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ARTICLE

Assessment of Urban Morphology through Local Climate Zone Classification and Detection of the Changing Building States of Siliguri Municipal Corporation and Its Surrounding Area, West Bengal

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ABSTRACT

Progressive population concentration in the urban centres has fuelled urban expansion in both horizontal as well as vertical directions, with consequences in the urban landscape change. This growth resulted in posing many complexities towards sustainable urban development which can be counted by observing the changing proportions of natural landscapes and built up areas. Local climate zones (LCZs), a systematic classification of natural lands and built up lands, are identified in Siliguri Municipal Corporation (SMC) and its surrounding region to explore the spatio temporal complexity of urban growth in recent years. Rapid urbanization and population growth of SMC have led to changes in the building states from low-rise to mid and high-rise which added an important feature to the urban landscape dynamics of the area. The work intends to provide the vision of the spatial urban morphology of the area through the investigation of its changing land use and changing urban built space using the LCZ classification. The study shows that the WUDAPT method can accurately generate LCZs, especially the built type LCZs. The results of the proposed LCZ classification scheme are tested using an error matrix for the years 2001 and 2021 having coefficient values of 0.79 and 0.81 respectively. The study explores the changing pattern of building states of SMC using LCZ products, which is essential for proper urban planning implementations.

1. Introduction

Urban growth incorporates both horizontal and vertical expansion through its complex spatio temporal process. With the physical expansion of built up land internal urban morphology also altered. In the context of rapid urban growth and limited territories, a new approach is needed for urban space planning through vertical construction [1]. Building distribution patterns, especially the upward growth of buildings can significantly transform urban built up morphology with compact rise, open rise and sparsely built areas [2]. This urges the need to study the

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complexities of horizontal as well as vertical urban growth of cities in the field of urban analysis. In developing countries' morphological unevenness can be vividly noticed in the town and cities were parts of the city is comprised of concrete and metal structured medium and high-rise buildings, metallic pavements, parking lots and parts of the city are still composed of low-rise buildings constructed of mud, tin and semi concrete materials that are compact or sparsely arranged with open and green space [3]. So it is necessary to quest the differences in the urban landscape at a local scale. A universal scheme of the local climatic zone was suggested by Stewart and Oke to characterise and capture this shot of micro level variations within the entire urban landscape [4].

A number of urban classification schemes such as Urban Terrain Zone (UTZ), Urban Climate Zone (UCZ) have been developed to facilitate knowledge in urban studies [5,6]. The previous classification of Oke on Urban Climatic Zone (UCZ) has been expanded and improved through LCZ scheme to make a standardised classification of the 'urban' and 'rural' (or built and land cover classes) landscapes [4]. Local climate zones are defined by Stewart and Oke as "regions of uniform land cover, surface structure, construction material and human activity that span hundreds of meters to several kilometres on a horizontal scale". It is a more effective classification system to study the spatial characteristics of landscapes on a local scale that fall in the category of 'urban' and 'rural'. LCZ mapping is considered the first step in the development of urban climate maps that contain information on the spatial distribution of land use classes [7]. Large extents of research works have applied the classification scheme for extracting the LCZ classes in their target regions [8-12]. The outcomes from the application of this process can be applied as input data for urban planning purposes. LCZ classification scheme has been applied to many cities of the world to classify urban surface conditions based on remote sensing data and primary observations [13]. A complex urban scenarios can be differentiated through analysis of the dissimilarity of textures of different urban LCZ types using high resolution satellite data set [14]. The findings of the case study of Hong Kong provide an in-depth understanding of different LCZ mapping methods and their advantages and limitations [9]. Zheng et al. examine the spatial sensitivity and spatial characteristics of LCZ classification in Hong Kong and establish the LCZ database [15]. The results of LCZs scheme can be implemented for modelling and mapping of intra urban structures based on various geometric properties [16-18]. The study by Ren et al. examines the relationship between socio economic status and LCZ products of the cities of China, essential for further implementations and urban growth monitoring [19].

Most of the previous studies attempted to explore the transformation of an urban landscape with the rapid transformation of LULC [20-22]. But LULC changes can only provide the horizontal transformation of the landscape. It fails to capture the vertical transformation which is an integral part of urban landscape study and that can be well understood in local climatic zones. The subdivision within the built up land can accurately determine the changes of built up types from sparse low-rise to compact high density high-rise built up land [23]. The LCZ classification scheme can provide distinct and unique partitions of landscapes that cover major urban forms and land cover types. In this context, LCZs provide a great potentiality to explore changing dynamics of the urban landscape in response to changing LULC and the inter categorical transformation of building states. In developing countries, information related to urban morphological characteristics remains scarce where the heterogeneous complex urban surface characteristics needed to be monitored. Various studies successfully incorporated WUDAPT method to derive LCZ maps in the cities having a homogeneous built surface with planned development [24-26]. But there are few studies of LCZ mapping in the cities of developing countries with heterogeneous built form having mixed urban fabric [26,27]. Those countries where land use information is not readily available are needed to generate LCZ classification results to meet the planning requirements of urban areas [9]. LCZ data sets can be developed from generalised knowledge of built forms and land cover types to enhance their usefulness especially in data poor but rapidly changing tropical cities [27]. So geospatial technologies should be adopted by the planners and scientists of those countries to enhance the understanding of urban forms of cities and promote sustainable urban development [28]. Documentation and presentation of proper data to describe the specific local features of urban built form in Indian cities are less in number. Most Indian cities are characterised by heterogeneous types of built form. The complex urban form and data inefficiency of such cities pose difficulties in the identification and classification of LCZ [29]. They have detected the variations in built LCZ classes in Nagpur, India, as a result of the intermi of compact low-rise areas with slums and squatters.

In recent years upward construction has become inevitable with the rapid population increase in the major cities of India to fulfil the growing demand for housing and Siliguri is none the exception. Siliguri Municipal

Corporation (SMC) is undergoing significant demographic growth and economic development hence, experiencing rapid conversion of its land use land cover pattern and built up forms. A number of high-rise multi storied complexes have come up both in SMC and its surrounding areas, as it tries to adjust its population pressure and land scarcity which added a new dimension its built up scenario. Expansion of the city brings changes in the land use and land cover (LULC) pattern, affecting its spatial characteristics. Being a town located near the Himalayan mountain region, high-rise construction was restricted in Siliguri. But after 2011, as high-rise constructions became permissible (The West Bengal Municipal building rules, 2008), the built up scenario of Siliguri has changed rapidly with the increasing number of high-rise buildings. To maximise the development potentials mid-rise and high-rise building development is adopted in SMC urban areas. The areas around the railway station considered the central business district, characterised by high density with mid to high-rise structures, have adversely affected the area under green cover and open spaces (City development plan for Siliguri-2041).

The city requires proper identification of the arrangement of built space associated with urban development for giving a proper direction to the growth and urbanization process. To meet this requirement the study employs the classification scheme of 'Local Climatic Zones' to conduct a spatiotemporal analysis of changing LULC condition and built up types of Siliguri and its surrounding area. No studies have yet been done to analyze the internal urban morphology and building alteration process using the LCZ scheme in SMC. So it is essential to investigate the spatial characteristics of urban land systematically in the context of the urban the predominance of SMC for the future implication of suitable policies in North Bengal.

Hence, the present study aims i) To delineate the local climate zones and identify the built up types and natural land cover types of SMC and its surrounding. ii) To investigate the change and alteration of building states in Siliguri Municipal Corporation through the output of LCZ classification scheme. The study tries to develop a local climate zone classification map using spatial data obtained from Landsat images in remote sensing and GIS environment to analyse urban morphology and establish the association between urban growth and the internal variations of building states within the city. This will ultimately help in understanding the local complexities in growing urban land and meeting the future planning requirements of the city by balancing the proportion of land use and land cover types.

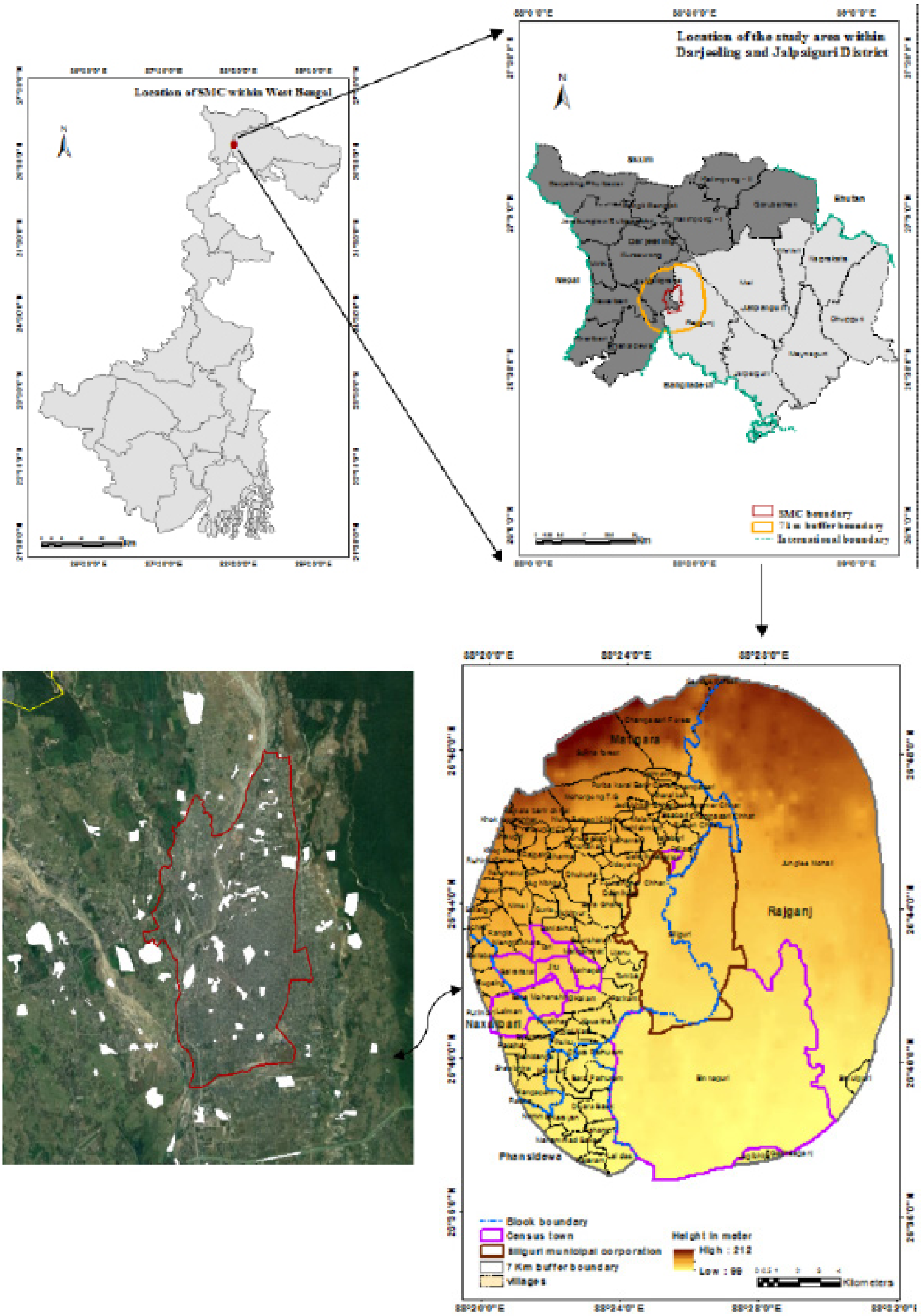
2. Study Area

The study area includes Siliguri Municipal Corporation (SMC) and its buffer of seven kilometres, taken as the area of interest (AoI), comprising both urban main land and suburban areas. SMC is the nodal unit of development of Siliguri Jalpaiguri planning area and has immense importance as a rapidly developing urban area in West Bengal. Siliguri is the gateway of the whole of North East India for its strategic location and is one of the fastest growing urban entities of the state. The town is located at the foot of the southern Himalayas which fall under the Terai physiographic region, connecting north east border states with the rest of India. SMC lies at 26° 41' N to 26° 42' N and 88° 23' E to 88° 28' E coordinates near the Mahananda river at an elevation of 121 meter above sea level with an area of 41.9 sq.km. The upgradation of Siliguri urban area from Municipal town in 1949 to the status of Municipal Corporation in 1994 was an indicator of its rapid pace of urbanization.

The study area comprises Siliguri Municipal Corporation, 9 census towns (namely Kalkut, Lalman, Tari, Bairatistal, Bara mohansing, Jitu, Mathapari, Dabgram and Binnaguri) and 92 villages within the buffer boundary of 7 km, covering total of 384 sq.km of area (Figure 1). Total population of Siliguri town as per the census report of India recorded 216950 in 1991 which has increased to 513,264 in 2011. Although SMC has a population of 513,264, according to the last census report, its urban agglomeration population is 705,579. It registered a population growth rate of 8.65% in the decade 2001-2011. Its population density has increased from 5178 persons per sq.km (in 1991) to 12250 persons per km^2 in 2011. Over the last 20 years, SMC has experienced rapid changes in terms of population density, land use pattern and building types.

3. Materials and Method

Landsat 8 TM and OLI TRIES images are used for preparing Local Climate Zones (LCZs) maps for the year 2001 and 2021. These input image data contain land use information and urban built up information which can be used by analysing their spectral and spatial information to develop the LCZ map. Details specifications of these Landsat images are shown in Table 1. downloaded from the U.S. Geological Survey website after considering their availability and quality.



Selected training samples in the study area.

Figure 1. Location map of the study area and selected training samples

Source: Google earth image

Table 1. Characteristic of Land sat Satellite Images used in the Study

Satellite	Sensor ID	Year	Acquisition date	Resolution	Path/Row	Projection
LANDSAT 5	TM	2001	2001-01-19	30 m	139/41	UTM-WGS1984
LANDSAT-8	OLI_TIRS	2021	2021-01-11	30 m	139/41	UTM-WGS1984

Source: earth explorer USGS

3.1 Methods for Delimitation of Local Climate Zones (LCZ)

The LCZ classification scheme is applied to Siliguri and its 7 km surrounding area, taken as an area of interest (AOI) following the World Urban Database and Access Portal Tools (WUDAPT) methodology [30]. WUDAPT is the remote sensing satellite image based method for LCZ mapping, which is adopted and applied by many researchers in their urban morphological and UHI studies [31,32]. WUDAPT gathers information on the form and functional aspects of urban areas that are used worldwide in a consistent manner. Based on the LCZ scheme, WUDAPT classifies natural and urban landscapes into climate relevant surface properties [30,33].

Out of 17 LCZ classes (Table 2), as developed by Stewart and Oke, a total of 15 types LCZ i.e. 10 built types and 5 natural surface covers were identified based on the LCZ classification criteria. 15 training samples, selected for each LCZ class, were collected through GPS survey according to the building heights and spacing. The total area of a training site for each LCZ has to range between 1 to 5 sq.km, collected from a place where homogeneous conditions covered at least 1 sq.km area as stipulated by Danylo et al. [26]. The area polygons for creating signature sample files are selected which consist of buildings and theirs close vicinity. After transferring the points on Google earth for extracting sample signatures for each LCZ class, polygons were digitized and saved in Kml format. The training samples selected for the LCZ classification are shown in Figure 1.

Table 2. LCZ classes and respective codes (Stewart and Oke, 2012)

Built types	Land cover types	Variable Land cover properties
LCZ 1- compact high-rise	LCZ A- dense trees	b - bare trees
LCZ 2- compact mid-rise	LCZ B- scattered trees	s - snow cover
LCZ 3- compact low-rise	LCZ C- bush, scrub	d - dry ground
LCZ 4- open high - rise	LCZ D- low plants	w - wet ground
LCZ 5- open mid-rise	LCZ E- bare rock/paved	
LCZ 6- open low-rise	LCZ F- bare soil/sand	
LCZ 7- lightweight low-rise	LCZ G- water	
LCZ 8- large low-rise		
LCZ 9- sparsely built		
LCZ 10- heavy industry		

Pre processed Landsat images, AOI and training samples are imported into the system for Automated Geosci-entific Analyses (SAGA) programme and then LCZ classifications are executed by using random forest classifier algorithm [33,34]. A random forest classifier is a prediction model with high computational accuracy which considers the similarity between training samples and the rest of the AOI to classify the whole input image into different LCZ types [35]. Lastly the final output of SAGA GIS software has been imported into ArcGIS to prepare the thematic map of LCZ. The whole methodological the procedure of LCZ classification using the WADPT method is summarised in Figure 2.

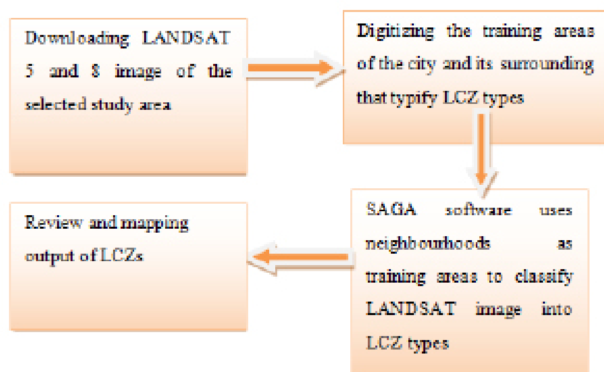


Figure 2. Methodological steps of LCZ classification using WUDAPT method.

3.2 Accuracy Assessment of LCZ Classes

Accuracy assessment was conducted through the confusion matrix to validate the LCZ classification scheme used in the study. Total of 225 reference points, collected randomly from field surveys, were generated on 2021 LCZ classification map for assessing user's accuracy, producer's accuracy, overall accuracy, and Kappa coefficient. In the case of LCZ 2001, the sample sites have been identified from Google earth image of 2001 and field interview of residents living there before 2001 to compare the land use/land cover and building types for validating the LCZ of 2001. Selected points are then superimposed on classified images to compare LCZ types of each point with existing ground truth using Google Earth data. The Kappa coefficient, one of the most reliable accuracy indicators is computed by the following formula:

$$K=\frac{\sum_{N}^{a}/ - \sum ef}{1-\sum ef}$$

Where, a is the sum of diagonal frequency, N is the total number of data in LCZ classes, and ef is the expected frequency. Expected frequency (ef) can be computed using the following formula:

$$ef = \frac{\text{Row total X column total}}{N}$$

3.3 Method for Detecting Conversion of Urban Built Type LCZs

Local climatic classified image pairs of two different time phases (2001 and 2021) are compared using cross-tabulation in order to determine the quantitative aspects of the conversion of buildings. Using the output data sets of LCZ mapping from SAGA GIS, a change matrix is generated from this alteration process over the ArcGIS platform. Quantitative areal data of the conversion of built type LCZ changes are then determined by compiling the amount of high and mid-rise buildings gained from each category of low-rise buildings and natural land use types. It is necessary to investigate such conversion of building states through LCZ classification for urban space planning.

4. Results

4.1 Delimitation of Local Climate Zones

Using the method described above, two LCZ maps of SMC and its surroundings have been prepared for the years 2001 and 2021. Figure 4 shows the spatial pattern of occurrence of individual LCZ class areas where, in 2001, thirteen and 2021, fifteen LCZs are identified. Ten built type LCZ classes were identified according to building height (high-rise, mid-rise and low-rise) and building compactness (compact and sparse). The descriptions of built type LCZs have been given in Figure 3. Classification of land use type LCZs reveals five dominant land cover types of the study area. The result features areal extent of built up LCZs has increased drastically from 2001 (43 sq.km) to 2021 (83.9 sq.km) in the study area with an increasing rate of 2.1 sq.km. per year.

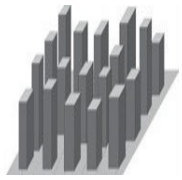
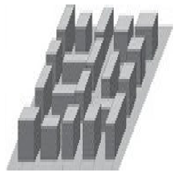
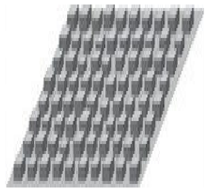
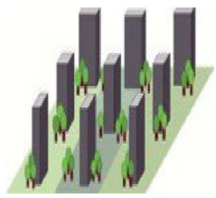
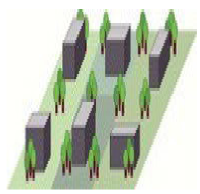
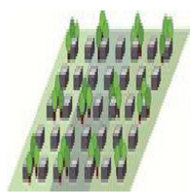
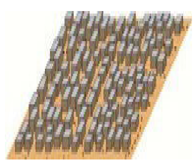
Within this 20 year of interval, some significant reorientation of LCZs is recognized e.g. in the previous phase, there was absolutely no open and compact high-rise class but in a late phase it significantly emerged in the north and north western part of the city and its periphery. Most of the pre-existing vacuum open spaces are now replaced with mid and high-rise buildings. Out of the total built up land of the study area, 5.62 sq.km and 18.1 sq.km areas are now covered with high-rise and mid-rise buildings respectively. Different low-rise built types prevail over 56.05 sq.km area out of 83.94 sq.km of the total built up land. LCZ 3 and LCZ 5 dominate the central parts of the city, LCZ 5 areas prevail with the fragments of LCZ 6, which spread from the external city centre borders up to the edge of the compact urban development, and LCZ 8 and 10 produce projections of significant development into the surrounding areas of SMC. The rapid growth of LCZ 7 and LCZ 8 indicates sprawling of the city. Changing built type and land cover type LCZs and their areal extension has shown details in Table 3. It can be observed that low-rise building categories are sometimes converted to midrise and high-rise buildings. The study has focussed on Siliguri Municipal Corporation to identify the alteration process of building states over the last decades.

4.2 Accuracy Level of LCZs

Four indices, overall accuracy, user's accuracy, producer's accuracy and Kappa coefficient, were applied for validation of the classification scheme. The results of accuracy assessment of LCZ classification shows that for the year 2001, the overall accuracy level is 82.66% and the kappa a coefficient is 0.79 (Table 4) and for the year of LCZ 2021, overall accuracy level is 83.56% and the kappa coefficient is 0.81 (Table 5). So the accuracy results of LCZ model for both the time period suggest validly and encouragement in using the classification scheme in this region. Though in the case of accuracy level variations were found in different LCZs. The highest degree of accuracy was recorded for LCZ 2 (92.86% in 2021) and the lowest degree of accuracy was recorded for LCZ 4 (68.75% in 2021).

4.3 Conversion of Building Types

An investigation is focussed on Siliguri Municipal Corporation to detect intra-zonal variability in built up LCZs. In the context of complex urban morphology and high density area, it is needed to study the morphological alteration of building types over time. The population of Siliguri is growing at a rapid pace which are subjected to the transformation of built up land and natural land cover. Significant alteration of buildings is predominant at the core and immediately surrounding areas of SMC with the expansion of urban land over the two decades.

Built types LCZ	Description	Building stories	By Stewart and Oke	Real photograph
Compact high rise LCZ 1	Dense mix of tall buildings. Few/ no trees. Mostly paved land cover. Concrete, steel, stone Construction materials.	> 9		
Compact mid rise LCZ 2	Dense mix of midrise buildings. Few/ no trees. Mostly paved land cover with stone, brick, tile and concrete construction materials.	3-9		
Compact low rise LCZ 3	Dense mix of low rise buildings. Few/no trees. Mostly paved land cover. Stone, brick, tile and concrete construction materials.	1-3		
Open high rise LCZ 4	Open arrangement of tall buildings. Abundance of pervious land covers having low plants, scattered trees. Concrete, steel, stone and glass construction materials.	>9		
Open mid rise LCZ 5	Open arrangement of mid rise buildings. Abundance of pervious land cover having low plants, scattered trees. Concrete, steel, stone and glass construction materials.	3-9		
Open low rise LCZ 6	Open arrangement of mid rise buildings. Abundance of pervious land cover having low plants, scattered trees. Wood, brick, stone, tile and concrete construction materials.	1-3		
Light weight low rise LCZ 7	Dense mix of one story buildings. Few/no trees. Mostly hard packed land cover. Lightweight construction materials e.g. Wood, thatch, corrugated metal.	1		

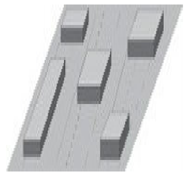
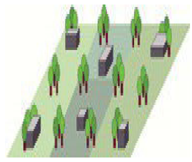
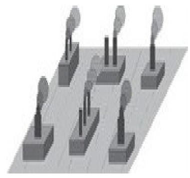
Large low rise LCZ 8	Open arrangement of large low rise buildings. Few/no trees. Land cover is mostly paved. Steel, concrete, metal and stone construction materials.	1-3		
Sparsely built LCZ 9	Sparse arrangement of small or medium-sized buildings in natural settings. Abundance of Lowplants, scattered trees.	1-3		
Heavy industry LCZ 10	Low rise and mid rise industrial Structures. Few/no trees. Land cover is mostly paved or hard packed. Metal, steel and concrete construction materials.	1-3		

Figure 3. Description of Local Climate Zones (after Stewart and Oke, 2012) identified in Siliguri Municipal Corporation.

Table 3. Areal extension of the Local Climatic Zones (LCZ) of the study area

	2001		2021		
Class name	Pixel count	Area in sq. Km	Pixel count	Area in sq. Km	Remark
LCZ 1 - compact high-rise	0	0	1950	1.76	Newly emerged
LCZ 2 - compact mid-rise	2633	2.37	12349	11.11	Increased significantly
LCZ 3 - compact low-rise	1408	1.27	9300	8.37	Increased significantly
LCZ 4 - open high – rise	0	0	4288	3.86	Newly emerged
LCZ 5 - open mid-rise	7982	7.18	7772	6.99	Decreases slightly
LCZ 6 - open low-rise	10841	9.76	6451	5.81	Decreases
LCZ 7 - lightweight low-rise	8596	7.74	22056	19.85	Increased significantly
LCZ 8 - large low-rise	4348	3.91	17527	15.77	Increased significantly
LCZ 9 - sparsely built	11571	10.41	6944	6.25	Decreases
LCZ 10 - heavy industry	337	0.30	4635	4.17	Increased significantly
LCZ A-dense trees	96081	98.47	107491	96.74	Decreases
LCZ B - scattered trees	41997	46.44	44376	39.94	Decrease
LCZ D - low plants	217648	177.88	134229	136.81	Decreases significantly
LCZ F - bare soil/sand	13868	9.48	29912	11.05	Increases
LCZ G - water	9312	8.38	17342	15.61	Increases

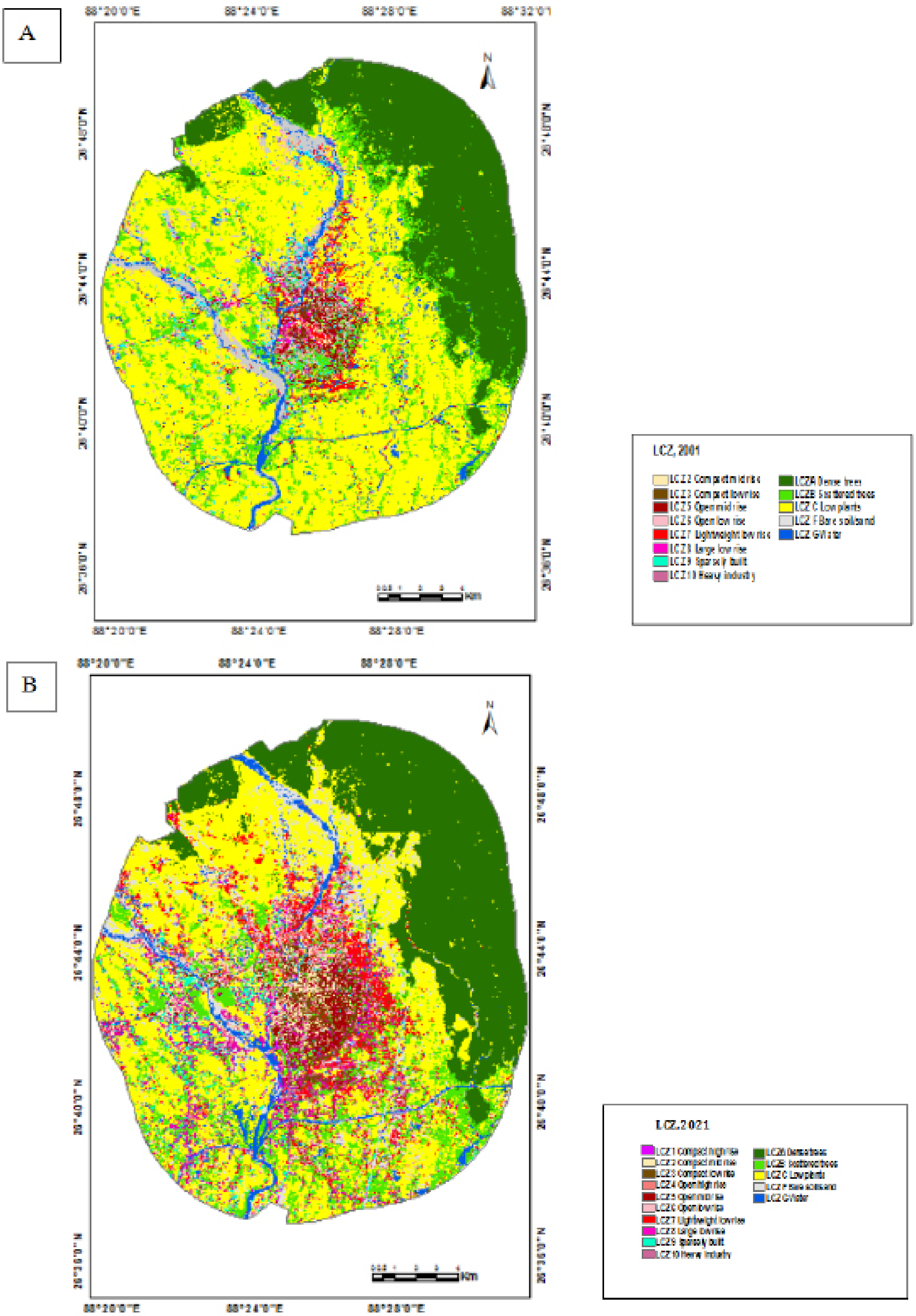


Figure 4. Local Climate Zones map of SMC and its surrounding. (a) 2001 (b) 2021

Table 4. Confusion matrix for classification accuracy assessment of LCZ, 2001.

LCZs	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ D	LCZ F	LCZ G	Row total	User accuracy (in %)
LCZ 1	11	0	0	0	0	1	0	1	0	0	0	0	1	0	1	15	73.33
LCZ 2	0	14	0	0	0	0	0	0	1	0	0	0	0	0	0	15	93.33
LCZ 3	0	0	13	0	1	0	0	0	0	0	1	0	0	0	0	15	86.66
LCZ 4	1	0	0	11	0	1	0	0	0	1	0	0	0	1	0	15	73.33
LCZ 5	0	0	0	0	12	0	1	0	1	0	0	0	0	0	1	15	80
LCZ 6	0	0	0	0	0	14	0	0	0	0	0	1	0	0	0	15	93.33
LCZ 7	0	0	0	1	0	0	13	0	0	0	0	0	0	1	0	15	86.66
LCZ 8	0	1	1	0	0	1	0	10	0	1	1	0	0	0	0	15	66.66
LCZ 9	0	0	1	0	0	0	1	0	11	0	0	1	1	0	0	15	73.33
LCZ 10	0	0	0	1	0	0	0	0	0	13	0	0	0	0	1	15	86.66
LCZ A	1	0	1	0	1	0	0	0	0	0	11	0	0	1	0	15	73.33
LCZ B	0	0	0	1	0	0	0	0	0	0	0	14	0	0	0	15	93.33
LCZ D	0	1	0	0	0	0	0	0	0	1	0	0	13	0	0	15	86.66
LCZ F	0	0	0	0	0	0	1	0	0	0	0	0	0	14	0	15	93.33
LCZ G	1	0	1	0	0	0	0	1	0	0	0	0	0	0	12	15	80
Column total	14	16	17	14	14	17	16	12	13	16	13	16	15	17	15	225	
Producer accuracy (in %)	78.57	87.5	76.47	78.57	85.71	82.35	81.25	83.33	84.62	81.25	84.61	87.5	86.66	82.35	80		
Over all accuracy (in %)	82.66																
Kappa	0.79																

Table 5. Confusion matrix for classification accuracy assessment of LCZ, 2021

LCZs	LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ D	LCZ F	LCZ G	Row total	User accuracy (in %)
LCZ 1	12	0	0	1	0	0	0	0	1	0	1	0	0	0	0	15	80
LCZ 2	0	13	0	0	0	0	1	0	0	0	0	0	1	0	0	15	86.67
LCZ 3	1	0	12	0	0	0	0	1	0	1	0	0	0	0	0	15	80
LCZ 4	0	0	1	11	0	1	0	0	0	1	0	0	0	1	0	15	73.33
LCZ 5	0	0	0	1	13	0	0	1	0	0	0	0	0	0	0	15	86.67
LCZ 6	0	0	0	0	1	12	0	0	0	1	0	1	0	0	0	15	80
LCZ 7	1	0	0	0	0	0	14	0	0	0	0	0	0	0	0	15	93.33
LCZ 8	0	0	0	1	0	0	0	13	1	0	0	0	0	0	0	15	86.67
LCZ 9	0	0	1	0	0	0	1	0	12	0	0	0	1	0	0	15	80
LCZ 10	1	0	0	0	0	0	0	0	0	14	0	0	0	0	0	15	93.33
LCZ A	0	0	0	0	1	0	0	1	0	0	12	0	0	1	0	15	80
LCZ B	0	1	0	1	0	0	0	0	0	0	0	13	0	0	0	15	86.67
LCZ D	0	0	1	0	0	1	0	0	0	1	0	0	12	0	0	15	80
LCZ F	0	0	0	1	0	0	0	0	0	0	0	0	0	14	0	15	93.33
LCZ G	1	0	0	0	1	0	0	1	0	0	1	0	0	0	11	15	73.33
Column total	16	14	15	16	16	14	16	17	14	18	14	14	14	16	11	225	
Producer accuracy (in	75	92.86	80	68.75	81.3	85.71	87.5	76.47	85.71	77.78	85.71	92.9	85.71	87.5	100		
Over all accuracy (in %)	83.56																
Kappa	0.81																

Transition matrix based on 'from' and 'to' changes of LCZs between 2001 and 2021 has been produced (Table 7) to assess this trend of changing building states in SMC. Figure 5 shows some LCZ training samples collected in SMC areas, documenting the intra urban alteration of building types from low-rise to high and mid-rise. Table 6 highlights that low-rise zone consisting of open low-rise, compact low-rise, lightweight low-rise, large low-rise and sparsely built cover, are collectively increased from 17 sq.km to 18.22 sq.km. Open and compact mid-rise building cover area has been increased from 7.58 sq.km to 11.64 sq.km. Out of the total study area of SMC, the newly emerged open and compact high-rise buildings cover an area of 2.04 sq.km. So, the low-rise zone has slightly increased within two decades but mid and high-rise zones are rapidly increasing and a major portion of these mid and high-rise buildings are made up from conversion of low-rise building types. From a total 13.68 sq.km area of high and mid-rise zone, 10.8 sq.km area which is 78.95%, is built from the alteration of low-rise buildings and natural lands. The transformation of different low-rise buildings to mid and high-rise buildings is shown in detail in Table 7. It is clearly visible from the conversion map (Figure 7) that the process of alteration to high-rise zone is very much active in the northern part and to mid-rise zone is in the south eastern part of SMC. Because of the presence of industries in the southern part and high density in the central part of the city, high-rise buildings (compact high-rise, open high-rise) are mostly spread in the northern part of the city. Significant decrease in open low-rise (4.89 sq.km to 3.59 sq.km) and sparse building cover area (3.94 sq.km to 0.94 sq.km) documents the compact growth of the city from dispersed one. Among the built LCZs, LCZ8 were mostly converted to LCZ 1(28.93%), LCZ 7 to LCZ 4 (18.69%), LCZ 9 converted to LCZ5 (70.97%) and LCZ 3 to LCZ 2 (60.39%). Among natural land cover types, LCZ B was mostly converted to compact high-rise (55.82%) and open mid-rise zone (41.22%) whereas low plant cover converted to compact mid-rise (41.18%). This process is continuous at the present and expectedly that in the near future more such urban capes will be turned into mid or high-rise zones.

Figure 5. Examples of building conversion from A) low-rise (2001) to B) high-rise (2021) of same training samples. Captured from Google earth image.

Table 6. Area (sq.km) of each LCZ in SMC

LCZ types	2001	2021
Compact high-rise	-	0.8
Compact mid-rise	1.61	5.26
Compact low-rise	1.15	6.22
Open high-rise	-	1.24
Open mid-rise	5.97	6.38
Open low-rise	4.89	3.59
Light weight low-rise	4.75	4.76
Large low-rise	2.22	2.71
Sparsely built	3.94	0.94
Heavy industry	0.03	0.77
Scattered vegetation	3.52	2.77
Low plant	11.89	2.68
Waste land	0.53	2.22
Water	1.29	1.44

Table 7. Land transition to mid-rise and high-rise LCZ of SMC, from 2001 to 2021

		LCZ types 2021	(area in Sq. km)	
LCZ types (2001)	Compact high-rise	Open high-rise	Open mid-rise	Compact mid-rise
Compact low-rise	0.065(8.55)	0.023(3.02)	0.21(27.63)	0.459(60.39)
Open low-rise	0.172(7.68)	0.134(5.54)	1.063(47.46)	0.875(39.06)
Light weight low-rise	0.221(26.31)	0.157(18.69)	0.233(27.73)	0.233(27.73)
Large low-rise	0.379(28.93)	0.086(6.51)	0.385(29.17)	0.466(35.30)
Sparsely built	0.126(10.24)	0.163(13.25)	0.873(70.97)	0.071(5.77)
Low plant	0.282(14.54)	0.426(21.96)	0.432(22.27)	0.799(41.18)
Scattered tree	1.323(55.82)	0.017(7.17)	0.977(41.22)	0.05(2.11)
West land	0.018(14.75)	0.041(33.60)	0.015(12.29)	0.048(39.34)

Computed by the author from image data extraction

Figures in the row cells depict the amount of former land cover contributed to the current land cover shown in columns. Values in parentheses are the corresponding percentage values.

5. Discussion

The study developed the LCZ classification maps, showing the spatial distribution pattern of LCZ classes which are also consistent with the actual land use pattern of Siliguri and its surrounding area. The importance of the LCZ scheme lies in the detailed classification of urban built types and explaining the conversion of built up forms with time. Intra urban landscapes can be analysed through the LCZ classification which demonstrates the outward and also upward growth of the city. Within the study period low, moderate and high state buildings are co-developed with the urban expansion and constitute an an important feature of the urban landscape of the study area.

5.1 LCZ Classification Based on Building Forms

A high concentration of heterogeneous surfaces in urban areas produces specific built LCZs units that are well differentiated from each other. The LCZ distribution exhibits compact development at the centre (LCZ 2, LCZ 3) and towards its outer boundary there is an increasing area of LCZ 7 and LCZ 9. LCZ 10 and LCZ 7 occur especially in the outer part of the city. Dominant built type LCZs of the study area is LCZ 7 and the natural type is LCZ D. In SMC the most prevalent built type is LCZ 3, compact low-rise and LCZ 5, open mid-rise and dominant land use type is LCZ D. Most parts of Siliguri and its surrounding areas are mainly covered by mid-rise and low-rise building types with emerging growth of high-rise sites. High-rise buildings are mainly developed in the ward no. 43, 41, 42 and 46 of SMC and notably developed in the census towns namely Tari, Jitu and Mathapari. A compact high-rise zone is characterised by closely spaced buildings with few or no trees. Open high-rise buildings set in an open arrangement with scattered trees and abundant plant cover. In some circumstances of low-rise classes (LCZ 9 and LCZ 6), the surface was covered by bare soil. Open low-rise and large low-rise classes outside SMC boundary characterised by well vegetation cover and spacious settlements.

Another significant proportion was lightweight low-rise zone (19.85 sq.km) characterised by a dense mix of single storey buildings mostly in the north eastern and south eastern part around SMC and often it merged with compact low-rise class. Rapid decrease in open low-rise area from 9.76 sq.km to 5.81 sq.km and sparsely built cover area from 10.41 sq.km to 6.25 sq.km signifies compact growth of the region.

Siliguri is witnessing immense demographic expansion due to migration from outside areas leading to housing demand that has changed its residential structure with a varied mix of buildings. In the last two decades mid-rise and high-rise high density dwelling types have significantly developed in the city. Increase of urban population, growth of socioeconomic activities of the a city with its hinterland and limited territory has led to an increase in the number of storeys of buildings.

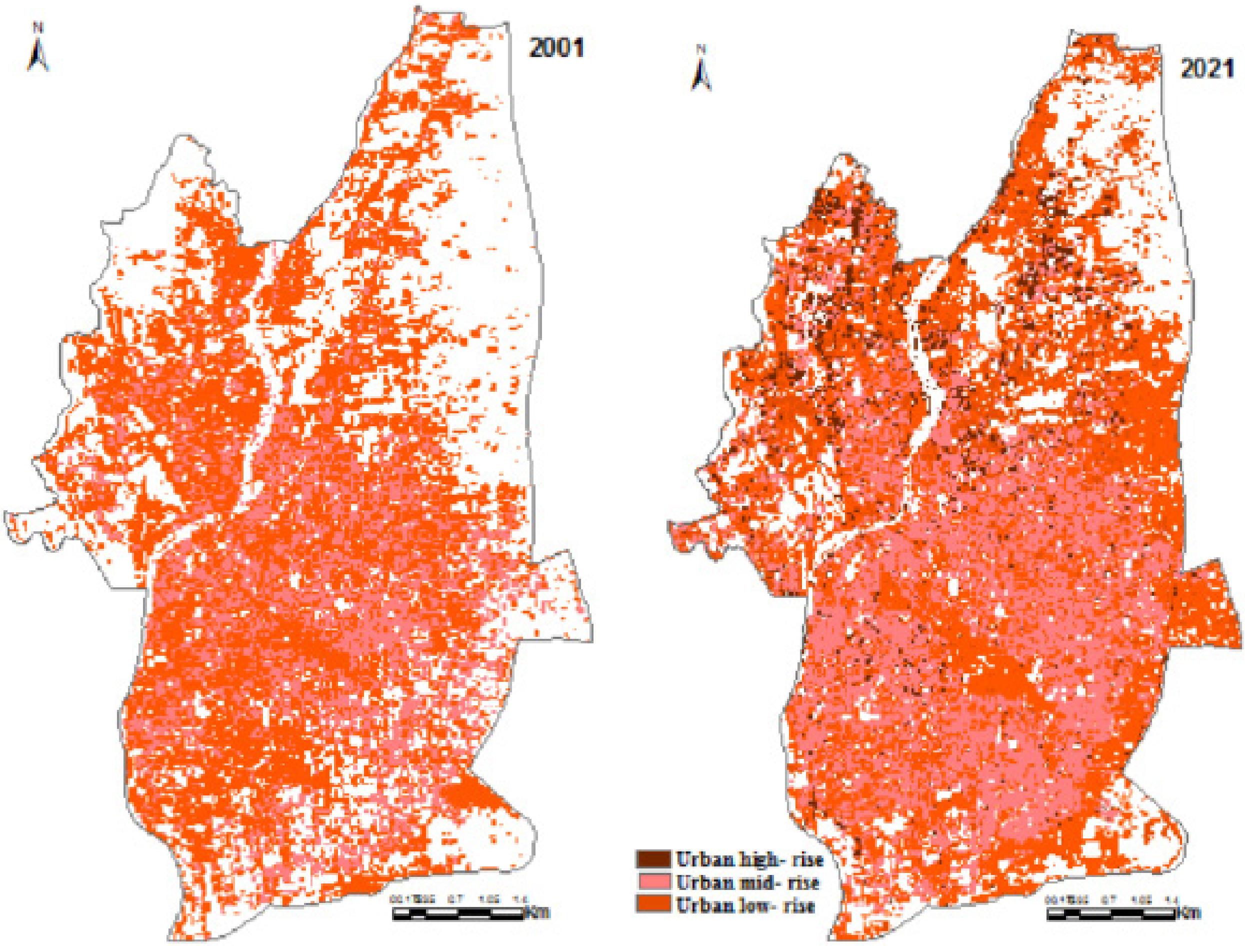


Figure 6. Spatial distribution of building states (low, moderate, high) of SMC in 2001 and 2021.

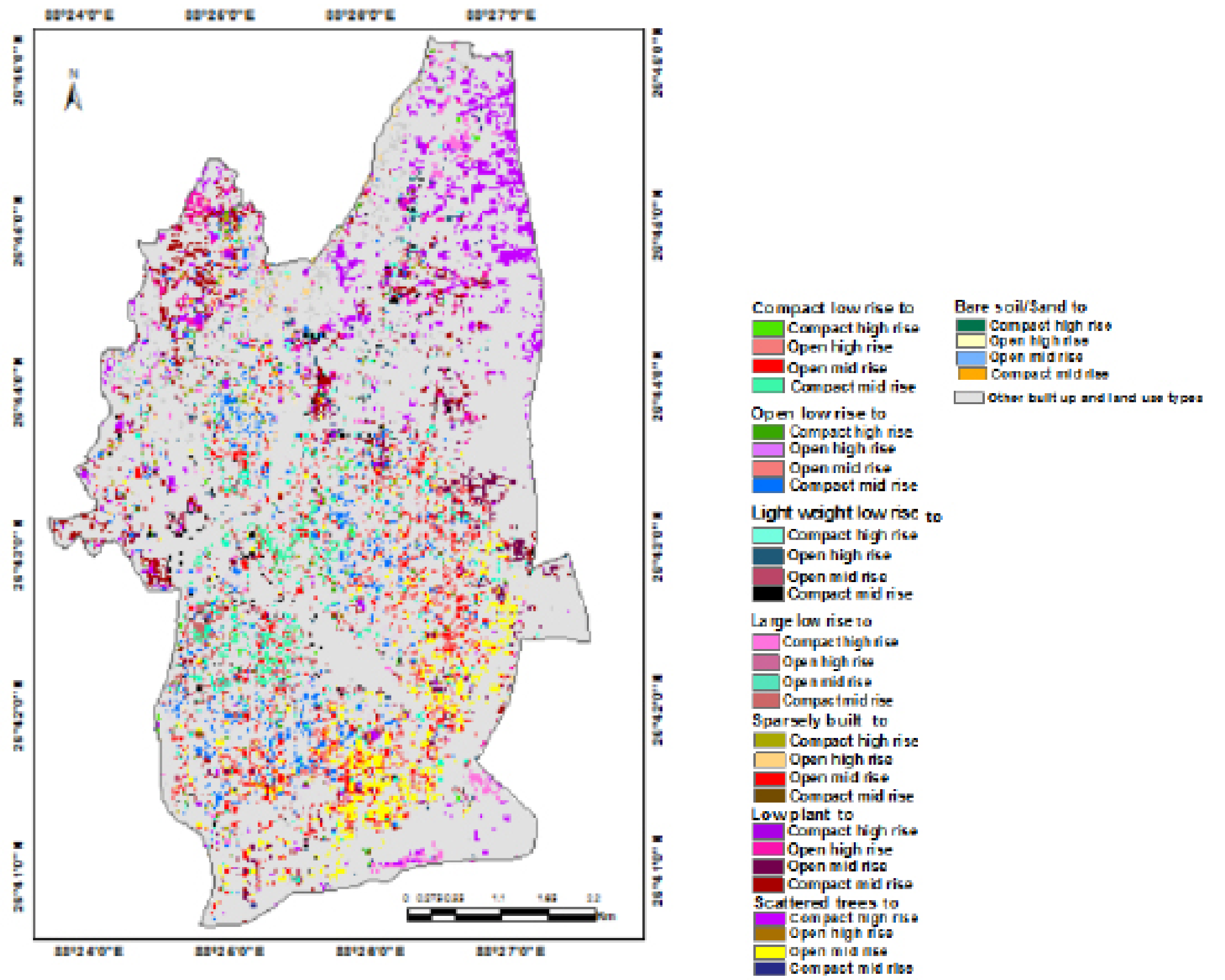


Figure 7. Conversion of land to mid rise and high rise buildings in SMC.

This upward rise of buildings allows being built within a smaller area of land to accommodate its population pressure.

5.2 LCZ Classification Based on Land Covers Forms

The generated LCZ maps assorted 5 natural land cover classes, where dense natural trees categorised as LCZ A, occupied a large portion in the eastern part of this study area. Scattered trees were classified as LCZB, while plantation and agricultural land were classified as low plant cover LCZD. Open space, bare soil and wasteland were categorized as LCZ E. Ponds, reservoirs, streams and nullahs were assigned to LCZ G. Development of compact buildings, sparsely built and lightweight rise has replaced low plant zone and scattered vegetated areas. The low plant zone has decreased significantly from 177.9 sq.km to 136.8 sq.km (Table 3). The compact growth of the city is pushing vegetated areas, low plant areas outwards the periphery of the city. The other natural LCZ F is composed of bare soil and sand having low spatial coverage.

5.3 Changing LCZs of SMC

The building distribution pattern of SMC reveals that the areas assigned to compact mid-rise zone are characterised with a denses mix of 3 to 9 storied tall buildings and mostly paved spread in and around the core part of the city. Places with a dense mix of 3 storied (or less) buildings, mostly paved with scanty trees constituted the compact low-rise zone at the centre part of the town, covering the both sides of Siliguri station road and Hill cart road and the places around the city. Older core and some other parts of the town were characterised by low-rise buildings, most of them with poor furnishing.

Built type LCZs classes according to building height (i.e. low-rise, mid-rise or high-rise) have shown in Figure 6 which reflects built up density is high in the middle and southern parts of SMC. As the conversion of built type LCZs is predominant at the core urban area, SMC has taken to visualize this conversion dynamics clearly (Figure 7). Increasing population pressure in SMC gives rise to the formation of the LCZ built type beyond the city borders. High-rise buildings (comprising LCZ 1 and LCZ 4) covers a total 5.62 sq.km of built up area, which was developed more in outskirts areas (3.58 sq.km i.e. 63.7% area) than SMC (2.04 sq.km i.e. 36.29% area). SMC has experienced an increase of compact low-rise and compact mid-rise buildings at a rate of 0.26 and 0.2 sq.km. per year respectively followed by a significant trend of upward building growth. The results obtained from the conversion matrix fortify the process of changing internal urban built forms. Hence from the analysis of 2001 and 2021 LCZ maps it is evident that with the expansion of urban land significant parts of SMC have undergone a transition in status from low-rise to mid and high-rise built zones.

5.4 Implication in Future Urban Planning

In the context of rapid urban development and planning for new town construction there is a need to delineate and update LCZs results to meet new needs that arise with rapid population growth. LCZs classification scheme using WUDAPT methodology provides a comprehensive database for scientific enquiry of the transformation that could be used in urban land use study. Planners should plan and develop new constructions with green space seeking sustainable urban development. LCZs classification ultimately emphasizes the need to classify urban land into specific local area zones to differentiate complex urban LCZ types. The analysis can assist urban planners estimating and better understanding urban morphological characteristics. The investigation and documentation of changing building states can provide very useful input for creating a proper urban built up plan with a rapidly growing population. LCZ classification recognizes 10 built types which are essential to understand the city morphology and controlling the built environment in terms of building height, plot size and spacing. The study highlights the areas of scanty open and green space that need to be preserved. Conversion of LCZ6, LCZ7 and LCZ8 to the development of LCZ1 and LCZ2 should be avoided, especially at the dense core area.

LCZ classification hierarchy provides useful urban information for the regions underwent unplanned urbanization, consisting of more heterogeneous urban forms and land cover types which are very much needed for further research work. The present study implies that LCZ is an effective method for urban planners to make appropriate decisions on urban land use planning.

6. Conclusions

LCZs classification map and the changing urban morphology with alteration of building states are the core results of the present work. Local Climate Classification has become the most accepted method in urban studies to explain internal urban forms. The study demonstrates that the adopted scheme can appropriately capture urban morphology through the detailed and comprehensive assessment of natural landscapes and building classes. The findings of LCZ mapping, especially the urban built up statistics of LCZ 1 to LCZ 10 have been identified consistent with those documented by Swert and Oke. Investigation of building distribution patterns through built type LCZs demonstrate that peripheral areas of SMC tend to construct high state LCZ zone while the the core urban area witnessed a significant increase in low and mid-rise LCZ zones. SMC witnessed a higher degree of compact building development, especially at the core city area. Beyond SMC active growth of compact high-rise and open high-rise buildings with lightweight low-rise and large low-rise buildings can be noticed. Analysing the alteration of urban built types plays a significant role in understanding the transformation of urban built up forms. Two-way land transition matrix has been produced to detect every possible land conversion from low-rise built types and other land cover classes to high and mid-rise zone. Significant growth of midrise and high-rise buildings in Siliguri and its surrounding area demonstrate that the city is undergoing a transition from horizontal to vertical one.

Nonetheless the study presents urban built up growth patterns across space and this would help urban planners in determining the appropriate proportion through integrating low, medium and high-rise buildings for promoting or discouraging building development keeping urban environmental sustainability (such as choice in surface material, planting trees). LCZs classification highlights the influence of large mix of buildings with different froms and structures in the urban scenario. The results pertaining to the of urban built up land influences this pattern greatly. Therefore, the study has established that LCZs classification can efficiently capture the urban surface dynamics through correct classification and characterization of existing urban built up zones. Our a novel approach to evaluating urban morphology is also directly relevant to current theoretical developments in both human geography [36-39] and planning theory [40-43], and future work should explore these theoretical linkages more explicitly.

Conflict of Interest

The authors declare no conflict of interest.

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