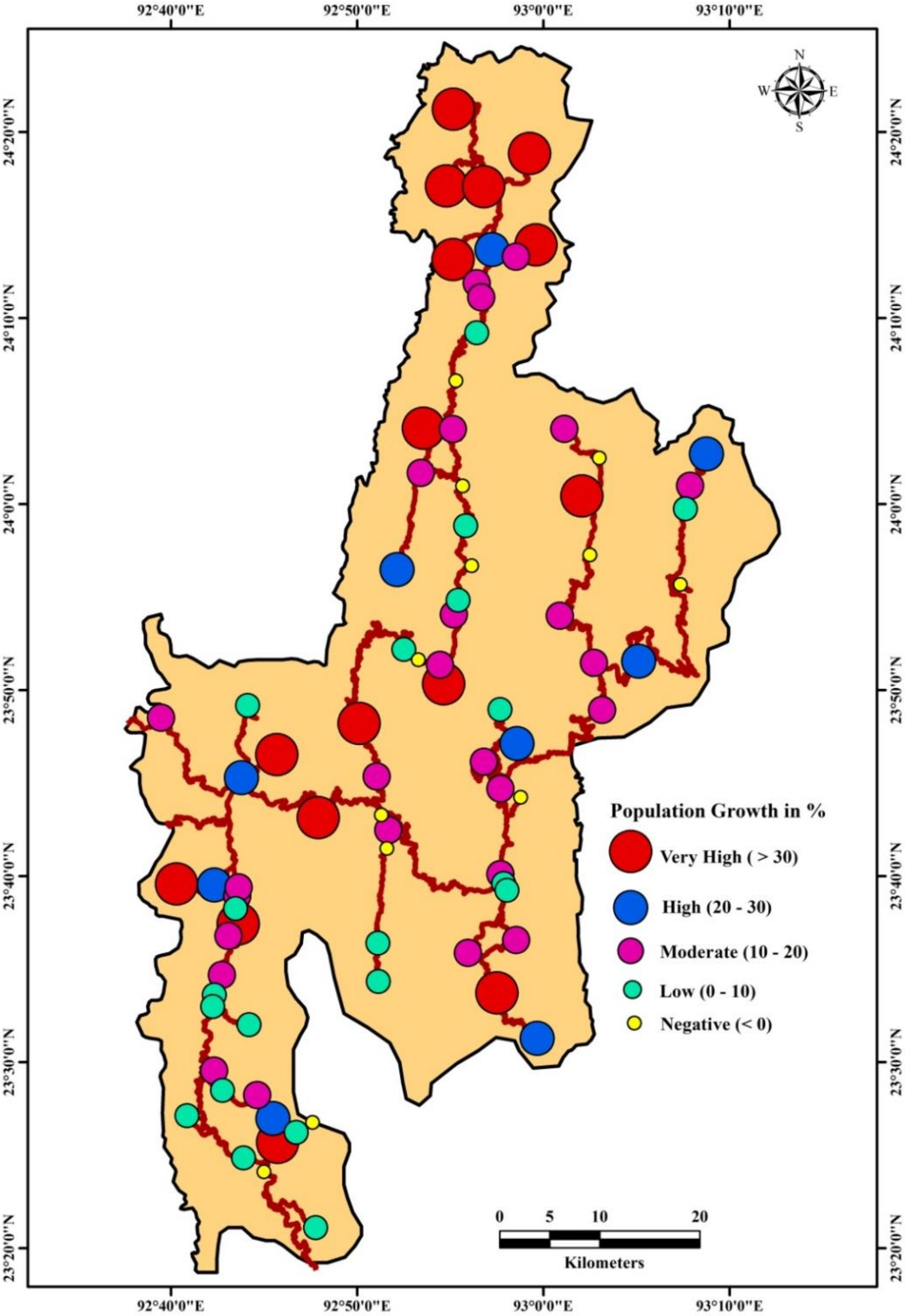

Figure 5.1: Decadal Change of Population Growth, 2001 - 2011

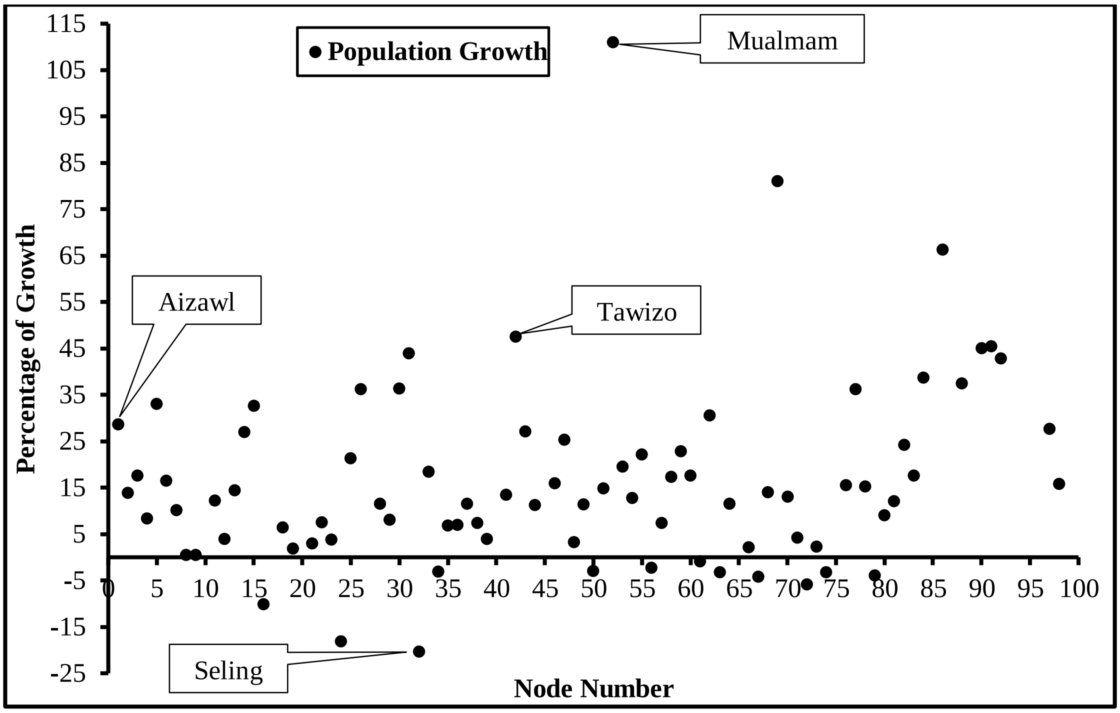

Figure 5.2: Changes in Population Growth, 2001 - 2011

5.2.2 Level of Literacy Rate

Literacy enables an individual to achieve their goals through enriching knowledge and potential. It is crucial for innovation, modernization, mobility, and adaptation to change. Accordingly, "Literacy rates and educational attainment are considered to be key variables affecting demographic indicators like fertility, mortality (especially infant mortality) rate and migration" (Census 2011). Therefore, literacy rate is considered as a reliable measure of socio-cultural and economic advancement and development. Moreover literacy speeds up the rate of socio-economic transformation that is ought to take place in society.

Again, towns and villages in Aizawl district were classified into classes – Very High (> 84 per cent), High (81 - 84 per cent), Moderate (78 – 81 per cent), Moderately Low (75 - 78 per cent) and Low (<75 per cent). Comparing it with other parts of the country, the crude literacy rate of 91.33 per cent in Mizoram is relatively high in comparison to the national average of 74.04 per cent as per the records of the 2011 Census. Aizawl district has a literacy rate of 85.91 per which is slightly lower than the state average. In Aizawl district the average crude literacy rate is quite high and therefore offers more opportunities than other districts.

(a) Very High Literacy Rate (> 84 per cent): Very High percentage of crude literacy rate was found in 23 villages (27.71 per cent). Samtlang village has the highest literacy rate with 88.86 per cent followed by Seling, Aizawl, Thingsul Tlangnuam and Tuirial ll of which are found in the central part of the region. More than two-thirds of settlements in this category are confined to the middle part of the district. Other villages in the Very High category like Sialsuk, Chawilung and Lamchhip are found in the southern tips of the region (Table 5.2). No villages in the northern and eastern parts of the region are found in this category. This implies that the central and southern portions of the study areas are more literate than other places of the study area. Interestingly, almost all the villages under this category are surrounded by villages having high literacy rates (Figure 5.3).

(b) High Literacy Rate (81 - 84 per cent): The distribution pattern of settlements under High literacy rate shows that they lie adjacent to the Very High category ones. High literacy rates were observed in 28 towns and villages which accounts for 33.73 per cent of the total number of village. Among them, Kelsih village ranks first and is followed by East Phaileng and Tlungvel. Sailam with 81.10 per cent of literacy rate ranks last in this category (Table 5.2). In this class Saitual town, Darlawn and Sakawrdai villages are important junctions that are bestowed with locational advantages which in turn may be considered as being more conducive for the spread of literacy awareness, better access to educational facilities, and greater accessibility. Figure 5.3 shows that the southern and middle parts of the region are completely dominated by high literacy rate.

(c) Moderate Literacy Rate (78 – 81 per cent): The percentage share of Moderate literacy was 18.07 per cent of the total villages. In this category Maite village with 80.68 per cent recorded the highest literacy rate and is followed by Tawizo, NE Tlangnuam, Phuaibuang and Hmunnghak, while North Khawlek registered the lowest crude literacy rate (Table 5.2). Towns and villages under this category are mostly found in the north and north-eastern parts of the study area (Figure 5.3). Villages like Ratu, Sesawng, Phuaibuang and Khawlian have relatively larger populations and also have well established educational institutions unlike other villages falling in the same class.

(d) Moderately Low Literacy Rate (75 - 78 per cent): Eleven villages were categorized under moderately low literacy. They constitute 13.25 per cent. North Thinghmun with 78.58 per cent occupies the first rank in this category. Village lying in the northern tips like Vaitin, Zohmun, Mauchar and Khawpuar are found in this category. Generally, low literacy villages are found in the northern flank of the study area bordering Manipur (Figure 5.3). In terms of geographical accessibility this region is one of the remotest in the district. Lack of infrastructure, low level of adult literacy, and remote location contribute to the discouraging pattern/rate of literacy.

(e) Low Literacy Rate (<75 per cent): Villages with less than 75 per cent of crude literacy rates are clubbed in the low literacy rate class. Lamherh (74.92 per cent), Thingsat, Zawngin, Lailak, New Vervek and Sunhluchhip all experienced the least crude literacy level in the study area. This category accounts for 7.23 per cent of the total villages (Table 5.2). These villages are scattered over the mid-north and north-eastern parts of the area. The low literacy rates may be attributed to the rapid growth of population coupled with lack of infrastructure, lack of awareness and the late introduction of education in these areas. The improvement of crude literacy rate is rather gradual and therefore adult literacy rate is comparatively low in this region.

Despite varying levels of literacy, Aizawl district towns and villages have consistent characteristics and a similar distribution pattern. Interestingly the towns and villages with very high and high category are concentrated in the middle and southern parts of Aizawl district (Figure 5.3). It appears that the settlements with high and very high like Aizawl, Seling, Saitual, Darlawn, and Sakawrdai have trickledown effect for promoting literacy awareness, improving access to educational facilities, and enhancing education in general. The distribution pattern reveals that the areas with high literacy rates are close to those with very high categories. The map (Figure 5.4) shows that the level of literacy declines towards the northern and north-eastern parts of the study area. It appears that moderately low and low literacy settlements experience marginally low literacy rates due to its stagnant adult literacy levels and education being given importance only when education is given value as an occupational prerequisite. Geographical distribution of literacy shows that the southern and middle parts of the area are more literate due to the early development of education, political and historical reasons, and effort of the Christian Missionaries, urbanization, and geographical proximity to urban areas. The villages that are located in the northern and north-eastern regions of the area have higher illiterate population which may be attributed to their peripheral location and limited availability of educational institutions. Factors such as location, proximity to urban centers, early development, attitude of villagers towards education, and levels of adult education are some of the more influential causes. But, each of these factors holds different levels of significance towards the difference in levels of crude literacy rate in their specificity to a category or village.

Table 5.2: Classification of Settlements on the Basis of Literacy Rate, Aizawl District, 2011

Class (in Percent)	No. of Village	Percentage	Name of Village
Very High (>84)	23	27.71	Samtlang, Seling, Aizawl, Thingsultlangnuam, Hualngohmun, Melriat, Sateek, Thanglailung, Tuirial, Aibawk, Falkawn, Sialsuk, Tachhip, Khawruhlian, Chawilung, Ruallung, Phullen, Sihphir, Sihfa, Khanpui, Dilkhan, Lamchhip, Buhban
High (81 - 84)	28	33.73	Kelsih, East Phaileng, Tlungvel, Sawleng, Thingsulthliah, Saitual/Keifang, Rulchawm, Mualmam, Muallungthu,Thiak, Sakawrdai, Sumsuih, Lungsei, Kepran, Phulpui, Phulmawi, Vanbawng, Muthi, Mualpheng, Lenchim, South Maubuang, Sairang, Daido, Suangpuilawn, North Lungleng, Pehlawn, Darlawn, Sailam
Moderate (78 - 81)	15	18.07	Maite, Tawizo, NE.Tlangnuam, Phuaibuang, Hmunnghak, Samlukhai, Tualbung, Hmuifang, Sesawng, North Khawdungsei, Khawlian, Palsang, Ratu, North Thinghmun, North Khawlek
Moderately Low (75-78)	11	13.25	Sailutar, Vaitin, Zohmun, Chamring, Mauchar, Luangpawn, Khawpuar, Chhanchhuahnakhawpui, Lungsum, North Lungpher, North Serzawl
Low (<75)	6	7.23	Lamherh, Thingsat, Zawngin, Lailak, New Vervek, Sunhluchhip

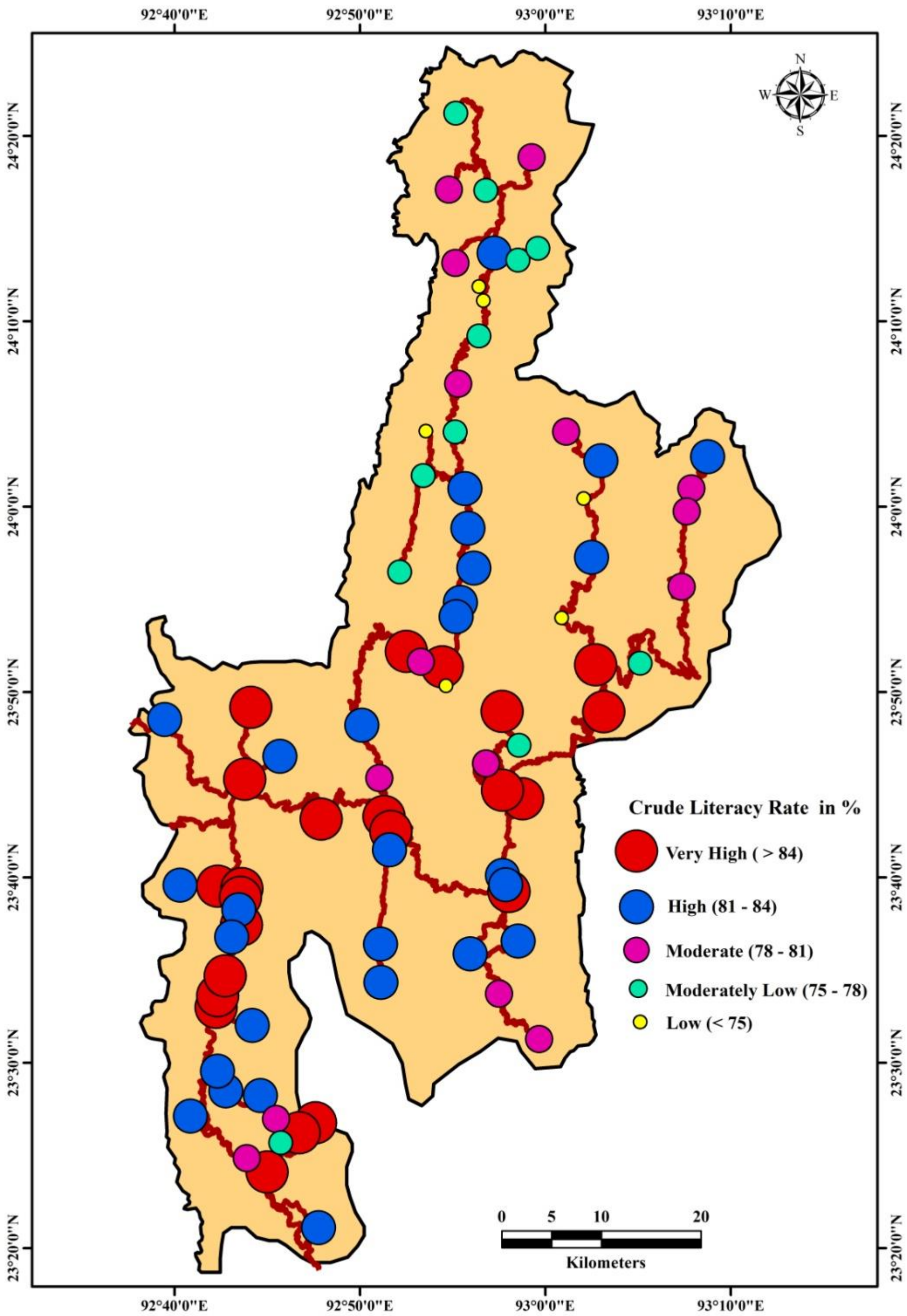

Figure 5.3: Crude Literacy Rate, 2011

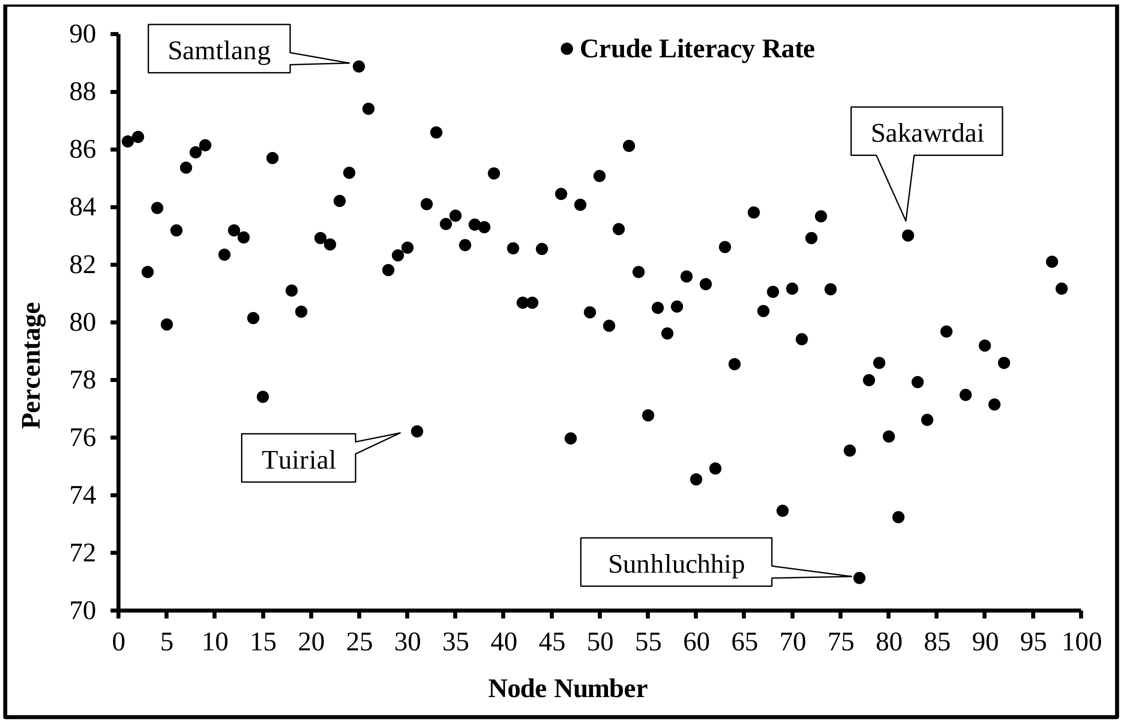

Figure 5.4: Graphical Representation of Crude Literacy Rate, 2011

5.2.3 Sex Ratio

Sex ratio is an important indicator of socio-economic development. "Changes in sex composition largely reflect the underlying socio-economic and cultural patterns of a society in different ways" (Census, 2001). In less developed countries, Sex ratio is considerably lower and has always remained unfavorable towards females due to the socio-cultural ethos, traditional beliefs and religious factors etc. On the other hand, the conception of sex has been changing in response to the socio-economic development of the region (Chandna, 2010).

The decadal growth of sex ratio in Aizawl district showed a positive increase of about 0.25 per cent growth during 2001-2011 Census years. In terms of absolute figures, the sex ratio increased from 952 to 1009 during the same period. In 2011 North East Tlangnuam village recorded the highest sex ratio with 1069 and the lowest sex ratio was witnessed in North Serzawl with 693 females for one thousand males. The study area was classified into five classesof decadal growth in Sex ratio - High, Moderate, Low, Low Negative and Highly Negative. A class-wise analysis of sex ratio brings out the spatial changes and composition of sex in the study area.

(a) High (>10 per cent): High decadal growth in Sex ratio was observed in eight villages that constitute 10.84 per cent of the total number of village (Table 5.3). During 2001-2011 Seling village showed a highly encouraging growth of female population of 66.27 per cent. Notable rates of increase were also recorded in Sairang town, Thingsulthliah and Lailak villages. Geographically, the sex ratio is higher in the middle and north-eastern parts of the district (Figure 5.5). It appears that male dominanted out-migration to urban areas and inter-state migration of female population from states have positive impact on high increase in female population.

(b) Moderate (5 – 10 per cent): In Aizawl district, a moderate increase in sex ratio was observed in 15 villages which accounts for 18.17 per cent of the total number of villages. In this category Sawleng village experienced the highest increase of female population with a 0.09 per cent increase. Samtlang, Saitual/Keifang and North Khawlek experienced more than 8 per cent of female population increase in the study period. Darlawn and Aizawl are the more important urban centres in this category. Figure 5.5 shows the spatial distribution of towns and villages with moderate increase of female population in Aizawl and also illustrates that nearly two-thirds of the settlements under moderate category are concentrated in the middle and southern parts of the study area.

(c) Low (0.0 – 5 per cent): This category observed minimal improvements in sex ratio during 2001 - 2011. Out of the 83 villages, the change in sex ratio was low in 25 villages with accounted 30.12 per cent of total. In Aizawl district Kelsih recorded the least increase in female population. It is observed that villages with low increase in sex ratio form an irregular pattern of distribution (Figure 5.5).

(d) Negative (0.0 – -5.00 per cent): The ratio of female population against male population showed an alarming pattern in 22 villages of the study area wherein the sex ratio showed low negative growth. This constitutes 26.51 per cent of the total villages. Rulchawm, East Pahileng, New Vervek, Mualpheng, Ratu, North Khawdungsei, Lungsei and Sumsuih villages reordered less than one per cent of decline in female population (Table 5.3).

(e) Highly Negative (< -5 per cent): This category represents the areas where female population had significantly declined during 2001 - 2011. This category constitutes 14.46 per cent of the total villages. The sharpest decline in female population in Aizawl district was recorded in Khawpuar village with a -15.47 per cent decline, or numerically from 1216 to 901. Khawpuar, North Serzawl, Thingsat, Lungsum and Mauchar villages are found in the northern part of the study area. Buhban and Phulmawi - villages that are located in the middle part and those in the south - Lamchhip, Samlukhai and Chawilung villages experienced a decline in female population against male numbers in 2011 census (Figure 5.5).

In Aizawl district, a numerical increase of females over males was observed in 49 towns and villages. However, a negative increase in female population was observed in 41 per cent of all villages and towns. The female population was significantly improved in the middle part of the district; the pace of change in the sex ratio usually decreases towards the north and south directions. The northern and southern tips of the study area experienced negative changes in sex ratio (Figure 5.5). Urbanisation had greatly pulled out male working population from rural areas and thereby brought about a change in the spatial variation of the sex ratio, consequently increasing the sex ratio in the rural areas. There are two possible explanations for the female population’s low rate of growth in the low sex ratio class. Firstly, excessive migration of female population from rural to urban areas has resulted in the decrease of female population in rural areas. Secondly, negligence of the reproductive period and the traditional practice of inter-village marriages have also led to a low increase of female population in some parts of the area. The study also reveals that sex ratio in this category is primarily expressed by natural sources of sex ratio. The figure also reveals that the declining trend of female populations is more prominent in the northern and southern parts of the region. There was a decline in female population in these villages; unemployment and related issues induced rural-urban migration, which then resulted in sex-selective migration to urban areas in search of affordable income and better living standards. Marriage migration is also a significant cause of the decline of the female population in rural areas.

Table 5.3: Classification of Settlements on the Basis of Change in Sex Ratio, Aizawl District, 2001-2011

Class (in Percentage)	No. of Village	Percentage	Name of Village
High (>10)	9	10.84	Seling, Sairang, Thingsulthliah, Lailak, Pehlawn, Lamherh, Falkawn, Vanbawng, Daido
Moderate (5 – 10)	15	18.07	Sawleng, Samtlang, Saitual_Keifang, North Khawlek, Muallungthu, Mualmam, Zawngin, Aibawk, Darlawn, Aizawl, Maite, Tualbung, Tuirial, South Maubuang, Khawruhlian
Low (0 – 5)	25	30.12	Sesawng, Tlungvel, Sihfa, Sihphir, Hualngohmun, Sailutar, Suangpuilawn, Muthi, Sunhluchhip, Khawlian, Sateek, North Lungpher, Thingsultlangnuam, Thiak, Tachhip, Phuaibuang, Lenchim, Khanpui, Melriat, Hmunnghak, Ruallung, Vaitin, Dilkhan, Hmuifang, Kelsih
Negative (0 - -5)	22	26.51	Sakawrdai, Rulchawm, East Phaileng, New Vervek, Mualpheng, Ratu, Phullen, North Khawdungsei, Lungsei, Sumsuih, Tawizo, Sialsuk, North Lungleng, Sailam, Chamring, Chhanchhuahna Khawpui, Zohmun, North Thinghmun, Thanglailung, Phulpui, Palsang, Luangpawn
Highly Negative (≤ -5)	12	14.46	Mauchar, Kepran, NE. Tlangnuam, Chawilung, Samlukhai, Buhban, Phulmawi, Lungsum, Thingsat, Lamchhip, North Serzawl, Khawpuar

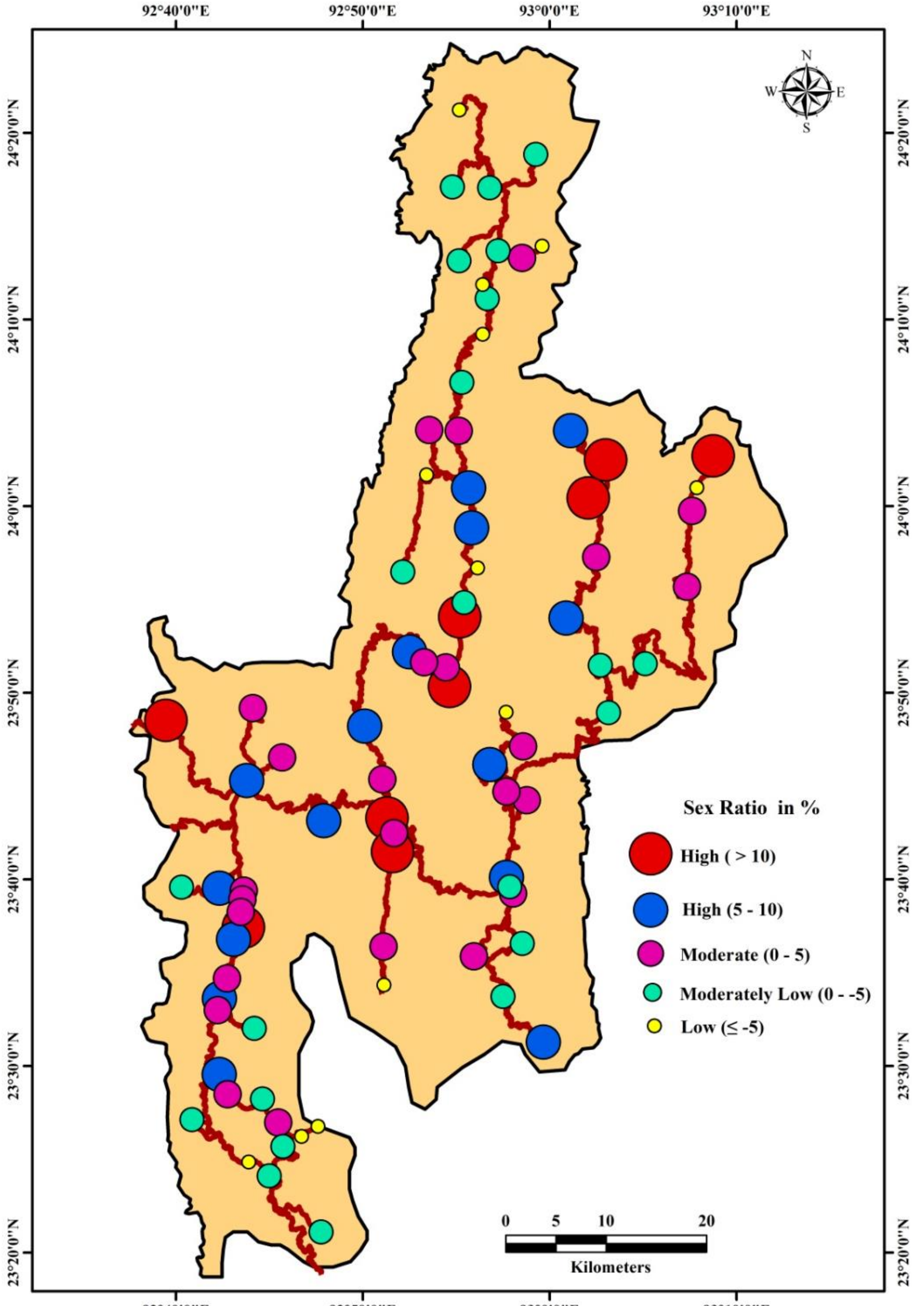

Figure 5.5: Decadal Changes of Sex Ratio, 2001 - 2011

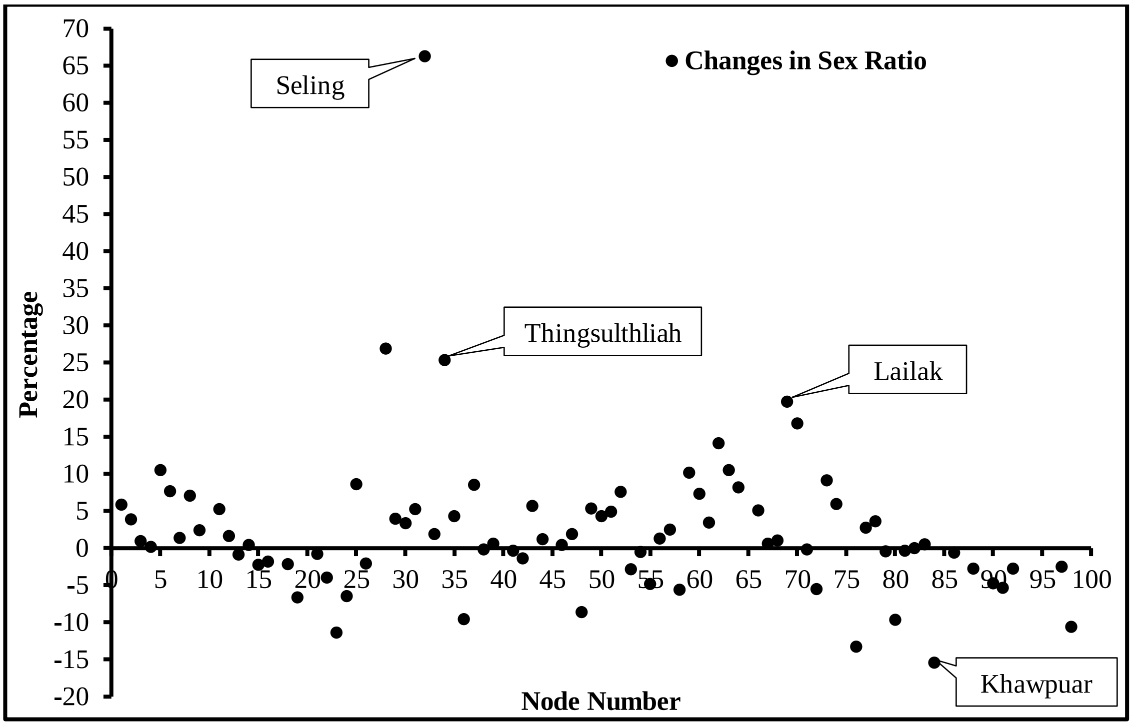

Figure 5.6: Changes in Sex Ratio, 2001 to 2011

5.2.4 Changes in Dependency Ratio

Any change in population structure brings about change in the composition of the workforce and it is likely to have significant implications on the levels of socio-economic development within the region. "It has been widely accepted that the structure of population of a country can have significant contribution towards its growth effort" (Bidisha *et al.*, 2020). It is argued that lower dependency ratio "allows for higher savings and investment in physical and human capital, and thus contributes to sustained economic growth" (Joe *et al.*, 2015). Here, the study assesses the spatial-temporal changes of dependency ratio based micro perspectives in order to highlight the shifting nature of age structure and its interconnected impact on the socio-economic development of the region. An area with a declining trend indicates an improvement in the dependency ratio which creates optimism for socio-economic development while areas with positive trends imply an addition of persons to the dependent population which becomes a source of economic burden on the working population.

In general, the dependency ratio of Aizawl district showed an increasing trend. It increased from 100.85 per cent to 128.98 per cent between the 2001 and 2011 Censuses. It is observed that change in dependency ratio in the study area is characterised by an uneven pattern throughout the area. The study classifies the variations into five categories which are as follows - Decline, Steady Increase, Moderate Increase, High Increase and Very High Increase classes.

(a) Decline (≤ 0 per cent): Settlements in this category experienced declining dependent population. Out of the total eight settlements, 9.64 per cent of the total towns and villages experienced decreasing trend in dependency ratio (Table 5.4). Dilkhan village experienced a considerable decline in dependency ratio and registered about -39.29 per cent decrease. From the eastern part of the study area Vanbawng, Suangpuilawn, Zawngin and Daido are noticeable. Sailutar (-12.77) and Zawngin (-10.94) recorded substantial rates of decline in the decade of the 2001 and 2011 Censuses. In the middle Dilkhan, Mualpheng and North Lungpher experienced minimal decline in dependency ratio. Spatial distribution shows that the eastern and north-eastern portions of the study area experienced a considerable decline in dependency ratio compared to the villages lying in the north, south and middle parts of the study area (Fig. 5.7).

(b) Steady Increase (0 - 30 per cent): Out of the 83 villages under the study area, 28 villages (33.37 per cent) fall under the steady increase category. Rulchawm village with 2.37 per cent experience the least degree of increase in dependency ratio and was followed by Seling, Aizawl and Hualngomhun with 14.90 per cent increased (Table 5.4). Interestingly, an increase in dependency ratio is observed in the interior and more rural areas which may be attributed to the out-migration ofrural youth, particularly to urban areas and also to surrounding villages in their quest to seek better job opportunities and access better education. A number of villages - Tuirial, Dilkhan, Khanpui and Sakawrdai have the potential for increase in employment opportunities due to the diversification of economic activities at this place which is brought about by the improvement in road transportation and the inherent locational advantages of the village. Apart from urbanization, the enhancement of health and the growing aging populations are important controlling factors of employment which is apparent in the Aizawl municipal area and the areas around it. For instance, Muthi, Sihphir, Samltang, Hualngohmun, Melriat, Kelsih, Falkawn and Muallungthu villages are in close proximity to the urban center (i.e. Aizawl) which offers employment avenues of employment for the working population from the surrounding rural areas which ultimately results in a trend of migration from the rural villages to other places of opportunity. Moreover, it appears that establishment of a Medical College at Falkawn village has a significant impact on the change in the dependency ratio of the region (Figure 5.7). The Aizawl municipal area is experiencing a steady increase of dependent population.

(c) Moderate Increase (30 – 60 per cent): The change in dependency rate moderately increased in 21.69 per cent of the total number of villages. This class comprises more than two-thirds of the villages located in the northern and southern halves of the region. Figure 5.7 indicates the distribution of moderate changes of dependency ratio and is mainly confined to the middle, mid-northern and southern parts of the study area. Further, the southern portion forms a compact type of distribution as seen.

(d) High Increase (60 – 90 per cent): Over the Census decade, this category experienced rising numbers in the youth and aged population. About 12.05 per cent (10 villages) of the villages in Aizawl district fall under this category (Table 5.4). High increase in dependency ratio with more than 80 percent was observed in Tawizo, Mualmam and North Khawlek. Figure 5.7 illustrates the spatial arrangement of villages that witnessed high increase and the pattern is characterised by the dispersed type of distribution. A high increase in dependency ratio was observed in remote rural and interior rural areas. It appears that most of the villages are typically being subjected to out-migration of the working population (job seekers) to nearby towns and urban areas where better work opportunities are on offer.

(e) Very High Increase (≥ 90 per cent)*:* This category accounts for 22.89 per cent of the villages of Aizawl district (Table 5.4). An almost exponential increase was witnessed in Phuaibuang with 190.46 per cent and is followed closely by a few like Vaitin and Phulmawi. The other villages with notable increase are that of Mauchar, North Thinghmun, Zohmun and Thingsat from the north. From southern portion only Chamring and Sumsuih experience high increase of dependency ration. The geographical distribution displays a dispersed pattern wherein more than half of the villages are found in the northern half of Aizawl district (Figure 5.7).

In Aizawl district, the annual dependency ratio is computed to have increased by about 2.79 percent per cent between the 2001 and 2011 Censuses. Conversely, the dependent ratio significantly declined in certain rural areas and thus, only 9.67 per cent of the total village experienced a decrease in dependency ratio. More than 90 per cent (75 out of 83 villages) of the total villages recorded an increase in dependency ratio (Table 5.4). Irrespective of their remote location, some of the rural settlements in north-eastern region had a significant reduction in their dependency ratio, but the economic condition of the people is very poor because, the economic activities they are engaged in generate low income returns. The middle part of the region of towns and villages experienced a steady increase in the dependency ratio. A significant increase in dependency ratio was observed in remote rural and interior rural areas of the northern and southern parts of the district (Figure 5.7). Especially in rural area, a change in the dependency ratio is a critical factor in impacting the levels of out-migration amongst the youth population and natural increase of population. In the urban areas, in spite of the urbanisation process, dependency ratio registered a steady increase which may be strongly attributed to the movement of dependent population in urban area. Further, such a significant change in the dependency ratio is also associated with improvements in standard of living which invariably bolsters the average life expectancy in rural areas. An area with a declining trend indicates an improvement in the dependency ratio which creates optimism for socio-economic development while areas with positive trends imply an addition of persons to the dependent population which becomes a source of economic burden on the working population.

Table 5.4: Classification of Settlements on the Basis of Change in Dependency Ratio, Aizawl District, 2001-2011

Class (in Percentage)	No. of Village	Percentage	Name of Village
Decline (≤ 0)	8	9.64	Dilkhan, Vanbawng, Suangpuilawn, Sailutar, Zawngin, Mualpheng, North Lungpher, Daido
Steady Increase (0 – 30)	28	33.73	Rulchawm, Selling, Aizawl, Hualngohmun, Ruallung, Muallungthu, Kelsih, Khawruhlian, Sairang, Samtlang, Sateek, Falkawn, Sawleng, Muthi, Hmunnghak, Thingsultlangnuam, Sialsuk, Thanglailung, Darlawn, Tuirial, Melriat, Khanpui, Phulpui, Saitual/Keifang, Sihphir, Maite, Sakawrdai, North Lungleng
Moderate Increase (30 – 60)	18	21.69	East Phaileng, Luangpawn, Lamchhip, Sihfa, Hmuifang, Lamherh, Samlukhai, North Serzawl, Buhban, ehlawn, Tachhip, Thiak, Ratu, Lungsei, Sesawng, Aibawk, Phullen, New Vervek
High Increase (60 – 90)	10	12.05	Sailam, South Maubuang, Tualbung, North Khawdungsei, Lungsum, Chawilung, Khawpuar, North Khawlek, Mualmam, Tawizo
Very High Increase (≥ 90)	19	22.89	Zohmun, Lailak, NE. Tlangnuam, Chamring, Kepran, Chhanchhuahnakhawpui, Lenchim, Palsang, Sumsuih, Thingsulthliah, Tlungvel, Khawlian, Sunhluchhip, Thingsat, North Thinghmun, Mauchar, Phulmawi, Vaitin, Phuaibuang

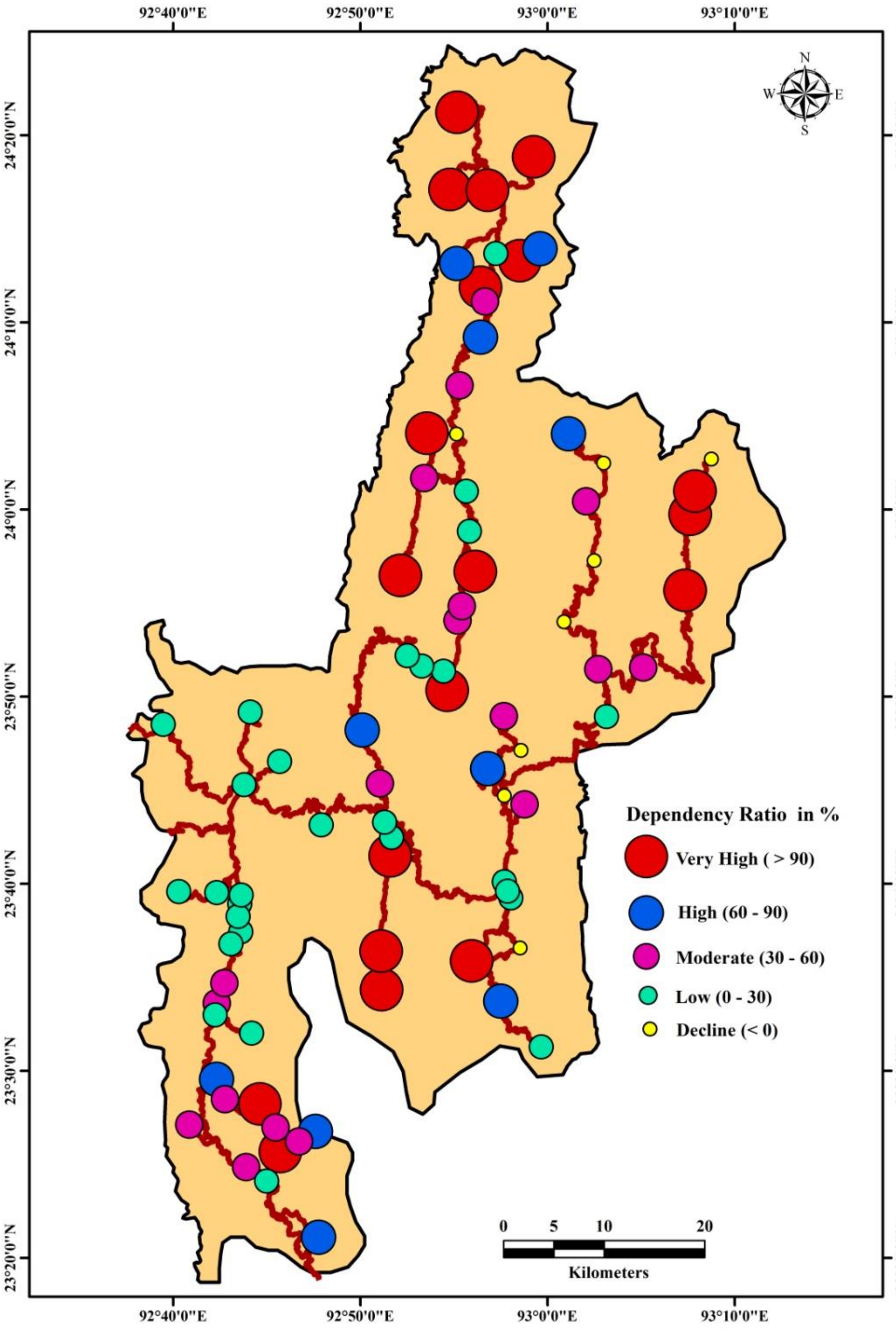

Figure 5.7: Decadal Changes of Dependency Ratio, 2001 - 2011

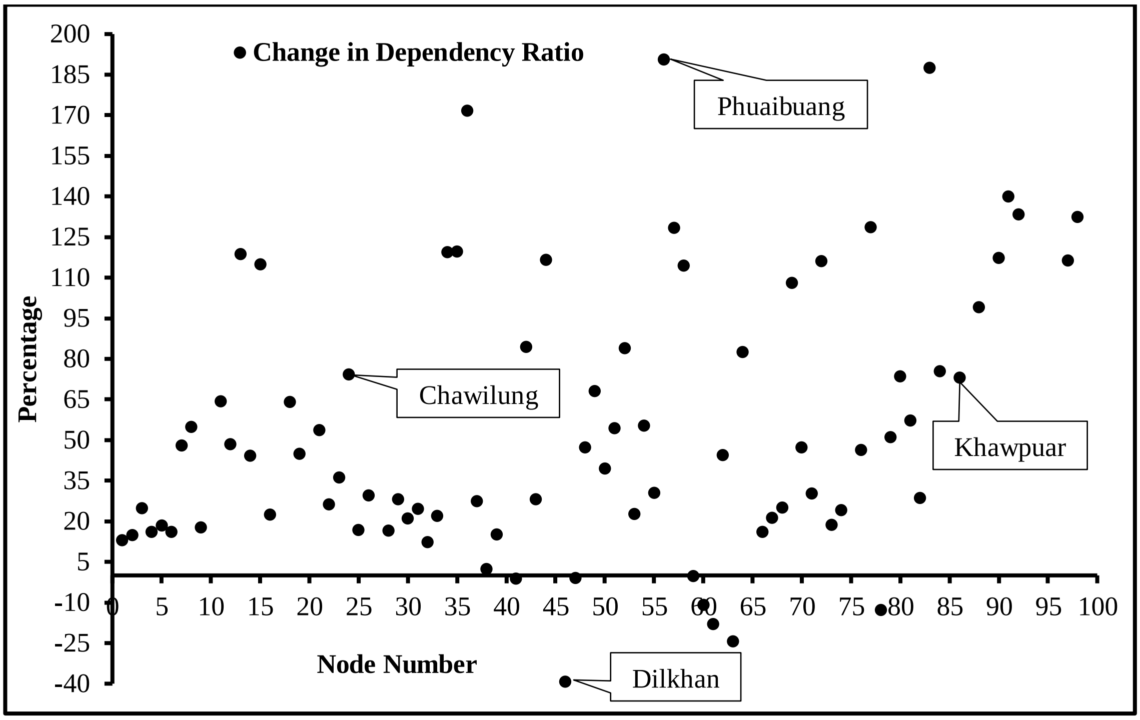

Figure 5.8: Changes in Dependency Ratio, 2001 - 2011

5.2.5 Change in Agriculture (Agricultural) Workforce

In the recent past, debates on socio-economic development have become a principal issue across different field of study. One of the central themes is focused on the changes in occupational structure and its consequent socio-economic development. A modern occupational structure leads to diversity in the occupational pattern with a high degree of specialisation and better wage. It has been observed that economies progress in developing country "like India, with a large and young population, a shift in the pattern of employment away from the agricultural sector to higher productivity jobs in urban areas is generally a positive indicator of structural transformation… There could be a "push factor" too - since agriculture cannot sustain the workforce, job-seekers are pushed to urban areas to take up any work that can give them some sustenance" (Gulati and Ritika 2022). Consequently, India has experienced a significant transformation, particularly evident in the rural workforce, with a notable impact on labor transitions. The workers predominantly shifting towards low-paying jobs and self-employment in the non-farm sector (Subramania, 2015). It is evident that this trend too exists in the study area. In the study area the economy of the rural area is mostly dependent on primary activities (as per 2011census, 77.71 per cent workforce engaged in agriculture and allied activities) since it has a long association with tribal culture, the pattern of change in the percentage share of workers engaged in the primary sector may show encouraging levels of socio-economic development of the Aizawl district.

It is also evident that the agricultural workers’ population has declined during the study period both in terms of percentage and as well as absolute numbers. At the district level, the percentage share of the agricultural workforce of the total main working population declined from 36.49 per cent in 2001 to 29.12 per cent in the 2011 Census. Also, the percentage share of agricultural workers in rural areas was quite high, but the proportion reduced from 83.29 per cent to 77.73 per cent during the same period. The changing pattern in agrarian workforce therefore reveals an underlying process of a structural change materialising in the workforce. This trend is one of the significant indicators of socio-economic development. In this regard, the study adopted a classification method for understanding the changing patterns in the agrarian sector such as High Decline, Moderate Decline, Steady Decline, Moderate Increase and High Increase classes.

(a) High Decline (≤ -20): It is observed that only 4.82 per cent of the total number of villages experienced a sharp decline in the share of agricultural workforce. The highest percentage of decline in agricultural workforce was -42.41 per cent which was recorded in Falkawn village, while Tuirial with -36.15 per cent secured the second position. Figure 5.9 clearly indicates a changing pattern in the agricultural workforce over the geographical space. During 2001 to 2011, agricultural workforce sharply declined in Hualngohmun, Falkawn, Aibawk and Tuirial villageswhich are lying at the periphery of Aizawl City. The influence of urbanisation and the development of infrastructure due to their proximity to an urban area offers opportunity for creating more robust platforms for agricultural workers to enhance their livelihood through the development of the transport system. In short, there is a current trend of agricultural workers moving out from the agricultural sector to other rural non-farm sector like agro-based marketing and resource base marketing etc.

(b) Moderate Decline (-20 - -10): Between the Census of 2001 and 2011 there was a moderate decline of agricultural workforce in 21 villages, which accounts for 25.30 per cent of the total villages in Aizawl district. Sialsuk, Saitual/Keifang, Dilkhan and Phullen registered moderate decline in the proportion of agricultural workers in the region. The distribution pattern illustrates a trend characterised by a moderate decline in agricultural workforce and this is witnessed in places that are located in the southern and middle sections of the region (Figure 5.9). It seems that structural changes in the primary sector are more substantial in the southern and middle sections of the region.

(c) Low Decline (-10 - 0 per cent): Census data reveals that the agricultural workforce has steadily declined in 40 villages that accounts for 48.19 per cent of the total villages in Aizawl district (Table 5.5). Spatially, the steady decline class portrays a scattered pattern of distribution. Here, agriculture plays an important role in the economy. Mainly the working population of the area follows the traditional method of farming that is typified by shifting cultivation, while the younger generation (job seekers) are gradually moving away from the agriculture sector. The agricultural productivity is low and based on the subsistence form of production that mainly caters to and provides for individual households. However there are also grown valuable cash crops like ginger, tobacco, vegetables and chilies. On the other hand, recent advancements in horticulture have slowed the rate of decline in the region's agricultural workforce, and it now seems that horticulture is a significant and emerging trend in the agricultural system that has gradually turned it into a necessary component of rural employment and the rural economy. Generally speaking, the process of urbanisation taking place within the Aizawl municipal area has helped transform traditional method of cultivation into a “semi-commercial”[15] based agriculture which has in turn helped to meet urban market demands. Sihphir, North Lungleng, North East Tlangnuam and Muthi are some of the ideal examples of this transformation (Table 5.5). At the same time, the younger generation has attempted to shift their involvement from the primary sector of the economy to activities that garner higher incomes.

(d) Moderate Increase (0 – 10 per cent): Despite the change in the structure of the workforce of the study area, 15.66 per cent of the total villages have experienced an increase in agriculture workforce. This trend implies that a significant proportion of the younger generation have joined the agriculture sector since 2001. The highest percentage increase in the class was seen in Vanbawng with 6.30 per cent, followed by Darlawn 5.84 per centand Buhban 4.99 per cent as per data registered by the 2001 and 2011 Censuses (Table 5.5). The reasons for such a trend can be interpreted in two ways. Firstly, an improvement in road conditions has enabled a shift from the traditional practice of agriculture system to the development of semi-commercial types of agriculture which is majorly based on horticulture and vegetable farming. This type of an agriculture system is evident in Sairang, Thingsulthliah, Tlungvel, and Darlawn areas, and their agriculture produce are being marketed in locally as well as in urban marketplaces. Secondly, Aizawl City is the sole market for the agricultural produce from nearby towns and villages like Sairang, Thingsulthliah and Tlungvel (Figure 5.9). Hence, the effects of urban economies and accessibility of road networks may be cited as the main causes of such moderate increase in the agricultural workforce in the villages that fall under this category. This type of transformation mainly materialises through the development of road transport improvement and a change in the agricultural system.

(e) High increase (≥ 10 per cent): During the study period, the highest increase in the growth rate of agricultural workers was observed in 5 villages, which is 6.02 per cent of the total village of the study area (Table 5.5). The highest percentage increase of agriculture workforces in Aizawl district was recorded in East Phaileng village with a 38.01 per cent increase from 2001 to 2011. Other villages in the northern part of the district like Thingsat, New Vervek, Chhanchhuahnakhawpui and Vaitin also registered high rates of increase. The northern part of the experienced high increase in the number of agricultural workers because agriculture plays a very big role in this area o absorb the main working population and thereby influencing the rural socio-economic conditions of the region (Figure 5.9). The region is characterised by little improvement in development of infrastructure, low level of investments in agriculture, poor economic diversity, remote location, and lack of skills and knowledge.

The current study presents the changing trends and patterns of agricultural workforce from 2001 to 2011. More than 78 percent of towns and villages have seen a decrease in the numbers of agricultural workers (Table 5.5). But the economy of the district is still largely dependent on primary activities with 77.71 percent of the workforce engaged in agricultural activities as per 2011 census. The changing pattern of the agricultural workforce in Aizawl district indicates transformation in the occupational structure. There are two critical factors that are responsible for changes in occupational structure. Firstly, the accelerated economic growth and availability of job opportunities in non-agricultural sectors has pulled rural population to the higher productivity sectors workers away from the agriculture sector. Secondly, the study reveals that the entire development process continues to breed a new urban culture that is largely based on a service-oriented economy. This modifies the occupational structure in the urban peripheral areas. Consequently, the agriculture sector acquires renewed importance for gainful employment in the urban peripheral region due to increasing demands for agriculture by urban markets; this helps to maintain a safe balance on the growth in the agricultural workforce of the urban periphery and other rural areas surrounding them.

Table 5.5: Classification of Settlements on the Basis of Change in Agriculture Workforce, 2001-2011

Class (in Percentage)	No. of Village	Percentage	Name of Village
HighDecline (≤ -20)	4	4.82	Falkawn, Tuirial, Hualngohmun, Aibawk
Moderate Decline (-20 - -10)	21	25.3	Saitual/Keifang, Selling, Thanglailung, Aizawl, Sesawng, Phullen, Muallungthu, Melriat, Phulmawi, Sialsuk, Tachhip, Dilkhan, Kepran, Sateek, Kelsih, Samtlang, Sawleng, Rulchawm, Lailak, Thingsultlangnuam, Sumsuih
Low Decline (-10 - 0)	40	48.19	Muthi, Sakawrdai, Ruallung, Khanpui, Lamchhip, Zawngin, Sihfa, North Lungleng, North Lungpher, Sailuta, Hmuifang, Luangpawn, Zohmun, Sailam, Sihphir, Phulpui, Sunhluchhip, NE. Tlangnuam, Khawpuar, Ratu, Lungsei, Lungsum, Thiak, Phuaibuang, Tualbung, Pehlawn, Samlukhai, Khawlian, Mualpheng, Palsang, South Maubuang, Mauchar, Lenchim, North Khawdungsei, Suangpuilawn, Tawizo, Khawruhlian, Lamherh, Mualmam, Chamring
Moderate Increase (0 – 10)	13	15.66	Tlungvel, Sairang, Maite, Thingsulthliah, Hmunnghak, Chawilung, North Thinghmun, North Khawlek, Daido, North Serzawl, Buhban, Darlawn, Vanbawng
High Increase (≥ 10)	5	6.02	Vaitin, Chhanchhuahnakhawpui, New Vervek, Thingsat, East Phaileng

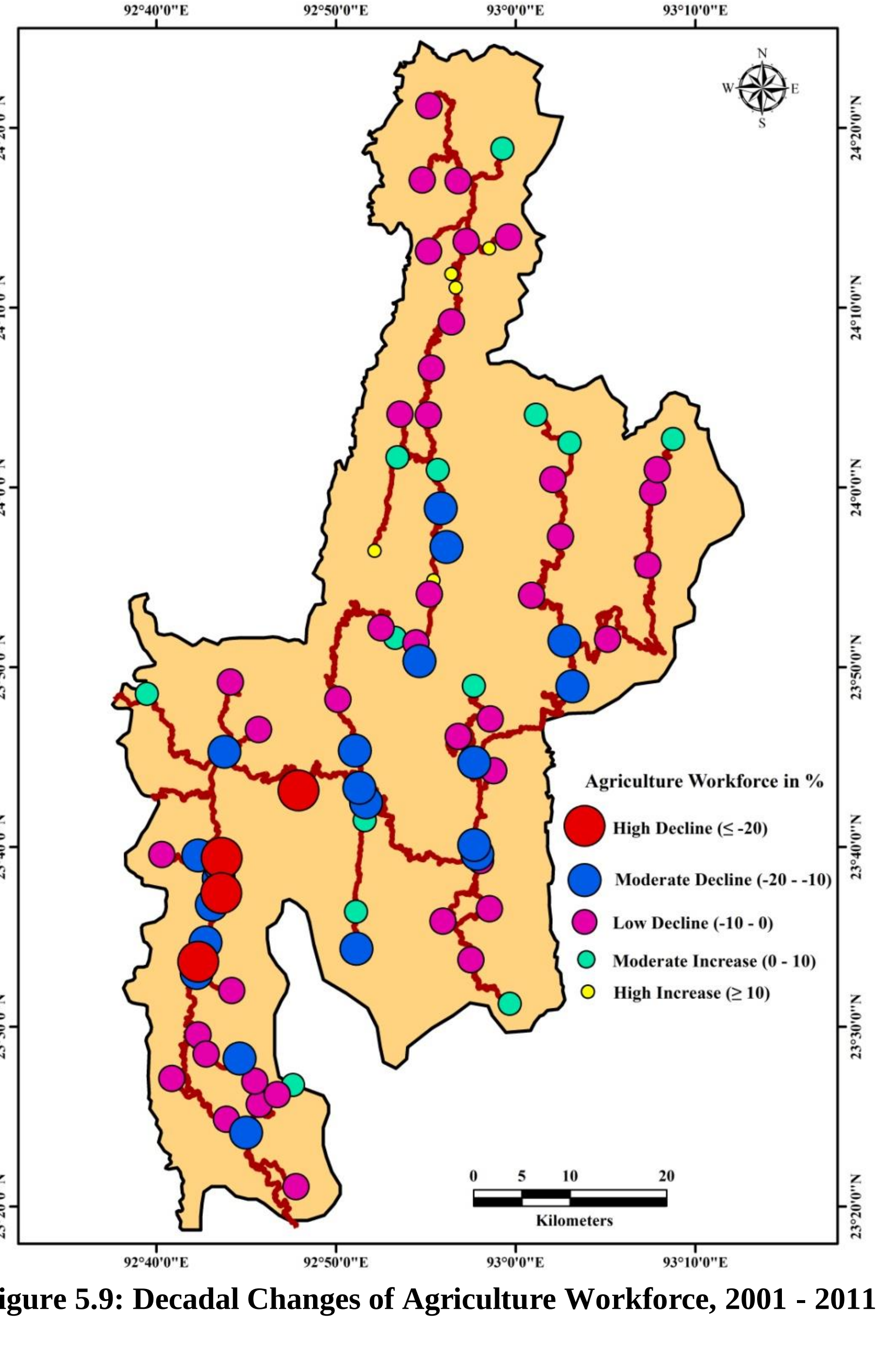

Figure 5.9: Decadal Changes of Agriculture Workforce, 2001 - 2011

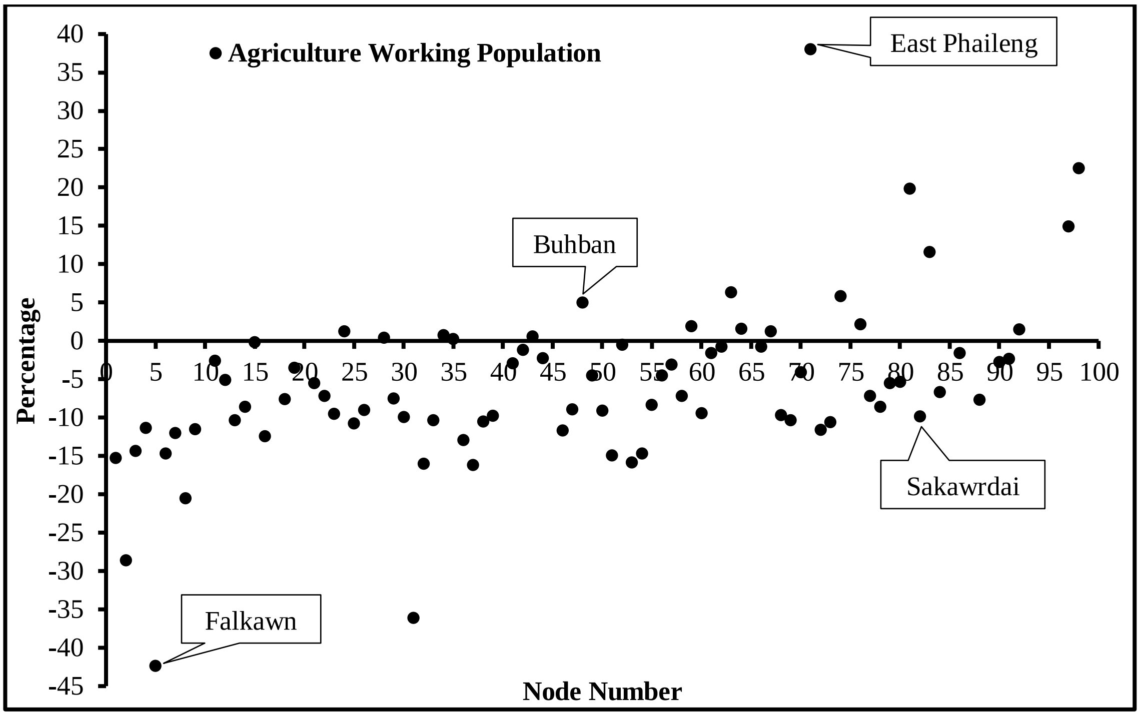

Figure 5.10: Changes of Agriculture Workforce, 2001 - 2011

5.3 Conclusion

The northern and middle parts of the region have experienced high population growth with Aizawl and its surrounding areas having the highest population growth. But, the north and north-eastern parts of the region also experienced negative population growth.

The diversity of literacy rates in Aizawl district is skewed towards extreme north. The southern and middle parts of the area are more. The northern and north-eastern regions of the study area have higher illiterate populations due to their remote location, limited availability of educational infrastructure, and low level of adult literacy, which can contribute to improving the literacy rate in those villages.

Over the decade the towns and villages of Aizawl district experienced a diverse range of changes from the positive to the negative in relation to sex ratio. Considering the changed pattern of sex ratio, the data shows that an increase in sex ratio was prominent in the western and more interior parts while a decreasing trend was witnessed in areas that are closer to the edges of the northern, southern and eastern parts of the study area.

There is an evidence of change in dependency ratio in remote rural areas to urban area with high concentration of population. Several rural communities in the north-eastern region have experienced a significant drop in the dependency ratio despite their remote locations; yet, the economic situation of the population is quite poor due to the involvement of the working population in low-income economic activities. Interestingly, urbanization has increased dependency ratio through improved in standard of living, life expectancy.

The shift of workers from the primary sector to the secondary and tertiary sector activities is the result of villages gaining better access to road connectivity and education. Therefore the introduction of non-agricultural activities is gradually bringing about a change in the occupational structure and pattern of the workforce because more people are being drawn away from primitive subsistence agriculture towards economic activities that assure higher and more stable returns.

CHAPTER VI

Road Transport and Socio-Economic Development

6.1 Introduction

Geography invariably seeks to analyse and interpret the relationship of spatial features and their pattern of interaction within a definite geographical space. The different modes of interactions change over space and time the system and pattern of interactions are changed substantially as a result of change in geographical, technological and socio-economic factors. As time and space progress, the various modes of interactions undergo transformations, leading to substantial changes in the system and pattern of interactions. These alterations occur due to shifts in geographical, technological, and socio-economic factors. Also the intensity of interactions is changed over space and time with respect to the constraints of parameters set by the investigator.

Ullman’s (1957 and 1980) spatial interaction theory chalks out three basic attributes on the conceptions for spatial interaction; complimentary, transferability and intervening opportunity. Consequently, spatial interactions build different systems of linkages and connectivity at various sizes and produce spatial relationships in geographic space. In transport network, transportation nodes and vertexes are the core figures and links of interaction in geographical space to build definitive relationship between spaces. The intensity of interaction through vertexes determined the degree of relationship between the geographical spaces. The degree of interconnections may range from one perspective to another at different periods in relation to geographic, economic, social, and technical inequality. The interaction processes may change over time in response to attraction and disapproval factors and it also varies according to the attributes of the space. The consideration of spatial interactions has played a significant role in understanding socio-economic development (Wang, 2017). The interaction between the spaces in a particular set of area forms a networking system, which is very crucial for the flow of information and commoditiesThe interaction between spaces is influenced by topology and structure of road network which is very crucial for socio-economic development in the region.

The concept of socio-economic development has been discussed in the previous chapter. The term and measure of level of socio-economic development is used as a general term in economic, political, social, spatial sciences, and development studies etc. for addressing the socio-economic conditions of particular groups or area. In earlier stage of study, measured a level of country's development by focusing on the growth of income (Gross Domestic Product or Gross National Product) and its components. More scholars from the various fields of study have criticized the inadequacy of the growth output or income based socio-economic development studies. Thus some of the studies introduced modified form of income based study called the 'Welfare Approach Development', and became more popular for comparative studies between countries and over time (Hicks and Streeten, 1979; Othick, 1983). Suggesting multidimensional context Bunge (1981), Hsaio and Wong, (1983), 'Social Indicators Approach' has gaining credence importance for addressing the issues of contemporary socio-economic development. Thus, scale of levels of socio-economic development studies is wide and complex, and is used as tools for addressing various concepts. In the recent past socio-economic development researchers have developed a number of 'Aggregate' or 'Composite Indices' for measuring the levels of socio-economic development (Milenkovic, 2014; Raut, 2015).

In this chapter the role of road transport network on socio economic development is examined by focusing on (a) Levels of accessibility of settlements in the study area by road transport (b) Levels of socio-economic, (c) Relationship between levels of accessibility of settlements and socio-economic development. The main objective of the chapter is to examine the significance of the road network on the level of socioeconomic development in Aizawl District.

6.2 Level of Nodes Centrality and Accessibility

W. R. Tobbler's (1970) first law of geography on distance decay function stated that everything is related to everything else, but nearby things are more related than those that are farther away. This is especially true for transport networks, in which nodes are connected to one another directly or indirectly. It is relevant in the case of connection position and distance, which may have an impact on changes in nodal situation, nodal qualities, and accessibility of nodes. This law is ideal for establishing the relationship (flow) of nodes in the network within a geographical space. In transport geography, networks (agents of flow) and nodes (origin and destination) play fundamental roles because they facilitate movements between locations. Nodes are strongly tied to the network, meaning that the node on its own is not important and only finds its worth with its existence within some form of connections (transport network). Hence the nodes are important only if they are well connected by a transport network, hence, accessibility becomes an indispensable aspect in the completion of a transport network (Raut, 2015).

The word 'accessibility' literally means the ability to access or right to entry. It is synonymously used for the measurement of openness. According to Hansen (1959), "accessibility is defined as the potential of opportunities for interaction". This definition not only implies the intensity of interaction, it also measures the intensity of the potential interaction. According to Ingram (1971), "accessibility means capable of being reached, thus, implying measure of the proximity between two points" in geographical space. The concept of accessibility connotes importance of a place and more particularly the ease with which one can travel from one place to another (Panday, 1986). The above definitions may enlighten one to a better understanding of the concept of accessibility. But, the problem lies in the measurement of accessibility because accessibility alone is abstract in nature unless the assessment or measurement of the intensity of interactions is done by considering two subsidiary concepts – relative accessibility[16] and integral accessibility[17]. Relative accessibility considered the degree of relationship between two points (or locations) on the same surface. Integral accessibility, on the other hand measures degree of interconnection of particular point with every other point on the same surface.

Theoretically, in a transport network, access is available to anyone located in the network when entry and exit is possible. The level of accessibility varies according to one's locations within the transport system (Rodrigue, 2006). So, "an examination of the accessibility of vertices in a transportation network (a graph) is an important element in any geographical analysis of transportation systems. It is therefore becomes obvious that the network vertices of high transportation accessibility may be considered privileged locations or places in the broader meaning of the term" (Mackiewicz and Ratajczak, 1996). The same concept is widely discussed and applied in the field of transport geography as well as in this work.

The study used road network centrality measurements to assess how accessible a node or region is, drawing on the social-network analysis concept from Freeman *et al.* (1991). Node accessibility in this context refers to measurement of the levels of openness that become sources of interaction or potential interaction between a specific vertex and other vertices in the network via the shortest path. On the other hand, node is also regarded as central and accessible when it is located between other nodes. It affects the shortest paths because it has the ability to facilitate, block, or otherwise affect flow of communication in the network.

Keeping the idea of centrality measure for accessibility analysis, the study make used A_I index for quantifying nodal accessibility in Aizawl district. A_I value provides logical and precise explanation node accessibility of each of the node in the network. Here, classification approach has been applied for a logical understanding of the nodal accessibility and overview of the results. Nodal accessibility is categorized in to five classes, such as Very High Accessibility, High Accessibility, Moderate Accessibility, Low Accessibility and Very Low Accessibility.

(a) Very High Accessibility (> 180): This category represents the most accessible nodes in the entire road network of the study area. According to the calculated A_I 8.43 per cent of the nodes are categorised as very high accessible settlements or nodes and they mostly confined to the middle part of the network (Table 6.1). The highest accessible node in the network is Seling with 218.20 A_I values, followed by Aizawl and Saitlual. They are the most important transport junctions in the entire network system. The level of accessibility as denoted by A_I is determined by the amount of clusters controlled by the nodes or complexity of network. Seling node has the highest degree of accessibility due to the fact that there is a direct link with clusters from the north and indirect connection with the southern and north eastern clusters. Aizawl city is a major administrative and commercial hub in the district. Other smaller settlements like Dilkhan, Tuirial, Khanpui and Sesawng are found in this category due to their influences on their peripheral areas and their adjacency to high A_I nodes. It indicates that accessibility level of a particular settlement is highly determined by the location and position of the settlements or nodes in the network.

(b) High Accessibility (135 - 180): This category includes nodes with A_I values between 135 and 180. Here, out of the 83 villages, 16 villages exhibit high accessibility values which account for 19.28 per cent of the total villages in the district (Table 6.1). In this class, Sairang town has the highest A_I value with 174.23 and villages having more than 160 A_I values are found in Mualmam, Hualngohmun and Phullen (Appendix III). The graphical representation in Figure 6.1 reveals that the middle and mid-central parts of the region are more accessible. The Figure also indicates that settlements in this category are immediate neighbours of Very High scoring nodes. This implies that direct link or adjacent location with higher nodes has significant implication for the degree of accessibility of a node (Figure 6.1).

(c) Moderate Accessibility (90 – 135): The moderate accessibility category constitutes 30.12 per cent of the total settlements in Aizawl district. Darlawn and Sakawrdai are notable junctions in the northern part of the district. Unlike the 'Very High Accessibility' and 'High Accessibility' classes, the geographical distribution of moderate accessibility class is more diverse in nature with no irregularity. The Figure 6.1 reveals that nodes with 'moderate accessibility' serve as intermediaries between nodes with high accessibility and those with low accessibility within the network. Usually, high accessibility nodes and low accessibility nodes sandwich the moderate accessibility nodes and, the level of interaction between high and low classes is intermediated by the A_I values of the moderate accessibility node.

(d) Low Accessibility (45 – 90): Low accessibility class node comprises 19 villages that constitute 22.39 per cent of the total settlements. This category constitutes the second highest proportion of the study area (Table 6.1). Figure 6.1 shows the spatial distribution of low accessibility nodes that are scattered over the network and spread across the northern, north-eastern and southern limits of the clusters. Settlements in this category have limited connectivity with adjoining nodes due to lack of diffusion of the network as well as the remote location of the nodes with respect to the high value nodes. It appears that network topology is significantly determined by the topography of the study area.

(e) Very Low Accessibility (≤ 45): The least accessible settlements comprise 16 nodes that make up 19.28 per cent of the total nodes in the study area (Table 6.1). It is found that Palsang and Mauchar villages with 5.36 $_{AI}$ values each are the least accessible villages. Most of the 'very low accessibility' nodes are located at the northern part of the district. A few villages including Sailam, Chailung, Lungsei and Phulpui are found in the southern part. The central part of the network is absent of this class of nodes (Figure 6.1). The illustration also signifies that the nodes with very low accessibly are topologically isolated which are called dead end nodes adjacent location to a single node or has absence of a passing edge.

The above analysis highlights the fact that nodes lying in the middle parts of the network are more accessible and has greater influence than those nodes lying in the north, south and north-eastern clusters of the network. In general the settlements of nodes in the low category are found in the north, south and north-eastern tips of the network. The least accessible nodes are also embodied in the dead-end-nodes. Structurally, the levels of accessibility of the nodes deviate/decline from the central part of the network towards the extreme north and southern parts of the network.

Table 6.1 reveals that the levels of accessibility are more uniform in the high category (*CV*= 8.12 per cent) and the very high category (*CV*= 8.36 per cent). Conversely, the lower categories exhibit higher coefficient of variation. This means that variations of accessibility are greater in the lower accessibility classes than those in the higher classes.

Table 6.1: Level of Accessibility, Aizawl District, Mizoram

Class	No. of Village	Percentage	CV%	Name of Village
Very High (> 180)	7	8.43	8.12	Selling, Aizawl, Saitual/Keifang, Dilkhan, Tuirial, Khanpui, Sesawng
High (135 – 180)	16	19.28	8.36	Sairang, Mualmam, Hualngohmun, Phullen, Khawruhlian, Thingsultlangnuam, Hmunnghak, Rulchawm, Melriat, Pehlawn, Thanglailung, Sateek, Samtlang, Sihphir, Ruallung, Thingsulthliah
Moderate (90 – 135)	25	30.12	10.62	Kelsih, Eeast Phaileng, Kepran, Darlawn, Sakawrdai, Sialsuk, North Lungpher, Zawngin, Sawleng, Falkawn, Muallungthu, Aibawk, Muthi, Sailutar, Tlungvel, Tachhip, Hmuifang, Phuaibuang, Mualpheng, South Maubuang, Suangpuilawn, Ratu, Samlukhai, New Vervek, Sihfa
Low (45 – 90)	19	22.89	17.46	Lungsum, Phulmawi, North Lungleng, Tualbung, Khawlian, Thiak, Tawizo, Lamherh, Sumsuih, Lailak, Zohmun, Chamring, NE. Tlangnuam, Vanbawng, Vaitin, Lenchim, Buhban, Lamchhip, Luangpawn
Very Low (≤ 45)	16	19.28	50.21	Maite, Phulpui, North Serzawl, Sunhluchhip, Chhanchhuahnakhawpui, Lungsei, Thingsat, Sailam, Daido, North Khawlek, North Khawdungsei, North Thinghmun, Khawpuar, Chawilung, Palsang, Mauchar

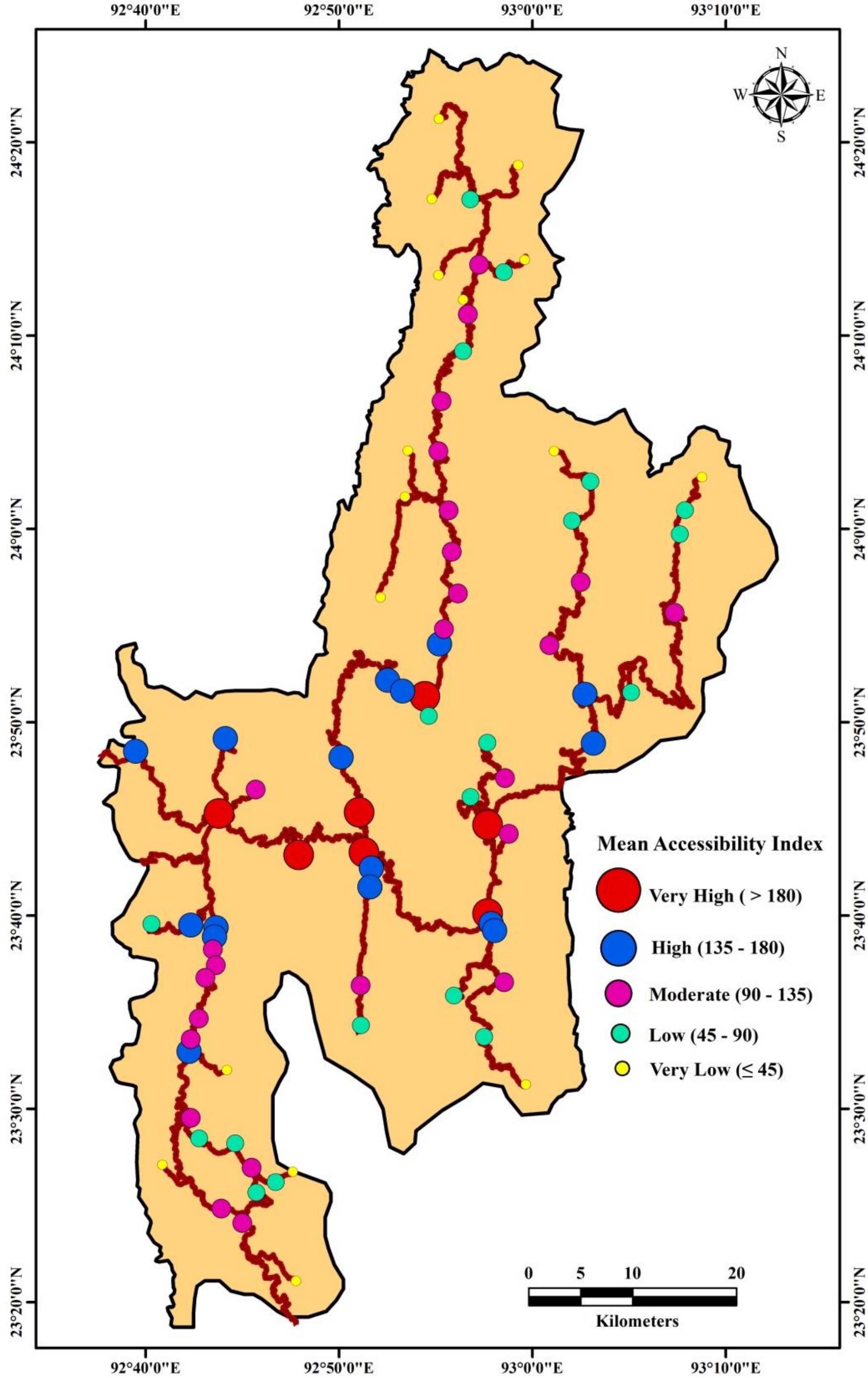

Figure 6.1: Mean Accessibility Index, Aizawl District, Mizoram

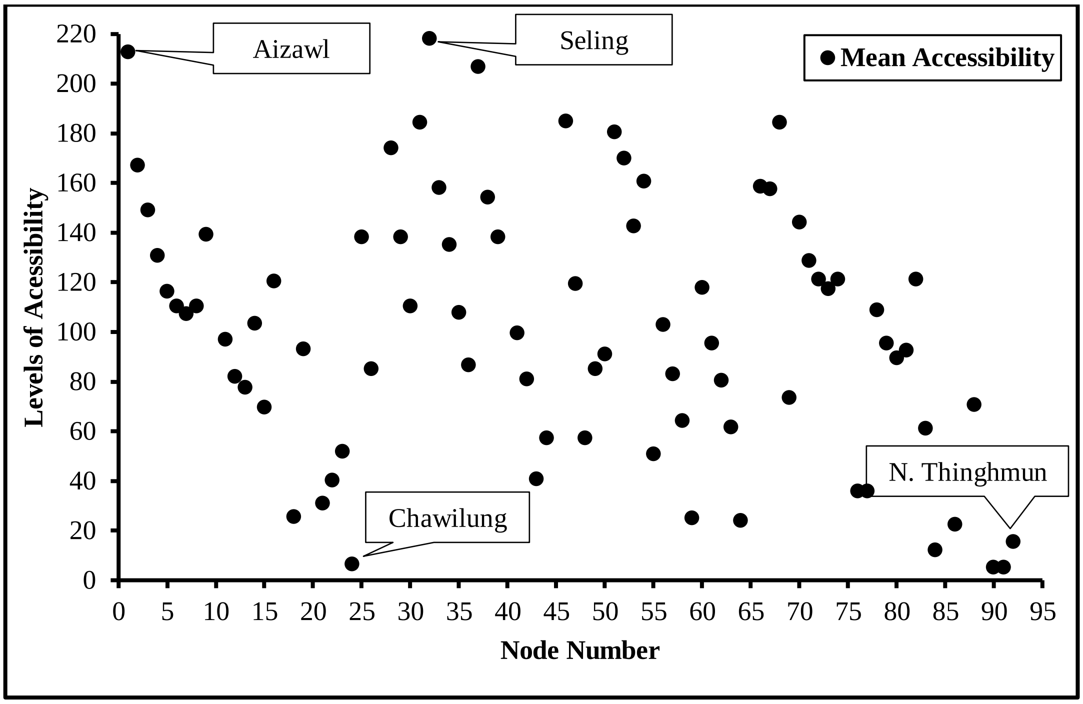

Figure 6.2: Grapical Representation of Mean Acessibility Index (A_I)

6.3 Levels of Socio-Economic Development

Development is a multidimensional process built upon wide range of social and economic indicators that reflect various aspects of the society (Khan, 1991). An 'Aggregate' approach is hereby selected to find out levels of socio-economic development. The levels of socio-economic development of all settlements in the study area have been categorised into five categories, such as Very High Socio-Economic, High Socio-Economic, Moderate Socio-Economic, Low Socio-Economic, and Very Low Socio-Economic classes.

(a) Very High Socio-Economy (≥140): This category is observed in 11 villages with a contribution of 13.25 per cent of the total villages in the study area (Table 6.2). Out of 83 villages Seling is found to have the highest D_I value with 190.49. Sateek village has the second highest D_I values with 156.19 followed by Hualngohmun. In the middle part of the study area, Aizawl and Saitual are noticeable in terms of size and their urbanization characteristics. It has been noticed that Aizawl city has significant impact on socio-economic development in its surrounding rural settlements like Aibawk, Samtlang, Falkawn, and Muallungthu. The spatial distribution pattern shows the socio-economic condition is better in the southern and middle portions of the study area. Due to geographical proximity of urban area and infrastructure development more than 63 per cent of the very high socio-economic class is found in the southern cluster of the district. From the northern cluster of the network Sawleng village is the only village that has very high socio-economic level. The north-eastern cluster is however conspicuously absent in this category (Figure 6.3).

(b) High Socio-Economy (105 - 140): The study observed that, 31.33 per cent of the total towns and villages fall under high socio-economic class. The geographical distribution of high socio-economically developed settlements is dispersed and depicts a semi-linear pattern of distribution. Out of the total 26 settlements, about 46 per cent are in the north and north-eastern parts of the district. Apart from this the middle part is completely dominated by the high socio-economic category. It is observed that the settlements with high socio-economic scores are either directly adjacent to each other with very high socio-economically developed ones (Figure 6.3). This indicates that the levels socio-economic development is determined by the location and position of a node in the network. In this category Ruallung village (139.52) ranks first and Sihfa village and Khawruhlian village come in second and third positions, respectively. Beyond these villages, Tuirial, Sihphir, Phullen, Sairang and Darlawn are important junctions and noticeable villages in the category (Table 6.2).

(c) Moderate Socio-Economy (70 -105): The moderate category accounts for the highest percentage share (34.9 per cent) of the total villages of the study area (Table 6.2). Figure 6.3 tells us that the moderate category villages mostly spread across the northern, north-eastern and southern clusters of the study area. But the distribution pattern over this space portrays a diverse pattern and follows a longitudinal direction that is directly aligned with the arrangement of the network. Out of 29 nodes, only 9 of them are from the southern, northern and north-eastern clusters and these together compose of almost two-thirds of the category (Figure

6.4). Most of the villages that fall under this category are located in isolated locations of the network and these nodes are considered dead end nodes.

(d) Low Socio-Economy (35 - 70): There are 10 villages (12.05 per cent) in the low socio-economic class in this category with Luangpawn village with 67.62 securing the highest D_I and the lowest D_I is observed in Vaitin village with a value of 41.90 (Table 6.2). In this category about 70 per cent of the total villages are from the northern cluster of the network. Two villages, Luangpawn and North East Tlangnuam are from the north-eastern cluster and Tawizo village represents the south-eastern portion of the network (Figure 6.3). It is worth mentioning that the central and southern parts of the network do not appear in the low node category.

(e) Very Low Socio-Economy (≤ 35): The lowest level of socio-economic development is identified in seven villages which accounts for only 8.43 per cent of the total villages in the study area. Thingsat village has the lowest score (24.29) followed by Mauchar and North Thinghmun, (Table 6.2). Very low socio-economic level is concentrated in the northern tip of Aizawl district. Chamring is the only village that represents the southern cluster of the network. On the other hand, the central and the north-eastern portions of the network do not appear in this category. Excluding Chamring village, the nodes with very low level of socio-economic category lie adjacent to atleast one node that experiences impeccable levels of socio-economic development (Figure 6.3).

With regard to socio-economic development, the analysis reveals that the settlements located in the southern and central parts of the district are more developed and well established than those in the northern and north-eastern parts of the study area. The north-eastern part of the study area is dominated by settlements that experience high and moderate levels of socio-economic development. On the other hand, the low and very low socio-economic categories are mostly concentrated in the northern tip of the network.

The coefficient of variation is low in very high and high socio-economic classes, which means that the low and very low categories have higher degrees of co-variation (Table 6.2). While the least socio-economic development class has higher coefficient values of 15.09 per cent and 12.36 per cent represented by the low category and very low category respectively, which implies that, at the least, economic development leads to inequality within the class. Contrary to this, it also indicates a pattern where higher socio-economic development results in a uniform level of socio-economic development amongst the high D_I class.

Table 6.2: Levels of Socio-Economic Development, Aizawl District, Mizoram

Class	No. of Village	Percentage	CV%	Name of Village
Very High (>140)	11	13.25	8.61	Selling, Sateek, Hualngohmun, Sawleng, Aibawk, Aizawl, Samtlang, Falkawn, Saitual/Keifang, Sialsuk, Muallungthu
High (105 - 140)	26	31.33	9.09	Ruallung, Sihfa, Khawruhlian, Dilkhan, Vanbawng, Tuirial, Kelsih, Rulchawm, Melriat, Thingsultlangnuam, Tachhip, Sihphir, Suangpuilawn, Khanpui, Thanglailung, Sairang, Phullen, Darlawn, Thingsulthliah, Sailutar, Zawngin, Thiak, Sesawng, Lamchhip, Pehlawn, Muthi
Moderate (70 – 105)	29	34.94	10.13	Mualpheng, Kepran, Hmunnghak, Daido, Sakawrdai, Phulpui, Lungsei, North Lungpher, Tlungvel, South Maubuang, Ratu, East Phaileng, Tualbung, Chawilung, Sailam, Phulmawi, Phuaibuang, Sumsuih, Maite, Buhban, Samlukhai, Lenchim, Hmuifang, North Khawlek, North Lungleng, Khawlian, Mualmam, Lailak, Lamherh
Low (35 - 70)	10	12.05	15.09	Luangpawn, NE. Tlangnuam, Lungsum, Sunhluchhip, New Vervek, Zohmun, North Khawdungsei, Tawizo, North Serzawl, Vaitin
Very Low (≤ 35)	7	8.43	12.36	Chamring, Khawpuar, Palsang, Chhanchhuahnakhawpui, North Thinghmun, Mauchar, Thingsat

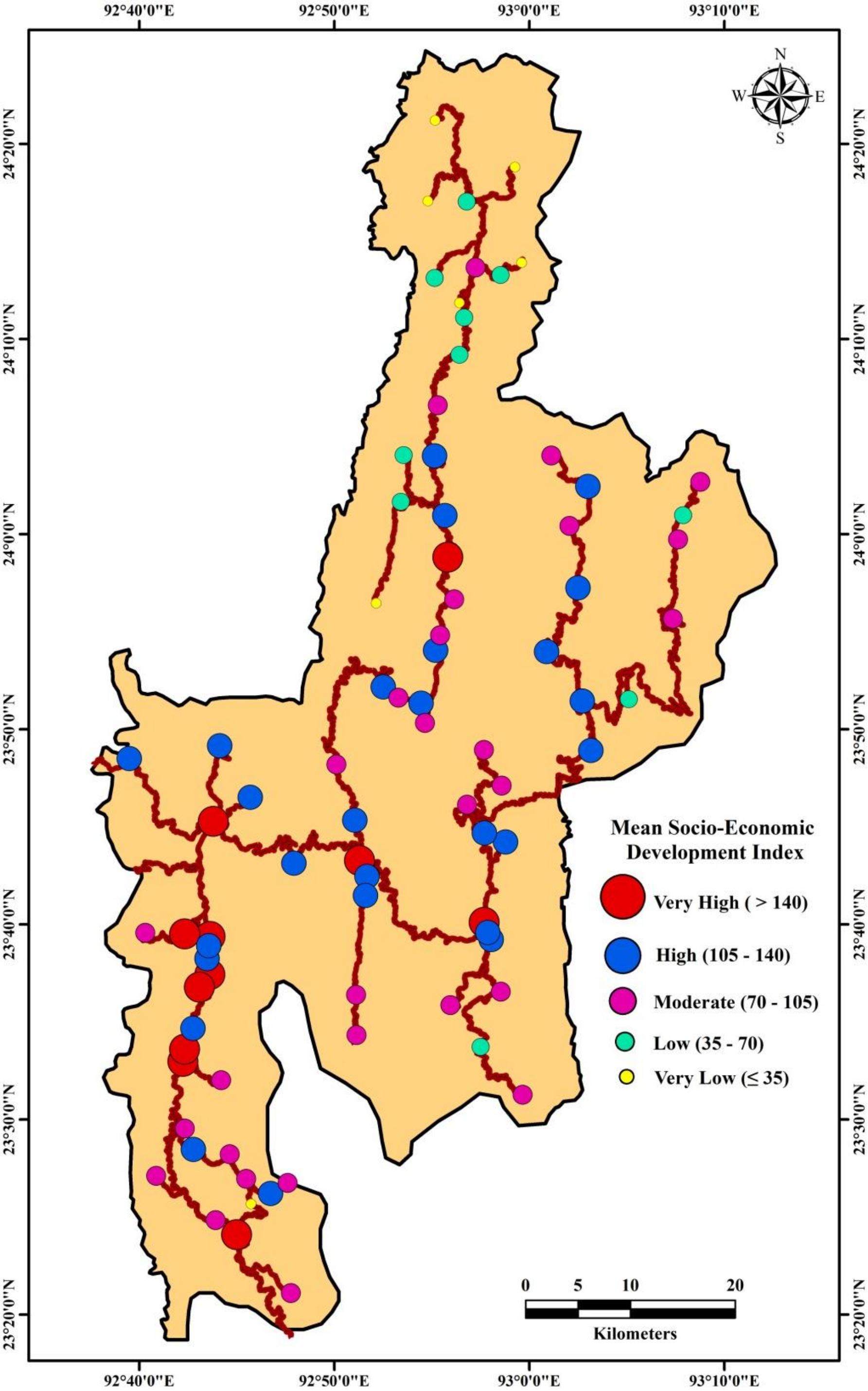

Figure 6.3: Mean Socio-Economic Development Index, Aizawl District, Mizoram

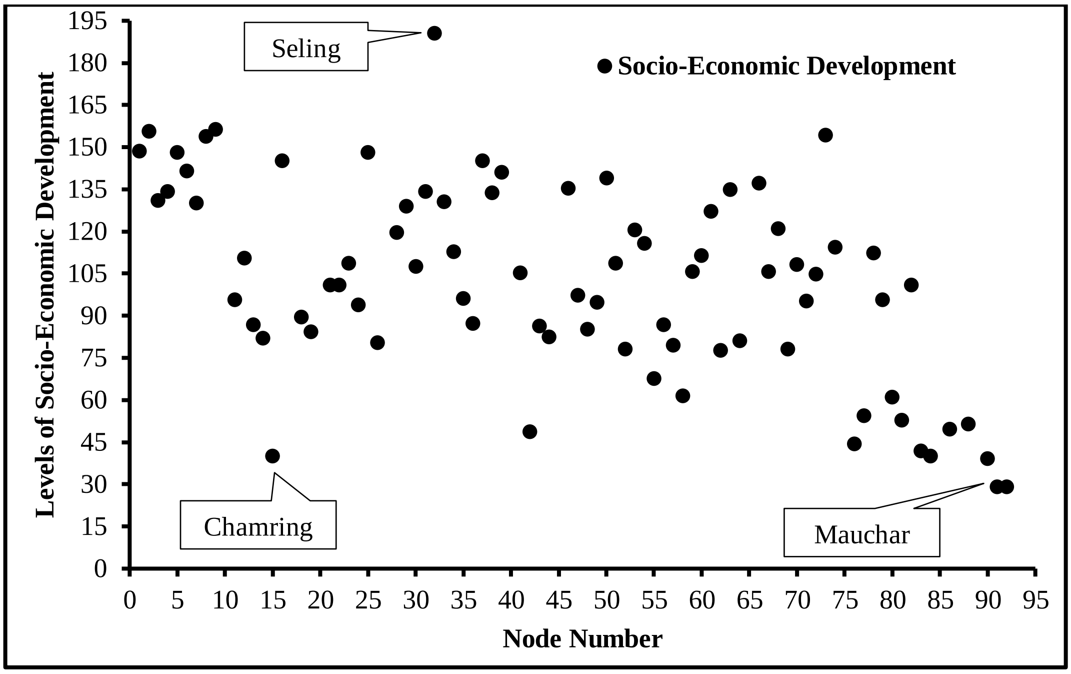

Figure 6.4: Grapical Representation of Socio-Economi Development Index (D_I)

6.4 Relationship between the Variables

Table 6.3 shows the values of correlation coeefficient between the indicators of accessibility and socio-economic development. The highest correlation is found between 'degree of centrality' and literacy rate with r_s=0.43 followed by Percentage of agriculture workers (r_s=0.42). Dependency ratio (r_s=0.37) is the third most considerable correlation. Sex ratio (r_s=0.23) and population growth (r_s=0.17) are in fourth and fifth positions (Table 6.3) respectively, by way of significance. It means that centrality has a moderately positive relationship with literacy and the agriculture working population.

The study found that there is correlation between closeness and socio-economic parameters like crude literacy rate (r_s=0.54), sex ratio (r_s=0.53), dependency ratio (r_s=0.48) with agricultural workers (r_s=0.44) having a moderately positive correlation. The result indicates that as the level of closeness accessibility increases the crude literacy rate also improves and the dependency ratio and agricultural working population also declines. But weakly positive correlation is found in the closeness and population growth with r_s=0.1, which means that the closeness centrality has significant implications on the increase in population (Table 6.3).

Considering table 6.5 the correlation of betweenness accessibility and socio-economic parameters (Table 6.3) can be explained in lucid way. Betweenness accessibility and literacy rate has r_s=0.47 and followed by agriculture working population (r_s=0.45), also betweeness accessibility and dependency ratio (r_s=0.40) lie in the realm of moderate correlation category (Table 6.5). Thus, vertices with a higher level of betweeness accessibility tend to have moderate association with literacy rate, agriculture working population and dependency ratio. It is clear that betweeness accessibility manifests a weaker relationship with sex ratio (r_s=0.35) and also that the relationship against population growth also significantly declines to a weak correlation of r_s=26.

The coefficient between the eigenvector and agricultural working population signifies moderate significance which is about r_s=0.53 and a moderate linear relationship is also noticed between eigenvector and sex ratio (r_s=0.53). In other words, eigenvector accessibility has moderate association with agriculture working population and sex ratio (the higher eigenvector accessibility the lower agricultural working population). The degree of association between the eigenvector and dependency ratio computes literacy rate as having a value r_s=0.38 and r_s=0.34 respectively with each and this is considered as a weak positive association. But the relationship between eigenvector accessibility and population growth falls under a positively negligible relationship having the calculated value r_s=0.07 only (Table – 6.3). This means that an increase or decrease of population is determined by the level of accessibility of the nodes in the network.

The correlation coefficient value shown in Table 6.3 points to a moderately positive correction existing between eccentricity accessibility and sex ratio with the value r_s = 0.52 and also a moderately positive correlation existing with literacy rate (r_s = 0.42). But, eccentricity accessibility has a weak correlation with dependency ratio (r_s = 0.39) and agriculture working population (r_s=0.31). Again, eccentricity and population growth have negligible relationship with r_s=0.08 (Table 6.3). For instance, Aizawl city is ranked fifth in eccentricity accessibility, while the rank against population growth during 2001 to 2011 is in the sixty seventh position (Annexure-III) which means that the association between the variables is considerably low or almost negligible at best.

The value R^2 indicates the variation of association between dependent and independent variables with regression being a powerful tool as a predictive device. Thus, regression analysis makes it possible to study cause and effect relationship of independent and dependent variables (Gupta, 2011). In view of Table 6.4 regression value crude literacy rate and agriculture working population has the highest predicted value against degree of accessibility with R^2= 0.18. Meanwhile the predictive values are significantly lower for sex ratio (R^2= 0.05) and population growth (R^2=0.03). The result also tells us that when the degree of centrality is increased the literacy rate will also be moderately increased while the agricultural working population moderately declines. It is worth mentioning that the degree of centrality has a weak correlation (r_s) as well as weak predictive value (R^2) with sex ratio and population growth.

The regression value for the highest regression is found between closeness and crude literacy rate R^2=0.30, followed by sex ratio R^2=0.28, dependency ratio R^2=0.23, agricultural working population R^2=0.20. All these relationships are considered to exhibit moderate association between dependent and independent variables. The lowest regression value is population growth R^2=0.01 in terms of closeness accessibility (Table 6.4). Theoretically it can be argued that nodal accessibility measures is based on closeness centrality measure and has much significance to the level of socio-economic development of the region. In addition, a high degree of closeness accessibility leads to an increase in population by means of migration and natural growth of population in the area.

According to the calculated regression value (Table 6.4), the association between betweenness and crude literacy rate has the highest R^2 value with 0.22 and R^2=0.21 for agriculture working population, with R^2=0.16 dependency ratio being considered as a moderate association. The regression analysis also reveals that the predicted value of Y is weak for both sex ratio (R^2=0.12) and population growth

(R^2=0.07). This highlights the fact that the level of betweenneess accessibility has significant implications on socio-economic attributes like crude literacy rate and agricultural working population. Since the predicted value is highest in these two variables, the study can expect to experience a moderate increase in crude literacy rate and moderate decline in agricultural working population in the study area.

The study observed that a variation of regression value exists between eigenvector accessibility and the selected socio-economic attributes. The analysis obtained the predicted value as being the highest for agriculture working population (R^2=0.28), crude literacy rate (R^2=0.20) and dependency ratio (R^2=0.19) and falls under moderate level of association against eigenvector accessibility. The dependent variable sex ratio (R^2=0.08) and population growth (R^2=0.005) are categorised as weak and very weak associations with eigenvector accessibility, respectively (Tables 6.4).

The following table 6.4 allows us to analyse and estimate the regression value of eccentricity accessibility and socio-economic attributes. Consequently, a moderate level of association is found for sex ratio (R^2=0.27) and crude literacy rate (R^2=0.17). The response variables of dependency ratio (R^2=0.15) and agricultural working population (R^2=0.10) have a weak association with eccentricity accessibility. But, it is found that there is a very weak association of eccentricity accessibility level with regard to population growth (R^2=0.007).

The results show that each of the parameters has a positive correlation spanning from mild to strong correlations. This means that the intensity of linear relationship varies with changes in the independent and dependent variables, and the association between variables is a product of the relationship between the independent and dependent variables. In other words a change in *X* and *Y* variables have implications on the results of linear correlation between the pair or that similar independent variable produce different results with changes in the values of dependent variables.

Table 6.3: Correlations between Dependent and Independent Variables

Accessibility Measures	Socio-Economic Development Measures (r_s)				
	Population	**Sex**	**Literacy**	**Dependency**	**Agriculture**
Degree	0.17	0.23	0.43	0.37	0.42
Closeness	0.11	0.53	0.54	0.48	0.44
Betweenness	0.26	0.35	0.47	0.40	0.45
Eigenvector	0.07	0.52	0.34	0.38	0.53
Eccentricity	0.08	0.52	0.42	0.39	0.31

Table 6.4: Strength of Relationship between Dependent and Independent Variables

Accessibility Measures	Socio-Economic Development Measures (R^2)					
	Population	**Sex**	**Literacy**	**Dependency**	**Agriculture**	**Average**
Degree	0.03	0.05	0.18	0.14	0.18	0.12
Closeness	0.01	0.28	0.30	0.23	0.2	0.20
Betweenness	0.07	0.12	0.22	0.16	0.21	0.16
Eigenvector	0.005	0.08	0.20	0.19	0.28	0.15
Eccentricity	0.007	0.27	0.17	0.15	0.10	0.14

Table 6.5: Measures of Correlation and Regression

Measures of Correlation and Association			
Range of 'r_s'	Level of Correlation	Range of 'R^2'	Level of Association *
0.80 to 1.00	Very Strong Positive	0.64 to 1.00	Very Strong
0.60 to 0.79	Strong Positive	0.36 to 0.63	Strong
0.40 to 0.59	Moderate Positive	0.16 to 0.35	Moderate
0.20 to 0.39	Weak Positive	0.04 to 0.15	Weak
0.00 to 0.19	Very Weak Positive	0.00 to 0.03	Very Weak

6.5 Relationship between Accessibility Index (A_I) and Socio-Economic Indicators

This section attempts to understand and explain the relationship between *AI* and socio-economic indicators. In this respect, *AI* is considered as independent variable and socio-economic parameters represent the dependent variable. Synthesisation of A_I and D_I parameters provide lucid explanations of the relationship between road network and socio-economic development in the region. In this case pair-wise comparison between the accessibility index rank and socio-economic parameters was carried out for analysing the relationship between the variables. The highest degree of relationship is noticed in crude literacy rate which is about r_s=0.59, followed by agricultural working population r_s=0.54, dependency ratio r_s=0.53 and sex ratio r_s=0.46 (Table 6.6 and Figure 6.6). From the data provided it may be concluded that a moderately positive correlation is found between accessibility and socio-economic attributes like literacy rate, agricultural working population, dependency ratio and sex ratio of the study area. Meanwhile, the association between accessibility and population growth is categorised as weak positive coefficient with a value of about r_s=0.19 (Figure 6.6). This simply means that there is an insignificant relationship between accessibility and population growth in the area. For example, more accessible villages like Aizawl, Saitual, Sihfa, Khanpui and Tuirial etc. have experienced high population growth while the least accessible villages Chawilung, Vanbawng, Sailam, Phulpui and Lamchhip etc. have seen negative or very low population growth during this period. These two factors are significant in effecting a weak relationship between the variables.

The study also employed the regression analysis technique in order to obtain the association between A_I rank index and socio-economic variables and it is important to explain the effect of an independent variable (A_I) on each of the dependent variables such as population growth, sex ratio, crude literacy rate, dependency ratio and agriculture. Accordingly, the study observed that the breakup of R^2 value of dependent variables are literacy rate (R^2=0.349), Agricultural working population (R^2=0.288), Dependency ratio (R^2=0.285) and Sex ratio (R^2=0.215) which are categorised as having moderate associations with independent variables. On the other hand, the association between A_I and population growth (R^2=0.19) is the lowest and is therefore considered to be experiencing moderate association (Table 6.6). In general, the aforesaid statement allows us to predict the levels of association of dependent variables with independent variables such as the impact of accessibility on socio-economic indicators. In other words it shows that the level of accessibility of a particular node has an influence on its socio-economic parameters. It is also found that literacy rate, dependency ratio, agriculture working population and population growth moderately increase with increasing levels of accessibility. But the intensity of change may vary with the value of R^2. For example, in the case of literacy rate when the correlation coefficient values are r_s=0.59 and R^2=0.349 it is revealed that the literacy rate has greater degrees of relationship and association with A_I than compared to other dependent variables (Table 6.6) since the p value between literacy rate and level of accessibility equal p=0.0001 is statistically significant.

The calculation of coefficient correlation between Accessibility Index (A_I) and Development Index (D_I) is an important method to enable the analysis of the relationship and synthesis of variables as numerical units of representation. This is important for the generalisation and better understanding of the relationship between variables. The result substantiates the role that road transport network has in affecting the socio-economic development of the study area. As mentioned in the methodology chapter the study inculcates a stepwise analysis for measuring the level of relationship of road network with socio-economic indicators.

The calculated coefficient of correlation between the ranks A_I and D_I *is* shown to be r_s = 0.73, which is considered as having a strongly positive correlation between the pair (Figure 6.5). The calculated p value is 0.0 or 3.37E-15 which is less than 0.05, indicating that the variables (road network and socio economic development) are statistically significant. It can therefore be argued that road network has significant implications on the socio-economic development of the region. The result also indicates that as the level of accessibility increases, the levels of socio-economic indicators becomes positive thereby the intensity of development increases. Here the R^2 value is found to be about R^2 = 0.538. The analysis also confirms that there is a strong association between the respondent variable and explanatory variable (Table 6.5). Based on this value we can predict that the change in socio-economic development will be R^2 = 0.538 when level of accessibility is increased by one unit. Specifically, a change in the *Y* axis either increased or decreased is proportionate to increased or decreased in one unit of *X* axis is equal to R^2 = 0.538 or an increase in the *X* axis causes an increase in the *Y* axis and a decrease in the *X* axis effects a decrease in the *Y* axis for R^2 = 0.538. This result therefore explains that there is a significant influence of road accessibility on socio-economic development in every village in the network and that there is a need to balance the level of accessibility at different nodes/villages in order to optimise the level of socio-economic development in the district.

Table 6.6: Measures of Correlation and Regression between Mean Accessibility Index (A_I) and Socio-Economic Indicators

Socio-economic Development Parameters	Measure of Associations	
	Rank Correlation	Regression
Population Growth	0.19	0.037
Sex Ratio	0.46	0.215
Literacy Rate	0.59	0.349
Dependency Ratio	0.53	0.285
Agriculture Workers	0.54	0.288

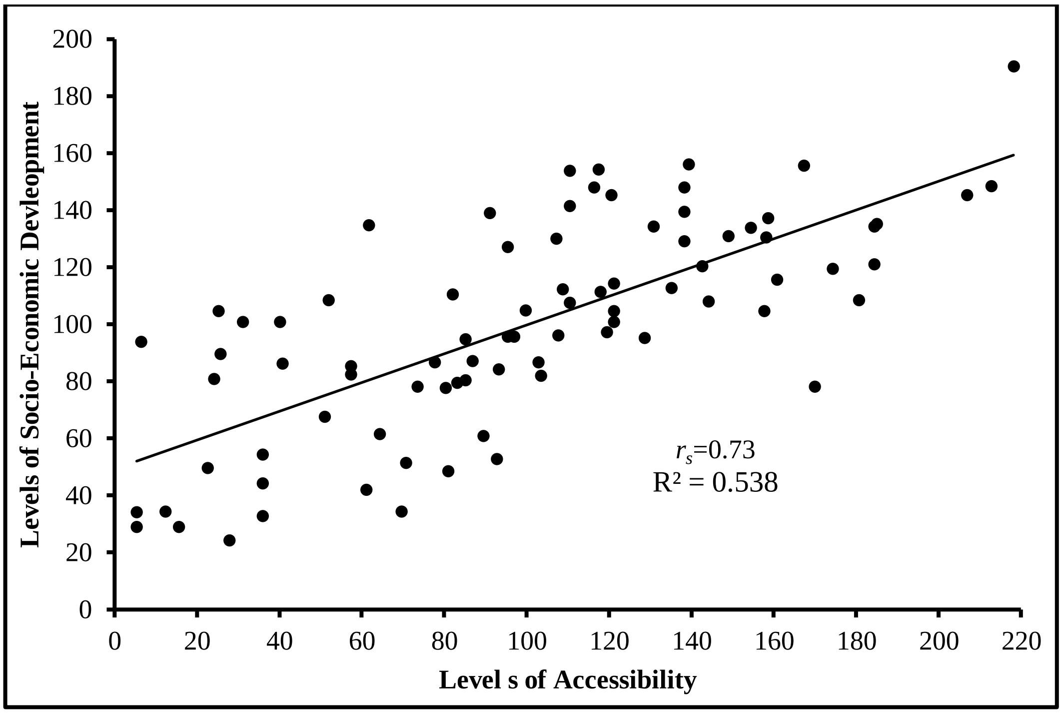

Figure 6.5: Relationship between Mean Accessibility Index (A_I) and Socio-Economic Index (D_I)

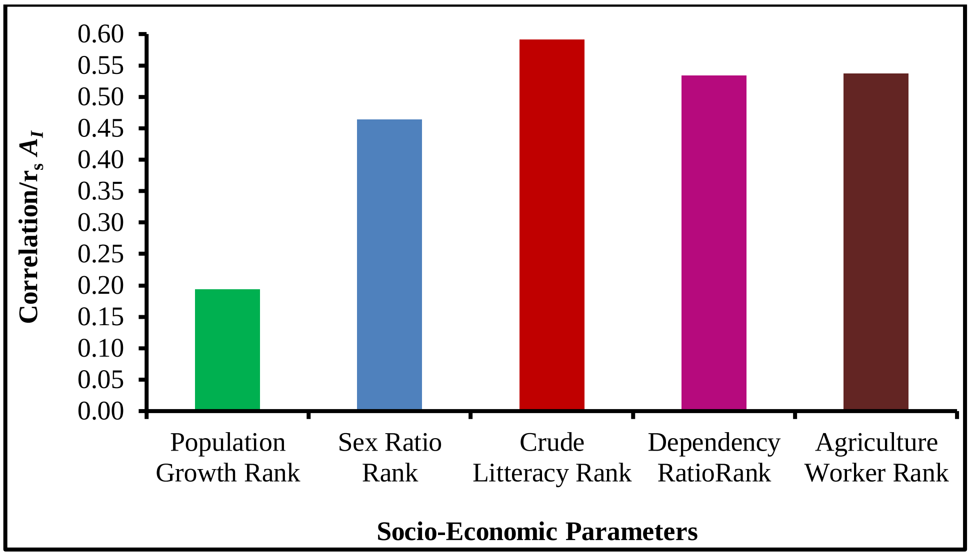

Figure 6.6: Correlation between Mean Accessibility Index (A_I) and Socio-Economic Indicators

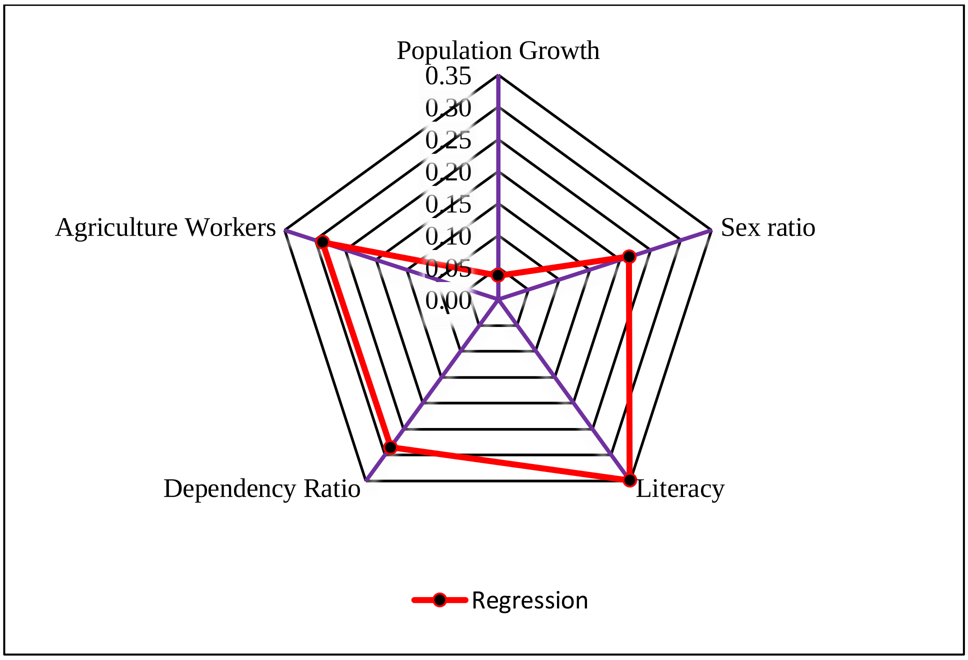

Figure 6.7: Regression between Mean Accessibility Index (A_I) and Socio-Economic Indicators

6.6 Conclusion

From the above analysis, it is found that the key element of socio-economic transformation is the level of accessibility that enables mobility, freight availability, and accessibility of information. High accessibility results in socio-economic development, while less-developed ones have lower level of accessibility. Thus accessibility is linked with the avenues of opportunity, both economic and social. On the other hand, transportation network development follows multiple processes which are dependent on multiplier effects like geographical, social, and economic factors, etc. Physical features hinder development in the transport system and pose many difficulties especially in terms of the mode of transportation, services available, cost, and capacity building. In the upland area, the geographical setting and difficulties in building the necessary infrastructure hinder the development of transportation and communication. Thus the study area being mountainous it becomes apparent that roadways are the only possible modes of transportation and communication. Since road networks are the primary means of transport and communication in the region, a road network therefore becomes an overwhelmingly significant apparatus for transforming the socio-economic circumstances of the area or of a particular places either directly or indirectly.

CHAPTER VII

Conclusion and Suggestions

7.1 Conclusion

The transport network plays a fundamental and crucial role in society by facilitating the efficient movement of people, goods, and information across vast geographical area. The combined impact of transportation and communication significantly affects diverse aspects of society, encompassing economic activities, social interactions, and overall socio-economic development. Geographically, networks serve as a foundation for shaping spatial interactions and relationships across geographic space, leading to diverse degrees of connectivity, accessibility and spatial organization.

The structural configuration of transport networks directly governs patterns of movement, leading to the integration and interaction of distinct spatial entities. The concentration of these interactions at critical nodes, known as vertices, determines the extent of relationships between different geographical areas. Such interactions are influenced by a variety of elements, ranging from geographical features, economy, society, and technology. Consequently, transport geography seeks to investigate the intricate interplay between the structure of road networks and various network properties, highlighting the critical role of transport networks in shaping complex spatial interaction systems.

The research involves both qualitative and quantitative analysis of data gathered from primary and secondary sources. The research utilized both primary and secondary data, which were acquired through field investigations and supplemented with pertinent information obtained from census reports, government departments, and reputable agencies. The study employed three methodological procedures. First, the topological structure of road networks was assessed using network centrality analysis techniques. This analysis served as a tool for modeling the network and evaluating the centrality of each node within it. Second, the research measured the socio-economic development of the study area by defining socio-economic attributes based on the road network and overall development indicators. Lastly, the study integrated these two parameters (network centrality measures and socio-economic development) to create a quantitative unit of measure for addressing the research questions. The collected data underwent processing, tabulation, and analysis using appropriate tools, and the results were visually presented through tables, maps, and statistical illustrations. The study examines how road network attributes influenced on socio-economic development which is the main infrastructural organ for an integrative development of the Aizawl district. Also spatial organisation of road transport network system consisting the structure, topology, accessibility, connectivity and road efficiency are analyzed in greater details.

The study area is predominantly mountainous and is distinguished by mountain ranges and deep river valleys. The elevation in this region averages between 1,000 and 1,300 meters above sea level. These mountain ranges run parallel to each other in a north-south direction. Prominent peaks such as Hmuifang, Tawi, Chalfilh, and Mawmrang are found in the Aizawl district. The drainage systems originate from the central parts of the state, flowing either northward or southward along north-south trending ridges. The area is directly influenced by the southwest monsoon, resulting in a humid tropical climate characterized by heavy rainfall, a short winter, and an extended summer. The soils prevalent in the Aizawl district are largely composed of red and yellow soils. These soils are relatively young and contain high levels of organic matter and nitrogenous materials. According to the 2011 census, Aizawl district holds the highest population density in Mizoram. From 1991 onward, there has been a more pronounced increase in the female population compared to males. The economy Aizawl district is dominated by the agriculture and allied activities. Agriculture plays an important role especially in the rural economy and it also acts as main absorber of the rural labour.

Since the proposed study area is situated in undulating mountainous terrain and its peripheral location, road transport networks become the primary mode of transportation accessible to the masses. Road networks act as the crucial veins or arteries of a region, facilitating the movement of people and goods, and enabling spatial interactions by linking major cities, towns, and villages within and beyond the region. The road transport networks and their interactions can serve as indicators for the socio-economic development of an area, as they provide the essential infrastructure for all kinds of development and strengthen its economic potential. Similarly, it is reasonable to argue that road transport networks significantly contribute to the socio-economic development of both the region as a whole and specific area within it.

Differences in topological structure arise between global and local centrality metrics. Specifically, global measures such as Closeness centrality, Betweenness centrality, and Eccentricity (belonging to the very high and high categories) exhibit a longitudinal distribution, primarily influenced by the arrangement of road segments. Geographical factors play a vital role in segmenting the road network and shaping the spatial distribution or alignment of nodes.

The study highlights the impact of geographic centrality on node centrality distribution. Node centrality types, like global, local, and isolated, relate to their geographic positions. Central and middle network parts house high centrality nodes that significantly influence information flow. Node location shapes information dissemination, with centrality affecting critical node probabilities. Models show efficient information spread regardless of Euclidean distance, but location and centrality also influence spatial heterogeneity. Geographical constraints like topography and population complexity impact the network. Seling and Aizawl are primary hubs offering full services, while Sialsuk and Keifang/Saitual serve as secondary hubs. This efficient network benefits administration, distribution, and services.

The correlation coefficient of centrality metrics quantifies the strength and extent of their relationships. Among these metrics, local centrality measures exhibit stronger associations than global ones. Table 5.8 illustrates positive relationships among all centrality measures, with varying degrees of connection. The highest correlation coefficient is noted between closeness centrality and eccentricity degree, indicating their near identical global nature. Conversely, the lowest correlation exists between degree centrality and eccentricity degree.

The study region exhibited population growth patterns in two specific areas. An urban population led to substantial growth in the central zone, while isolated villages in the northern region see increased population due to improved medical access, aiding natural growth by reducing mortality and increasing life expectancy. The most significant growth occurred in the central part, primarily driven by urbanization process in Aizawl and its surrounding areas. In contrast, the southern and northeastern regions experienced limited growth and decline due to out-migration and low natural growth rate.

Very high and high literacy rates are mostly found in the middle and southern parts of Aizawl district. Literacy rates decrease towards the northern and northeastern areas. The southern and middle regions are more literate due to early educational development, historical and political factors, efforts by Christian Missionaries, urbanization, and urban proximity. Villages in the northern and northeastern areas experience higher illiteracy due to their peripheral location and limited educational resources. Influential factors such as location, urban proximity, early development, and adult education levels are important determinants.

In 49 villages, the female population exceeds the male population, but 41% faced declining female numbers. The middle part of the district notably improved female numbers; sex ratio shifts weakened towards the north and south. The northern and southern regions displayed unfavorable sex ratio shifts. Urbanization drew males from rural to urban areas, positively affecting rural sex ratios. Conversely, in villages with limited female growth, urban migration and inter-village marriages played significant roles.

There is evidence of a change in the dependency ratio from isolated rural regions to densely populated urban areas. Despite being in remote locations, several rural communities in the northeast have observed a significant decline in the dependency ratio. However, these communities still confront economic challenges due to involvement in low-income economic activities. Interestingly, urbanization has heightened the dependency ratio by improving living standards and life expectancy.

In Aizawl district, a noticeable transition of workers from the primary sector to secondary and tertiary activities is apparent. This shift stems from improved road connectivity and education in villages. The integration of non-agricultural endeavors is progressively altering the occupational structure, as more individuals move from basic subsistence farming to economic pursuits offering increased and consistent returns. Two key factors drive changes in occupational structure: rapid economic growth with non-agricultural job opportunities attracting rural workers, and urbanization fostering service-based economy.

The analysis emphasizes that accessibility, enabling mobility, freight access, and information, drives socio-economic transformation. Higher accessibility fuels development, while underdeveloped areas face limited access. Accessibility is vital for economic and social opportunities. Transportation network growth hinges on various factors like geography, social dynamics, and economics. Physical features hinder transport development, creating challenges in mode choice, services, cost, and capacity. In upland regions, geography and infrastructure hurdles hinder transport and communication. Thus, due to the mountainous terrain, roadways are the sole viable transport and communication mode. Road networks, as the primary communication and transport means, play a pivotal role in directly or indirectly transforming socio-economic conditions in the study region.

On the basis of present study, the following discussion cans summarized ongoing chapter in vivid way.

(i) Aizawl district is physically characterised by a hilly and rugged topography which then act as a major constraint to the progress and development of transport networks and systems. Geographical features like drainage, elevation and slope have had significant implications on the prevailing regional inequalities in different spheres.

(ii) The uniformity in physical landforms, common ethnicity and homogeneity of natural environment affords the study area a high degree of consistency in the levels of socio-economic indicators. But, upon close examination, at the macro and micro levels, the dynamics of road network attributes are significantly varied (detailed discussion is done in chapter five and previous section) in the area. Thus, the result might be conducive for aerial differentiation in socio-economic development.

(iii) Even as the importance of road transport network for the region is irrefutable, the process of road transport development was slow in terms of their horizontal and vertical expansion. As a consequence, it appears that the level of socio-economic development was minuscule and solely depended on the local subsistence economy.

(iv) Generally speaking, the economy of the district is mainly characterised by a rural economy which is basically engaged in agriculture with a subsistence type of production. As per the 2011 Census records, there are four notified towns in Aizawl District - Aizawl, Darlawn, Sairang and Saitual. Excluding the Aizawl town area, it is fair to argue that studying the effect of a town-economy on the socio-economic status of the surrounding areas is imperative.

(v) In rural areas shifting cultivation is extensively and dominantly practiced in the hill slopes in order to raise crops like rice, maize, ginger and vegetables and all these are mostly produced on a subsistence basis. In some areas agricultural produce and forest produce are marketed to nearby towns and appropriate places that in turn results to the establishment of a semi-commercial system which is mainly because of improvement in road network accessibility.

(vi) The socio-cultural characteristics are essentially uniform throughout the area which is dominated by tribal traditions, customs and organisation systems. It is manifested in the use of traditional technology and indigenous tools in their agricultural pursuits. However, an increase in the population and changes in the socio-economic conditions (urbanisation) have persuaded and encouraged the adoption of modern techniques (in minimum quantity or mixing with traditional methods) in agriculture and allied activities in order to increase production.

(vii) As a consequence, the production performance of the agriculture sector has followed an uneven path and large gaps have developed in productivity between different geographic locations across the district.

(viii) The spatial location of the points indicated that the development of road network has impact on establishment of non-agriculture based economy in nature, road based economy like businesses and services sector are developed in particular.

(ix) Regardless of the insubstantial progress in road transport development in the region, nevertheless a road transport network is an essential component since it is the only feasible means by which mobility and communication can be made possible. However, all the nodes in the network have the potential to interact with each other either directly or indirectly. The study assumes that the socio-economic conditions of a node (village) depend on the levels of accessibility it holds and is the product of the degree of interactions of one node with other nodes in the network.

(x) Betweenness centrality measures how often a node acts as a bridge along the shortest path between two other nodes. Nodes with higher betweenness centrality have more control over the flow of information and commodities because they lie on critical paths. Seling has 917 more effective or betweenness degrees than Aizawl, it suggests that Seling plays a more crucial role in connecting different parts of the network and controlling the flow of information and commodities.

(xi) The accessibility and efficiency of node depend on the number of interaction of the ones with other nodes, or the ability to reach a node is proportional to the proximity of other nodes. In this context, the level of accessibility refers to the ease of reaching a destination through the shortest path in the network (especially on the road transport and communication facilities) or the availability of a short route to a node.

(xii) The analysis validated a significant correlation between transportation and development, particularly in relation to the spatial arrangement of socio-economic factors. It can be asserted that this relationship may or may not follow a linear pattern in Aizawl district. The impact of spatial interaction and accessibility levels distinctly shape socio-economic development, encompassing both negative and positive aspects.

The results show that centrality measures are effective for differentiating road network topological structures. Specifically, geographical factors proficiently portray the form and configuration of road networks. This is due to the fact that the distribution of centrality values in the network is influenced by the region's topography. Moreover, the road network structure of the Aizawl district can be used as an indicator of socio-economic development levels, as road networks with similar A_I values also exhibit similar levels of D_I values. Correlation analysis additionally validates the statistically significant connection between road network attributes and the level of socio-economic development. As a result, this research offers a lucid perspective for understanding the association between road networks and socio-economic development. Additionally, it enhances the existing methodologies for studying road networks and socio-economic development in the field of geography.

7.2 Suggestions

The road network has significant implications on spatial interaction, connectivity, and accessibility of spaces. These factors subsequently influence different facets of regional growth and societal welfare. Especially, the implications of centrality measures for road network analysis help to quantify the importance and connectivity of individual road segments or nodes within a network, which is more significant for spatial planning. The key suggestions are highlighted as follows:

(i) The study area is characterized by rugged and undulating topography; establishing a road network proves to be a challenging task. However, the significance of this endeavor is even more pronounced compared to that in other types of landforms. The study proposes that the road network should be strategically aligned to support regional development and enhance the local community. This approach would facilitate the sustainable use of resources and enhance the road networks resilience.

(ii) The study recommends the application of centrality measures to foster road network planning. These techniques help us avoid unnecessary and underutilization of the road network. Centrality measures, such as betweenness centrality and closeness centrality, help identify critical road segments or nodes that act as hubs for traffic flow. Also, centrality measures assist in identifying optimal locations for key facilities, such as hospitals, public distribution centers, emergency services, and administrative towns. Planners can focus on upgrading or expanding these central elements to improve overall mobility, reduce travel times, and enhance accessibility.

(iii) Strategic road network planning should be implemented for spatial planning. It is necessary to ensure easy access to essential services such as healthcare, emergency services, education, markets and public facilities. This enhances social equity and improves the overall standard of living.

(iv) By identifying areas with low accessibility, spatial planners can target infrastructure investments to reduce transportation inequalities. This helps ensure that all settlements, regardless of their location, have equitable access to vital services and opportunities.

(v) Identifying central road segments aids emergency response planning. Emergency services can prioritize routes that are highly connected and efficient, enabling faster response times during crises.

(vi) The study reveals Aizawl as the central hub within the studied network, providing comprehensive services throughout. However, this centrality poses challenges for peripheral or isolated nodes, hindering their access to essential services. To address these disparities and facilitate socio-economic development across the network, the establishment of minor hubs would become as a crucial strategy. These minor hubs should be strategically located, with sites such as Sialsuk serving the southern region, Seling for the central area, and Keifang/Saitual and Darlawn for the eastern and northern parts, respectively.

(vii) The geographical challenges within the study area necessitate the implementation of hub-and-spoke road network planning. Regarding interaction, the hub-and-spokes network system proves to be more efficient and facilitates the optimal use of transport network in the study are. Additionally, hub-and-spoke based road network planning offers numerous advantages for socio-economic development. These include improved transportation accessibility and efficiency, enhanced access to services and markets, cost-effective infrastructure development, stimulation of trade and commerce, regional development, as well as enhanced connectivity and integration.

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[1] Manual extraction applied visual interpretation and digitization methods to extract road network data from the image or geographic information platform.

[2] Semi-Automatic and Automatic network data extraction is an object based data extraction method. It involves applications of extraction algorithms for edge detection for removing undesirable objects from the image.

[3] Primal Graph illustrated junctions, settlement and intersections etc. are in the form of nodes and roads are illustrated by edges.

[4] Dual graph model exemplified roads by nodes and junctions are represented by edges.

[5] Undirected Graph is also called simple graph, without self-loops $\{v_i, v_i\}$ and, flow of information is free to move both directions.

[6] Path is considered as a road connected between the villages.

[7] When vertices v_i and v_j is connected by edge e_i, then vertices v_i and v_j are adjacent vertices.

[8] In connected graph every point/vertex on the graph is designed to accessible from the any other point/vertex through edges.

[9] Centrality is the concept, deal with the location and position of vertex and edge on the entire network system.

[10] Gephi is one of the popular tools for data analysts and to explore and understand graphs.

[11] Centrality Measure is mathematical equations referring the location and position of point in network.

[12] The highest valued component is the most central and is considered as the eigencentre of the graph.

[13] Vertexes with similar classes or vertexes fall under similar class may have different values, i.e. within very high, high and so on.

[14] Hub and spoke" is a term often used to describe transportation or communication system structure where there is a central hub or node that is connected to various peripheral nodes or spokes.

[15] Partly subsistence and partially commercial

[16] Relative accessibility can be assumed as the degree to which two points (or places) on the same surface are connected.

[17] Integral accessibility refers a given point as the degree of interconnection with all other points on the same surface.

APPENDICES

Appendix I: Network Centrality Values

Sl. No.	Name of Village	Network Centrality Parameters				
		Degree	Eccentricity	Closeness	Betweeness	Eigenvector
1	Aizawl	7	23	0.1085	2286	1.0000
2	Hualngohmun	2	24	0.1026	1628	0.4230
3	Melriat	2	25	0.0971	1575	0.2079
4	Kelsih	2	26	0.0920	1520	0.1355
5	Falkawn	2	27	0.0872	1463	0.1152
6	Muallungthu	2	28	0.0828	1404	0.1137
7	Tachhip	2	29	0.0786	1343	0.1247
8	Aibawk	2	30	0.0748	1280	0.1567
9	Sateek	3	31	0.0712	1229	0.2297
10	South Maubuang	2	33	0.0639	425	0.1815
11	Thiak	2	34	0.0606	343	0.1475
12	Sumsuih	2	35	0.0577	263	0.1603
13	Hmuifang	3	36	0.0551	198	0.2192
14	Chamring	2	36	0.0551	25	0.2156
15	Sialsuk	4	35	0.0579	286	0.2865
16	Sailam	1	36	0.0548	0	0.1201
17	Samlukhai	2	34	0.0608	353	0.2258
18	Lungsei	1	34	0.0603	0	0.1056
19	Phulpui	1	32	0.0665	0	0.0982
20	Lamchhip	2	37	0.0523	95	0.1249
21	Chawilung	1	38	0.0497	0	0.0579
22	Samtlang	2	24	0.0982	95	0.3930
23	North Lungleng	1	25	0.0895	0	0.1365
24	Sairang	3	24	0.0984	189	0.4621
25	Sihphir	2	24	0.0982	95	0.3930
26	Muthi	1	24	0.0980	0	0.3427
27	Tuirial	2	22	0.1124	2079	0.5362
28	Seling	4	21	0.1164	3203	0.5363
29	Thingsultlangnuam	2	22	0.1053	368	0.2585
30	Thingsulthliah	2	23	0.0959	279	0.1510
31	Tlungvel	2	24	0.0879	188	0.1072

32	Phulmawi	2	25	0.0810	95	0.0775
33	Saitual/Keifang	3	22	0.1106	1953	0.4188
34	Rulchawm	2	23	0.1009	540	0.2275
35	Ruallung	2	24	0.0927	455	0.1680
36	Mualpheng	2	26	0.0791	188	0.1239
37	Tawizo	2	27	0.0735	95	0.0858
38	Maite	1	28	0.0685	0	0.0450
39	Lenchim	1	26	0.0788	0	0.0790
40	Dilkhan	4	24	0.0970	1321	0.3743
41	North Lungpher	2	25	0.0886	95	0.1819
42	Buhban	1	26	0.0815	0	0.0755
43	Tualbung	1	25	0.0885	0	0.1476
44	Sihfa	1	24	0.0939	0	0.1363
45	Sesawng	2	20	0.1114	1943	0.2605
46	Mualmam	2	19	0.1065	1904	0.1588
47	Thanglailung	2	25	0.0905	1008	0.2605
48	Phullen	3	26	0.0847	965	0.2734
49	Luangpawn	1	28	0.0731	0	0.0962
50	Phuaibuang	2	28	0.0734	279	0.1505
51	Khawlian	2	29	0.0686	188	0.1107
52	NE. Tlangnuam	2	30	0.0643	95	0.0793
53	Daido	1	31	0.0605	0	0.0427
54	Zawngin	2	27	0.0786	368	0.1714
55	Suangpuilawn	2	28	0.0733	279	0.1250
56	Lamherh	2	29	0.0685	188	0.1004
57	Vanbawng	2	30	0.0643	95	0.0759
58	North Khawlek	1	31	0.0604	0	0.0418
59	Khawruhlian	2	20	0.1019	1863	0.1314
60	Hmunnghak	2	21	0.0975	1820	0.1381
61	Khanpui	3	22	0.0932	1799	0.1659
62	Lailak	1	23	0.0853	0	0.0781
63	Pehlawn	2	23	0.0890	1679	0.1354
64	East Phaileng	2	24	0.0850	1628	0.1197
65	Kepran	2	25	0.0812	1575	0.1163
66	Sawleng	2	26	0.0775	1520	0.1264
67	Darlawn	2	27	0.0741	1463	0.1574
68	North Serzawl	1	30	0.0623	0	0.0803

69	Sunhluchhip	1	30	0.0623	0	0.0803
70	Sailutar	2	29	0.0676	1148	0.1586
71	Ratu	2	30	0.0644	1079	0.1312
72	Lungsum	2	31	0.0615	1008	0.1321
73	New Vervek	2	32	0.0588	935	0.1631
74	Sakawrdai	3	33	0.0562	876	0.2372
75	Vaitin	2	34	0.0533	95	0.1328
76	Khawpuar	1	35	0.0506	0	0.0605
77	North Khawdungsei	1	35	0.0509	0	0.1048
78	Zohmun	2	36	0.0489	279	0.1659
79	Palsang	1	38	0.0447	0	0.0694
80	Mauchar	1	38	0.0447	0	0.0694
81	North Thinghmun	1	36	0.0487	0	0.0965
82	Chhanchhuahna Khawpui	1	30	0.0623	0	0.0803
83	Thingsat	1	33	0.0562	0	0.0965

Appendix II: Village wise Socio-Economic Attributes

Sl. No.	Name of Village	Socio-Economic Development Parameters				
		Population Growth	Literacy Rate	Sex Ratio (Δ)	Dependency Ratio (Δ)	Agriculture Workers (Δ)
1	Aizawl	28.55	86.96	5.86	13.04	-42.42
2	Hualngohmun	13.79	86.44	3.90	14.90	-36.15
3	Melriat	17.57	86.16	0.93	24.66	-28.60
4	Kelsih	8.39	83.97	0.17	16.10	-20.53
5	Falkawn	33.09	85.88	10.50	18.50	-16.17
6	Muallungthu	16.47	83.19	7.63	15.94	-15.99
7	Tachhip	10.08	85.35	1.38	47.89	-15.83
8	Aibawk	0.53	85.89	7.02	54.81	-15.26
9	Sateek	0.47	86.15	2.37	17.60	-14.98
10	South Maubuang	12.24	82.33	5.26	64.36	-14.70
11	Thiak	3.88	83.18	1.63	48.31	-14.70
12	Sumsuih	14.46	82.93	-0.86	118.73	-14.40
13	Hmuifang	26.96	80.14	0.41	44.27	-12.93
14	Chamring	32.60	77.41	-2.28	114.97	-12.41
15	Sialsuk	-10.21	85.70	-1.80	22.43	-12.03
16	Sailam	6.45	81.10	-2.15	63.94	-11.67
17	Samlukhai	1.91	80.36	-6.61	44.96	-11.58
18	Lungsei	3.00	82.92	-0.76	53.51	-11.52
19	Phulpui	7.52	82.70	-3.97	26.11	-11.38
20	Lamchhip	3.81	84.20	-11.43	36.21	-10.76
21	Chawilung	-18.10	85.18	-6.49	74.23	-10.62
22	Samtlang	21.32	88.86	8.63	16.63	-10.49
23	North Lungleng	36.25	81.31	-2.09	29.44	-10.39
24	Sairang	11.55	81.80	26.84	16.59	-10.34
25	Sihphir	8.06	85.07	3.97	27.97	-10.32
26	Muthi	36.39	82.58	3.31	20.94	-9.97
27	Tuirial	43.97	86.01	5.29	24.48	-9.85
28	Seling	-20.31	87.07	66.27	12.20	-9.79
29	Thingsul Tlangnuam	18.43	86.58	1.87	21.84	-9.66
30	Thingsulthliah	-3.13	83.40	25.33	119.29	-9.55
31	Tlungvel	6.85	83.69	4.31	119.49	-9.41

32	Phulmawi	6.95	82.67	-9.58	171.70	-9.12
33	Saitual/Keifang	11.45	83.39	8.49	27.34	-8.99
34	Rulchawm	7.31	83.29	-0.16	2.37	-8.93
35	Ruallung	3.98	85.17	0.56	14.96	-8.64
36	Mualpheng	13.45	82.56	-0.38	-1.20	-8.60
37	Tawizo	47.54	80.67	-1.37	84.43	-8.37
38	Maite	27.11	80.68	5.67	28.11	-7.70
39	Lenchim	11.18	82.54	1.20	116.50	-7.57
40	Dilkhan	15.98	84.44	0.42	-39.29	-7.49
41	North Lungpher	25.29	75.96	1.90	-1.12	-7.22
42	Buhban	3.25	84.08	-8.67	47.21	-7.19
43	Tualbung	11.35	80.34	5.34	68.06	-7.15
44	Sihfa	-2.94	85.07	4.31	39.46	-6.72
45	Sesawng	14.79	79.88	4.94	54.31	-5.55
46	Mualmam	110.98	83.24	7.55	83.95	-5.51
47	Thanglailung	19.48	86.11	-2.90	22.56	-5.36
48	Phullen	12.74	85.09	-0.51	55.20	-5.12
49	Luangpawn	22.14	76.76	-4.86	30.46	-4.49
50	Phuaibuang	-2.24	80.51	1.30	190.46	-4.49
51	Khawlian	7.32	79.60	2.47	128.44	-4.10
52	NE. Tlangnuam	17.29	80.55	-5.64	114.30	-3.56
53	Daido	22.81	81.59	10.19	-0.31	-3.14
54	Zawngin	17.52	74.55	7.28	-10.94	-2.91
55	Suangpuilawn	-0.92	81.32	3.47	-18.03	-2.75
56	Lamherh	30.57	74.92	14.13	44.31	-2.60
57	Vanbawng	-3.22	82.62	10.49	-24.45	-2.31
58	North Khawlek	11.45	78.54	8.21	82.40	-2.30
59	Khawruhlian	2.18	85.22	5.10	16.11	-1.60
60	Hmunnghak	-4.24	80.38	0.59	21.29	-1.59
61	Khanpui	13.99	85.06	1.00	24.96	-1.19
62	Lailak	81.00	73.47	19.70	108.07	-0.76
63	Pehlawn	13.04	81.17	16.81	47.32	-0.75
64	East Phaileng	4.20	83.79	-0.18	30.13	-0.50
65	Kepran	-5.85	82.91	-5.56	116.14	-0.17
66	Sawleng	2.25	83.68	9.14	18.56	0.23
67	Darlawn	-3.23	81.14	5.93	24.13	0.36
68	North Serzawl	15.58	75.54	-13.31	46.30	0.59

69	Sunhluchhip	36.21	71.13	2.76	128.53	0.71
70	Sailutar	15.27	77.99	3.59	-12.77	1.23
71	Ratu	-3.89	78.58	-0.47	50.97	1.24
72	Lungsum	8.97	76.03	-9.66	73.54	1.50
73	New Vervek	12.12	73.23	-0.33	57.05	1.54
74	Sakawrdai	24.13	83.01	-0.04	28.63	1.86
75	Vaitin	17.60	77.92	0.54	187.51	2.18
76	Khawpuar	38.65	76.62	-15.47	75.30	4.99
77	N. Khawdungsei	66.23	79.68	-0.60	72.97	5.84
78	Zohmun	37.49	77.48	-2.74	98.92	6.30
79	Palsang	45.10	79.19	-4.74	117.25	11.54
80	Mauchar	45.51	77.15	-5.36	139.94	14.88
81	North Thinghmun	42.88	78.58	-2.80	133.42	19.82
82	Chhanchhuahna Khawpui	27.62	76.12	-2.53	116.33	22.48
83	Thingsat	15.79	74.68	-10.65	132.30	38.00

Appendix III: Village wise Mean Accessibility Index (A_I) and Mean Socio-Economic Development Index (D_I)

Sl. No.	Name of Village	A_I	D_I	Sl. No.	Name of Village	A_I	D_I
1	Aizawl	212.83	148.57	43	Tualbung	85.24	94.76
2	Hualngohmun	167.27	155.71	44	Sihfa	91.14	139.05
3	Melriat	149.04	130.95	45	Sesawng	180.67	108.57
4	Kelsih	130.81	134.29	46	Mualmam	169.95	78.10
5	Falkawn	116.34	148.10	47	Thanglailung	142.60	120.48
6	Muallungthu	110.44	141.43	48	Phullen	160.83	115.71
7	Tachhip	107.22	130.00	49	Luangpawn	50.93	67.62
8	Aibawk	110.44	153.81	50	Phuaibuang	102.93	86.67
9	Sateek	139.39	156.19	51	Khawlian	83.10	79.52
10	South Maubuang	97.04	95.71	52	NE. Tlangnuam	64.33	61.43
11	Thiak	82.02	110.48	53	Daido	25.20	104.71
12	Sumsuih	77.74	86.67	54	Zawngin	117.94	111.43
13	Hmuifang	103.47	81.90	55	Suangpuilawn	95.43	127.14
14	Chamring	69.69	34.45	56	Lamherh	80.42	77.62
15	Sialsuk	120.62	145.24	57	Vanbawng	61.65	134.76
16	Sailam	25.73	89.52	58	North Khawlek	24.12	80.95
17	Samlukhai	93.28	84.29	59	Khawruhlian	158.69	137.14
18	Lungsei	31.09	100.95	60	Hmunnghak	157.62	104.71
19	Phulpui	40.21	100.95	61	Khanpui	184.42	120.95
20	Lamchhip	52.00	108.57	62	Lailak	73.45	78.10
21	Chawilung	6.43	93.81	63	Pehlawn	144.21	108.10
22	Samtlang	138.32	148.10	64	East Phaileng	128.67	95.24
23	North Lungleng	85.24	80.48	65	Kepran	121.16	104.76
24	Sairang	174.23	119.52	66	Sawleng	117.41	154.29
25	Sihphir	138.32	129.05	67	Darlawn	121.16	114.29
26	Muthi	110.44	107.62	68	North Serzawl	35.92	44.29
27	Tuirial	184.42	134.29	69	Sunhluchhip	35.92	54.29
28	Seling	218.20	190.48	70	Sailutar	108.83	112.38
29	Thingsul Tlangnuam	158.15	130.48	71	Ratu	95.43	95.71
30	Thingsulthliah	135.10	112.86	72	Lungsum	89.53	60.95
31	Tlungvel	107.76	96.19	73	New Vervek	92.75	52.86

32	Phulmawi	86.85	87.14	74	Sakawrdai	121.16	100.95
33	Saitual/Keifang	206.94	145.24	75	Vaitin	61.12	41.90
34	Rulchawm	154.40	133.81	76	Khawpuar	12.33	34.45
35	Ruallung	138.32	139.52	77	North Khawdungsei	22.52	49.52
36	Mualpheng	99.72	104.84	78	Zohmun	70.77	51.43
37	Tawizo	80.95	48.57	79	Palsang	5.36	34.05
38	Maite	40.74	86.19	80	Mauchar	5.36	29.05
39	Lenchim	57.36	82.38	81	North Thinghmun	15.55	29.05
40	Dilkhan	184.96	135.24	82	Chhanchhuahna Khawpui	35.92	32.86
41	North Lungpher	119.55	97.14	83	Thingsat	27.88	24.29
42	Buhban	57.36	85.24	-	-	-	-

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Bio-data

A. Personal Informations

Name : Zoramkhuma

Date of birth : 24th August, 1988

Father's Name : Lalvulthanga

Mother's Name : Chawngchhingi

Contact number : 8732078104

Email address : zoramkhum24@gmail.com

Permanent address : NE. Khawdungsei, Siatual District, Pin-796290

Temporary address : Kolasib, Venglai

Marital status : Single

Religion : Christianity

Nationality : Indian

B. **Educational Qualification**

Master of Science (Geography), Master of Philosophy (Geography)

C. Academic Profile

<table>
<tr><th colspan="2">Degree</th><th>Institution</th><th>Year</th><th>Details</th></tr>
<tr><td colspan="2">B.A</td><td>Pachhunga University College</td><td>2009</td><td>First Class</td></tr>
<tr><td colspan="2">M.Sc.</td><td>Mizoram University</td><td>2011</td><td>First Class</td></tr>
<tr><td rowspan="2">Others</td><td>M.Phil</td><td>North Eastern Hill University</td><td>2013</td><td>A</td></tr>
<tr><td>PGD in Geo-informatics</td><td>North Eastern Hill University</td><td>2015</td><td>O</td></tr>
</table>

D. List of Publications

Year	Title	Publishers/Journals
July, 2017	GIS Base Assessment of Ground Water potential in Tlawng Watershed	Geographic, ISSN O975 - 4121
May, 2018	Spatial-Temporal Variations of Agricultural Productivity in North East India: Agro-Ecological Zone Analysis	Proceedings of the national Seminar on Shifting Cultivation and its impact on Environment in North-East India, 15th - 16th ,March, 2018, ISBN-9788193508350
July, 2019	Nodes Centrality in Urban Road Network, Aizawl City with Network Centrality Measures	Geographic, ISSN O975 - 4121
April 2023	Slake Durability and Point Load Indices of Shale in Zuangtui Sliding Area, Aizawl, Mizoram	Science Vision, ISSN (Print) 0975-6175, ISSN (Online) 2229-6026
April 2023	Characteristics of Soil with Seasonal Change and their Effects on Slope Stability	Science Vision ISSN (Print) 0975-6175, ISSN (Online) 2229-6026
July, 2023	Node Centrality and Road Accessibility in Mountainous Area: a Study of Aizawl District, Mizoram	Geographic, ISSN O975 – 4121

E. Conference/Workshop/Seminar etc. Attended as Resource Person

Date	*Name*	*Organizer*
15th – 16th, March, 2018	National Seminar on Shifting Cultivation and its Environmental Impact in North-East India	Dept. of Geography, Pachhunga University College
10th – 14th February, 2020	National Workshop on Geo-Spatial Technology	Dept. of Geography, Pachhunga University College
31st July, 2020	Hands-on Workshop on Geographic Information System Using Qgis	Developmental Biology and Herpetology Laboratory, Department of

		Zoology, Mizoram University
24^{th} – 25^{th}, March, 2022	National Seminar on Climate and Development Interface	Department of Geography, Govt. Aizawl North College & State Institute of Rural Development and Panchayati Raj
23^{rd} to 27^{th}, May, 2022	Geoinformatics Hands-on Training/Workshop	Geoinformatics Laboratory, Department of Environmental Science, Pachhunga University College
26^{th} – 27^{th} April, 2023	National Seminar on Climate Change, Environment & Development: Indian Perspectives,	Department of Geography & RM, Mizoram University

Particulars of the Candidate

Name of Candidate: Zoramkhuma

Degree: Doctor of Philosophy (Ph.D.)

Department: Geography and Resource Management

Title of Thesis: Role of Road Transport Network on Socio-Economic Development of Aizawl District, Mizoram

Date of Admission	: 22/08/2016
Approval of Research Proposal:	
Departmental Research Committee	: 14th March, 2017
Board of Studies	: 28th April, 2017
School Board	: 31st May, 2017
Mzu Registration No.	: 1703913
Ph.D Registration No.	: MZU/Ph.D./1030 of 31.05.2017
Extension	: No.16-2/MZU(Acad)/21/179-182, Dated. 30th August, 2022

Head

Department of Geography and Resource Management

ABSTRACT

ROLE OF ROAD TRANSPORT NETWORK ON SOCIO-ECONOMIC DEVELOPMENT OF AIZAWL DISTRICT, MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

ZORAMKHUMA

MZU REGISTRATION NO.: 1703913

Ph.D REGISTRATION NO.: MZU/Ph.D./1030 of 31.05.2017

DEPARTMENT OF GEOGRAPHY AND RESOURCE MANAGEMENT

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCE MANAGEMENT

AUGUST, 2023

ROLE OF ROAD TRANSPORT NETWORK ON SOCIO-ECONOMIC DEVELOPMENT OF AIZAWL DISTRICT, MIZORAM

ZORAMKHUMA

Department of Geography and Resource Management

Name of supervisor: Prof. Benjamin L. Saitluanga

Submitted

In partial fulfillment of the requirement of the degree of Doctor of Philosophy in Geography of Mizoram University, Aizawl

Introduction

Transport networks create patterns of linkages and spatial interactions that shape the movement of people, goods, and information. These networks serve as the backbone of social and economic activities, facilitating the flow of population, commodities, and information across different spaces. Transport network is a critical component of human society. Transportation facilitates the movement of people, goods, and information across geographical spaces. It plays a key role in shaping societies throughout history by influencing social interactions and thereby socio-economic development. The transport network overcomes the spaces that are brought on by both human and physical constraints and includes distance, time, administrative divisions and topography. It transforms space across different dimensions and having significant impact on the transformation of the space over which relationships and interactions occur. Interaction of one point with another through a network creates connectivity of one point with another, and forms a spatial network and a spatial interaction system which then becomes the central medium of the mobility of information, population, freight, and flow of commodity etc. The location and position of the node in the network reflect the efficiency and intensity of the interaction. According to the intensity and efficiency of the interaction of a particular node (village) in relation to other nodes in the network the level of node accessibility varies. Accessibility varies according to one's own location within the network system. Basically, all the locations (node) in the network have different levels of accessibility, but some are more accessible than others in the network (considered as locational advantage of a node). Thus, in transport network some mode of transportations is perceived as more significant than others due to its geographical hindrance of the region.

Geographers examine the location, accessibility, and spatial organization of transportation nodes, such as ports, terminals, and transport hubs. Geography tries to understand the link between transport networks and the surrounding environment, such as physical and social environments to understand the transport network and its multifaceted effects on human society. In Aizawl district the geographical situation impedes the building up of modern transport and communication infrastructures

Road transport networks serve as catalysts for connectivity and accessibility, bridging the gap between remote/isolated areas and more accessible areas. Road transportation provides isolated regions with improved access to essential services such as education, healthcare, and markets, and road networks improve connectivity, accessibility, and other development needs that promote social experience in positive ways. This connectivity drives mobility, trade, and commerce, which stimulate socio-economic growth and create employment opportunities, ultimately leading to poverty reduction and improved living standards. Road systems enhance rural agricultural marketing and food security. It also facilitates the access of farmers to essential inputs, such as fertilizers, seeds, and tools, thereby enhancing agricultural productivity. Thus, an efficient transport network is essential for maintaining and improving the socio-economic conditions of a village and ensuring sustainable socio-development.

In this research work, the role of road transport networks on socio-economic development is considered as the topic of attention for two main reasons. First, road transport networks and their components - the network, junctions, infrastructure, and equipment–are considered important determinants of spatial interaction and controlling the flow of resources, consequently form the basis of a complex spatial system. Second, since geography is considered as the study of spatial relationships, the analysis of road transport networks is of specific interest because they are the major inducers of these interactions. Similarly, this study presumes that road transport networks are the primary means of connecting local resources, infrastructure, and people to distant locations and population centers.

Statement of the Problem

Since the advent of the human race, the means of transport have been evolving in accordance with the development in science and technology. Road transport network plays a critical role in regional socio-economic development with respect to space and time. Owing to physical and economic strains, road transport is the only vital means mobility in Mizoram. Hence, the road network structure and accessibility of the region or nodes play an important role in the socio-economic development of the region. The entire gamut of geographical, economic, social, and cultural interaction provided by road network has been significant for the region’s socio-economic development.

Transport network not only provides mobility for people and their goods between fixed points over time and distance but also determines future growth and development of the region. The geographical location and opportunities may influence the entire development of the region. Also, the structure of the road network might give locational advantages than others for socio-economic development. The existing literatures argue that road network structure and accessibility are the product of the geographical characteristics of the area as well as its degree of socio-economic viability (Yang *et. al*, 2008; Kumar and Sen 2014; Jain and Dhiman, 2017; Li *et. al*, 2018). On the other hand, in a network, one must be located in a specific location that has significance for accessibility, interaction, and efficiency compared to the other nodes in the network. Especially in this proposed study area, the road transport network enables the topological structure of the network, which has implications for socio-economic development in relation to the levels of interaction and accessibility of various nodes in the network. To understand the levels of socio-economic development in a region, it is important to analyze the geographical location, topological structure of the network, accessibility, spatial interaction patterns and opportunities. By investigating the impact of spatial interaction and accessibility, we can identify areas for improvement to facilitate the growth and socio-economic development of the region.

In the present stage of development, the road network is a major channel for both inter and intra-village transportation of people and goods. On the other hand, spatial variations in road network structure and accessibility over space may lead to regional variations in socio-economic development in the proposed study. Meanwhile, the entire structure and accessibility of the road network may be determined by geographical phenomena. Keeping the above discussion in mind, the study would analyze the role of the road transport network on the socio-economic development of Aizawl district, Mizoram, which is expected to yield valuable conclusions.

Scope of the study

Transport networks play important roles in the development and changes of socio-economic and cultural spheres. Due to the existing transport planning, unequal geographical landforms, and rugged topography, the structure and accessibility of road network varied depending on the availability and locations of the vertex and edge in the proposed study area. The location of vertexes and edges varies depending on the geographical landforms in the proposed study area. The structure of road network determines various structural properties of transport network, such as connectivity, accessibility, and efficiency, which may be determined by geographical factors in the region. Thus, topological and structure analysis of road network is needed to address for investigating socio-economic development processes in the district.

It appears that the road network plays a determining role in regional characteristics and economic structure. The patial variations in connectivity, accessibility, and efficiency of vertexes and edges play a significant role in the development of a particular region. Network structure and accessibility of the region or an area does not only produce tangible produce and is also useful for satisfying some other need. The proposed study seeks to examine the spatial interaction of accessibility of road network and economic structure in the proposed study area. Understanding the relationship between nature of road network structure and accessibility of the road network and its mechanisms may provide the principle forces and variations in the proposed study area. The nature of the road network and accessibility may lead to the formation of specialisation in the region. Such findings may gather essential information for forecasting or predicting future road network growth and demand, policy formulation in the future, and planning action to achieve sustainable economic development in the proposed study area.

Both primary and secondary data sources are used in the proposed effort. This study utilizes appropriate statistical methods and tools for improved analysis, comprehension, and illustration. Remote sensing, geographic information systems (GIS), and network visualization and exploration software play an important role in this research, offering effective tools that have been extensively used for spatial data integration and data mining. The study also incorporated statistical approaches and suitable cartographic methods with the help of reliable network analysis software and GIS software. These tools assist in recognizing spatial patterns, connectivity connections, and potential congestion zones. It also helps us network visualization and handling complex network issues and data modelling.

Objectives

The objectives of the research are as follows:

1) To examine the characteristics of road transport network in the study area.
2) To analyze spatial variations of road network structure in the study area.
3) To analyze the spatial pattern of accessibility of the study area in terms of linkage relationship and efficiency.
4) To examine the socio-economic significance of road network in the study area.
5) To make appropriate suggestions on road transport network for spatial planning and development.

Study Area

Aizawl district is located in the northeastern state of Mizoram, India. The district is geographically situated between 23° 18′ N - 24° 25′ N latitudes and 92° 37′ E - 93° 11′ E longitudes. It is one of the eight districts of Mizoram and is the biggest and most populous district of the state. The district is home to several small towns and villages, including the capital city of Aizawl, which is the largest and most populous city in Mizoram. Predominantly mountainous and is characterized by mountain ranges and deep river valleys with an average elevation of 1,000–1,300 meters above sea level. The mountain ranges are aligned from north to south and run parallel to one another. The ranges are separated by narrow and deep river valleys, which contribute to the rugged terrain of the area. The overall relief is higher, and the slopes are much steeper in the eastern half of the study area. The low-lying areas are mostly formed by river valleys, while the mountain ranges run parallel and aligned from north to south. The drainage systems are originated from the central parts of the state and flow either towards the north or south direction along north-south trending ridges. The region is under the direct influence of the southwest monsoon, which brings a significant amount of rainfall within short period, typically between June and September. The major types of soils in Aizawl district are red and yellow soils, rich in organic matter and nitrogenous materials. The study area has a significantly high population density of 113 persons per square kilometer, which is significantly higher than the state average density of 52 persons per square kilometer in the 2011 census. High population concentration was seen in the middle part of the district, especially along National Highway number 54, as well as along the main arterial roads. Aizawl is the largest and capital city of Mizoram with a population of more than 228,442 peoples. According to census reports, the total literacy rate in Aizawl district increased from 82.8 per cent in 2001 to 86.91 per cent in 2011. Settlements are normally built on hilltops, rural settlement patterns depend on topographical factors and urban settlement patterns are characterized by the arrangement of the transport network and the location of administrative centers, educational institutes.

Significance of the study

The impact of transportation networks on socio-economic development has been widely discussed across various academic fields. However, the geographical aspects and perspectives of this subject have received insufficient attention. Given that the field of transport geography is relatively new, there is a vast area to explore in understanding the connection between transportation networks and socio-economic development. Therefore, this study plays a crucial role in addressing the knowledge gaps concerning the correlation between road networks and socio-economic development from a geographical standpoint.

The insufficiency of research hampers researchers, policymakers, planners, and decision-makers in comprehending the underlying fundamental issues and challenges related to socio-economic development in relation to road transport systems. However, research can provide valuable insights that can be used to identify problems, determine their causes, and develop effective solutions for establishing an efficient transport network. The results of this study can signify decisions regarding infrastructure investments, transportation policies, and sustainability initiatives.

The road network is indispensable for socio-economic growth as it enables physical connectivity between different locations, facilitating the transportation of goods, services, and people. It serves as a vital connection between locations and acts as the principal catalyst for socio-economic growth. As a crucial component of the interaction system, road networks are associated with various aspects of socio-economic development. Consequently, this study is significance for investigating the spatial interaction systems and its impact on socio-economic development in a specific study area.

The geographical limitations of the study area have resulted in a lack of diverse transportation options, which poses significant challenges for transportation in Aizawl district. Consequently, road transportation has become the sole means of transportation available to the masses. Therefore, investigating the effectiveness of the road transport network is necessary to understand its role in supporting socio-economic development in mountainous area. This investigation will serve as a basis for policymakers, planners, and stakeholders and further studies in Mizoram as a whole and Aizawl in particular.

The incorporation of network theory to assess the effects of road networks on accessibility and spatial interaction is rare, but the results are significant for understanding the causes of socio-economic development. The use of network theory for strategic planning and solving site suitability problems is more appropriate. It reflects the relationship between entities and the information flow through the network, which are important parameters for explaining heterogeneity (entropy), importance (centrality), and the connection pattern of the road networks. The study also demonstrates the significance of spatial modeling and analysis tools for road transport network analysis. This emphasizes the relevance of geographical aspects in transport analysis.

Limitation of the Study

Extraction of road network from remotely-sensed imagery is rather difficult as the appearance of a road varies according to satellite sensor types, spectral and spatial resolution, ground and weather conditions. Even the appearance of roads in the same image is also different due to the materials used for road construction. Moreover, spectral characteristic appears differently with differing physical conditions such as roads in deserts, vegetation fields, hills and valleys, village roads, city roads, cycle tracks (Ahmad and Deore, 2014). Several problems related to road data extraction from remotely sensed data can result in geographical and technical errors. Geographic features like the topography and vegetation cover that are characteristics of the study area also result in radiometric and atmospheric errors which too can be considered as technical errors. These errors create tricky and confusing issues in the extraction of road data network and point features from satellite images. Therefore the process of data extraction becomes a complicated and problematic task.

The limitation of local centrality measure lies in the fact that the degree of centrality value is influenced by euclidean distance and local measures since the value of a vertex is determined by the number of neighbors, and failed to depict its position in the entire network.

Organization of Chapter

The present study is orderly arranged into seven chapters.

Chapter I: The first chapter deals with the introduction of the research, which consists; general introduction of the topic, a statement of problems, the scope of the study, geographical perspectives of the study area, relevance of the study and chapterization.

Chapter II: The second chapter is devoted to a literature review that elaborates the earlier contributions of the present study so as to establish a strong foundation for the research.

Chapter III: The third chapter highlights the methodology adopted in this study. It also discusses the concept and principles of the methods adopted for road network analysis (centrality measures), socio-economic attributes, and data integration techniques.

Chapter IV: This chapter is devoted to analyzing the topological structure of road networks in the Aizawl district. First, it analyzed the spatial distributions of node accessibility using centrality parameters, such as degree of centrality, degree of Centrality, degree of Eccentricity, Closeness Centrality, Betweenness Centrality and Eigenvector Centrality.

Chapter V: Spatial variations in socio-economic development and its consequences are described in detail in this chapter. The chapter also analyzed the spatio-temporal variations in population growth, sex ratio, crude literacy rate, dependency ratio, and agricultural working population.

Chapter VI: Chapter six describes the role of the road transport network and socio-economic development in Aizawl district. The study analyzed the accessibility of nodes (settlements) and levels of socio-economic development by calculating the Mean Accessibility Index (A_I) and Mean Socio-Economic Development Index (D_I).

Chapter VII: The last chapter provides a summary of all six chapters, drawing synthesized concluding remarks. It traces the major conclusions and summarizes the findings of the study.

Methodology

The study addressed three methodological problems. Firstly, topological structure of road networks was measured on the basis of network centrality analysis techniques. The topological centrality analysis was used as tools for network modeling and examining the centrality of each node in the entire network. Secondly, this work measured socio-economic development of the study area. The socio-economic attributes were specified on the basis of road network and socio-economic development. Thirdly, the study integrated these two parameters (centrality measures and socio-economic development) into a quantitative unit of measure to answer the research questions.

The spatial attributes including point and line features are the basic parameters of road network analysis. Road intersections representing nodes or villages and the other, the edge of a line which is considered as a node that represents 'dead-end connectivity' as well as 'dead-end-node'. A line feature represents road network while a point signifies villages or nodes. Google Earth, United State Geological Survey (USGS), BHUVAN (Indian-Geo Platform of Indian Space Research Organization), and Open Street Map (OSM) were heavily utilized to obtain point and line features in this work. The extracted data were then transformed and converted into readable and manageable formats in order to perform further manipulation and analysis. To facilitate further analysis the extracted data was first stored in the ArcGIS and QGIS database and other computable programming software. Afterward, the extracted data underwent transformation and conversion into readable, manageable formats for further manipulation and analysis. Geometric correction was employed to mitigate topological errors. To enable in-depth analysis, the extracted data was initially stored in the ArcGIS and QGIS database. Centrality measures were utilized for simplification of the complex network system that is influenced by the topological structure of the network. The study employed network centrality measures to scrutinize each network point, directly or indirectly linked to road network topology and arrangement. The fundamental of the network analysis is based on simple undirected graph techniques. Centrality measures such as Degree of centrality, closeness centrality, betweenness centrality, eigenvector centrality, and eccentricity centrality are basis of node centrality measures. The centrality values (structural attributes) of nodes were used to measure degree of accessibility of nodes of the network.

Suitable socio-economic data were also collected to examine the role of road networks on socio-economic development of Aizawl district. Socio-economic attributes like population growth, crude literacy, sex ratio, dependency ratio, agriculture workers and other necessary information was collected from both primary and secondary sources of data. The study was largely dependent on secondary data (especially socio-economic data). Primary data surveys were conducted only in instances where the available secondary data encountered challenges with reliability and inconsistencies in record-keeping. This means that primary data was utilised as a supplementary source in order to strength data and also limit errors in secondary data. Secondary data were collected from government publications on a temporal basis. Apart from this, additional data related to road network and historical information was collected from departmental records, books, NGO publications, etc.

The study used synthesis method to simplify node centrality analysis and socio-economic indicators. Both independent and dependent dimensions were aggregated and ranked by calculating the Mean Accessibility Index (A_I) and Mean Socio-Economic Index (D_I). The former provided the basis for the levels of road network accessibility and thereby reveal the significance of a node within the network. The later indicates the overall level of socio-economic development. Transformed values were utilised as the basis of categorisation of villages in terms of accessibility and levels of socio-economic development. Understanding and observation of the relationship between the selected indicators and variables (composite indices) utilised statistical programs, such as coefficient of correlation, regression and appropriate statistical data representation techniques were implemented in this research. The study also employed Geographic Information software, ArcGis 10.3 and QGIS-Madeira for geospatial analysis and cartography. GIS techniques were also utilised in four main categories; stores and analyse data from the spatial perspective, modeling spatial variations of road network accessibility and socio-economic development, analyzing and visualisation of spatial changes in accessibility and socio-economic development, and the identification of changing trends in both variables.

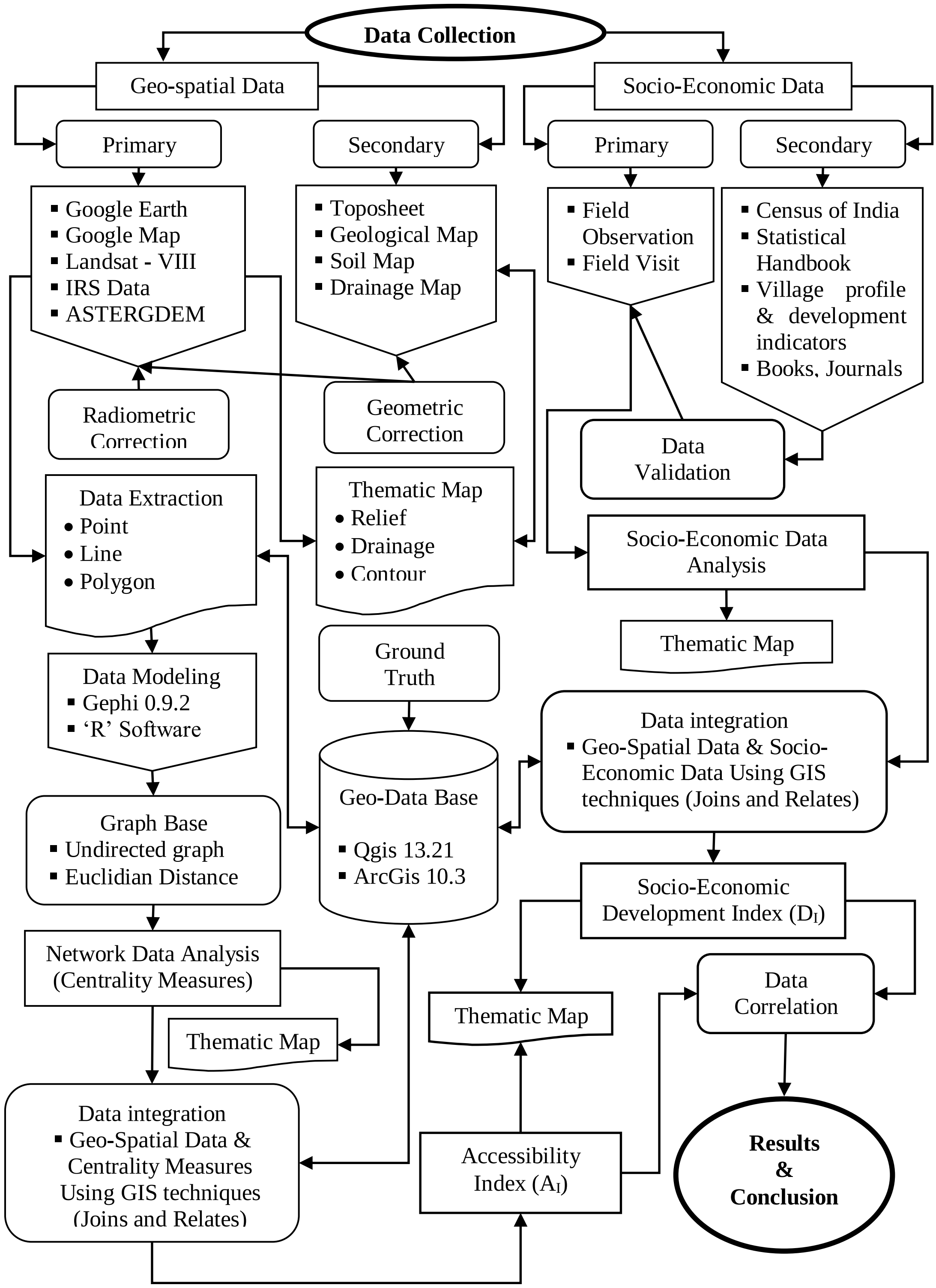

Figure : Flow Chart

Conclusion and Suggestions

Since the proposed study area is situated in undulating mountainous terrain and its peripheral location, road transport networks become the primary mode of transportation accessible to the masses. The structural configuration of transport networks directly governs patterns of movement, leading to the integration and interaction of distinct spatial entities. The concentration of these interactions at critical nodes, known as vertices, determines the extent of relationships between different geographical areas. Such interactions are influenced by a variety of elements, ranging from geographical features, economy, society, and technology. Road networks act as the crucial veins or arteries of a region, facilitating the movement of people and goods, and enabling spatial interactions by linking major cities, towns, and villages within and beyond the region. The road transport networks and their interactions can serve as indicators for the socio-economic development of an area, as they provide the essential infrastructure for all kinds of development and strengthen its economic potential. Similarly, it is reasonable to argue that road transport networks significantly contribute to the socio-economic development of both the region as a whole and specific area within it.

Differences in topological structure arise between global and local centrality metrics. Specifically, global measures such as Closeness centrality, Betweenness centrality, and Eccentricity (belonging to the very high and high categories) exhibit a longitudinal distribution, primarily influenced by the arrangement of road segments. Geographical factors play a vital role in segmenting the road network and shaping the spatial distribution or alignment of nodes.

The study highlights the impact of geographic centrality on node centrality distribution. Node centrality types, like global, local, and isolated, relate to their geographic positions. Central and middle network parts house high centrality nodes that significantly influence information flow. Node location shapes information dissemination, with centrality affecting critical node probabilities. Models show efficient information spread regardless of euclidean distance, but location and centrality also influence spatial heterogeneity. Geographical constraints like topography impact the network. Seling and Aizawl are primary hubs offering full services, while Sialsuk and Keifang/Saitual serve as secondary hubs. This efficient network benefits administration, distribution, and services.

The study region exhibited population growth patterns in two specific areas. An urban population led to substantial growth in the central zone, while isolated villages in the northern region see increased population due to improved medical access, aiding natural growth by reducing mortality and increasing life expectancy. In contrast, the southern and northeastern regions experienced limited growth and decline due to out-migration and low natural growth rate. The diversity of literacy rates in Aizawl district is skewed towards extreme north. The southern and middle regions are more literate due to early educational development, historical and political factors, efforts by Christian Missionaries, urbanization, and urban proximity. Over the decade the towns and villages of Aizawl district experienced a diverse range of changes from the positive to the negative in relation to sex ratio. Considering the changed pattern of sex ratio, the study shows that an increase in sex ratio was prominent in the western and more interior parts while a decreasing trend was witnessed in areas that are closer to the edges of the northern, southern and eastern parts of the study area. There is an evidence of change in dependency ratio in remote rural areas to urban area with high concentration of population. Despite being in remote locations, several rural settlements in the northeast have observed a significant decline in the dependency ratio. But, these settlements still confront economic challenges due to involvement in low-income economic activities. Interestingly, urbanization has heightened the dependency ratio by improving living standards and life expectancy. The shift of workers from the primary sector to the secondary and tertiary sector activities is the result of villages gaining better access to road connectivity and education. Two key factors drive changes in occupational structure: rapid economic growth with non-agricultural job opportunities attracting rural workers, and urbanization fostering service-based economy.

The correlation coefficient of centrality metrics quantifies the strength and extent of their relationships. Among these metrics, local centrality measures exhibit stronger associations than global ones. The highest correlation coefficient is noted between closeness centrality and eccentricity degree, indicating their near identical global nature. Conversely, the lowest correlation exists between degree centrality and eccentricity degree.

It is found that the key element of socio-economic transformation is the level of accessibility that enables mobility, freight availability, and accessibility of information. High accessibility results in socio-economic development, while less-developed ones have lower level of accessibility. Thus accessibility is linked with the avenues of opportunity, both economic and social. The results show that centrality measures are effective for differentiating road network topological structures. Specifically, geographical factors proficiently portray the form and configuration of road networks. This is due to the fact that the distribution of centrality values in the network is influenced by the region's topography. Moreover, the road network structure of the Aizawl district can be used as an indicator of socio-economic development levels, as road networks with similar A_I values also exhibit similar levels of D_I values. Correlation analysis additionally validates the statistically significant connection between road network attributes and the level of socio-economic development. As a result, this research offers a lucid perspective for understanding the association between road networks and socio-economic development. Additionally, it enhances the existing methodologies for studying road networks and socio-economic development in the field of geography.

Suggestions

The road network has significant implications on spatial interaction, connectivity, and accessibility of spaces. These factors subsequently influence different facets of regional growth and societal welfare. Especially, the implications of centrality measures for road network analysis help to quantify the importance and connectivity of individual road segments or nodes within a network, which is more significant for spatial planning. The key suggestions are highlighted as follows:

(i) The study area is characterized by rugged and undulating topography; establishing a road network proves to be a challenging task. However, the significance of this endeavor is even more pronounced compared to that in other types of landforms. The study proposes that the road network should be strategically aligned to support regional development and enhance the local community. This approach would facilitate the sustainable use of resources and enhance the road network,s resilience.

(ii) The study recommends the application of centrality measures to foster road network planning. These techniques help us avoid unnecessary and underutilization of the road network. Centrality measures, such as betweenness centrality and closeness centrality, help identify critical road segments or nodes that act as hubs for traffic flow. Also, centrality measures assist in identifying optimal locations for key facilities, such as hospitals, public distribution centers, emergency services, and administrative towns. Planners can focus on upgrading or expanding these central elements to improve overall mobility, reduce travel times, and enhance accessibility.

(iii) Strategic road network planning should be implemented for spatial planning. It is necessary to ensure easy access to essential services such as healthcare, emergency services, education, markets and public facilities. This enhances social equity and improves the overall standard of living.

(iv) By identifying areas with low accessibility, spatial planners can target infrastructure investments to reduce transportation inequalities. This helps ensure that all settlements, regardless of their location, have equitable access to vital services and opportunities.

(v) Identifying central road segments aids emergency response planning. Emergency services can prioritize routes that are highly connected and efficient, enabling faster response times during crises.

(vi) The study reveals Aizawl as the central hub within the studied network, providing comprehensive services throughout. However, this centrality poses challenges for peripheral or isolated nodes, hindering their access to essential services. To address these disparities and facilitate socio-economic development across the network, the establishment of minor hubs would become as a crucial strategy. These minor hubs should be strategically located, with sites such as Sialsuk serving the southern region, Seling for the central area, and Keifang/Saitual and Darlawn for the eastern and northern parts, respectively.

(vii) The geographical challenges within the study area necessitate the implementation of hub-and-spoke road network planning. Regarding interaction, the hub-and-spokes network system proves to be more efficient and facilitates the optimal use of transport network in the study are. Additionally, hub-and-spoke based road network planning offers numerous advantages for socio-economic development. These include improved transportation accessibility and efficiency, enhanced access to services and markets, cost-effective infrastructure development, stimulation of trade and commerce, regional development, as well as enhanced connectivity and integration.