# CHAPTER 5:

# DEVELOPMENT OF TRANSPORT NETWORK AND ASSOCIATED LAND USE AND LAND COVER CHANGE

## 5.1 Introduction

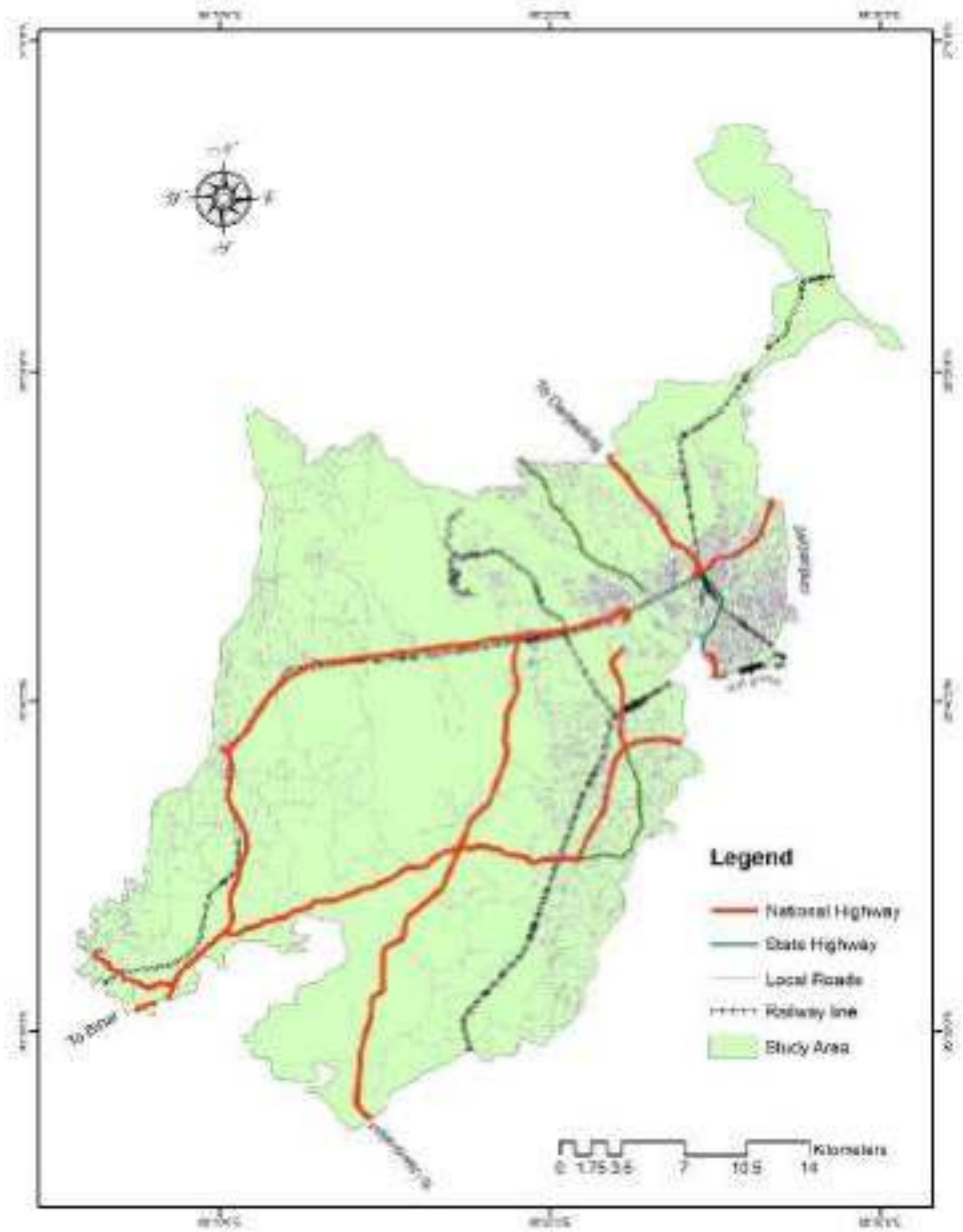
The regional transport network is a collection of multiple and varied point-to-point movement that takes place between several points of origin and destination. Siliguri Municipal Corporation and its surrounding provides high-quality marketing, administrative, medical, educational, welfare, leisure and recreational and other services to urban residents as well as the rural residents of its embracing areas. Popularly known as the "gateway to the North-eastern India", Siliguri enjoys the status of administrative, economic and educational capital of northern part of West Bengal. Consequently over the last two-three decades, the study area has witnessed changes in the population composition along with significant economic advancements.

Being the centre of all activities, there is a high degree of mobility of people as well as goods between the city area and the surrounding fringe area/outskirts which automatically creates demand for better quality transportation network for easy movement of people as well as goods along with easy access to goods and services. The villages of this sub-division and other adjacent areas are connected to the service area of city via roads and railway lines. Network analysis thus seems relevant in the present study as it makes for an important assessment technique in transportation analysis. Network analysis portrays the arrangement of vertices and their relationships with plotlines, appears relevant for the study. In this regard, by using graph theory the present study aims to analyze the road connectivity and network accessibility of the villages within the sub-division. In addition, connectivity index, shimbel index and associated number have been used to define the magnitude of network accessibility in the study area. It has been observed that geographic imbalances in connectivity and network accessibility are evident. The results indicate that while the overall road network connectivity is more or less good, it is Siliguri Municipal Corporation and its outskirt villages that have the maximum accessibility and well-organized connectivity. However, the villages that are remotely located far away from Siliguri Municipal Corporation suffer poor accessibility and poor road network. Based on the above discussion it can be suggested that there is an urgent need to improve the connectivity and accessibility of the villages that lack proper connectivity and accessibility for unhindered development of the study area in the coming future.

## 5.2 Transport network in the study area

The flow of goods and services is highly dependent on the transportation system which in turn stimulates the overall socio-economic development of an area. Transportation system is indispensable to any part of the world. The improved road system improves accessibility and mobility, thus greatly reducing travel time and travel costs. The improvement of the road network not only facilitates easy movement of people and goods, but also promotes overall socio-economic development as a result of improved access to education, medical services, employment opportunities and consequent increase in family income and poverty reduction. Siliguri is situated in the northern part of West Bengal and connects the north-east India to the rest of the country. Neighbouring countries like Nepal, Bhutan and Bangladesh rely heavily on Siliguri for trade and commerce as a result the road network plays a vital role in the development process. To fulfil the objective, the study has been carried on using some secondary data sources like village level map of Siliguri sub-division published by the Census of India, 2011.

**Map No. 5.1 Road and rail network in the study area**




Source: Prepared by the Researcher.

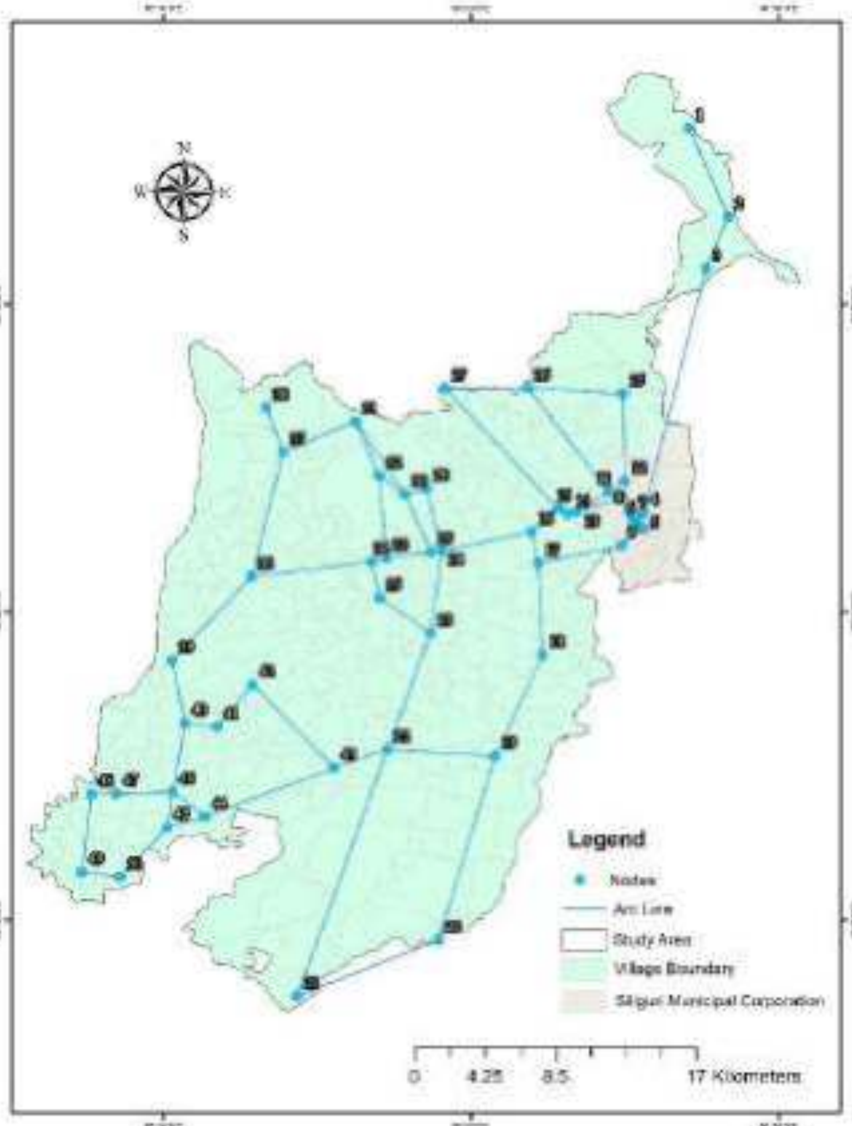
This road and rail network map has been prepared from the West Bengal Administrative Atlas and Census of India, 2011. All villages in Siliguri Sub-division on this map have been manually digitized after geo-referencing the map in Arc GIS v.10.5 software with UTM projection. The roads are manually digitized from Google Earth Platforms followed by preparation of a network dataset by creating nodes and arcs in the selected villages. For calculation of different indices, the nodes and arcs are counted on the basis of important road junctions. For identifying the accessibility and connectivity of 50 nodes various measures such as Connectivity Index, Shimbel Index, Associated Number, and Average Shortest Path Length have been computed using Microsoft Excel v.2007. For better understanding, maps are further elaborated by using Inverse Distance Weighted (IDW) method in the ArcGIS platform as these maps are very efficient in identifying the most accessible and the most efficient network zones in the study area.

**Fig. No. 5.1 Flow chart of the study showing the methodological hierarchy of road network accessibility**


## 5.3 Transport network model based on graph theory

In order to analyze the transport network, it is necessary to idealize the network in the form of a graph. In topological networks, several components are recognized that describe the observed relationships in the network and evaluate the accessibility and performance of the network analysis. The vertices or nodes are points on the basic elements of the graph that are located at the junction of two or more areas. These nodes are connected to one another through lines, called edges. Different indices such as Alpha Index, Beta Index, Gama Index and Cyclomatic Number have been used to evaluate the degree of connectivity. The present study is based on some selected indices of graph theory. Total 50 nodes have been taken into consideration based on important road junctions of the study area.

**Map No. 5.2 Road network along with the nodes in the study area**




Source: Prepared by the Researcher.

Alpha Index (a) is one of the significant measures of network connectivity. The value of Alpha index varies within 0 to 1. The value 0 indicates lesser connectivity and the value 1 means higher connectivity. This index is also expressed in percentile.

Alpha Index (a) is calculated as

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

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

Beta Index (b) is calculated as:

Beta Index$(\beta) = e/v$

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

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

Pi Index (p) is used to analyze the relationship between the transportation network as a whole and its diameter. Higher the value of Pi index means higher the connectivity and vice versa which is computed as:

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

Eta Index (g) is network's cumulative mileage ratio to the number of linkages observed. Low eta value indicates a complex network. Eta value decreases when adding new nodes, which is express as:

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

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

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

The degree of Connectivity (DC) is a simple measurement of network connectivity. It compares the relative position of an observed network's connectivity on a scale limited by maximum connectivity ratio. A higher value of the degree of connectivity means a higher level of connectivity. The degree of connectivity index is computed as:

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

Cyclomatic number (l) is also an elementary measure of network connectivity. It is show by counting the number of basic circuits existing in a graph. A higher value indicates a higher degree of connectivity. The Cyclomatic number of the study area is calculated as:

Cyclomatic Number $(\mu) = e - v + p$

*e is the number of edges, v is the number of nodes, p is the number of non-connected sub graphs.

Accessibility, like connectivity, is another important attribute of a transportation structure. Therefore, *connectivity matrix* is one of the important indicators of level of accessibility of a given area. Places with high connectivity are considered as the best location whereas lower value of connectivity index indicates lower connectivity and vice-a-versa. Connectivity matrix is represented by the connectivity of node (i) with adjacent nodes (j). If two nodes are directly connected by an edge, the value is equal to 1 and if two nodes are not directly connected by an edge, the value is equal to zero. The Connectivity Matrix is thus represented as:

$$CI = \sum Cij,$$

where, CI is the Connectivity Index, Cij indicates the direct connection between $i^{th}$ and $j^{th}$ nodes (either 1 or 0) and n represents the number of nodes.

Shimbel Index is used to calculate the accessibility of the network. The index represents the summing-up of the length of all the shortest path distances among all links in a network structure. Lower the value of Shimbel Index higher is the accessibility and vice versa.

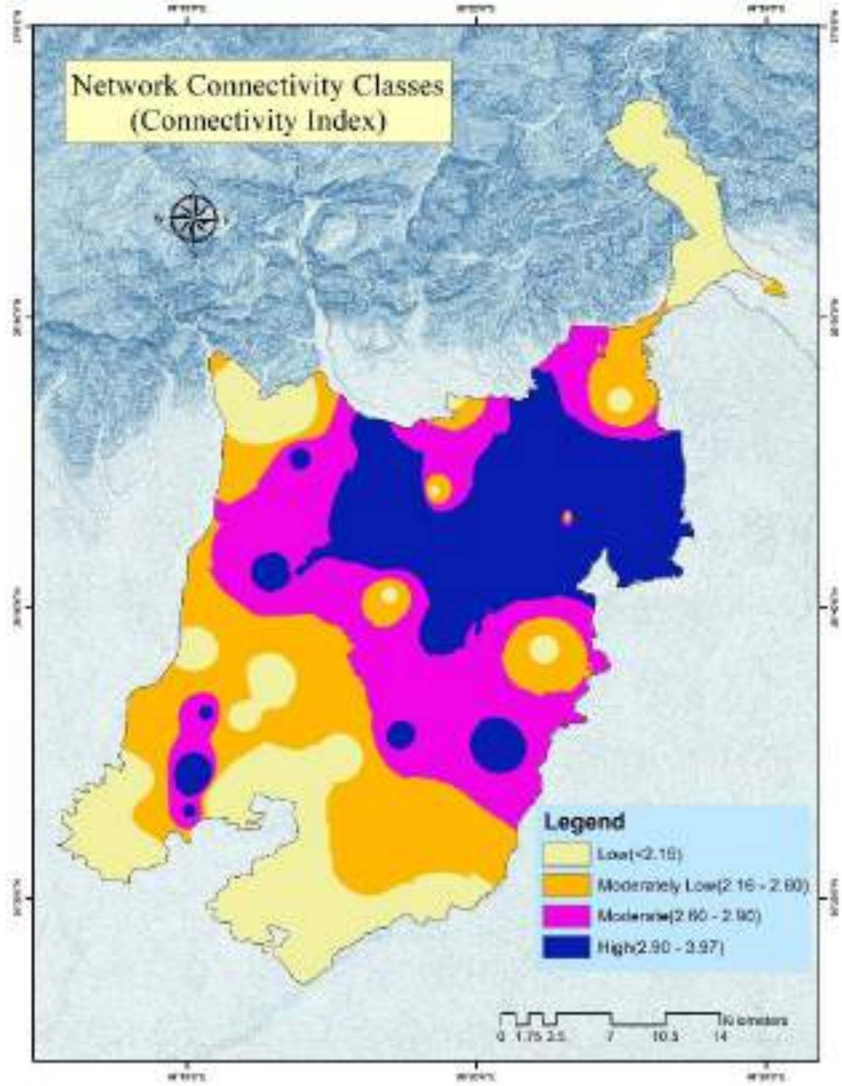
Shimbel Index is expressed as:

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

Where, SI is the Shimbel Index, dij indicates the shortest distance between i and j nodes and n represent the number of nodes.

Associated Number is yet another simple elementary measure of network accessibility. It is also known as Centrality Index. It is defined as the maximum distance from one location to all other places. It involves the number of arcs needed to connect the farthest nodes. The Associated Number is the highest number for each row. High value of the Associated Number indicates lower accessibility and vice versa.

**Map No. 5.3 Network connectivity classes in the study area**

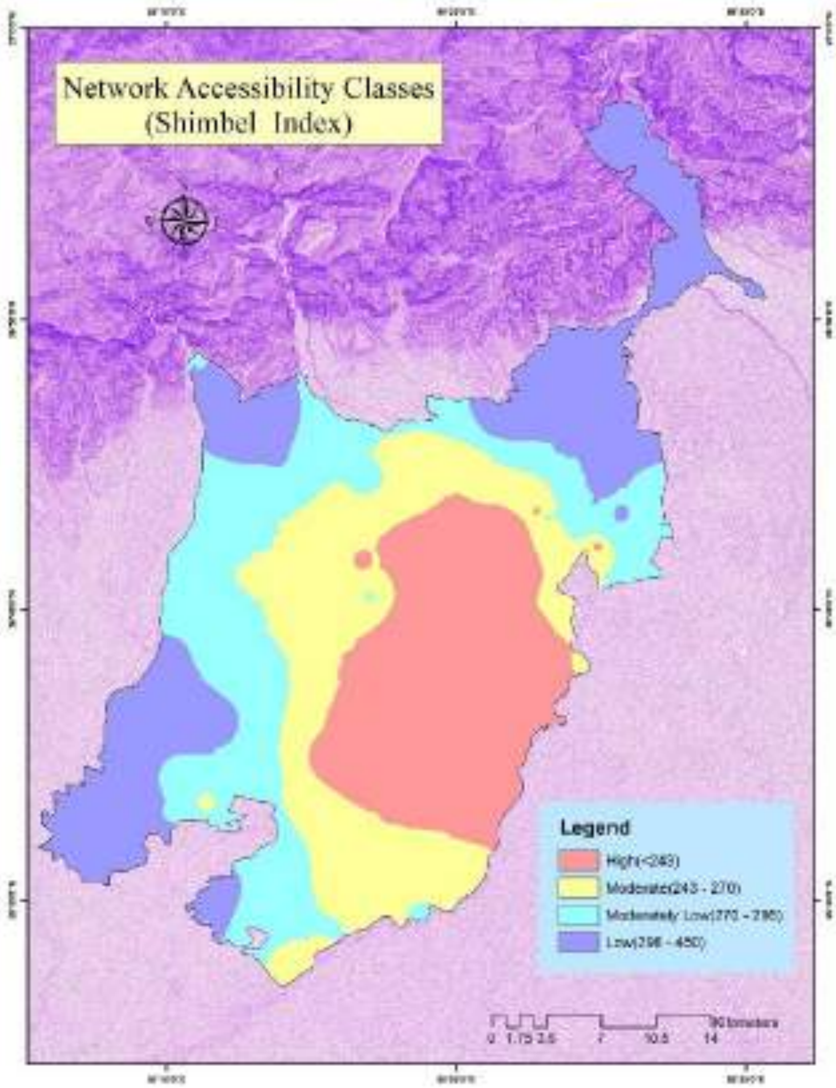



Source: Prepared by the Researcher.

In the map given above, network connectivity classes have been derived from connectivity matrix which basically shows the level of connectivity between two nodes. If two nodes are connected directly then the connectivity value will be 1, otherwise it will be 0. Thus, by calculating the values for all nodes it has been found that the highest connectivity value is 4 for the nodes located at Air View more and Darjeeling more of Siliguri Municipal Corporation, Khaprail more near Matigara bazar, Bagdogra, Khoribari and Ghoshpukur while the lowest connectivity value of 1 has been observed for distant nodes at Kalijhora and Bara Chenga. An accessibility map has also been prepared by showing 4 connectivity classes like high connectivity (2.90-3.97), moderate connectivity (2.60-2.90), moderately low connectivity (2.16-2.60) and very low connectivity (less than 2.16). However, from the above map we can say that the nodes located at the middle and eastern region of the Siliguri sub-division like Bagdogra, Sivmandir, Matigara, Naxalbari, Ghoshpukur, Kharibari and nodes under Siliguri

Municipal Corporation have very high connectivity; on the other hand the nodes situated at southern, south-western, north-western and north-eastern region of the Siliguri sub-division like Bidhannagar, Galgalia, Panitanki, Tari, Bara Chenga, Panighata, Sivok Bazar and Kalijhora have low connectivity with other regions of the map. The villages and nodes situated at the middle-eastern side of the map seem to be more connected with each other with a well-formed road network. However, it is to be noted that with increasing distance from Siliguri Municipal Corporation there is a decline in the connectivity status.

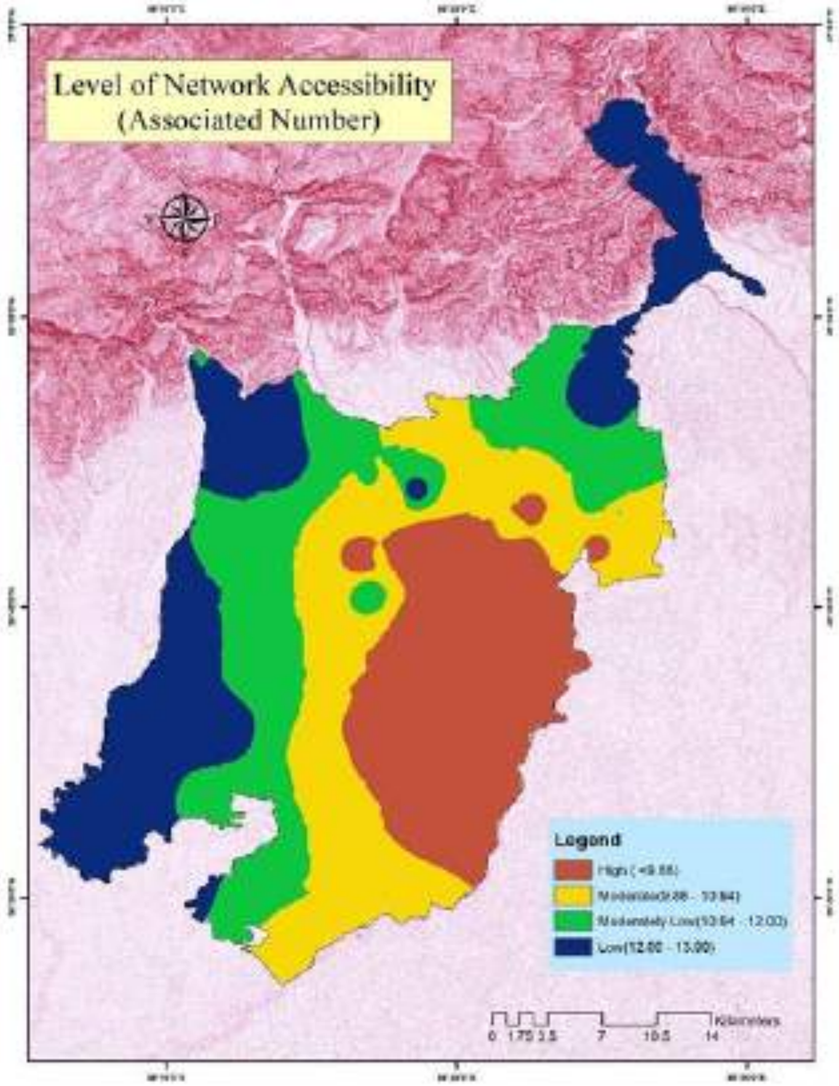
**Map No. 5.4 Network accessibility classes in the study area**




Source: Prepared by the Researcher.

Shimbel index (S.I) values for each node have been calculated by adding all the topologically shortest path distance among all nodes of the network graph. After calculating all the values it was found that the lowest S.I of 199 was for the node located at Bagdogra and the highest S.I of 452 was for the node located at Kalijhora. A map has also been prepared having 4 S.I classes showing high accessibility (less than 243) for the nodes at Ghoshpukur, Baraigachh, Bagdogra, Shiv Mandir; moderate accessibility (243-270) for the nodes at Jalpai More and Air View More of Siliguri Municipal Corporation and Naxalbari, moderately low (270-296) for the nodes at Darjeeling More of Siliguri Municipal Corporation, Matigara, Haftia, Pataram, Dohaguri etc. and low accessibility (296-450) for the nodes at Bara Chenga, Champasari, Sivok Bazar, kalijhora, Tari, Galgalia etc. However, the only Municipal Corporation of this subdivision i.e., Siliguri Municipal Corporation falls mostly under moderately accessible zone as it is quite hard to reach the farthest nodes of the sub-division from Siliguri Municipal Corporation whereas nodes at Sivmandir and Bagdogra are comparatively more accessible because of their intermediate position and the passing of National Highway. Moreover, from the above map it can be comprehended that the middle region of Siliguri sub-division is more accessible and as we move outward from this region the accessibility decreases with increasing distance.

**Map No. 5.5 Level of network accessibility (Associated Number) in the study area**




Source: Prepared by the Researcher.

Associated Number is the topological distance of a node that connects it with the most distant node. After calculating all the associated numbers, it was found that the lowest associated number is 8 for the nodes at Bagdogra, Mahipal and Mahammadbaksa village and the highest is 14 for the nodes at Kalijhora and Galgalia. A map has also been prepared showing a total of four classes of associated numbers, i.e., high (less than 9.86) comprising node like Bagdogra, Jalpai More of Siliguri Municipal Corporation, Khaprail More etc.; moderate network accessibility (9.86-10.94) for the nodes at Venus More of Siliguri Municipal Corporation, Haribhita etc.; moderately low (10.94-12) for the nodes at Kharibari, Trihana, Sevok More and Darjeeling More of Siliguri Municipal Corporation etc.; low (12-13.99) for the nodes at Sivok bazar, Kalijhora, Bara Chenga, Galgalia etc. It is to be noted that the most distant places have the most associated number; at the same time the nodes situated at the middle region of the sub-division have less associated number because these are the central points and from these nodes it is very much easy to travel anywhere.

Owing to the elongated shape of Siliguri sub-division, the network graph also takes an elongated shape. The study area comprises well forested tracks, mountains and hills, foothills or terai areas and cultivable plain areas. The network graph and the accessibility analysis show that the mountainous and adjoining foothill areas enjoy lesser accessibility than the plain areas. On the other hand, road network is very much developed in the densely populated municipal areas of Siliguri. However, beyond the densely populated municipality area of Siliguri, the road networks remain under developed. Development of road network in forested areas, mountains and hills not just requires huge capital investment and man power but is also environmentally taxing at the same time especially in the already vulnerable mountain and hill ecosystem. These impediments however remain absent in plain areas giving way to better developed road networks. Due to the elongated shape of the network graph the two corners i.e., north eastern and the south western region of the sub-division remain less accessible in nature, whereas the middle region of the sub-division is well connected and accessible because of their locational advantage. Here lies one important aspect about the Sliguri Municipal Corporation, i.e., from the perspective of connectivity index this municipal region is well connected and falls under high accessible zone but from the perspective of Shimbel index and Associated Number the same area is not very accessible and falls under moderate or moderately low accessible zone, this ambiguous result is due the elongated shape of the network graph. Due to the well-connected road network Siliguri Municipal Corporation has high connectivity but its location makes it moderately accessible from other part of the sub-division. But from the broader aspect it can be said that Bagdogra and its adjoining areas are the most accessible areas of this sub-division.

### 5.4 Road density network analysis

Roadways are the main lines of communication in the study area. However, the availability of roads is not uniform over the entire region. Normally, it is observed that areas which are at the close proximity of a large urban centre have high road density. As one moves away from a large urban centre, the availability of good quality roads tends to decline. In this section road density of the study area has been calculated to get an idea about the disparity in road development in Siliguri sub-division. Road network density refers to the ratio of the total length of the centreline of roads to the land area.

The fundamental equation is

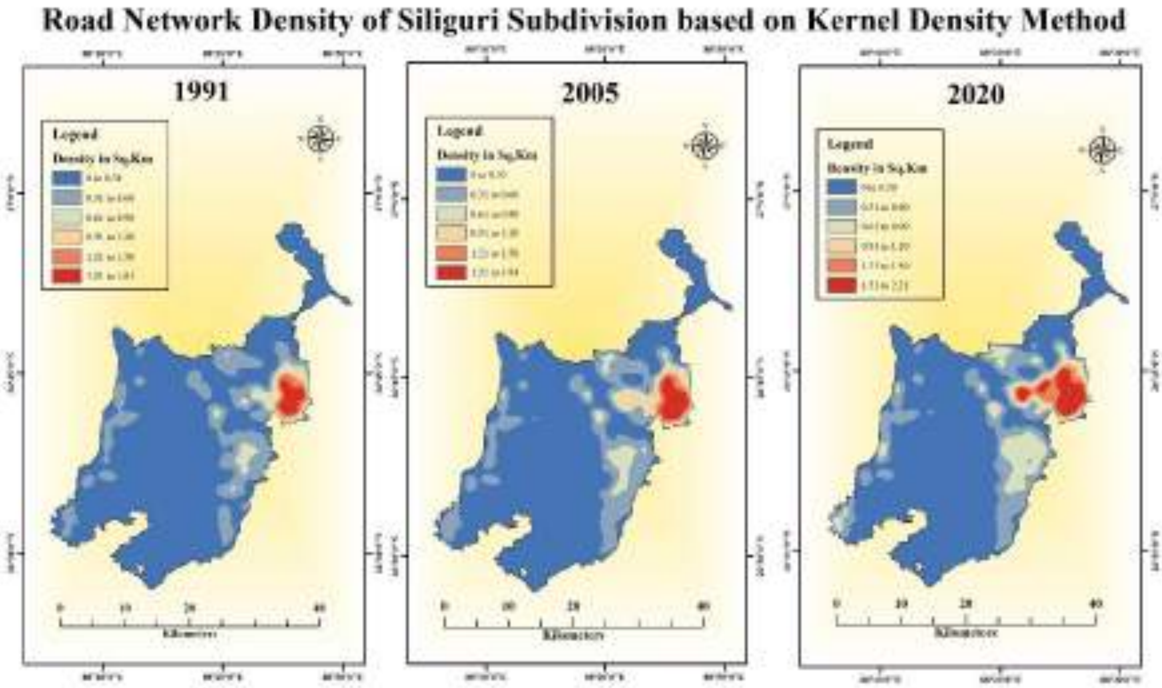
$$D = \sum_{i=1}^{n} L_i / \sum_{j=1}^{n} A_j$$

Where, D is the road density in km/km2,$\sum_{i=1}^{n} L$ is the length of the road centreline in km, and$\sum_{j=1}^{n} A$ is theland area in km2.

The kernel density is a widely used density analysis technique for spatial analysis that fits each point or line over a smooth tapering surface using characteristics from points or polyline data to calculate the value of a unit area. In the ArcGIS density analysis tool, the population field can be used to weight some features more heavily than others, depending on their meaning or to allow one point to represent several observations. By using default bandwidths, one can calculate the length of every road, and kernel density analysis was used to produce road network density maps. The area within which the density is determined is known as the search radius. The units are based on the output spatial reference's linear unit of projection. When an output area unit's factor is specified, it converts the unit of both length and area. For Example, if the linear unit is meter, the output area unit will default to square kilometers and the resulting line density unit will convert to kilometer per square kilometer. The end result, comparing an area scale factor of meters to kilometers, will be the density values being different by a multiplier of 1000.

To collect the road network data for different time period data were derived from the Open Street Map database in vector data format associated with the spatial distribution of the roads. For the network analysis of Siliguri sub-division, vector dataset is added in ArcGIS software. Hence this analysis in done for three time periods which is followed by block level analysis. Then zone wise road network analysis has also been done.

**Map No. 5.6 Road network density of Siliguri sub-division by Kernel density method**

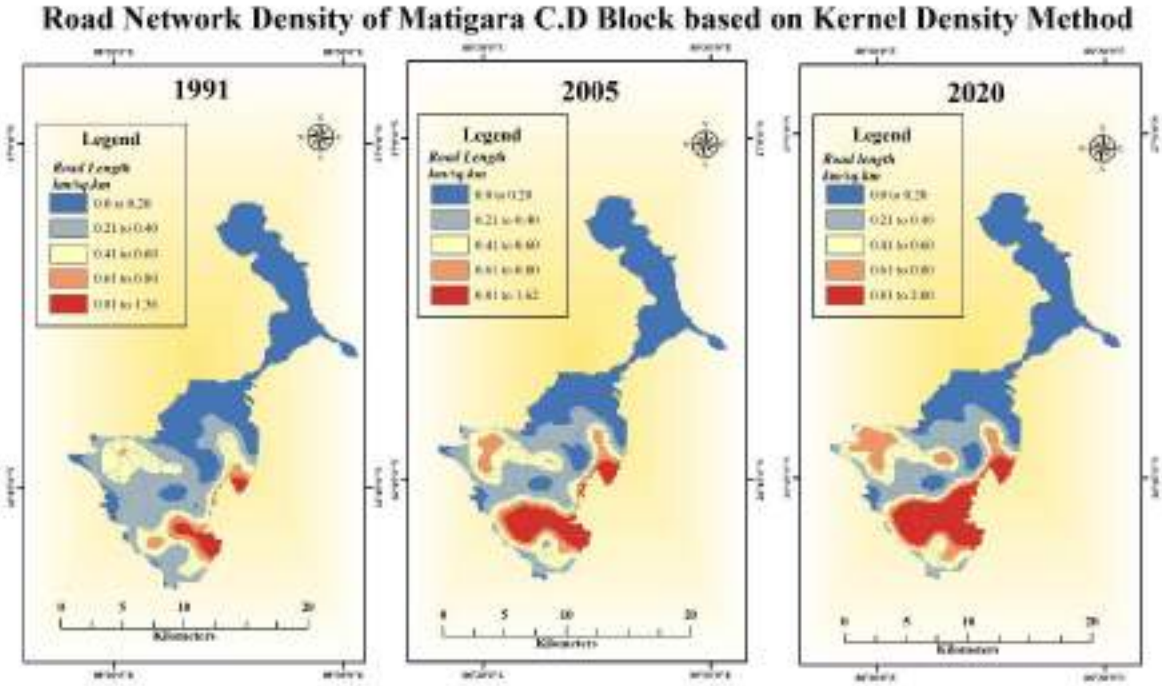



Source: Prepared by Researcher

Map 5.6 shows the road network density of Siliguri sub-division for three-time period viz. 1991, 2005 and 2020 respectively. Road network density map of Siliguri sub-division reveal that road network density in 1991 and 2005 was relatively low in comparison to 2020 (Map No. 5.6). Road density in the study area ranges from 0 to 1.81 km/sq. km. in the year 1991. The study area experienced a gradual increase in its road density with the highest value increasing to 1.94 km/sq. km. and 2.21 km/sq. km. in 2005 and 2020 respectively. It is worth mentioning that the road density in and around Siliguri Municipal Corporation area has consistently remained higher for three consecutive time period. It is also observed that the road density decreases in the study area with increasing distance from Siliguri Municipal Corporation. The concentration of road network near Siliguri Municipal Corporation could be attributed to the concentration of trade and commerce in the area. With time the population also witnessed gradual increase in the surrounding area which demands efficient development of transport facilities with greater connectivity at the surroundings. Among four blocks of the study area Matigara recorded the highest increase in road density from 1991 to 2020.

In the following section the road network density for each of the four blocks of the study area has been calculated for 1991, 2005 and 2020 respectively.

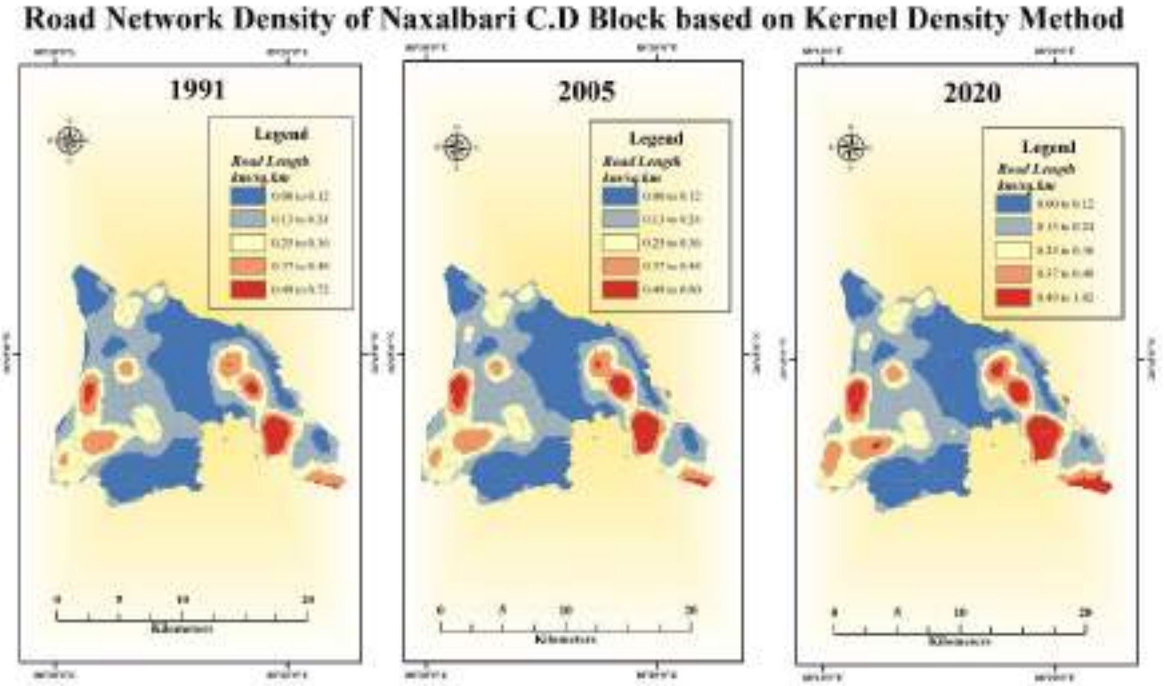
**Map No. 5.7 Temporal change of road network density: Matigara**




Source: Prepared by the Researcher.

Map No 5.7 shows the road network density of Matigara block in 1991, 2005 and 2020. It can be seen that the road density in Matigara block has increased by leaps and bounds from 1991 to 2020. The rate of increase was lot higher during 2005-2020 compared to 1991 -2005. The road density in Matigara block ranges from 0 to 1.36 km/sq. km. in 1991 which increases up to 1.62km/sq. km. in 2005. The Matigara block experienced further increase in terms of its road density in 2020 with density ranging between 0 to 2 km/sq. km. The southern part of this block recorded highest density than the northern part throughout these period. In 1991 a small portion of south-east corner of Matigara block had the highest road density. From the south-east corner, the highest road density zone captures almost the whole southern part of this block as depicted by the road density map for the year 2020. It is worth mentioning that Tomba and Patiram have the highest road density in Matigara due to the construction of a new bridge over the river Mahananda in that area.

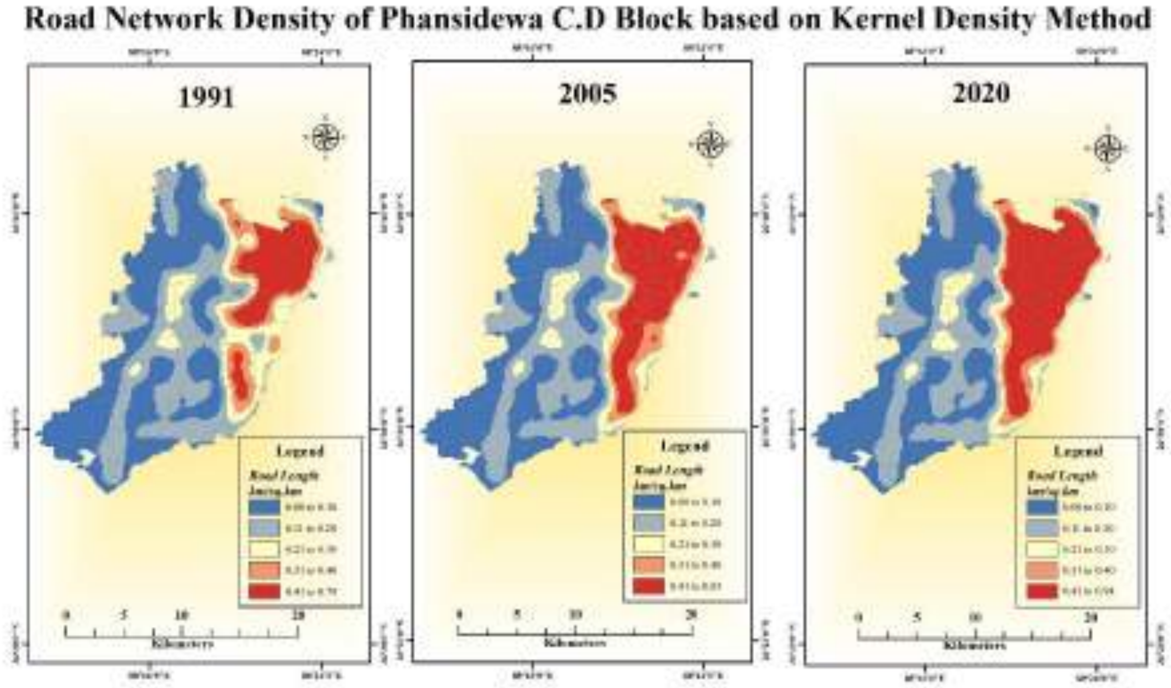
**Map No. 5.8 Temporal change of road network density: Naxalbari**




Source: Prepared by the Researcher.

Map No. 5.8 reveals the road density of Naxalbari block in 1991 2005 and 2020. The road density in Naxalbari block ranges from 0 to 0.72 km/sq. km. in the year 1991. Naxalbari experiences a relatively low increase in terms of road density in 2005 and 2020 ranging from 0 to 0.80km/sq. km. and 0 to1.02 km/sq. km. respectively. The highest road density i.e. greater than 0.49 km/sq. km. is observed over Uttar Bagdogra and Dakshin Bagdogra census towns in the eastern part of the block and near Jeni, Bhimram and Naxalbari in the western part.

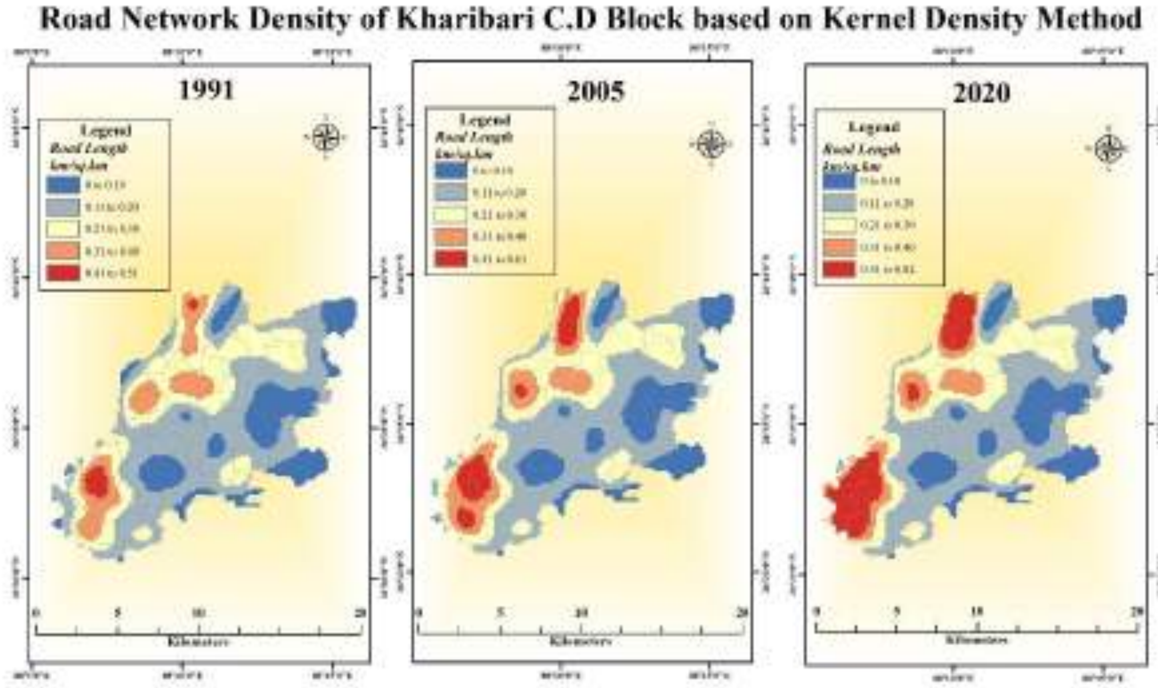
**Map No. 5.9 Temporal change of road network density: Phansidewa**




Source: Prepared by the Researcher.

Road network density of Phansidewa block of 1991, 2005 and 2020 is shown in Map No. 5.9. The road density in Phansidewa block ranges from 0 to 0.79 km/sq. km. in 1991 and 0 to 0.83km/sq. km. in 2005 and 0 to 0.94km/sq. km. in 2020. Phansidewa block recorded very low increase in road density from 1991 to 2020. The highest road density is observed over Purba Banshgoan, Madhya Banshgoan, Paschim Banshgoan due to the presence of an old village market centre. Later in the years 2005 and 2020 these two separate nucleus merged into a one large area of high road density covering the whole eastern part of this block after the construction of Fulbari-Ghoshpukur bypass road.

**Map No. 5.10 Temporal change of road network density: Kharibari**

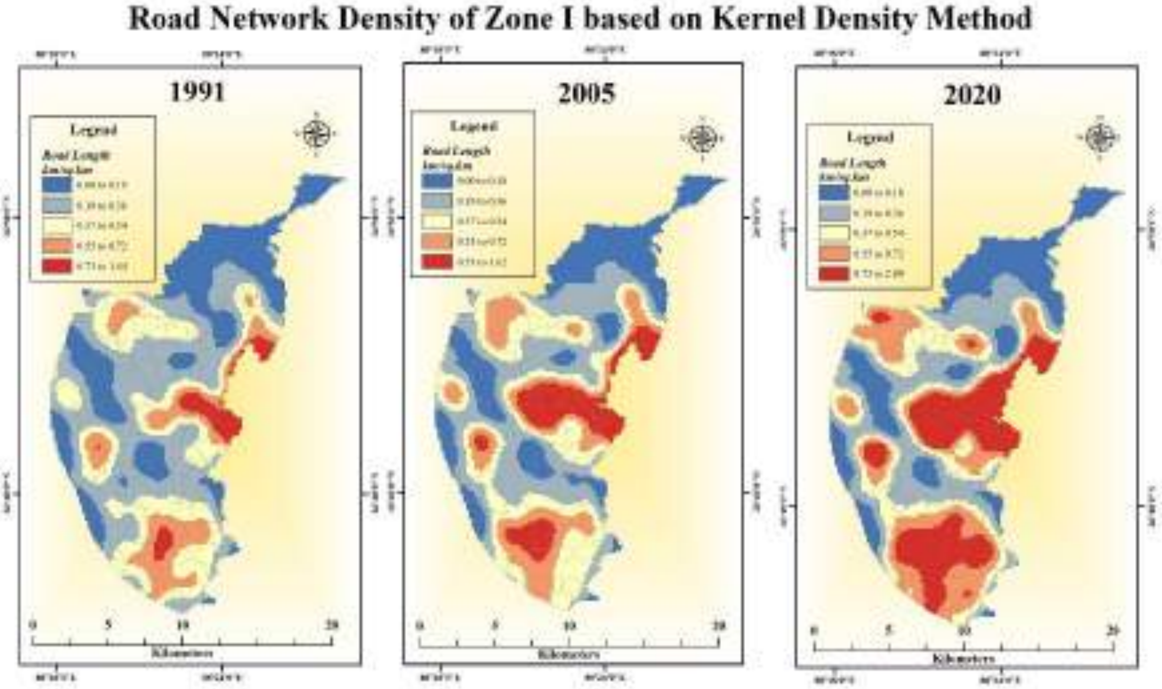



Source: Prepared by the Researcher.

Map No. 5.10 indicates that road network density of Kharibari block has shown a substantial improvement from 1991-2020. It can be seen that the rate of increase in road density was higher during 2005-2020 compared to 1991-2005. Road density in Kharibari block ranges from 0 to 0.51km/sq. km. in 1991. As depicted from the above maps, Kharibari experienced a gradual increase in road density in 2005 and 2020 ranging 0 to 0.61 km/sq. km. and 0 to 0.82 km/sq. km. respectively. The highest road density zone i.e. greater than 0.41 km/sq. km. was observed around Rangmuni, Gayen and Maynaguri in the south-western part and in the surrounding areas of Madanand Uttar Ramadhan in the north-western part of Kharibari block.

In this section, the road network density has been shown for the three zones delineated on the basis of distance from the outer boundary of Siliguri Municipal Corporation for 1991, 2005 and 2020 respectively.

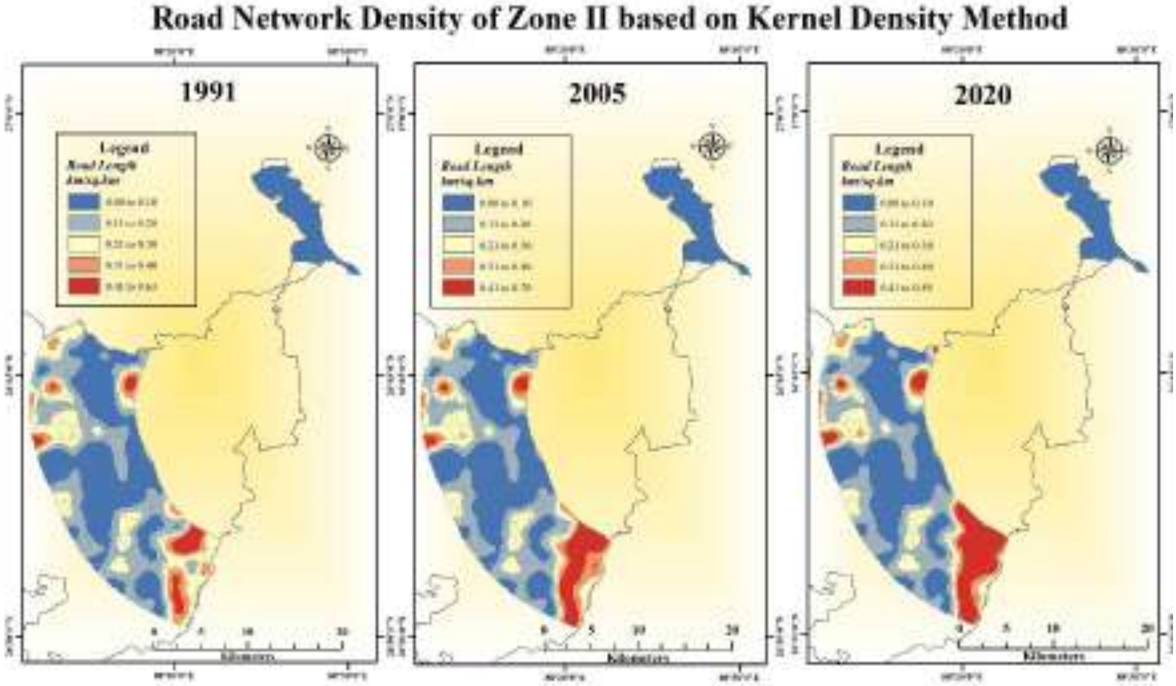
**Map No. 5.11 Temporal change of road network density: Zone I**




Source: Prepared by the Researcher.

Map No. 5.11 shows the road network density of Zone I in 1991, 2005 and 2020. It can be seen that the road density of this Zone increased very rapidly from 1991 to 2020. The rate of increase was much higher during 2005-2020 compared to 1991 -2005. The road density in Zone I range from 0 to 1.44 km/sq. km. in 1991 which increases up to 1.62 km/sq. km. in 2005. This Zone experienced further increase in terms of its road density in 2020 with density ranging from 0 to 2 km/sq. km. The middle and southern part of this zone recorded highest density compared to the northern part throughout this time period. This is because the northern part is heavily forested. In 1991, middle and southern outer edge of Siliguri Municipal Corporation had the highest road density. With the passage of time this small edge continued to grow as the area with highest road density zone and captured almost the entire middle and southern part of this Zone in 2020. Ujanu, Lachka, Tomba, Patiram have the highest road density in this Zone due to the establishment of a shopping mall (City Centre) and construction of a new bridge over river Mahananda.

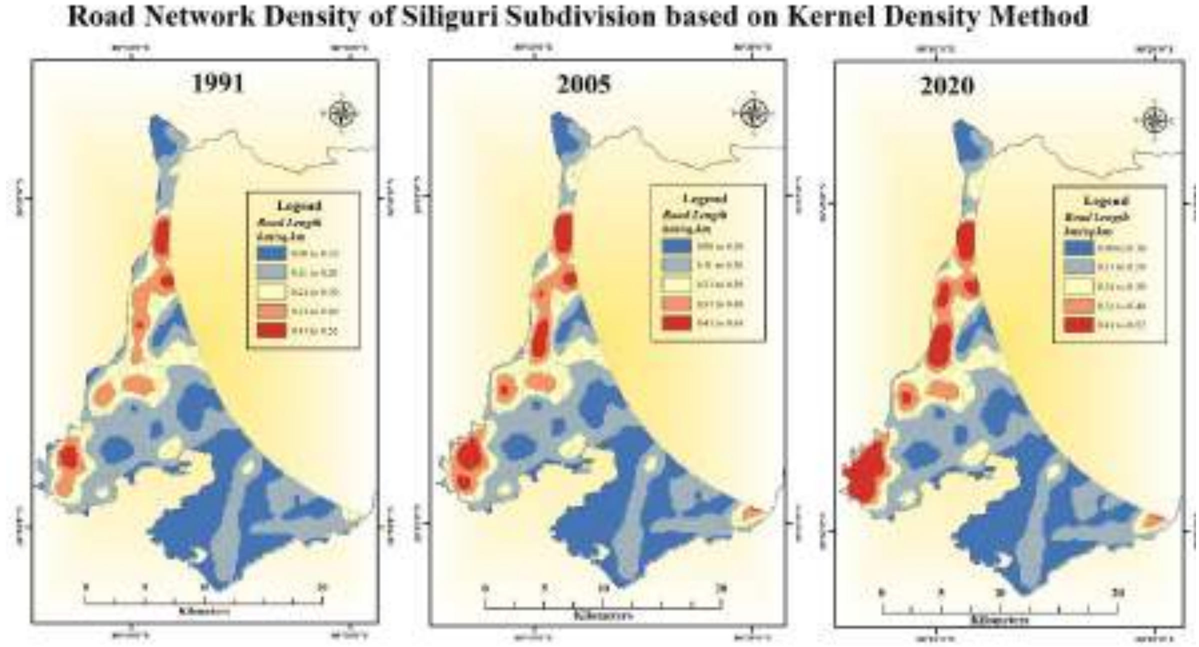
**Map No. 5.12 Temporal change of road network density: Zone II**




Source: Prepared by the Researcher.

Road network density of Zone II of 1991, 2005 and 2020 has been shown in the Map No. 5.12. The road density in Zone II ranges from 0 to 0.63km/sq. km. in 1991 and 0 to 0.70 km/sq. km. in 2005 and 0 to 0.85km/sq. km. in 2020. Zone II recorded very low increase in road density from 1991 to 2020. The highest road density is observed in surrounding areas of Purba Banshgoan, Madhya Banshgoan, Paschim Banshgoan in the southern part and Uttar Bagdogra and Dakshin Bagdogra in western part due to faster development of transport facilities with greater connectivity over the surrounding areas.

**Map No. 5.13 Temporal change of road network density: Zone III**



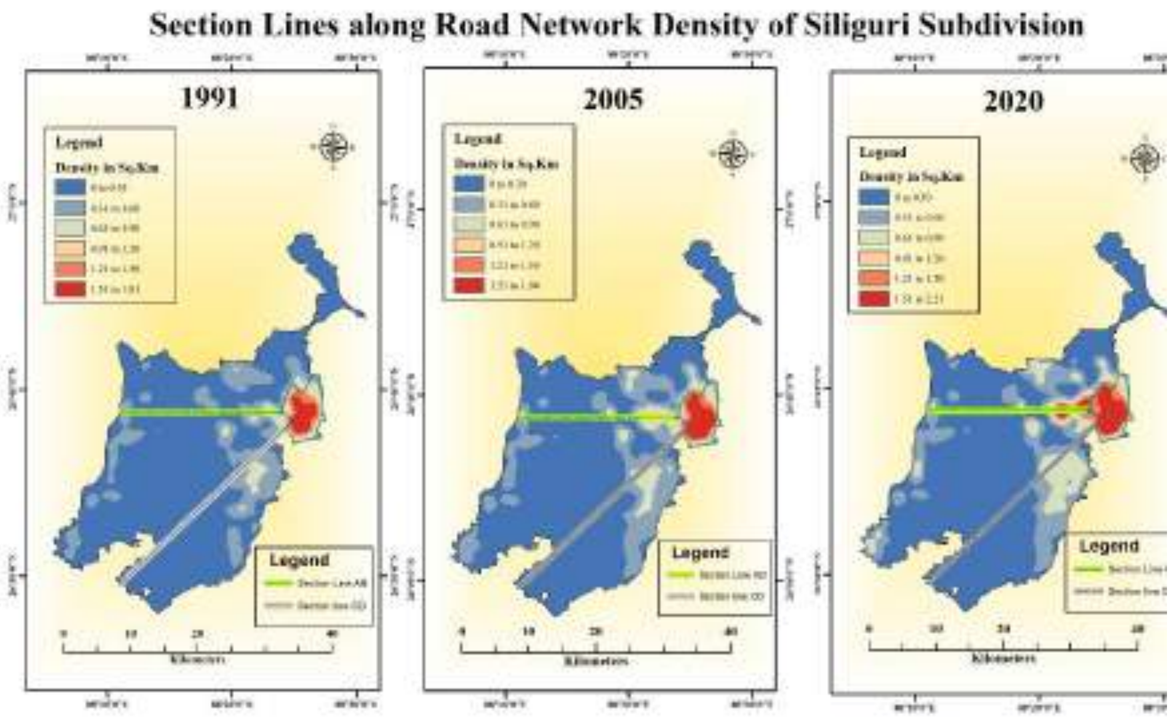

Source: Prepared by the Researcher.

Map No. 5.13 shows the road network density in Zone III. It indicates that road network density of Zone III in 1991, 2005 and 2020 witnessed a gradual change over the years. It can be seen that the rate of increase in road density was higher during 2005-2020 compared to 1991-2005. Road density in Zone III ranges from 0 to 0.52km/sq. km. in 1991. Zone III experienced a gradual increase in road density in 2005 and 2020 ranging 0 to 0.63km/sq. km. and 0 to 0.82 km/sq. km. respectively. The highest road density was found in areas surrounding Rangmuni, Gayen, Maynaguri in the south-western part and around Madan and Uttar Ramadhan in the north western part of this Zone. This can be attributed to the presence of business activity with the surrounding state like Bihar.

Road network is more developed over urban areas compared to rural areas. Road density is also much higher over urban areas compared to rural areas. Within rural areas also road density varies. Rural areas located close to large urban centres have relatively higher road density compared to rural areas located far away from the urban centre. In this part two section lines have been drawn from the outer boundary of Siliguri Municipal Corporation, one along the western direction (section line AB) and the second along the south-western (SW) direction (section line CD). Along these lines road density in km./sq.km. has been plotted for 1991, 2005 and 2020 respectively. For both the section lines and for all the years it is clearly visible that road density is maximum near the outer boundary of Siliguri Municipal Corporation and it has gradually decreased with increase in distance from outer boundary of Siliguri Municipal

Corporation. The regression equation showing the relationship between distance from outer boundary of Siliguri Municipal Corporation and road density is also negative for both the section lines for all the years. The coefficient of determination calculated is also significant, varying from 0.3304 to 0.6504. Therefore, the third hypothesis that road density decrease with an increase in distance from Siliguri Municipal Corporation is validated and proved and it can be said that within the study area with an increase in distance from Siliguri Municipal Corporation the road density also decreases.

**Map No. 5.14 Section lines along road network density of Siliguri sub-division**




Source: Prepared by the Researcher.

Fig. No. 5.2 Relationship between distance from SMC and road density along the Section Line AB- 1991

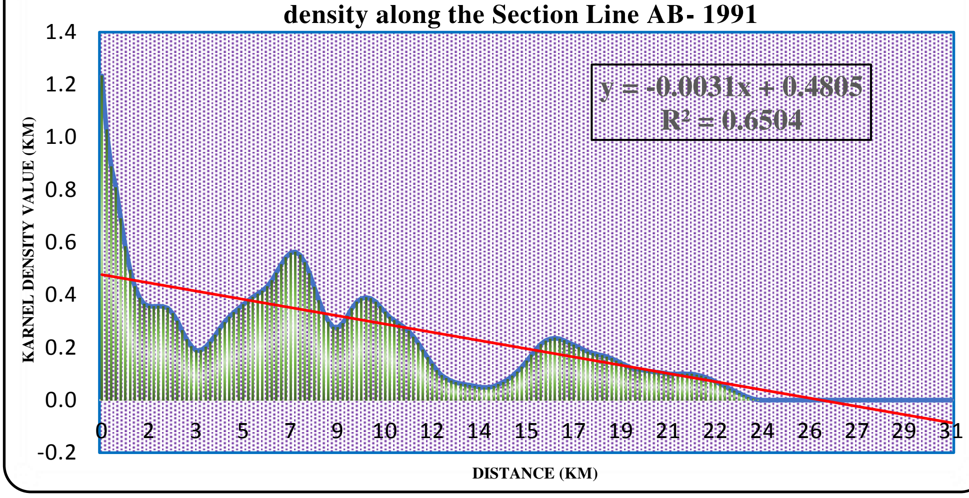



Fig. No. 5.3 Relationship between distance from SMC and road density along the Section Line AB- 2005

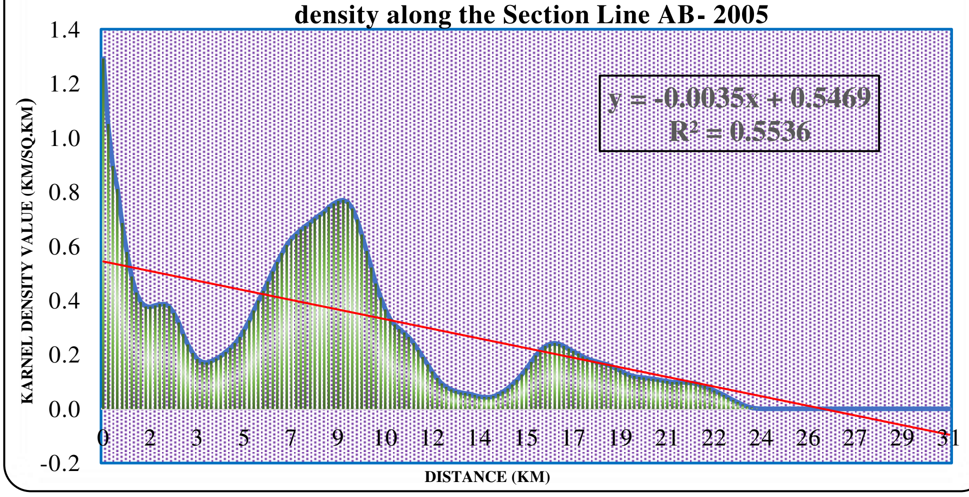



Fig. No. 5.4 Relationship between distance from SMC and road density along the Section Line AB- 2020

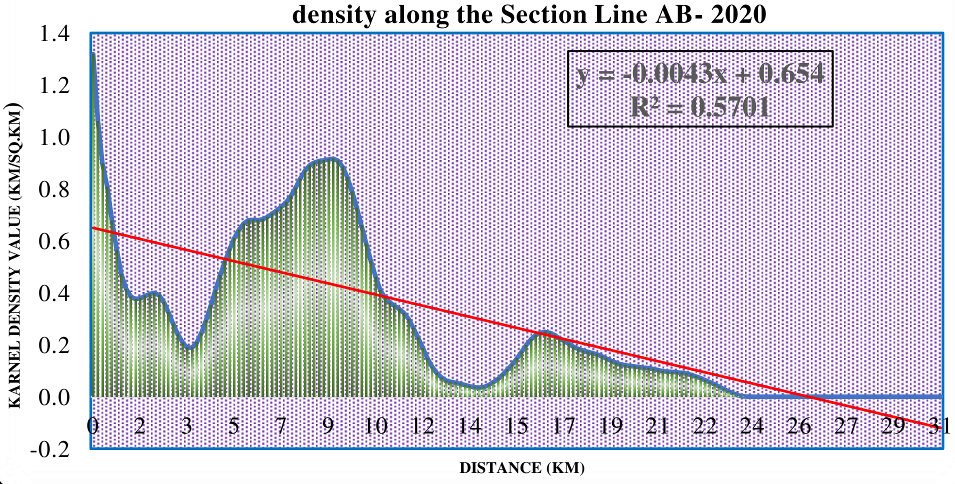


**Fig. No. 5.5 Relationship between distance from SMC and road density along the Section Line CD- 1991**

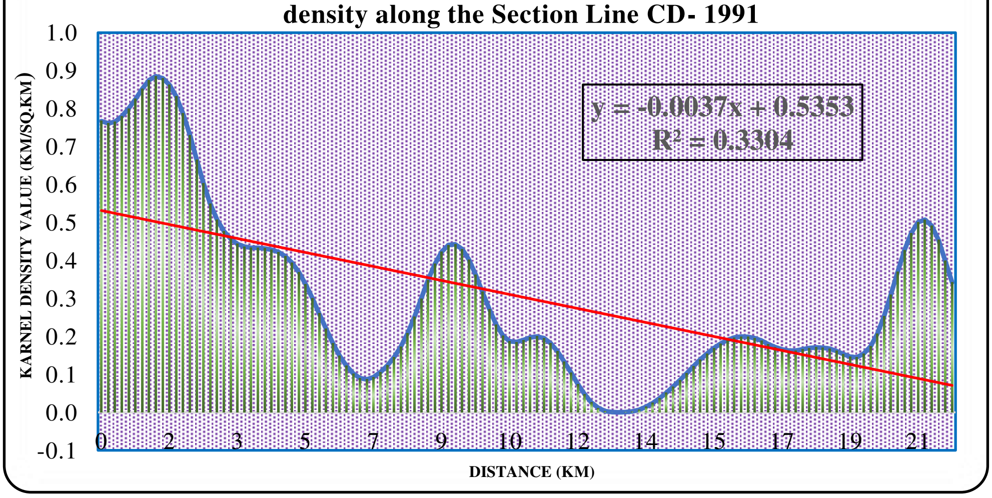



**Fig. No. 5.6 Relationship between distance from SMC and road density along the Section Line CD- 2005**

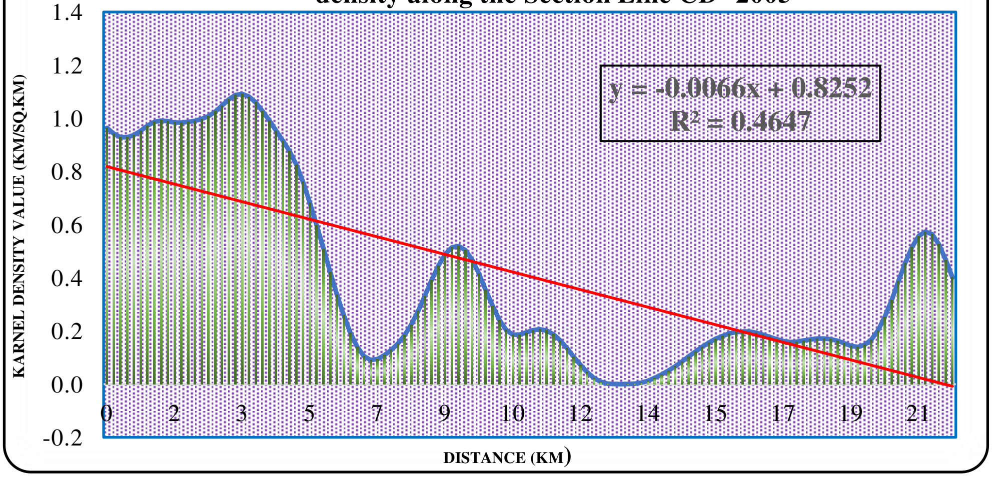
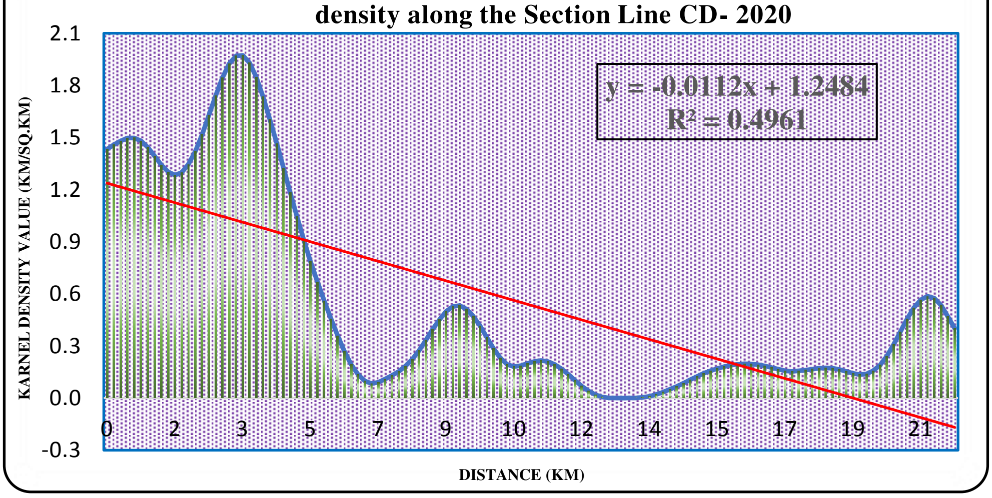



**Fig. No. 5.7 Relationship between distance from SMC and road density along the Section Line CD- 2020**



## 5.5 Land use and land cover analysis

Developmental activities in the recent years have inflicted a diverse range of environmental changes throughout the world, more so among the third world countries. While majority of these changes are human induced some are caused naturally. Urbanization and development are two sides of the same coin and has a cause and effect relationship. With Siliguri being the fastest growing urban centres in the Siliguri sub-division, the increased rate of urbanization in Siliguri and the surrounding area have been affected by natural as well as human induced environmental changes. Degradation/loss of agricultural land coupled with large scale deforestation for the purpose of conversion of forested areas into tea garden, residential and commercial land continue to remain one of the major environmental challenges since many years. As stated before, Siliguri City has been expanding at an alarmingly rapid rate to its surrounding region in order to cater to the needs of the increasing population growth. With large scale changes in the built up area of Siliguri, as a result of extensive construction of residential as well as commercial building, the city went on to become a concrete jungle. As a consequence of concentrated developmental activities in the last two or three decades have had multiple impact on the environment of the study area. Hence, in this study the land use and land cover change has been analyzed for the year 1991, 2005 and 2020. Remotely sensed data in geospatial software platform has been used for mapping, analysing, and disseminating the outcomes.

For this purpose three sets of rectified images of Landsat, five Thematic Mapper (TM) and Landsat 8 Operational LandImager (OLI) with 15-year intervals (images of 1991, 2005, and 2020) were downloaded from the United States Geological Survey (USGS) Glovis (http://glovis.usgs.gov) website and used for identification of the land use and land cover changes in Siliguri sub-division (Table No. 5.1). All of these images had UTM projection and WGS84 datum. In order to obtain cloud free images (< 10% cloud cover), the month of January was preferred and, accordingly, two scenes were downloaded for each year to cover the whole study area.

**Table No. 5.1 Details of the collected Landsat data**

| Date of Acquisition | Satellite/ Sensor | Reference System/Path/Row |
|---|---|---|
| 1991/01/22 | Landsat 5 TM | UTM-45N/139/42 |
| 2005/01/14 | Landsat 8 OLI | UTM-45N/139/42 |
| 2020/01/27 | Landsat 8 OLI | UTM-45N/139/42 |

Landsat TM images consist of seven bands. It collected images in visible, near infrared, mid-infrared, and thermal bands with a spatial resolution of 30 and 120 meters. Landsat 8 consists of Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The Operational Land Imager (OLI) produces 9 spectral bands (Band 1 to 9) at 15, 30, and 60-meter resolution. Then, the Thermal Infrared Sensor (TIRS) consists of 2 thermal bands with a spatial resolution of 100 meters.

**Table No. 5.2 Landsat 5: Spectral and spatial resolution of the bands**

| Band | Band1 | Band2 | Band3 | Band4 | Band5 | Band6 | Band7 |
|---|---|---|---|---|---|---|---|
| Name | Visible | | | NIR | MIR | Thermal | SWIR |
| | B | G | R | | | | |
| Spectral resolution (µm) | 0.45 - 0.52 | 0.52 - 0.60 | 0.63 - 0.69 | 0.76 - 0.90 | 1.55 - 1.75 | 10.4 - 12.3 | 2.09 - 2.35 |
| Spatial Resolution (m*m) | 30×30 | 30×30 | 30×30 | 30×30 | 30×30 | 120×120 | 30×30 |

**Table No. 5.3: Landsat 8: Spectral and spatial resolution of the bands**

| Band Feature | Band1 | Band2 | Band3 | Band4 | Band5 | Band6 | Band7 | Band8 | Band9 | Band10 | Band11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Costal | Visible | | | NIR | SWIR | SWIR | Panchromatic | Cirrus | LWIR | LWIR |
| | | B | G | R | | | | | | | |
| Spectral resolution (µm) | 0.43-0.45 | 0.45-0.52 | 0.52-0.60 | 0.63-0.69 | 0.84-0.88 | 1.56-1.66 | 2.10-2.30 | 0.52-0.90 | 1.36-1.39 | 10.3-11.3 | 11.5-12.5 |
| Spatial Resolution (m*m) | 30×30 | 30×30 | 30×30 | 30×30 | 30×30 | 30×30 | 30×30 | 15×15 | 30×30 | 100×100 | 100×100 |

Pre-processing of the downloaded images was conducted in Arc-GIS software. Multi spectral datasets were prepared by the ‘Band Set’ process with different band combinations for each of the Landsat 5 TM and Landsat 8 OLI images. Thereafter, geometric corrections were conducted on all datasets having level-I processing. Image geo-referencing was done using several ground control points (GCPs) located by GNSS-based surveys (handheld Garmin 12 channel device). These GCPs were collected during pilot surveys, based on random sampling method. Subsequently, radiometric correction and atmospheric correction were also performed using the arc-catalog toolbox, to obtain accurate spectral reflectance values and to remove various noises. Subsequently, corrected set of multi spectral images were mosaiced and Siliguri sub-division was then clipped as the region of interest using the ‘clip’ raster tool.

### 5.5.1 Image classification

In order to identify the changing patterns in the LULC of Siliguri sub-division from 1991 to 2020, primarily dominant land use or land cover types were classified through supervised classification based on the maximum likelihood algorithm in Arc-GIS. Seven major

LULC classes were identified for the Siliguri sub-division based on prior field experience and high-resolution images of Google Earth geo-visualizer, viz. water body, forest cover, tea garden, built-up, agricultural land, barren land, and sand land. Amongst these, water body consisted of major rivers, water channel, small rivers etc. The extent of area falling under different types of forests like natural forest, manmade forest and social forestry were considered under the forest class. Built-up area consisted of houses, markets, shopping malls and government as well as private offices and commercial buildings to name a few. The Agricultural land class on the other hand comprised agricultural plots with/without crops during the time of image acquisition i.e., the month of January. Besides, the barren land class was primarily constituted of open spaces, playgrounds, industrial fallow, and tea gardens that were kept vacant. As the image acquisition date was during the month of January, sand bars were present in the rivers in the surrounding areas. For each land-use class, nearly 50 training sample signatures have been collected from the target area which is merged further into a single class. LULC patterns of the 100 plots identified during fieldwork and high-resolution Google Earth images were considered as references to validate the classification accuracy. Producer's accuracy, user's accuracy, overall accuracy and Kappa Coefficient were estimated under this assessment procedure. The overall classification accuracy for the year 1991 is 88.25%, for 2005 is 90.75% and for 2020 is 94.17% respectively.

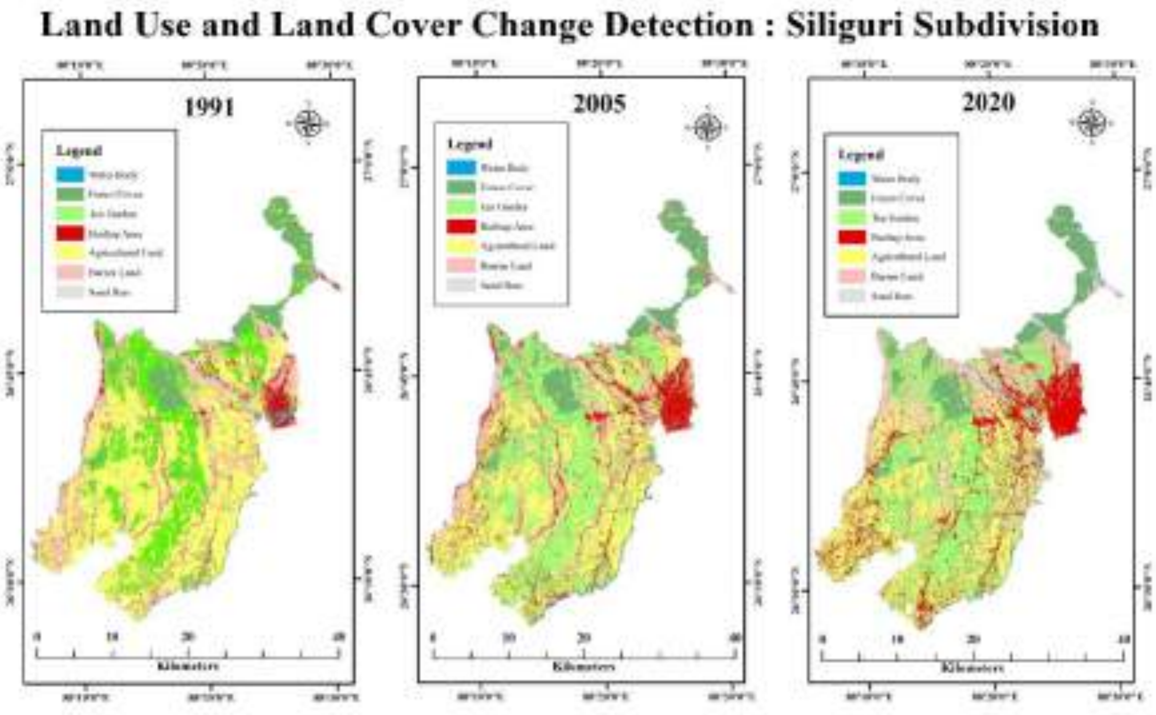
### 5.5.2 Analysis of inter‐ class LULC transformation

To fulfil the purpose of an in-depth analysis of LULC using the multi-ring buffer tool of ArcGIS, the entire sub-division has been divided into four blocks and three zones. It has been observed that, in case of Siliguri, the continuous built-up spreads over the boundary of Siliguri Municipal Corporation. A pre-defined conventional value of 10 km is chosen to create the multi ring buffers in order to examine as to how and why the changes in LULC have been taking place along different directions in different parts of the study area.

The LULC scenario of Siliguri Municipal Corporation from 1991 to 2020 portrayed intricate interplay between various land uses and land cover which varied considerably both at temporal and spatial scales. Between the year 1991 and 2000, notable increase in area under built-up and sizeable decrease in agricultural land had been found in all the zones of Siliguri sub division (Map No. 5.15). Primarily, a west oriented pattern of urban growth and emergence of new patches of built-ups were evident which had consumed considerable amount of agricultural land. Growth of new residential sectors to accommodate incessantly growing population and development of new shopping clusters had caused fragmentation of the agricultural lands and tea garden in most of the areas surrounding the urban centre. Surprisingly, slight increase in vegetation cover had also occurred in three sequential years 11% in 1991, 12% in 2005, and 13% in 2005, mostly at the cost of existing agricultural lands. Thus, growth of vegetation was probably related with the increase in acreage of tree crops during this phase.

Agricultural land witnessed a sharp decline from 45% in 1991to 30% in 2005 and subsequently to 25% in 2020. Decrease in area under agricultural land consequent to its conversion into built-ups and fallow lands continued in the period between1991 and 2020. Continued spread of urban built-up had occurred mainly at the cost of vegetation as well as by engulfing agricultural lands, and barren lands particularly in the areas near to urban area. Notably, an increase in area under tea garden is found in this region. For example, 1991 recorded an amount of 154.74 sq. km land under tea garden which increased to 229.30 sq. km. in 2020 denoting primarily the conversion from agricultural areas. The reduction in croplands was most prominent in describing the LULC changing scenario. The growth of built-ups has been overwhelming throughout the Siliguri Subdivision.

**Map No. 5.15 Land use & land cover change detection : Siliguri sub-division**



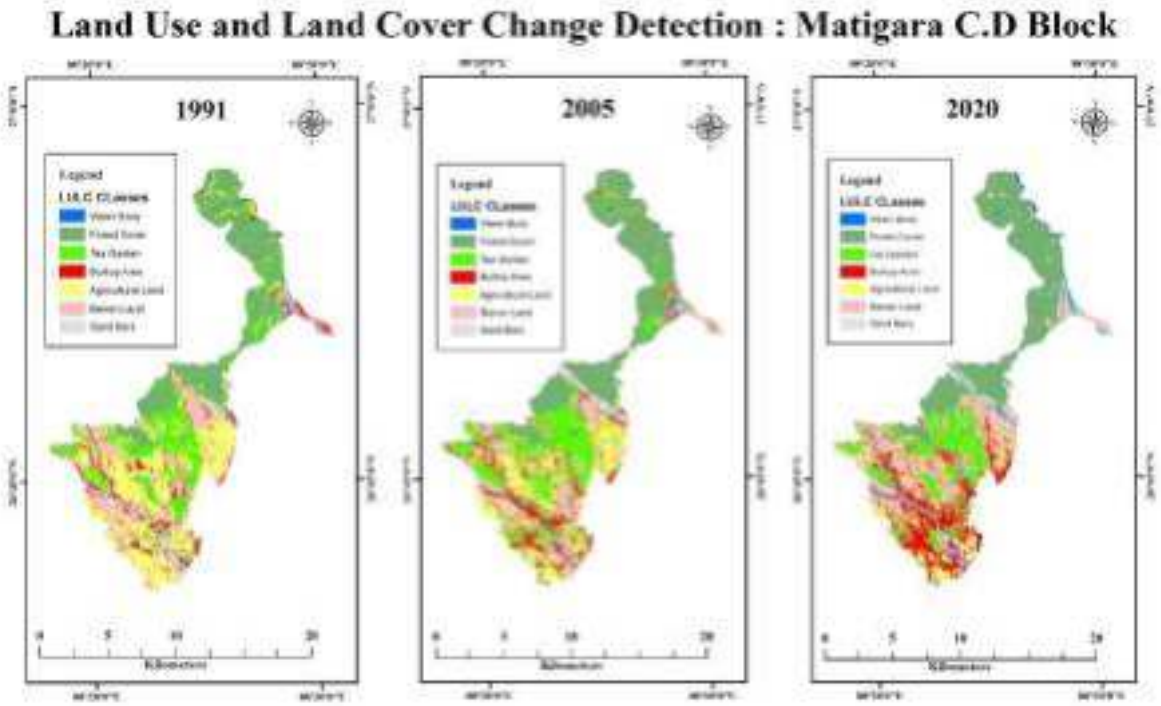

Source: Prepared by Researcher

| **Table No. 5.4 Land use & land cover change detection: Siliguri sub-division** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 368.82 | 45 | Agricultural Land | 247.47 | 30 | Agricultural Land | 207.92 | 25 |
| Barren Land | 122.94 | 15 | Barren Land | 108.59 | 13 | Barren Land | 131.33 | 16 |
| Builtup Area | 49.18 | 6 | Builtup Area | 96.10 | 12 | Builtup Area | 119.48 | 15 |
| Forest Cover | 90.23 | 11 | Forest Cover | 95.22 | 12 | Forest Cover | 104.98 | 13 |
| Sand Bars | 21.47 | 3 | Sand Bars | 10.80 | 1 | Sand Bars | 11.60 | 1 |
| Tea Garden | 154.71 | 19 | Tea Garden | 250.10 | 3 | Tea Garden | 229.30 | 28 |
| Water Body | 8.01 | 1 | Water Body | 11.33 | 1 | Water Body | 15.00 | 2 |
| Grand Total | 819.61 | 100 | Grand Total | 819.61 | 100 | Grand Total | 819.61 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

In this section the LULC change for each block of Siliguri sub-divusion has been analyzed.

Matigara Block - Located nearest to Siliguri Municipal Corporation, Matigara block has the highest area under built-up category of 18.32 sq. km. Since 1991, continuous and consistent growth of urban built-up area in Matigara block resulted into encroachment of scattered and tiny patches of agricultural fields, tea gardens and forest covers. As a result, agricultural land reduced by approximately 13 sq. km. between 1991 and 2005 which further got reduced by 11 sq. km. from 2005 to 2020. Similarly, area under tea plantation also reduced from 22.78 sq. km. to 18.20 sq. km. between 1991 and 2020. However, it is worth mentioning that during the same period of time, area under forest cover increased from 28% to 33% in the Matigara block.

**Map No. 5.16 Land use & land cover change detection : Matigara**

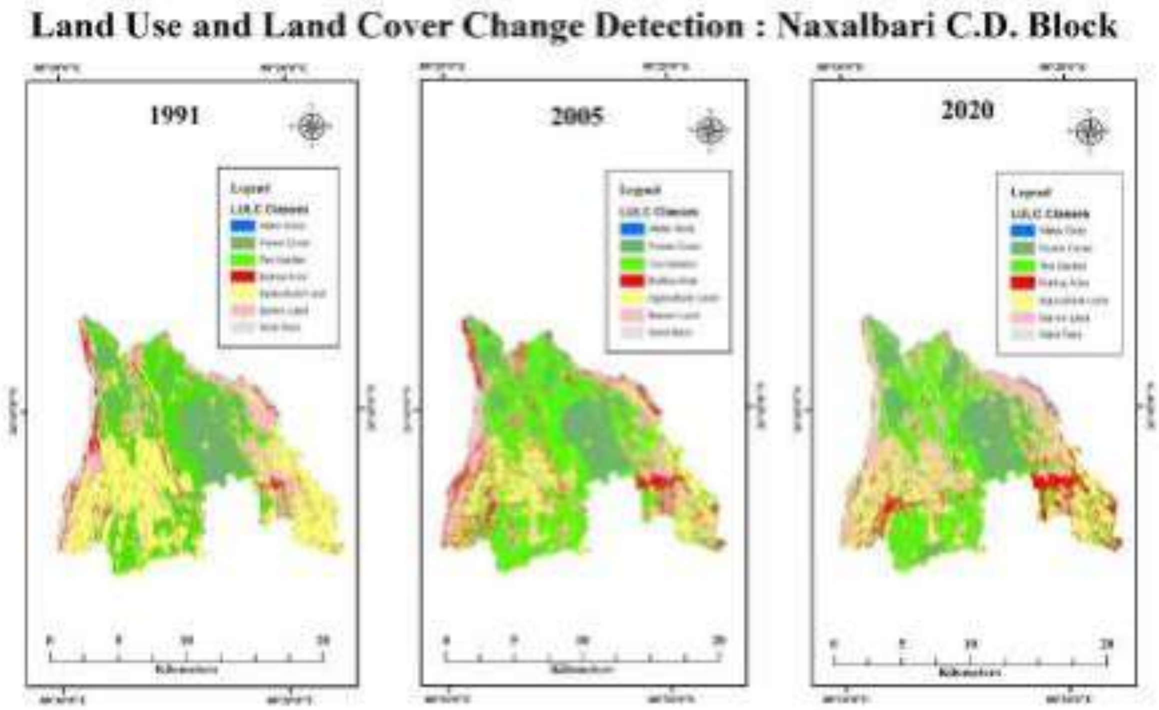



Source: Prepared by the Researcher.

| Table No. 5.5 Land use & land cover change detection : Matigara | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 35.64 | 27 | Agricultural Land | 22.15 | 16.7 | Agricultural Land | 11.58 | 9 |
| Barren Land | 21.14 | 16 | Barren Land | 21.91 | 16.5 | Barren Land | 32.94 | 25 |
| Built-up Area | 9.19 | 7 | Built-up Area | 15.90 | 12 | Built-up Area | 18.32 | 14 |
| Forest Cover | 36.77 | 28 | Forest Cover | 39.87 | 30 | Forest Cover | 43.95 | 33 |
| Sand Bars | 5.85 | 4 | Sand Bars | 3.99 | 3 | Sand Bars | 3.24 | 2 |
| Tea Garden | 22.78 | 17 | Tea Garden | 27.26 | 21 | Tea Garden | 18.20 | 14 |
| Water Body | 1.24 | 1 | Water Body | 1.53 | 1 | Water Body | 4.38 | 3 |
| Grand Total | 132.61 | 100 | Grand Total | 132.61 | 100 | Grand Total | 132.61 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Naxalbari Block - Naxalbari block also experienced significant changes in its land use dynamics owing to increase in the commercial activities. It can be observed from the above maps and tables that the spread of built-up area and the fragmentation of cropland have mainly taken place along the arterial road in the block. Agricultural land has showed a steady decline with respect to the total area over the given time period. Nonetheless, there remains a complex land use transformation dynamic between the agricultural land, built-up area, forest cover and tea gardens. For instance, the total area under cropland decreased by 27 sq. km. between 1991 and 2005 and by 2 sq. km. between 2005 and 2020 and at time was transformed into built-up areas and tea gardens. Consequently, one can notice an increase in the built-up area from 7.15 sq. km. to 13.50 sq. km. during the given assessment period. Given a long duration of time, it has been observed that the change in area under tea plantation has remained inconsistent wherein the area under tea plantation increased to 35% from 27% between 1991 and 2005 which later on declined to 29% in the year 2020. In the context of barren land, the block has had experienced sharp increase in area especially in areas located near Balason and Mechi rivers. The areal extent of barren land was 30.31 sq. km. in 1991, 32.18 sq. km. in 2005 and 46.72 sq. km. in 2020 indicating increase in the areal extent of barren land at an increasing rate. However, it is worth mentioning that among all the classes, it is the forest cover that has the highest percentage of area i.e. 54.54% in Naxalbari block.

**Map No. 5.17 Land use & land cover change detection : Naxalbari**



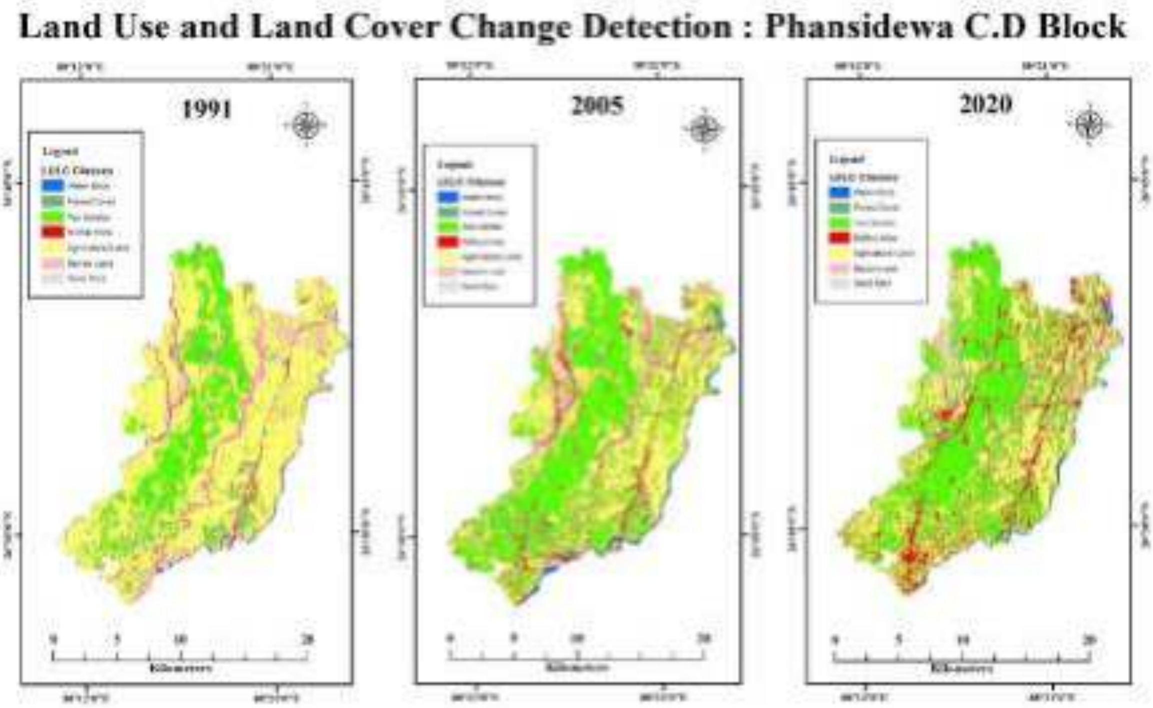

Source: Prepared by the Researcher.

**Table No. 5.6 Land use & Land cover change detection : Naxalbari**

| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
|---|---|---|---|---|---|---|---|---|
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 62.03 | 33 | Agricultural Land | 35.63 | 19 | Agricultural Land | 32.87 | 17 |
| Barren Land | 30.31 | 16 | Barren Land | 32.18 | 17 | Barren Land | 46.72 | 25 |
| Builtup Area | 7.15 | 4 | Builtup Area | 16.40 | 9 | Builtup Area | 13.50 | 7 |
| Forest Cover | 29.20 | 16 | Forest Cover | 32.60 | 17 | Forest Cover | 34.24 | 18 |
| Sand Bars | 7.73 | 4 | Sand Bars | 4.13 | 2 | Sand Bars | 4.61 | 2 |
| Tea Garden | 51.57 | 27 | Tea Garden | 66.61 | 35 | Tea Garden | 54.54 | 29 |
| Water Body | 0.14 | 0 | Water Body | 0.58 | 0 | Water Body | 1.65 | 1 |
| Grand Total | 188.12 | 100 | Grand Total | 188.12 | 100 | Grand Total | 188.12 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Phansidewa Block - Towards the southern part of Siliguri sub-division, along Teesta - Mahananda canal is the Phansidewa block. Following the suit, Phansidewa block also experienced sharp decline in the share of agricultural land from 59% in 1991 to 38.4% in 2005 and 31% in 2020. It is however noted that the percentage of agricultural area has been decreasing at a decreasing rate. Similarly, the forest cover has witnessed a decline from 12.92 sq. km. to 10.81 sq. km. area. Contrary to this, the block has witnessed a striking change in the built-up area as it saw an increase from 11.14 sq. km. in 1991 to 26.42 sq. km. in 2005 and 37.49 sq. km. in 2020. Interestingly, area under tea plantation also increased considerably from 61.41 sq. km in 1991 to 118.96 sq. km in 2005 and 124.40 sq. km area in 2020 considering the large scale conversion of agricultural land into tea gardens.

**Map No. 5.18 Land use & land cover change detection : Phansidewa**

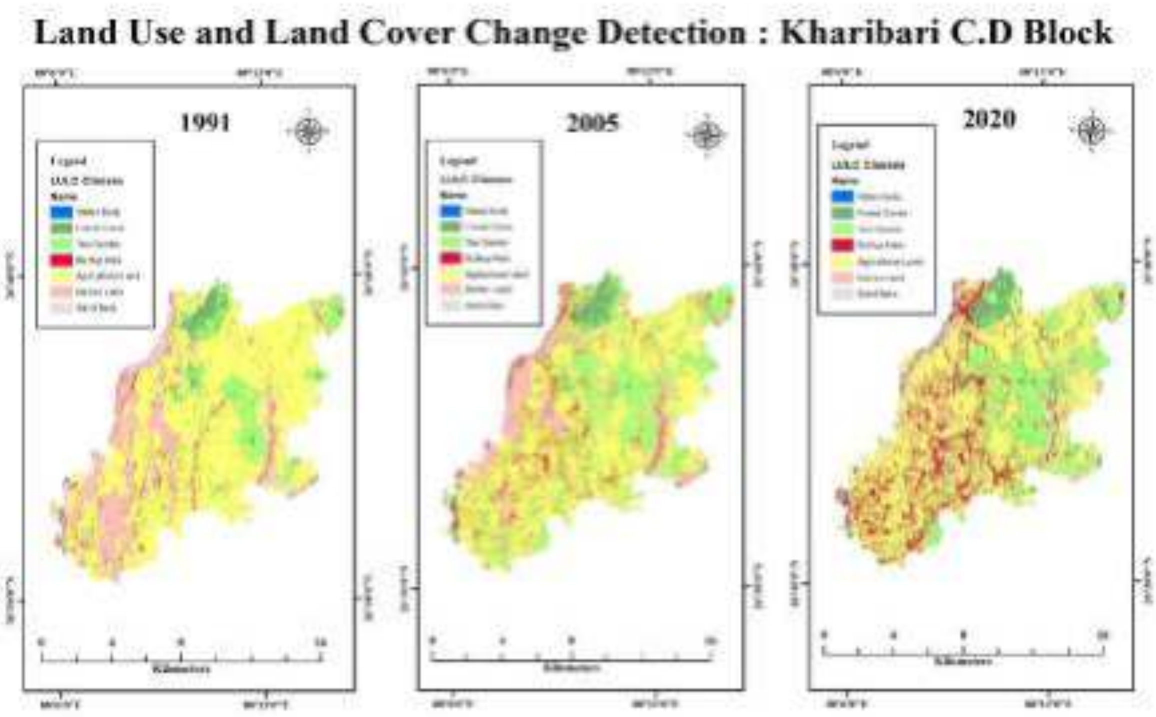



Source: Prepared by the Researcher.

| Table No. 5.7 Land use & land cover change detection : Phansidewa | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 184.39 | 59 | Agricultural Landa | 118.84 | 38 | Agricultural Land | 98.18 | 31 |
| Barren Land | 35.51 | 11 | Barren Land | 30.44 | 10 | Barren Land | 32.66 | 10 |
| Builtup Area | 11.14 | 4 | Builtup Area | 26.42 | 8 | Builtup Area | 37.49 | 12 |
| Forest Cover | 12.92 | 4 | Forest Cover | 9.25 | 3 | Forest Cover | 10.81 | 3 |
| Sand Bars | 3.73 | 1 | Sand Bars | 0.78 | 0 | Sand Bars | 1.83 | 1 |
| Tea Garden | 61.41 | 20 | Tea Garden | 118.96 | 38 | Tea Garden | 124.40 | 40 |
| Water Body | 2.99 | 1 | Water Body | 7.41 | 2 | Water Body | 6.73 | 2 |
| Grand Total | 312.1 | 100 | Grand Total | 312.1 | 100 | Grand Total | 312.1 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Kharibari Block - Kharibari block of Siliguri sub-division is the farthest located block from Siliguri Municipal Corporation. Being distantly located, the block exhibits dwindling urban characteristics while rurality gains prominence. Needless to say, Kharibari block has the highest percentage of agricultural land among all the four blocks in the study area despite a considering decline in the agricultural land from 62% in 1991 to almost 50% in 2020. Similarly, barren land also decreased in the given period of time from 26.06% 1991 to 12% in 2020. Total urban area in Kharibari block is the lowest among the four blocks. Though the total urban area increased from 4.86 sq. km. in 1991 to 11.68 sq. km, the value is comparatively low when compared to other blocks. It is interesting to note that the forest cover saw an increase by only 1 percent during the assessment period mainly because of the conversion of agricultural land. Lastly a steady growth of tea gardens has been observed which could be an outcome of changes in the agricultural practise in the block.

**Map No. 5.19 Land use & land cover change detection : Kharibari**



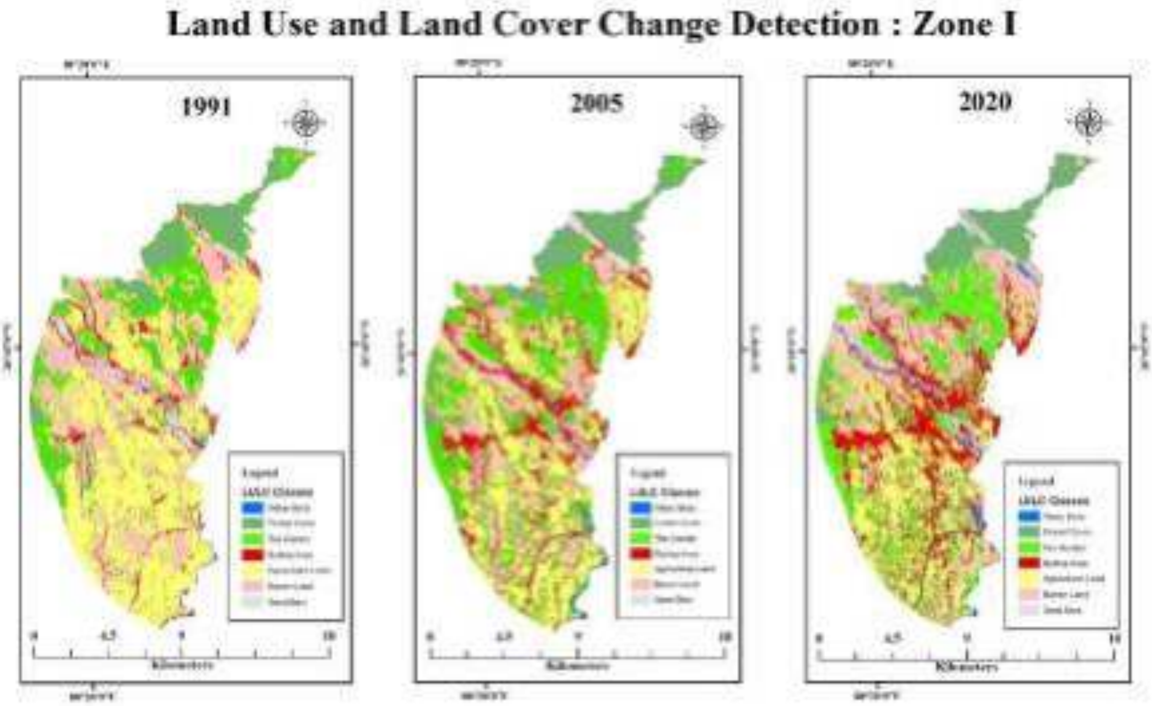

Source: Prepared by the Researcher.

| Table No. 5.8 Land use & Land cover change detection : Kharibari | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 89.65 | 62% | Agricultural Land | 73.01 | 50% | Agricultural Land | 73.011 | 50% |
| Barren Land | 26.06 | 18% | Barren Land | 17.65 | 12% | Barren Land | 17.650 | 12% |
| Builtup Area | 4.86 | 3% | Builtup Area | 11.69 | 8% | Builtup Area | 11.689 | 8% |
| Forest Cover | 4.73 | 3% | Forest Cover | 5.39 | 4% | Forest Cover | 5.393 | 4% |
| Sand Bars | 2.62 | 2% | Sand Bars | 1.08 | 1% | Sand Bars | 1.083 | 1% |
| Tea Garden | 16.56 | 11% | Tea Garden | 35.37 | 24% | Tea Garden | 35.373 | 24% |
| Water Body | 0.40 | 0% | Water Body | 0.68 | 0% | Water Body | 0.681 | 0% |
| Grand Total | 144.88 | 100% | Grand Total | 144.88 | 100% | Grand Total | 144.88 | 100% |
| Source: Calculated by the Researcher. | | | | | | | | |

In this section the LULC change has been analyzed for each of the three zones considered for this study.

Zone I - Zone I consists of 67 villages of Matigara block, 20 villages of Naxalbari block, 26 villages of Phansidewa block, and represents the most urbanized part of sub-division. Since 1991, continued growth of urban built-ups continued in this zone resulting in encroachment of scattered as well as tiny patches of agricultural lands, tea garden, barren lands etc. A reduction in agricultural land area had occurred approximately by 30.24 sq. km. between 1991 and 2005 and approximately by 17.21 sq. km. between 2005 and 2020. The built-up areas increased by approximately 6% between 1991 and 2005 and approximately by 5 % between 2005 and 2020. Spread of built-ups along the arterial roads and fragmentation of existing agricultural lands were prominent in this part during the entire assessment periods, thereby severely defragmenting the Chandmoni Tea Estate and its adjoining agricultural plots. Distinct growth of tea gardens especially in place of forest and barren land during 1991- 2005 and 2005–2020 has been observed.

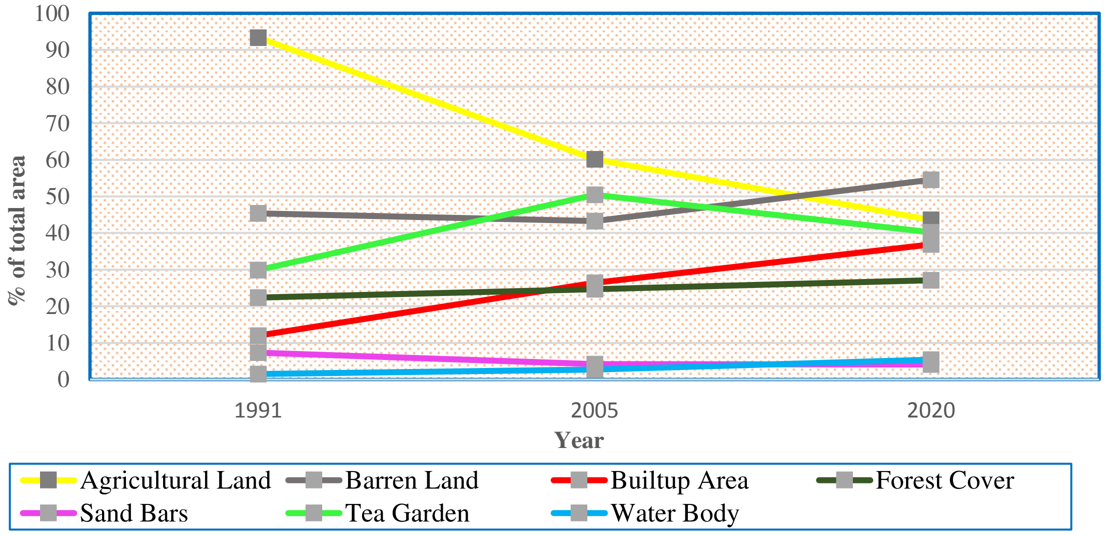
**Map No. 5.20 Land use & land cover change detection : Zone I**




Source: Prepared by the Researcher.

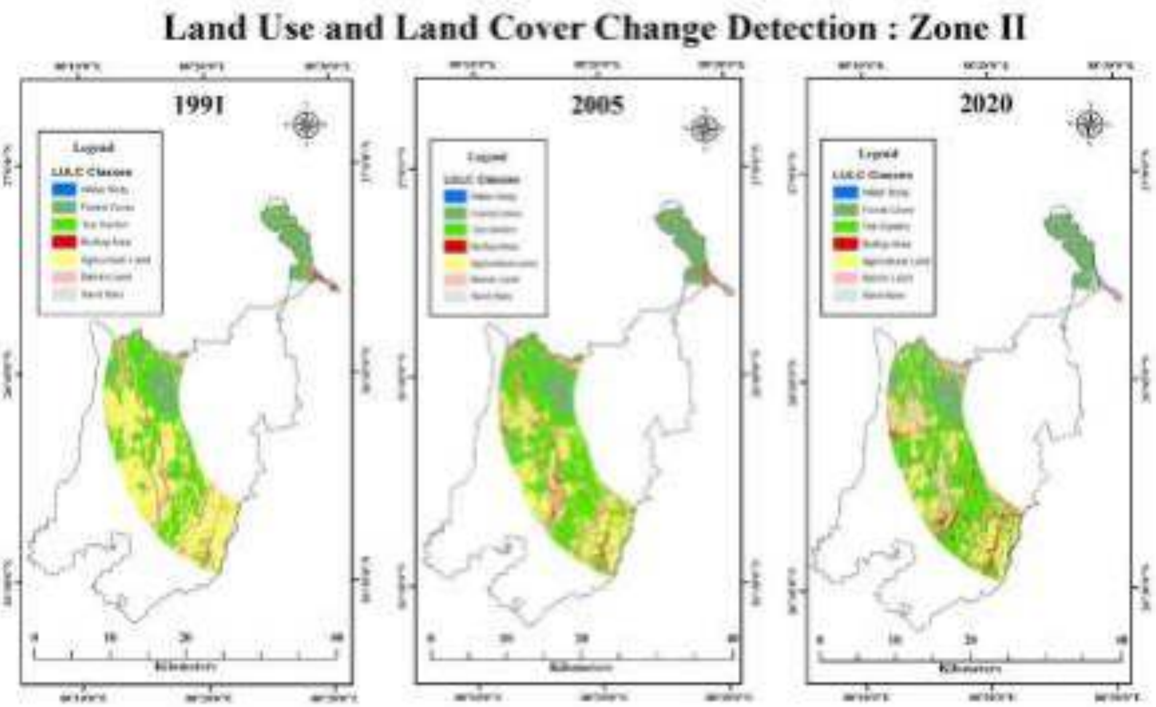
| Table No. 5.9 Land use & Land cover change detection : Zone I | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 93.38 | 44 | Agricultural Land | 60.14 | 28 | Agricultural Land | 43.58 | 21 |
| Barren Land | 45.35 | 21 | Barren Land | 43.27 | 20 | Barren Land | 54.53 | 26 |
| Builtup Area | 11.99 | 6 | Builtup Area | 26.41 | 12 | Builtup Area | 36.87 | 17 |
| Forest Cover | 22.37 | 11 | Forest Cover | 24.69 | 12 | Forest Cover | 27.11 | 13 |
| Sand Bars | 7.33 | 3 | Sand Bars | 4.18 | 2 | Sand Bars | 4.10 | 2 |
| Tea Garden | 29.90 | 14 | Tea Garden | 50.43 | 24 | Tea Garden | 40.21 | 19 |
| Water Body | 1.50 | 1 | Water Body | 2.70 | 1 | Water Body | 5.42 | 3 |
| Grand Total | 211.82 | 100 | Grand Total | 211.82 | 100 | Grand Total | 211.82 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Fig. No. 5.8 Landuse & landcover change: Zone I




Zone II - Zone II consists of 5 villages of Matigara block, 62 villages of Naxalbari block, 72 villages of Phansidewa block and 7 villages of Kharibari block. With the continued outward spread of the urban built-up, it eventually engulfed the non-urban LULCs lying immediate to the Zone I. Thus, the buffer Zone II primarily represents an areas which experienced steady growth of residential sectors and commercial activities at the expense of agricultural lands, vegetation, and barren lands in the last few decades. Although, agricultural land showed a steady decline with respect to total area during the entire assessment period, a complex land use transformation dynamics existed between agricultural land, forest cover, and built-up area. For instance, the total area under agricultural land had decreased by 45.49 sq. km. between1991and 2005 and had been transformed to built-up and other land use classes; considerable amount of forest cover had also been transformed into tea garden during the same period. The tea garden continued displaying an increasing trend in this zone as well during the given time period. Although forest cover remained more or less same between 1991 and 2005, it did increase a little during between 2005 and 2020 (17% in 1991 and 2005 and 19% in 2020).

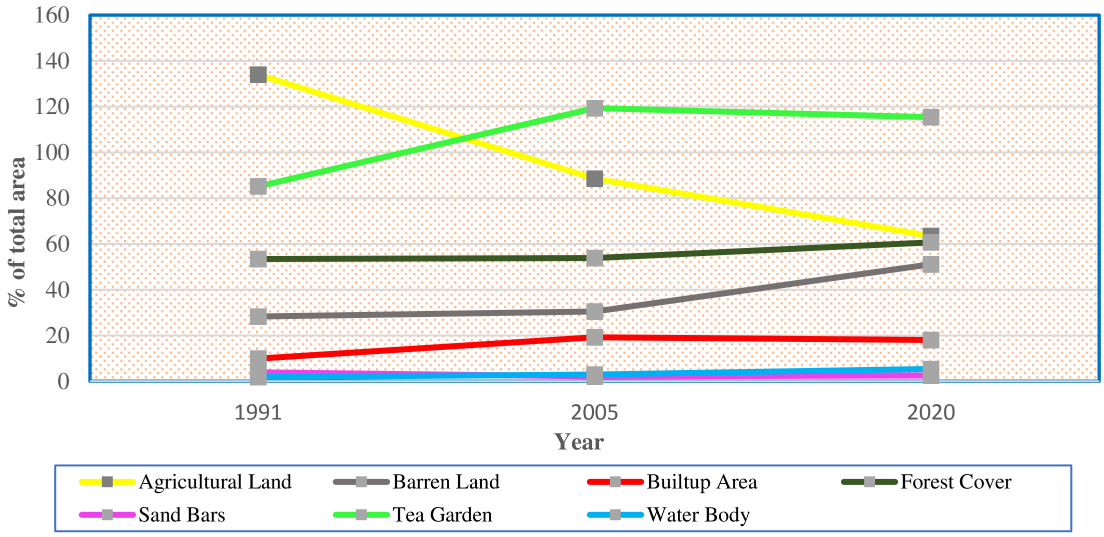
**Map No. 5.21 Land use & land cover change detection : Zone II**




Source: Prepared by the Researcher.

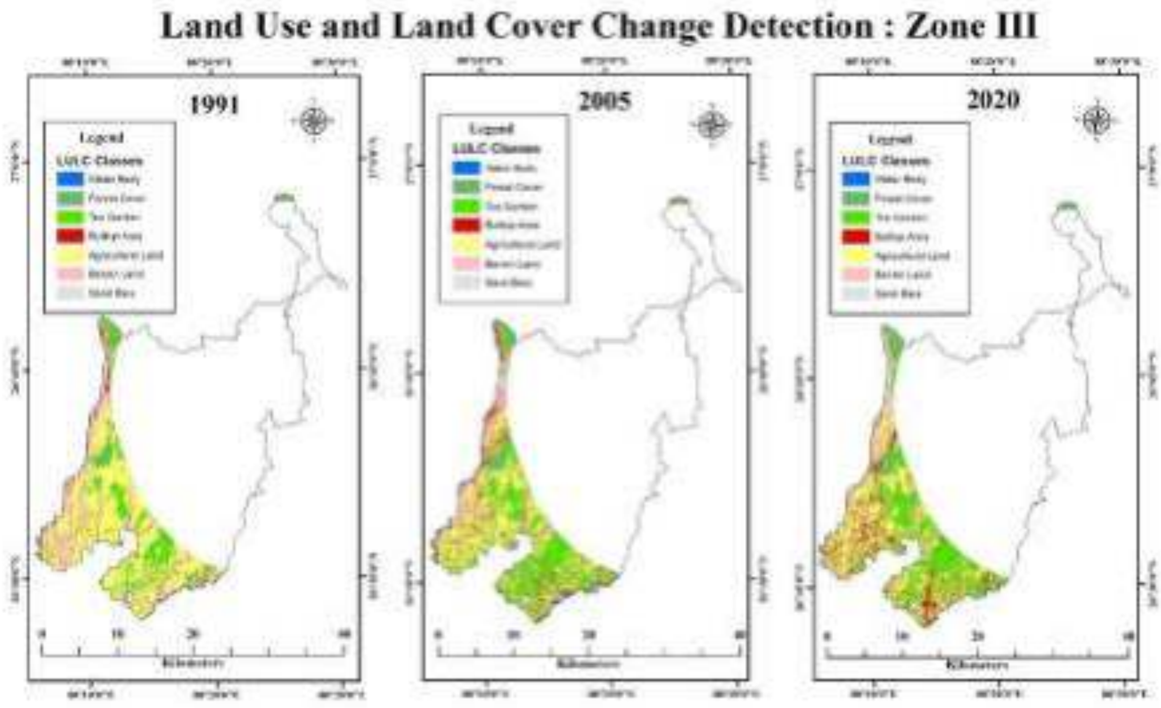
| Table No. 5.10 Land use & Land cover change detection : Zone II | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 133.95 | 42 | Agricultural Land | 88.46 | 28 | Agricultural Land | 63.432 | 20 |
| Barren Land | 28.28 | 9 | Barren Land | 30.42 | 10 | Barren Land | 51.102 | 16 |
| Built-up Area | 9.90 | 3 | Built-up Area | 19.21 | 6 | Built-up Area | 18.019 | 6 |
| Forest Cover | 53.42 | 17 | Forest Cover | 53.89 | 17 | Forest Cover | 60.670 | 19 |
| Sand Bars | 3.89 | 1 | Sand Bars | 2.12 | 1 | Sand Bars | 2.454 | 1 |
| Tea Garden | 85.12 | 27 | Tea Garden | 119.35 | 38 | Tea Garden | 115.314 | 36 |
| Water Body | 1.80 | 1 | Water Body | 2.92 | 1 | Water Body | 5.370 | 2 |
| Grand Total | 316.36 | 100 | Grand Total | 316.36 | 100 | Grand Total | 316.36 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Fig. No. 5.9 Landuse & landcover change: Zone II




Zone III - Zone III consists of 12 villages of Naxalbari block, 15 villages of Phansidewa block and 67 villages of Kharibari block, represents the farthest zone of the sub-division. Despite expansion in built-up areas, substantial amount of croplands also existed in these area as it lay comparatively far from the urban core. The amount of cropland reduced from 136.59 sq. km. (1991) to 98.63 sq. km. (2020) between total assessment periods owing to conversion to other classes of land. Subsequently, percentage growth of built-up (6%) was found to be slightly higher in this zone, especially between 1991 and 2005. In spite of relatively greater distance from the urban core, the growing demand of green-field sites for new commercial and industrial clusters had actually triggered the rampant acquisition of agricultural lands in the south-western parts of this zone. Shrinkage of agricultural lands continued during total assessment period mainly to accommodate built-ups and fallow lands. Barren land and water body also decreased in area from 1991 to 2005 and also from 2005 to 2020 to accommodate growth of built-up as well as tea garden.

**Map No. 5.22 Land use & land cover change detection : Zone III**




Source: Prepared by the Researcher.

| Table No. 5.11 Land use & land cover change detection : Zone III | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 136.59 | 54 | Agricultural Land | 94.67 | 38 | Agricultural Land | 98.63 | 39 |
| Barren Land | 40.54 | 16 | Barren Land | 30.62 | 12 | Barren Land | 23.25 | 9 |
| Builtup Area | 11.22 | 4 | Builtup Area | 25.73 | 10 | Builtup Area | 34.06 | 14 |
| Forest Cover | 13.71 | 5 | Forest Cover | 15.26 | 6 | Forest Cover | 16.26 | 6 |
| Sand Bars | 9.55 | 4 | Sand Bars | 4.34 | 2 | Sand Bars | 4.78 | 2 |
| Tea Garden | 39.00 | 15 | Tea Garden | 77.12 | 31 | Tea Garden | 71.91 | 29 |
| Water Body | 1.46 | 1 | Water Body | 4.34 | 2 | Water Body | 3.18 | 1 |
| Grand Total | 252.07 | 100 | Grand Total | 252.07 | 100 | Grand Total | 252.07 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

Table 5.11 shows the percentage change in LULC under each of the seven landuse/landcover class for Zone III in the study area during 1991, 2005 and 2020 respectively. It is evident from the table that agricultural land and built-up area has undergone the major change in this zone.

Fig. No. 5.10 Landuse & landcover change: Zone III

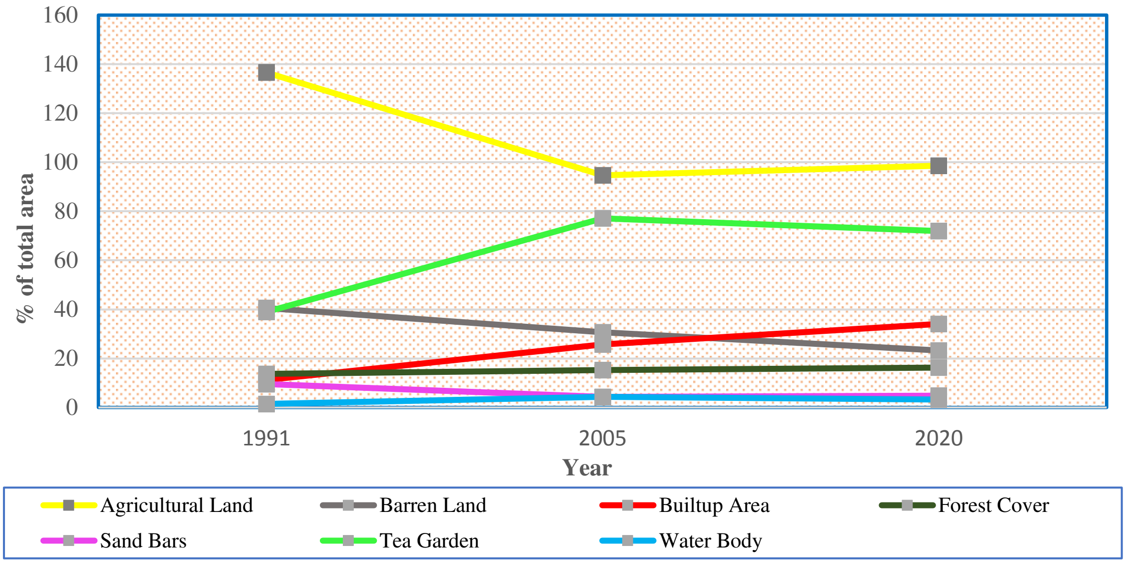



**Table No. 5.12 Change in LULC in the study area**

| LULC Change Category | Zone I | | Zone II | | Zone III | |
|---|---|---|---|---|---|---|
| | Area In Sq.km.(1991-2005) | Area In Sq.Km.(2005-2020) | Area In Sq.Km.(1991-2005) | Area In Sq.Km.(2005-2020) | Area In Sq.Km.(1991-2005) | Area In Sq.Km.(2005-2020) |
| Agricultural land → Barren Land | 14.42 | 19.37 | 11.54 | 18.18 | 8.09 | 6.96 |
| Agricultural land → Builtup Area | 8.98 | 9.00 | 6.90 | 4.95 | 5.26 | 5.94 |
| Agricultural land → Forest Cover | 1.76 | 0.30 | 1.67 | 0.98 | 3.05 | 0.99 |
| Agricultural land → Sand Bars | 0.24 | 0.09 | 0.06 | 0.10 | 0.03 | 0.03 |
| Agricultural land → Tea Garden | 18.93 | 5.21 | 32.90 | 15.46 | 19.19 | 6.73 |
| Agricultural land →Water Body | 0.49 | 0.46 | 0.43 | 0.43 | 1.10 | 0.20 |
| Barren Land → Agricultural Land | 6.36 | 9.51 | 3.72 | 6.16 | 5.60 | 7.43 |
| Barren Land → Builtup Area | 8.36 | 6.27 | 4.66 | 1.24 | 2.02 | 2.37 |
| Barren Land → Forest Cover | 1.17 | 0.60 | 1.17 | 1.07 | 0.97 | 0.48 |
| Barren Land → Sand Bars | 0.38 | 0.52 | 0.29 | 0.48 | 0.40 | 0.77 |
| Barren Land → Tea Garden | 6.98 | 5.63 | 6.22 | 6.98 | 5.32 | 4.95 |
| Barren Land → Water Body | 0.30 | 0.46 | 0.30 | 0.53 | 0.51 | 0.38 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Builtup Area → Agricultural Land | 2.06 | 3.54 | 1.35 | 3.42 | 2.95 | 2.92 |
| Builtup Area → Barren Land | 2.11 | 5.10 | 1.99 | 5.57 | 2.36 | 3.69 |
| Builtup Area → Forest Cover | 0.18 | 0.28 | 0.26 | 0.55 | 0.14 | 0.32 |
| Builtup Area → Sand Bars | 0.98 | 1.34 | 0.52 | 1.07 | 0.65 | 1.09 |
| Builtup Area →Tea Garden | 0.52 | 1.03 | 0.76 | 1.69 | 0.94 | 1.83 |
| Builtup Area → Water Body | 0.74 | 2.11 | 0.72 | 1.98 | 0.71 | 0.94 |
| Forest cover →Agricultural Land | 0.14 | 0.27 | 0.28 | 0.19 | 0.38 | 1.86 |
| Forest cover →Barren Land | 0.50 | 0.63 | 0.49 | 1.58 | 0.16 | 0.34 |
| Forest cover → Builtup Area | 0.55 | 1.51 | 0.70 | 1.05 | 0.52 | 1.59 |
| Forest cover →Sand Bars | 0.02 | 0.01 | 0.06 | 0.01 | 0.03 | 0.00 |
| Forest cover → Tea Garden | 3.35 | 2.10 | 11.31 | 7.39 | 5.51 | 3.64 |
| Forest cover →Water Body | 0.05 | 0.24 | 0.10 | 0.23 | 0.09 | 0.10 |
| Sand Bars →Agricultural Land | 0.37 | 0.25 | 0.11 | 0.09 | 0.22 | 0.43 |
| Sand Bars → Barren Land | 1.60 | 0.99 | 1.03 | 0.86 | 2.26 | 0.71 |
| Sand Bars → Builtup Area | 2.43 | 0.27 | 1.24 | 0.14 | 2.86 | 0.47 |
| Sand Bars →Forest Cover | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| Sand Bars →Tea Garden | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 |
| Sand Bars →Water Body | 0.68 | 0.82 | 0.51 | 0.45 | 0.96 | 0.26 |
| Tea Garden →Agricultural Land | 0.94 | 4.10 | 2.31 | 4.93 | 2.33 | 4.89 |
| Tea Garden → Barren Land | 2.66 | 7.70 | 3.38 | 10.62 | 1.25 | 1.76 |
| Tea Garden → Builtup Area | 0.77 | 6.27 | 0.99 | 5.31 | 0.96 | 7.41 |
| Tea Garden → Forest Cover | 3.78 | 5.96 | 10.22 | 14.59 | 4.01 | 6.72 |
| Tea Garden → Sand Bars | 0.18 | 0.02 | 0.08 | 0.05 | 0.00 | 0.00 |
| Tea Garden →Water Body | 0.03 | 0.21 | 0.08 | 0.21 | 0.14 | 0.05 |
| Water Body →Agricultural Land | 0.15 | 0.20 | 0.22 | 0.25 | 0.05 | 1.20 |
| Water Body → Barren Land | 0.09 | 0.45 | 0.05 | 0.35 | 0.06 | 0.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Water Body → Builtup Area | 0.59 | 0.57 | 0.42 | 0.42 | 0.38 | 0.92 |
| Water Body → Forest Cover | 0.11 | 0.02 | 0.08 | 0.03 | 0.03 | 0.03 |
| Water Body →Sand Bars | 0.04 | 0.27 | 0.14 | 0.18 | 0.08 | 0.45 |
| Water Body → Tea Garden | 0.08 | 0.06 | 0.10 | 0.15 | 0.04 | 0.31 |
| Grand Total | 94.11 | 103.78 | 109.38 | 119.94 | 81.59 | 81.37 |
| Source: Calculated by the Researcher. | | | | | | |

Table No. 5.12 shows the change in LULC from each class to rest of the six classes in the study area for the three zones during 1991-2005 and 2005-2020 respectively. It is evident from the table that major change in LULC has taken place from agricultural land to barren land, agricultural land to built-up area, agricultural land to tea garden, barren land to agricultural land, barren land to built-up area, barren land to tea garden, forest to tea garden and tea garden to forest respectively. For rest of the categories the change is negligible. Table No. 5.13 shows the total change in LULC across the seven classes for each zone along with their respective percentage to total area during 1991-2005 and 2005-2020. It is evident from the table that Zone I locted nearest to Siliguri Municipal Corporation recorded the maximum change for both the time period followed by Zone II and Zone III respectively. Thus it can be said that with increase in distance from Siliguri Municipal Corporation, LULC change has decreased in the study area. Therefore, the third hypothesis that there is a negative relationship between distance from Siliguri Municipal Corporation and land use and land cover change in the study area is validated and accepted.

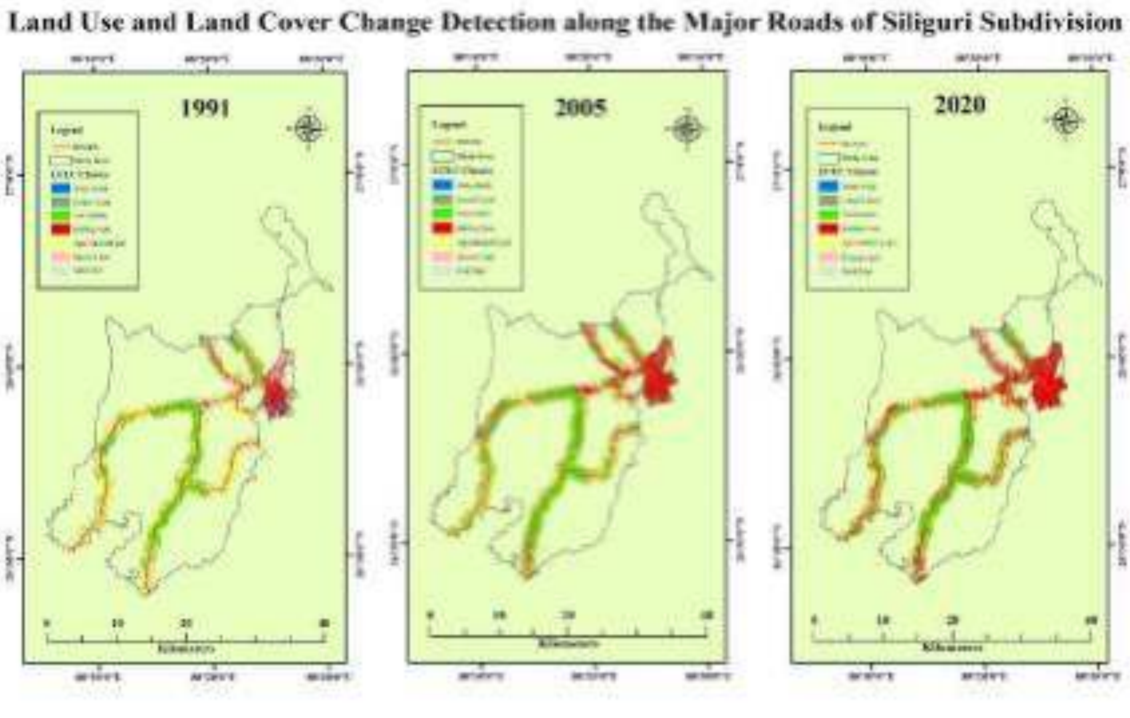
**Table No. 5.13 Percentage change in LULC in the study area**

| Zone | TotalArea (sq. km) | 1991-2005 | | 2005-2020 | |
|---|---|---|---|---|---|
| | | Actual Change (sq. km) | % Change | Actual Change (sq. km) | % Change |
| I | 211.82 | 94.11 | 44.43 | 109.38 | 48.99 |
| II | 316.36 | 103.78 | 34.57 | 119.94 | 37.91 |
| III | 252.07 | 81.59 | 32.36 | 81.37 | 32.28 |
| Source: Calculated by the Researcher. | | | | | |

### 5.5.3 Landuse & land cover change of Siliguri sub-division through main transport lines

Along transportation lines the landuse and landcover change is maximum. In the study area the main transportation lines are Asian Highway 2, NH 31, NH 31A, NH 55 and SH 12. Therefore, in this section landuse and landcover change has been along these roads for 1991, 2005 and 2020 respectively. 1 km buffer has been taken along both side of these roads, and landuse and landcover change has been analyzed accordingly. The LULC change has been done following the earlier process used for identifying the change both for the blocks as well as for the three zones. Map No 5.23 shows the change in LULC along the major roads in the study area and table 5.14 shows the actual area and percentage change under each category. The most important change in LULC is with respect to agricultural land. It was 45% in 1991, which decreased 28% in 2005 and 22% in 2020 respectively. Area under barren land has also gone down considerably from 1991 to 2020. Built-up area has seen a rapid increase along the main roads and its percentage went up from 10% in 1991 to 21% in 2005 and further went to 31% in 2020. Area under forest cover, sand bar and water body has remained more or less same from 1991 to 2020. However, area under tea garden went up from 19% in 1991 to 28% in 2020. Therefore, along the main roads in the study area, agricultural land has been mostly converted to built-up area and tea garden during 1991 to 2020.

**Map No. 5.23 Land use & land cover change of Siliguri sub-division through main transport line,1991-2020**




Source: Prepared by the Researcher.

| Table No. 5.14 Land use & Land cover change of Siliguri sub-division through main transport line, 1991-2020 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC 1991 | | | LULC 2005 | | | LULC 2020 | | |
| LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area | LULC Class | Area in sq. km | % of total area |
| Agricultural Land | 111.96 | 45 | Agricultural Landa | 69.70 | 28 | Agricultural Land | 53.82 | 22 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Barren Land | 39.72 | 16 | Barren Land | 27.71 | 11 | Barren Land | 29.70 | 12 |
| Builtup Area | 25.24 | 10 | Builtup Area | 51.25 | 21 | Builtup Area | 75.26 | 31 |
| Forest Cover | 14.72 | 6 | Forest Cover | 13.11 | 5 | Forest Cover | 13.04 | 5 |
| Sand Bars | 3.67 | 1 | Sand Bars | 0.78 | 0 | Sand Bars | 1.38 | 1 |
| Tea Garden | 47.05 | 19 | Tea Garden | 80.57 | 33 | Tea Garden | 69.04 | 28 |
| Water Body | 4.30 | 2 | Water Body | 3.51 | 1 | Water Body | 4.41 | 2 |
| Grand Total | 246.69 | 100 | Grand Total | 246.66 | 100 | Grand Total | 246.67 | 100 |
| Source: Calculated by the Researcher. | | | | | | | | |

### 5.6 Summary

The major objective of this chapter was to study the transport network and analyze the land use and land cover change within the study. The road and rail network of the study area shows that roadways are the most important mode of communication for the rural population in the study area to interact with Siliguri Municipal Corporation. Although, railway network is present but lack of suburban rail connectivity with Siliguri does not make it a popular mode of transportation for the rural population of Siliguri sub-division to connect with Siliguri. The transport network is most developed in Siliguri Municipal Corporation and its surrounding rural areas and as one moves away from the main urban centre the transport network also became less developed. The transport network analysis done for the study area shows that Siliguri Municipal Corporation and its surrounding areas around Bagdogra, Shivmandir and Matigara covering the east-central part of the study area have the highest network connectivity and as moves towards the north, west and south-western part of the sub division the transport network connectivity deteriorates considerably. The road density within the study area also varies with the highest road density observed around Siliguri Municipal Corporation and its surrounding area and the lowest road density observed along the border areas of the subdivision. Among the blocks, Matigara has the highest road density while Kharibari and Phansidewa has the lowest road density. Among the zones, Zone I has the highest road density and Zone III has the lowest road density.

The land use and land cover change in the study area has been analyzed for seven classes which are agricultural land, barren land, built-up area, forest cover, sand bars, tea garden and water bodies. For all the zones as well as the blocks from 1991 to 2020, the area under built-up area and tea garden has increased while the area under agricultural land has declined. For rest of the classes there has not been too much of a change from 1991 to 2020.

The built-up area has increased due to spread of urbanization and associated construction activities. The area under tea garden has gone up considerably by conversion of agricultural land to tea garden as the small farmers find tea plantation to be more profitable than conventional agricultural practices. Land use and land cover change along the main transportation lines in the study area has also undergone a lot of change with the agricultural land being converted to built-up area.

## 5.7 References


1. Al-Sahili, K., & Aboul-Ella, M. (1992) *Accessibility of public services in Irbid, Jordan*. Journal of Urban Planning and Development, 118(1), 1–12.
2. Bhatta, B. (2009) *Analysis of urban growth pattern using remote sensing and GIS: a case study of Kolkata, India*. Int J Remote Sens 30(18):4733–4746
3. Cervero, R. (2003) *Road expansion, urban growth, and induced travel: a path analysis*. J Am Plann Assoc 69(2):145–163
4. Chen, S., Claramunt, C., & Ray, C. (2014) *A spatio-temporal modelling approach for the study of the connectivity and accessibility of the Guangzhou metropolitan network*. Journal of Transport Geography, 36, 12–23.
5. Cliff, A., Haggett, P., & Ord, K. (1979) *Graph theory and geography.* Applications of Graph Theory, 293, 326.
6. Das, D., Ojha, A., Kramsapi, H., Baruah, P.P., Dutta, M.K. (2019) *Road network analysis of Guwahati city using GIS*. SN Applied Sciences, Springer Nature Switzerland AG.1:906.
7. Dill, J. (2004) *Measuring network connectivity for bicycling and walking*. Presented at 83rd annual meeting of the transportation Research Board, Washington DC, pp. 11–15.
8. Dinda, S., Ghosh, S., & Chatterjee, N. D. (2019) *An analysis of transport suitability, modal choice and trip pattern using accessibility and network approach: A study of Jamshedpur city, India*. Spatial Information Research, 27(2), 169–186
9. Ford, A. C., Barr, S. L., Dawson, R. J., & James, P. (2015) *Transport accessibility analysis using GIS: Assessing sustainable transport in London*. ISPRS International Journal of Geo-Information, 4(1), 124–149.
10. Freiria, S., Ribeiro, B., & Tavares, A. O.(2015) *Understanding road network dynamics: Link-based topological patterns*. Journal of Transport Geography, 46, 55–66.
11. Garrison, W. L. (1960) *Connectivity of the interstate highway system*. Papers in Regional Science, 6(1), 121–137.
12. Hegazy, I.R., Kaloop, M.R. (2015) *Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt*. Int J Sustain Built Environ 4(1):117–124.
13. Holl, A. (2007) *Twenty years of accessibility improvements. The case of the Spanish motorway building programme.* Journal of Transport Geography, 15(4), 286–297.