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Analyses of land use land cover (LULC) change and built-up expansion in the suburb of a metropolitan city: Spatio-temporal analysis of Delhi NCR using landsat datasets

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ABSTRACT

During past four decades, in post economic reforms period, Delhi and its surrounding regions has attracted a large number of populations which led to the rapid transformation of its LULC pattern. Therefore, this study is aimed to analyze the LULC changes during 1990–2018 as well as the growth and pattern of built-up surfaces in relation to the population growth and migration in the suburbs of Delhi metropolitan city which is also known as the National Capital Region (NCR). The Landsat 5 (TM) and Landsat 8 (OLI/TIRS) data has been used for the LU/LC classification of Delhi NCR. The K means clustering technique was applied on the Landsat data for the LULC classification and then the change detection technique was used to quantify the LULC change. The result shows that the considerable changes in LULC have occurred with continuous increase in built-up area and open/fallow land and decrease in agriculture land and vegetation over the study time period. Built-up area increased by about 326 percent and open/fallow land by 44 percent while the agricultural land and vegetation cover have decreased by 12 percent and 34 percent of the total area of study respectively during the study period. Built-up area has mostly increased at the expense of agricultural land and vegetation cover while vegetation cover has been transformed into Built-up area, Ridge and Agriculture. The statistical analysis shows that the association between built-up expansion and the population and migrants varies from weak to high but the coefficient of determination was always positive.

1. Introduction

Though the environmental transformation of earth by human activities began in late-Pleistocene, it increased with the emergence of agriculture and urbanized societies (Stephens et al., 2019). Among varied forms of man and environment relationship manifestations land use is the dominant one. Land cover is the observed (bio) physical cover on the earth's surface (Gregorio, 2016, pp. 1–40), while Land use represents the actual use of this biophysical cover (Cihlar & Jansen, 2001). Land use land cover (LULC) is the product not only of geological structure, altitude and slope but also socio-economic and institutional setups (Rai, Sharma, & Sundriyal, 1994). During recent decades the LULC dynamics has been transformed dynamically. This transformation in LULC pattern has been brought by both human as well as natural factors (Hassan et al., 2016). Therefore, the quantitative assessment of LULC change dynamics is one the most efficient means to manage and understand the landscape transformation (Singh, Mustak, Srivastava, Szabó, & Islam,

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2015).

The land use modifications are dynamic in nature and are caused by multiple factors operating on local, regional and global scales (Hassan et al., 2016; Rahman, Kumar, Fazal, & Siddiqui, 2012). The rapid and uncontrolled population growth, coupled with industrial development and economic growth has been continuously transforming the land use pattern (Dutta, Rahman, Paul, & Kundu, 2019). Several potential causes of LULC changes have been identified such as industrial growth and urban agglomeration (Walker, 2001), climate change and population growth (Hassan et al., 2016), urban expansion (Dutta & Das, 2019; Rahman, Aggarwal, Netzband, & Fazal, 2011a; Voogta & Okeb, 2003) and policy provisions (Thiha et al., 2007). The changes in LULC in the suburbs occur because of the expansion of urban areas due to the urban sprawl (Bhat, Shafiq, Mir, & Ahmed, 2017) and the development of public transport system which allows a bulk of labour force to commute daily (Kasraian, Maat, & van Wee, 2017). The urban areas expand outwards as a consequence conversion of agricultural and other natural land cover types into built-up area (Dutta, Rahman, Paul, & Kundu, 2020). These changes in the natural land cover types into artificial land use types is considered to be the most important factor behind the global environmental changes (Turner, Meyer, & Skole, 1994).

The global changes are brought about as a consequence of the LULC changes which are being driven by the human to fulfil their need for food, water, fibre and shelter (Foley et al., 2005). Therefore, the study of LULC changes can provide frameworks for the management and planning of natural resources at different spatial as well as temporal scales (Lai, 2020; Guyassa et al., 2018; Fenta et al., 2017). The analysis of LULC changes also provides plausible explanation not only man and environment relationship of the past but also hints about the future relationships (Lu et al., 2019). Hence, LULC studies can help in solving the pressing environmental problems (Mohamed & Worku, 2019; Yuan, 2008), urban and regional planning (Dutta et al., 2020; Patra, Sahoo, Mishra, & Mahapatra, 2018), urban heat island (UHI) mitigation (Gogoi et al., 2019), watershed management (Paiboonvorachat & Oyana, 2011) and disaster management (David, Yetta, Agung, Sharon, & Alison, 2016). Thus there is a growing trend in the study of the relationship between LULC changes and other socioeconomic and physical variables (Li, Wang, Li, & Lei, 2016). The studies have already done on the association of LULC change with LST (Fan et al., 2017; Mallick, Rahman, & Singh, 2013), population density (Shahfahad et al., 2020), groundwater potentiality and quality (Mallick et al., 2015; Patra et al., 2018) and atmospheric pollution aerosols (Qian, 2016; Xian, 2007).

The LULC changes have shown to have both direct and indirect impacts on the various aspects of environment (Patra et al., 2018). In their study, Rahman et al. (2012b) pointed that the anthropogenic LULC changes influences the urban environment significantly. The previous studies also suggest that the rapid changes in LULC also led to the changes in climate pattern especially in the urban areas (Kalnay & Cai, 2003; Mallick et al., 2013; Singh, Kikon, & Verma, 2017). The adverse impacts of LULC changes have been already identified on the biodiversity (Bailey, McCleery, Binford, & Zweig, 2016), hydrological systems (Patra et al., 2018; Dwarakish & Ganasri, 2015), urban thermal environment (Gogoi et al., 2019; Hang & Rahman, 2018), urban landscape quality (Shahfahad et al., 2019), air quality (Sun et al., 2016), ecosystem services (Das & Das, 2019; Talukdar et al., 2020), climate change (Dong, Liu, Luo, Fang, & Lin, 2019). In their study of Delhi, Dutta et al. (2019) described that how an increase in the impervious surface led to the variations in land surface temperature (LST). Similarly, Jones et al. (2009) shows that the planned agricultural expansion results in the decline of habitat quality. Further, Talukdar et al. (2020) described how the ecosystem services are being affected significantly by the LULC changes.

Numerous studies have analyzed the quantitative and qualitative changes in the LULC pattern and its drivers using different approaches and techniques. Wentz, Nelson, Rahman, Stefanov, and Roy (2008) used an expert system classification approach for the detailed mapping of urban LULC change of Delhi. Shahfahad et al. (2020) used indices based index (IBI) to map the built-up expansion of Surat city and its relationships with population growth and distribution. Chen, Ye, Cai, Xing, and Chen (2014) analyzed the association between rural out migration and LULC change and observed that the LULC pattern experiences low changes in the areas of out-migration while it changes more in the areas of in-migration. The main driving forces behind the LULC changes are population growth and urbanization (Msofe, Sheng, & Lyimo, 2019). Further, the conversion of forest into agricultural land to meet the demand for food grains is another major driver of LULC change (Nugroho, van der Veen, Skidmore, & Hussin, 2018). Most of the LULC change occurs in the form of expansion of built-up area at the cost of agricultural land, vegetation cover and open spaces (Dutta et al., 2020).

Population density of Delhi has increased from 6352 persons per sq. Km in 1991–11,297 per sq. Km in 2011 (Census of India, 2011). It had resulted not only in the formation of separate and extended regional planning Unit which is called National Capital Region or Delhi NCR (Dupont, 2011), but have also attracted tremendous industrial development to a limit that the present operational SEZs in this region is in double digits besides copious other manufacturing units. This twin concentration of population and industrial development has been leading to gross alteration of LULC in Delhi National Capital Region (Delhi NCR), which has led to numerous policy challenges (Mohan, Pathan, Narendrareddy, Kandya, & Pandey, 2011). Though there have been studies related to the LULC change (Chadchan & Shankar, 2012; Dutta et al., 2020; Hang & Rahman, 2018; Suzanchi & Kaur, 2011), however there is a lack of comprehensive study incorporating the recently extended area of the NCR. Several studies have pointed that the peri-urban areas (suburbs) of large metropolitan cities have experienced significant changes in their landscape pattern during past few decades because these areas holds a strong link with the urban area in terms of flow of people and goods (Karg et al., 2019; Tian, Ge, & Li, 2017). In this context, this present study has been aimed to analyze the LULC changes in the Delhi-NCR from 1991 when the industrial development was given a policy push, to the 2018. The uniqueness of this study is that it studies the pattern of LULC changes in the suburb of a metropolitan city, i.e. Delhi. Further, this study also analyzes the role of population growth and migration in the LULC change.

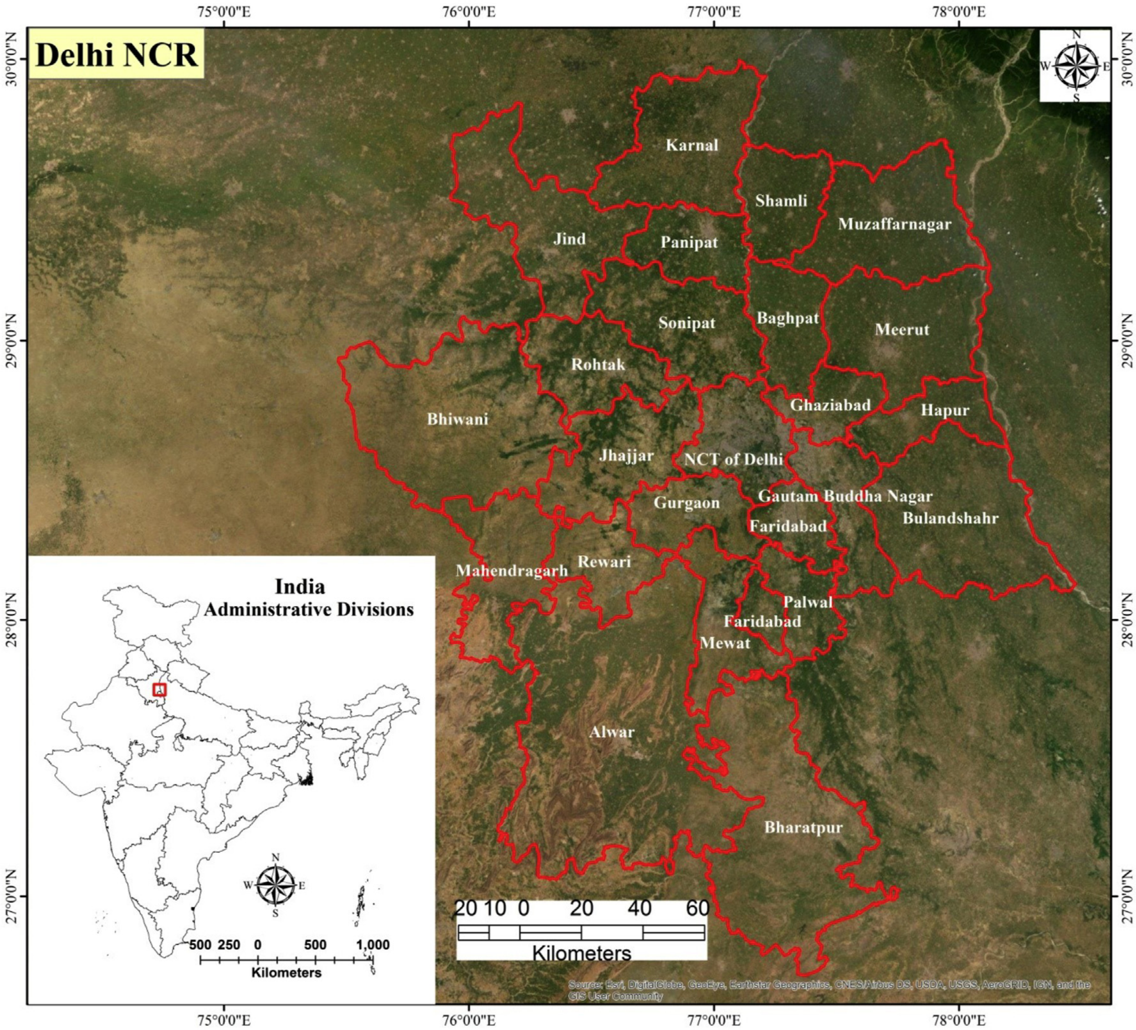


Fig. 1. Location of the study area.

2. Study area

Delhi NCR is the Indian central planning region comprising of National Capital Territory Delhi in its core with 18 adjacent districts from the states of Haryana, Uttar Pradesh and Rajasthan surrounding it (Fig. 1). It has a total area of 55,038 sq. Km and constitutes about 1.67 per cent area of the India and has a population of 46,069,000 (Census of India, 2011) constituting about 3.8% population of the country. NCR was created in 1985 for the regional development of the Delhi and surrounding districts and to formulate the synchronised policies for the use of land and infrastructural development. NCR has semi-arid climate and laces itself along the Aravalli ridge with Ganga River on the eastern boundary and Yamuna in the middle.

In NCR, Delhi has the dominances of impermeable concrete surfaces comprising of residential, industrial and commercial areas in its land use (Hang & Rahman, 2018). Such land use practices are now becoming conspicuous throughout the NCR region at a very fast rate (Suzanchi & Kaur, 2011). Delhi at the centre of NCR has been witnessing tremendous population growth, Delhi's population was only 1.7 million in 1951 which has reached over 16 million in 2011 (Census 2011), thereby making it as one of the high spread suburbs in the world. This astonishing growth has caused widespread changes in LULC which has attracted many studies in recent times (Dutta et al., 2020; Hang & Rahman, 2018; Rahman et al., 2012; Shahfahad et al., 2019; Wentz et al., 2008).

3. Materials and methods

3.1. Materials

For 1990 and 2003 the Landsat 5 (TM) data while for 2018, the Landsat 8 (OLI/TIRS) data downloaded from United States Geological Survey (USGS) Earth Explorer has been used in this study for LULC mapping and change analysis. The spatial resolution of

Table 1
Details of the satellite data used.

S. No.	Satellite	Sensor	Spectral Bands	Month/Year of Acquisition	Path/Row	Av. Cloud Cover
1	Landsat 5	TM	7	Nov–Dec 1990	146/40, 146/41, 147/39,147/40, 147/41	0.3%
2	Landsat 5	TM	7	Nov–Dec 2003	146/40, 146/41, 147/39,147/40, 147/41	4.1%
3	Landsat 8	OLI/TIRS	11	Dec 2018	146/40, 146/41, 147/39,147/40, 147/41	02%

Landsat TM data was 30 m and OLI/TIRS data was 15 m (after incorporating the panchromatic band). The data were downloaded for same season of the each study year, i.e. March or April months. The details of the satellite data used in this study are given in Table 1. The map of study area was extracted from the Survey of India Toposheet with 1:50,000 scale. The demographic data like district wise population and total migrants were obtained from the Census of India District Census handbook. For ground validation of the LULC maps prepared were done using samples collected through Google Earth Pro (for 1990 and 2003) or through field survey (for 2018).

3.2. Methods

3.2.1. Method for land use land cover (LULC) classification

LULC classification is one of the methods for obtaining the information from satellite imageries (Srivastava, Han, Rico-Ramirez, Bray, & Islam, 2012). Among various LULC classification techniques, supervised and unsupervised classifications are used the most (Lang et al., 2008). The two techniques differ in the binarity of using a training set with its absence in unsupervised classification. The unsupervised classification is based on the principle of internal homogeneity in spectral values within a feature space and external heterogeneity of the same among the feature spaces (Lillesand, Kiefer, & Chipman, 2004, pp. 556–557). There are many methods that are used for the execution of unsupervised classification like Iterative Self-Organizing Data Analysis Technique (ISODATA), K Means etc. (Gonçalves, Netto, Costa, & Júnior, 2008). The previous studies on LULC change of Delhi metropolitan city as well as Delhi NCR used the maximum likelihood classifier technique. In this study, the K Means clustering technique has been applied using ERDAS Imagine software 2014 version. The K Mean technique uses Euclidean mean value to divide n observations embedded in m-dimensional space into k clusters (Gupta & Venkatesan, 2020) which is suitable in dealing with numerically attributed data (Ahmad & Dey, 2007). A total of Six LULC classes i.e., Agricultural Land, Water Body, Built-up, Vegetation, Open/Fallow Land and Ridge were identified based on NRSC level I classification scheme. Identified LULC classes were further authenticated by ground validation with the complementary use of GPS and post classification field visits. Finally, LULC change was estimated by generating multi temporal raster layers for 1991, 2007 and 2018 and comparing their corresponding statistics.

3.2.2. Accuracy assessment

The post classification accuracy assessment is an important part of the LULC classification and mapping which is used to analyze the precision of the classified maps (Manandhar, Odeh, & Acnev, 2009). The classification accuracy quantifies the quality of maps produces and helps to evaluate the applicability of a map for a particular use. For an accurate interpretability and identification, the minimum accuracy of a classified map should not be less than 80 per cent (Anderson, Hardy, Roach, & Witmer, 1976). The techniques like Kappa coefficient, error matrix and indices-based techniques have already been used in several studies for the accuracy assessment of LULC maps produced (Manandhar et al., 2009; Rahman, Mohiuddin, Al Kafy, Sheel, & Di, 2019; Shahfahad et al., 2020; Talukdar et al., 2020).

In this study, Kappa coefficient technique is used to evaluate the accuracy of LULC maps of Delhi-NCR using 400 randomly selected points. The points were selected in a way that covers each LULC classes in almost equal proportion and from all parts of the study area. The ground observation for 1990 and 2003 were taken from Google Earth Pro domain as the field data was not available for these years. Further, for 2018, the ground observations were taken partially both from field visit as well as using Google Earth pro domain for the areas having either no or difficult access. The results of accuracy assessment show an overall accuracy level of 87.79 percent, 90.41 percent and 89.57 percent for 1990, 2003 and 2018, respectively and the corresponding Kappa statistics was 0.8763, 0.8909 and 0.8872, respectively.

3.2.3. Statistical analysis

To analyze the relationships between the LULC demographic changes, the linear regression technique has been performed using scatter plot technique on the Microsoft Excel (MS Excel) software 2010 version. In this study, the district-wise built-up area and population and migration data has been used for the year-wise regression analysis. For this the built-up area was extracted from the LULC maps prepared using Landsat (TM and OLI) data while the data of population and total migrants were taken from Census of India. The scatter plots are used to show the trend of linear relationship. The uphill trend line shows the positive linear relationship between the variables while the downhill trend line shows the opposite. The magnitude of the relationship is calculated by the coefficient of determination (R^2) which can be high, medium or low.

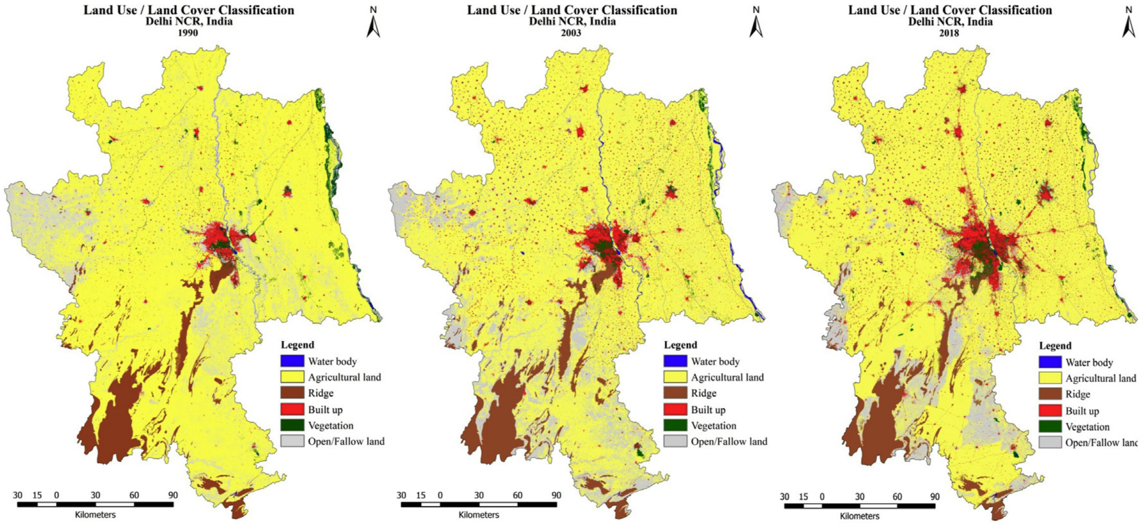


Fig. 2. Pattern of LU/LC of Delhi NCR between 1990 and 2018.

4. Results

4.1. Spatio-temporal distribution of LULC

In 1990, there is predominance of agricultural land throughout the landscape embedded with built-up area in the central region and in random manner representing the various cities and settlement of the study area. Ridge is present in the South western part of the study area and laces itself in the South West to North East direction while Fallow land is mostly present in the western and South-Central part of the study area. Though vegetation is dominantly located near the water bodies flowing in North-South direction, yet patches of vegetation are present throughout the study area. During 2003 the visibility of the built-up areas is more pronouncing encroaching into other land use categories (Fig. 2). Fallow land shifts its dominance from West to South West. However, in 2018 there is clear dominance of Built-up areas. Not only big cities but also the smaller scattered settlement has grown in extent. The bird's eye view reveals a star shape arrangement of settlements with Delhi at the centre Meerut and Muzaffarnagar in north-east, Panipat in north, Rohtak and Bhiwani in West and Gurgaon and Faridabad in south, forming the other Satellite cities in the anti-clockwise direction. Besides there appears to be marked decrease in vegetation cover in central parts as well as the agriculture land in peripheral areas.

The district-wise analysis shows that the agricultural land in 1990 was maximum (Fig. 3a) in Alwar fallowed by Bharatpur, Bulandshahr, Bhivani and Jind while in was minimum in Shahdara, East Delhi and SE Delhi. However, in 2003 it was maximum in Alwar fallowed by Bhivani, Bulandshahr and Bharatpur while it was minimum in Shahdara, NE Delhi and SE Delhi. Similarly, in 2018 agricultural land was maximum in Alwar fallowed by Bhivani, Bulandshahr and Jind while it was minimum in Shahdara, SE Delhi and East Delhi. The area under fallow/open land was maximum (Fig. 3b) in Bhivani fallowed by Bharatpur, Bulandshahr and Gautam Budha Nagar Districts while it was minimum in Shahdara, East Delhi and Central Delhi in 1991. However, in 2003 the area under fallow/open land was maximum in Alwar fallowed by Bharatpur, Bhivani and Mahendragarh while it was minimum in East Delhi, Shahdara and SE Delhi. Similarly, in 2018 the area under fallow/open land was maximum in Bharatpur, Alwar, Bhivani and Mahendragarh while it was minimum in East Delhi, Central Delhi and NE Delhi.

In 1990 the built-up area was highest (Fig. 3c) in West Delhi followed by New Delhi, North Delhi, SE Delhi, NW Delhi, Central Delhi and Bhivani and minimum in Mewat, Palwal, Hapur, NE Delhi and Bharatpur. In 2003 the built-up area was maximum in Gautam Budha Nagar fallowed by Meerut. Gaziabad, Bulandshahr, Jind, Bhivani and Faridabad while it was minimum in Mewat, NE Delhi, Shamli and East Delhi. Similarly, in 2018 the built-up area was maximum in Gautam Budha Nagar followed by Meerut, Gurgaon, Faridabad, Gaziabad and Bhivani while it was minimum in NE Delhi, East Delhi, Shahdara and Mewat. The area under vegetation in 1990 was maximum (Fig. 3d) in Meerut fallowed by Muzaffarnagar, Bulandshahr and New Delhi while it was minimum in Mewat, Mahendragarh and Rewari. The districts with maximum area under vegetation in 2003 has similar trend as in 1991 however, in 2003 it is minimum in Palwal, Mahendragarh and Mewat. However, in 2018 the area under vegetation is maximum in Muzaffarnagar fallowed by Gautam Budha Nagar, Meerut and Faridabad while it is minimum in Shahdara, Shamli and Sonipat. The area under water bodies in 1990 was maximum (Fig. 3e) in Bulandshahr fallowed by Muzaffarnagar, Sonipat and Meerut while it was minimum in New Delhi, South Delhi and NW Delhi. Similarly, in 2003 the area under water bodies was maximum in Bulandshahr fallowed by Meerut, Muzaffarnagar and Sonipat while it was minimum in New Delhi, South Delhi and Shahdara. However, in 2018 the area under water bodies was maximum in Bulandshahr, Meerut and Muzaffarnagar while it was minimum in Shahdara, New Delhi and South Delhi.

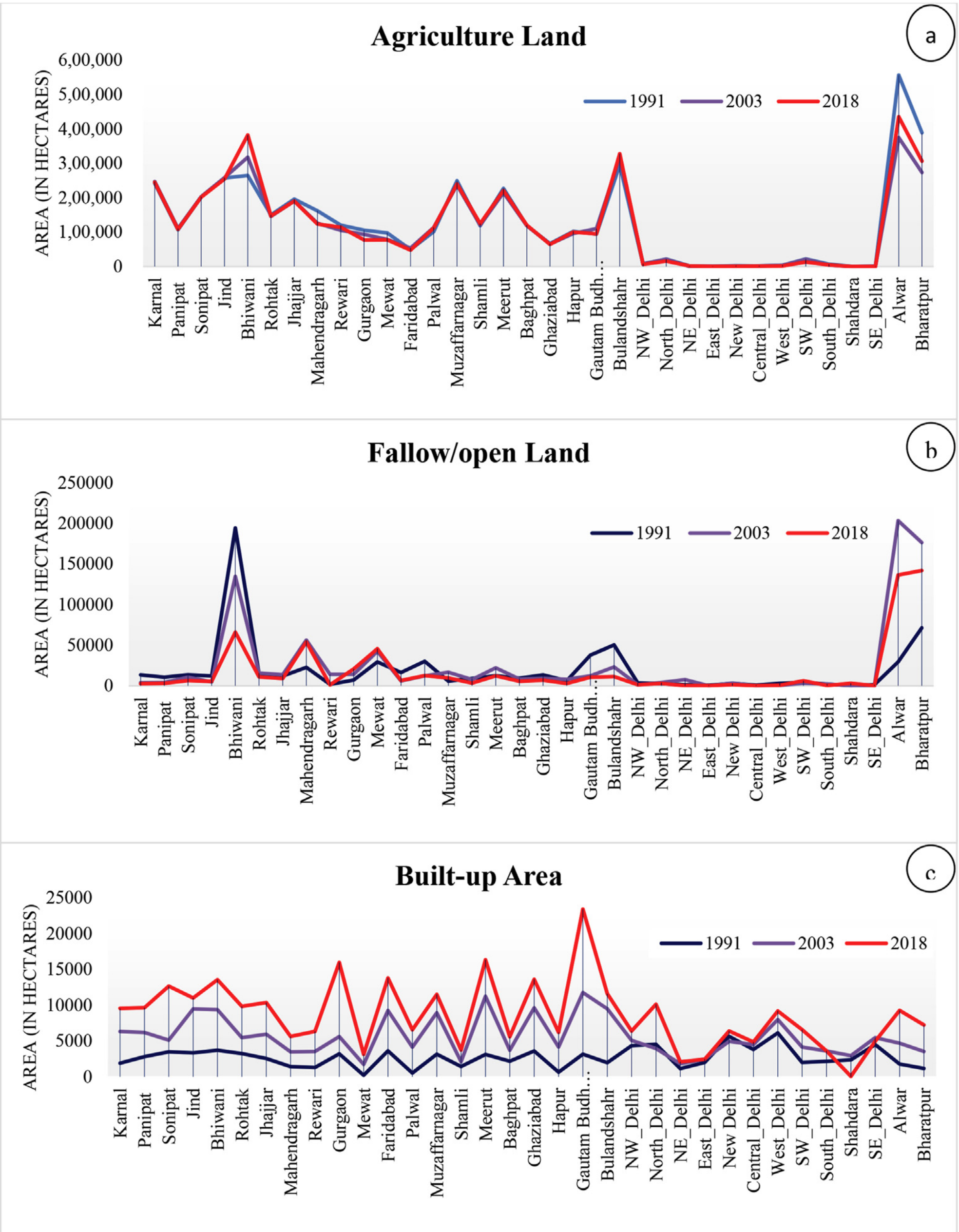


Fig. 3. District-wise of variation of area under (a) agricultural land, (b) Fallow land, (c) Built-up area, (d) Vegetation cover and (e) water body.

4.2. Dynamics of land use land cover (LULC) change

In general NCR has witnessed changes in all the LULC categories but maximum changes have been witnessed in Built-up. Built-up area has witnessed a gigantic growth of 114 percent from 1990 to 2003 and 99.02 percent from 2003 to 2018, making an overall growth of 326 percent during the study period (Table 2). Built-up area has mostly encroached into vegetation, water bodies and agriculture from 1990 to 2003 to the tone of 9.94 percent, 2.93 percent and 1.98 percent respectively (Table 3). However, built-up intruded into the classes of vegetation, water bodies and fallow land by 37.29 percent, 11.75 percent and 7.17 percent respectively from 2003 to 2018 (Table 4). Thus overall, built-up area encroached mostly into vegetation, fallow land and waterbodies by 34 percent, 13.7 percent and 5.3 percent respectively (Table 5) during the study time period. Built-up area has seen growth mainly in NCT Delhi and in its immediate vicinity besides in the major cities like Meerut, Muzaffarnagar, Rohtak, Sonipat, Bulanshahr etc (Fig. 4).

Fallow land is next to Built-up that has witnessed massive increase of 44 percent during the study period, however rate of increase

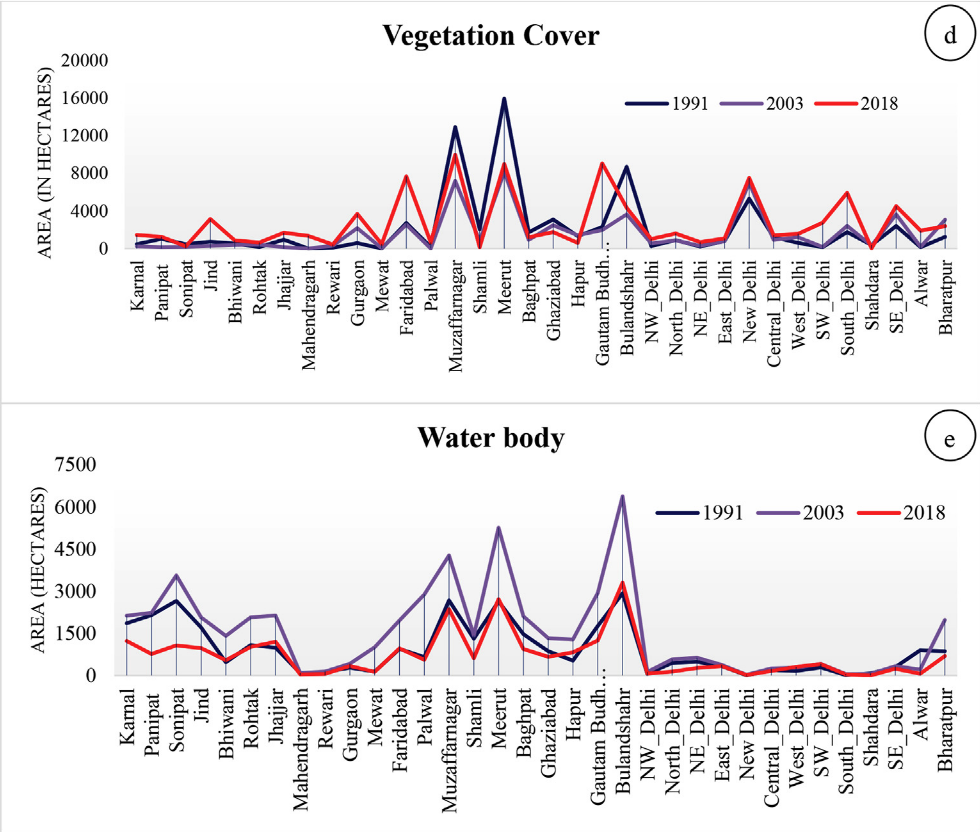


Fig. 3. (*continued*)

Table 2
Change dynamics of area under each LULC classes during 1990–2018.

Land use/land cover categories	1990		2003		2018		Area Change (in Percent)		
	Area in Hectares	Area in Percent	Area in Hectares	Area in Percent	Area in Hectares	Area in Percent	1990–2003	2003–2018	1990–2018
Water body	31282.6	0.57	42218.7	0.76	24242.2	0.44	34.96	−42.58	−22.51
Agricultural land	4334310	78.43	4047340	73.24	3795260	68.67	−6.62	−6.23	−12.44
Ridge	351,483	6.36	350,020	6.33	350,002	6.33	−0.42	−0.01	−0.42
Built up	92176.8	1.67	197,607	3.58	393,274	7.12	114.38	99.02	326.65
Vegetation	71101.8	1.29	54590.6	0.99	46330.1	0.84	−23.22	−15.13	−34.84
Open/Fallow land	646,064	11.69	834,642	15.10	917,309	16.60	29.19	9.90	41.98
Total	5526418	100	5526418	100	5526418	100	–		

Table 3
Land use land cover (LULC) change matrix 1990–2003.

		1990 (Hectare)						
		Water body	Agricultural land	Ridge	Built-up	Vegetation	Open/Fallow land	Total 2003
2003(Hectare)	Water body	12920.6	2110.6	50.2	0.0	1209.2	25928.1	42218.7
	Agricultural land	13789.4	3593910.0	534.7	0.0	29274.7	409831.3	4047340.0
	Ridge	40.9	17765.2	331861.5	0.0	352.5	0.0	350020.0
	Built up	917.6	86001.0	1610.4	91869.9	7065.4	10142.3	197606.5
	Vegetation	980.8	15819.2	1546.8	200.0	30103.5	5940.3	54590.6
	Open/Fallow land	2633.4	618704.0	15879.5	106.9	3096.5	194221.5	834641.9
	Total 1990	31282.6	4334310.0	351483.0	92176.8	71101.8	646063.5	5526417.7

Table 4
Land use land cover (LULC) change matrix 2003-18.

		2003 (Hectare)						
		Water body	Agricultural land	Ridge	Built-up	Vegetation	Open/Fallow land	Total 2018
2018(Hectare)	Water body	19642.30	3078.22	14.02	0.00	602.95	904.71	24242.2
	Agricultural land	5004.80	3603580.0	64.90	0.00	5134.30	181476.0	3795260.0
	Ridge	67.30	4806.14	336252.0	0.00	8857.56	19.00	350002.0
	Built up	4958.79	109647.9	1117.87	197354.0	20356.30	59839.14	393274.0
	Vegetation	1507.90	27171.74	6071.18	221.70	6990.86	4366.72	46330.10
	Open/Fallow land	11037.61	299056.0	6500.03	30.80	12648.63	588036.33	917309.40
	Total 2003	42218.70	4047340.0	350020.0	197606.5	54590.60	834641.90	5526417.7

Table 5
Land use land cover (LULC) change matrix 1990-18.

		1990 (Hectare)						
		Water body	Agricultural land	Ridge	Built-up	Vegetation	Open/Fallow land	Total 2018
2018(Hectare)	Water body	18308.5	1878.0	21.7	0.0	1119.6	2914.4	24242.2
	Agricultural land	7112.0	3392027.0	699.3	0.0	23406.8	372015.0	3795260.0
	Ridge	286.6	52.1	337293.8	0.0	12347.7	21.8	350002.0
	Built up	1668.0	179746.0	6871.1	92015.8	24409.0	88564.2	393274.0
	Vegetation	1622.3	28207.0	6575.0	161.0	9609.8	155.0	46330.1
	Open/Fallow land	2285.2	732399.9	22.1	0.0	209.0	182393.2	917309.4
	Total 1990	31282.6	4334310.0	351483.0	92176.8	71101.8	646063.5	5526417.7

was 29.19 from 1990 to 2003 and 9.90 percent from 2003 to 2018. This growth is mostly at the expanse of agriculture which contributes to about 57.6 percent to the total increase of fallow land during the study period. While fallow land has witnessed an increase on western side it has undergone decrease on south-western side of the study area. The Vegetation cover has witnessed the maximum decrease of 34 percent among all the LULC classes during the study period however it decreased by 23 percent from 1990 to 2003 and 15.13 percent from 2003 to 2018 (Fig. 4). Vegetation has been replaced by built-up, agriculture and ridge in the order of 34.3 percent, 32.9 percent and 17.4 percent respectively during 1990–2018. However, it was mostly replaced by built-up, fallow land and ridge by 37.29 percent, 23.17 percent and 16.23 percent from 2003 to 2018 while agriculture, built up and fallow replace it by 41.17 percent, 9.94 percent and 4.36 percent respectively from 1990 to 2003. Similar is the case of agriculture land which has recorded a decrease of 12 percent during the study period. However, this decrease was about 6.62 percent from 1990 to 2003 and 6.23 percent from 2003 to 2018. Agricultural land was mostly replaced by fallow/open land and built up by about 14.27 percent and 1.98 percent from 1990 to 2003, 7.39 percent and 2.71 percent from 2003 to 2018. Overall agricultural land was converted into fallow/open land, built up and vegetation by about 16.9 percent, 4.1 percent and 0.7 percent respectively during the study period. Water bodies have shown a decrease of 22 percent from 1990 to 2018 and water body has changed to agriculture, fallow land and built up by about 22.7 percent, 7.3 percent and 5.3 percent respectively. Baring minor skirmishes, ridge has seen an equivalent proportion of area thought out the study period.

Despite the number of years being more during 2003–2018, all LULC classes except water bodies have witnessed more changes during 1990–2003. From 1990 to 2003 the area under water body increased by about 34 percent while it decreased by about 42 percent from 2003 to 2018. The changes in built-up, vegetation, agriculture and fallow land are 114 percent, 23.22 percent, 6.62 percent and 29.19 percent during 1990–2018 and their respective changes during 2003–2018 are 99.02 percent, 9.90 percent 6.23 percent and 15.13 percent. Fig. 5 shows the increase and decrease in area under each LULC classes. The area under water bodies and ridge shows very low and insignificant variation while the built-up area and fallow land shows a continuous increase throughout the study period. On the other hand, the agricultural land has experienced a sharp decline in area and the vegetation cover shows a comparatively low but significant decline in the area under it.

4.3. Analysis association of built-up expansion with population and migration

For the analysis of association of built-up expansion with population growth and migration, the district-wise data of population, migration and built-up areas has been used. The Delhi NCR covers 34 districts; 11 districts of Delhi, 2 districts of Rajasthan, 13 districts of Haryana and 8 districts of Uttar Pradesh state. The result shows that the coefficient of determination (R^2) varies from very low to high. The association between total migrants and built-up area was positive but very weak (0.03) in 1990 while it was moderate and positive (0.44) in 2003 and high positive (0.56) in 2018 (Fig. 6). On the other hand, the association between built-up and population was moderate and positive in 1990 but it was positive but weak in 2003 and 2018. The R^2 value of association between built-up and population was 0.46 for 1990, 0.04 for 2003 and 0.03 for 2018 (Fig. 6). Therefore, it is clear that the association

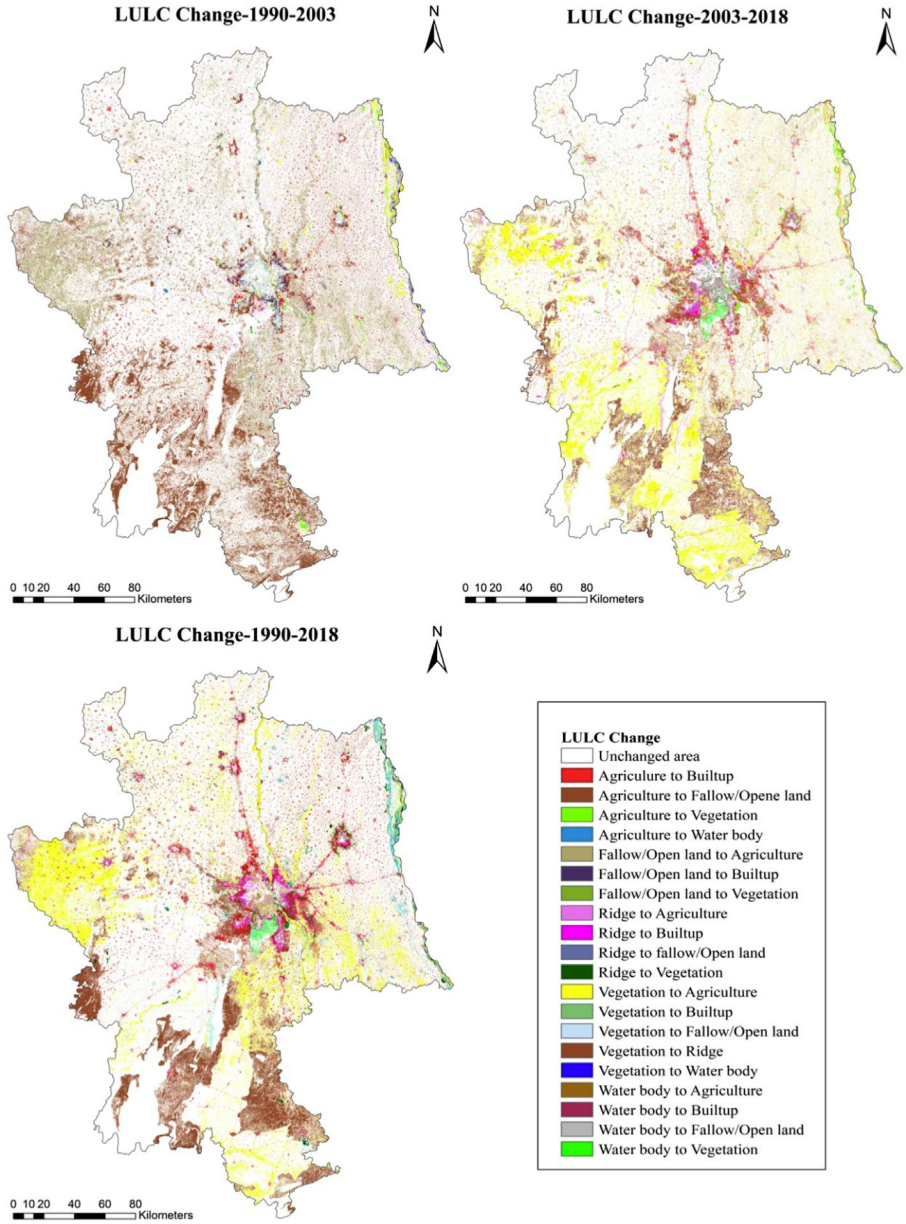
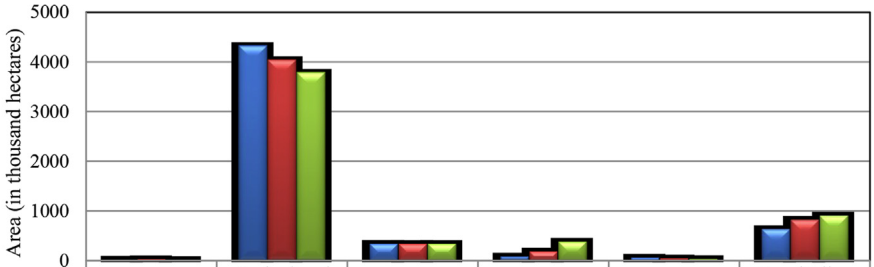


Fig. 4. Dynamics of Land use land cover change in Delhi NCR.

between built-up and total migrants have increased during 1990–2018 as revealed by coefficient of determination but has declined between built-up and population. This is because more than half of the increase in built-up area was noticed in the NCT of Delhi or its surrounding areas (Fig. 3). On the other hand the population increase is also high in NCT of Delhi and its surroundings but it is not low in other parts of NCR as in the case of built-up area.

5. Discussion

In India, the urbanization has taken place at an unprecedented rate during past few decades, especially after the economic reforms of 1991 (Chadchan & Shankar, 2012; Sarkar, 2019). The result shows that the LULC pattern of Delhi NCR has changed significantly during the study period. The maximum change is observed from the built-up area, followed by crop land and barren land. The evidences from previous studies suggest that the LULC change in peri-urban areas occurs mostly in the form of built-up expansion at the cost of agricultural land, vegetation cover and barren lands (Chen et al., 2014; Dutta, 2012; Kleemann et al., 2017). Delhi NCR has also witnessed a drastic change in LULC, especially in the urban areas such as in the adjoining cities like Meerut, Gurgaon, Noida, etc. Where the built-up areas has increased many fold (Dutta et al., 2020; Hang and Rahman, 2018). Further, the agricultural land and



	Water body	Agricultural land	Ridge	Built up	Vegetation	Open/Fallow land
1990	31282.6	4334310	351483	92176.8	71101.8	646063.5
2003	42218.7	4047340	350020	197606.5	54590.6	834641.9
2018	24242.2	3795260	350002	393274	46330.1	917309.4

Fig. 5. Temporal variation of area under LULC classes.

vegetation cover has experienced rapid decline in area during the same period while the barren land has also experienced continuous decline in its area. The agricultural land and open spaces are the main land use types get converted into built-up surfaces in the process of urbanization (Mohan et al., 2011). The water bodies on the other hand increased during 1990–2003 but declined during 2003–18. Suzanchi and Kaur (2011) also noted an increase in the area under water bodies in NCR during 1990–2000.

The maximum expansion of built-up area has been noticed from the Gautam Buddha Nagar district in which the fast growing Noida city is located and the NCT of Delhi, located in the centre of NCR. Both these cities (Noida and Delhi) have experienced rapid urbanization during the past few decades due to population growth and economic development (Rahman et al., 2012; Singh & Singh, 2011). On the other hand, the built-up area has very low increase in the districts like Mewat, Bharatpur, Baghpat, Bhiwani and Shamli as these districts are dominated by rural landscape features and the agricultural land and vegetation cover are most dominant LULC types in these districts. The agricultural land and fallow land has experienced a sharp increase in these districts. The vegetation cover on the other hand has experienced continuous increase in not only rural districts like Meerut, Muzaffarnagar and Jind, nut also in the highly urbanized districts such as Gautam Buddha Nagar, Faridabad, and NCT of Delhi. This is because the forest covers in these districts have increase due to large scale plantation drive sponsored by the government and local communities (Imam & Banerjee, 2016). In their study, Paul and Nagendra (2015) noted that the vegetation cover in core areas of Delhi have declined but has increased sharply in the peripheral areas. All these factors have contributed to the increase in vegetation cover in urban areas of the study area.

Land is the main and primary natural resource available for human and is utilized in various ways for various purposes. Thus any change in human population directly affects the land and land use pattern of an area (Nelson et al., 2010). The changes in population occur mostly in the form increase due to either natural increase or through migration (Bavel, 2013). In Delhi NCR, the both the natural increase and immigration has almost equally and continuously contributed in the population increase, especially in the urbanized districts of NCT of Delhi as well as Gautam Buddha Nagar, Faridabad, Gurgaon, etc. Studies have been already done to analyze the association between land use changes and their drivers using different methods of regression analysis (Hu & Hu, 2019; Kamwi et al., 2018), Pearson correlation technique (Satya, Shashi, & Deva, 2020), spatial auto-correlation technique (Hu, Batunacun, Zhen, & Zhuang, 2019), etc. Millington et al., (2007), emphasized that all the regression techniques have their own advantages and disadvantages based on the size of samples as well as the number of variables. The linear regression technique applied in this study shows a variation in the association between the growth of built-up land and population as well as migration from weak to a strong and positive association between built-up land and population and weak to a moderate and positive association between built-up land and migration. This is due to both the population growth and migration is uneven in the study area due to uneven distribution of rural and urban areas in the region. The urban areas such as Delhi, Noida, Faridabad and Gurgaon have experienced a rapid population growth due to migration of a large labour force (Rahman et al., 2012a) while the rural districts such as Bharatpur, Rewari, Muzaffarnagar and others have experienced a low population growth. The growth of private sector financial and industrial firms after the economic reforms of 1991 and development of special economic zones (SEZ) such as Noida and Gurgaon attracted a large number of labours towards Delhi NCR (Aggarwal, 2010; Kumari, Tayyab, Shahfahad, & Rahman, 2018). Therefore, the population growth and development of large financial and industrial firms significantly altered the LULC pattern of Delhi NCR during past decades.

6. Conclusion

This comprehensive study is done to examine the Spatio-temporal pattern of LULC changes in Delhi NCR, which is an inter-state planning region and has experienced rapid population growth and economic development during past decades. The land use land cover (LULC) maps were prepared using Landsat 5 (TM) and Landsat 8 (OLI/TIRS) satellite data and then the change matrix was calculated. The result shows that LULC pattern of the Delhi NCR has been altered significantly during the study period. The maximum

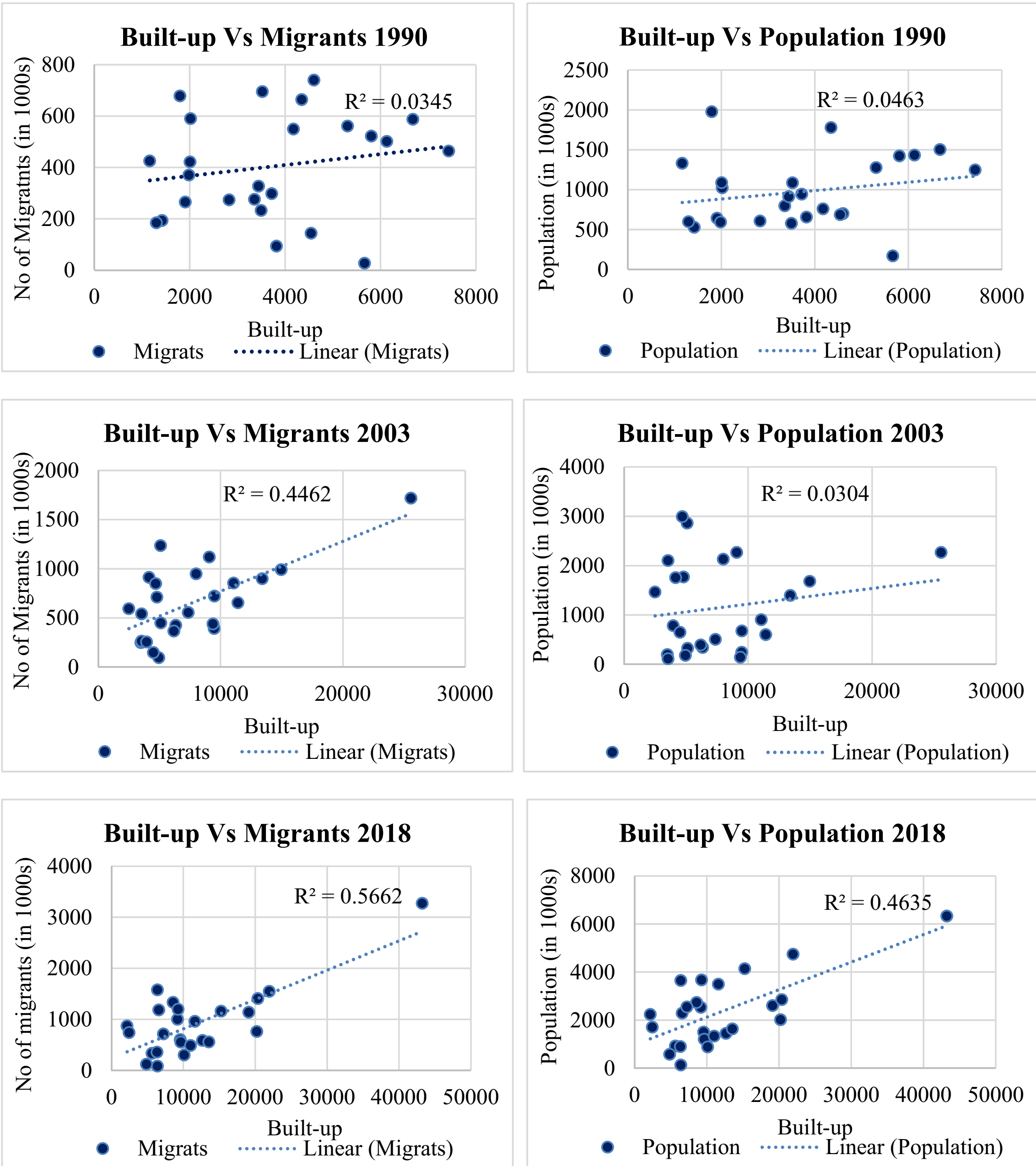


Fig. 6. Association of district-wise pattern of built-up area with total migrants and population.

change is noticed from the built-up area which has increased to about 326.65 percent, followed by open/fallow land which is increased by about 41.98 percent during 1990–2018. At the same time the vegetation cover, water bodies and agricultural land are declined by −34.84, −22.51 and −12.44 percent, respectively, while the ridge part has noticed a negligible decline in its area. The result also shows that the agricultural land and fallow land are the major contributors in the growth of built-up area, as the built-up area has expanded mostly over these land use classes, while the vegetation cover also has significant contribution in built-up expansion. Further, the analysis of relationship between built-up and population distribution shows that in 1990 and 2003, the association was positive but weak but in 2018, relationship significant and positive. On the other hand, the relationship between total migrants and built-up distribution was weak in 1990, but is moderate and positive in 2003 and high-positive in 2018. This implies that the increasing migration is the major determinant of built-up expansion; however, it does not completely determine the built-up expansion and land use change. Thus the authors suggests for the future research to incorporate the data of economic growth and industrial development (like number of industries) in the study of LULC change of such region with high economic and administrative importance.

Declaration of competing interest

The authors declare that there is no financial or any other conflict of interest.

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