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Geospatial Analysis of Land Use and Land Cover Dynamics and its Impact on Urban Wetland Ecosystems in Delhi NCR Region, India

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Urban wetlands are highly neglected and are encroached upon to accommodate more settlements or to dump waste materials. They are susceptible to encroachment and undergo Land Use/Land Cover (LULC) change thereby diminishing their value. This study aims to examine and assess the spatial-temporal LULC change for selected wetlands of Delhi NCR vis-à-vis ecosystem services. Landsat imageries for the years 1998, 2008 and 2018 are used to understand the change dynamics using supervised classification with overall accuracy of more than 80% for all years. Classification was done separately for Delhi NCR and 5 km buffer around the wetlands. In Delhi NCR the net percent change during the 20-year period was found to be +5.22% and +8.56% for built-up and cropland respectively. During the same period, the plantations/forest cover and water bodies changed by –8.30% and –0.50% respectively. Plantations/forest cover has shown a negative net percent change in six wetlands, with Najafgarh experiencing the highest (–10.75%), followed closely by Surajpur wetland (–10.68%), Bhalswa lake wetland (–9.93%), Yamuna Biodiversity Park (–6.77%), Pusa Hill Forest (–5.18%) and Asola Wildlife Sanctuary (–5.21%). The LULC change analysis has pointed to the loss of wetland area to built-up and/or cropland which is going to affect the ecosystem services provided by these wetlands. Geospatial tools are an important tool to understand the changing LULC in such sensitive ecosystems. It is needed to manage wetlands sustainably so that the corresponding ecosystem services could be preserved.

Keywords: Change detection, Ecosystem services, Landsat, LULC, Wetlands

Introduction

Wetlands are most valuable among different ecosystems present on earth.[1,2] In general, wetlands are the areas of marshy, peatland, natural or man-made, perennial, or temporary water surface.[3] It provides several benefits and functions to preserve the Earth's ecosystem from local to global scale.[4–6] Wetlands are of global significance as recognized by The Ramsar Convention.[7] Costanza *et al*.[8] stated that wetlands are much more valuable than lakes, rivers, forests, and grasslands.

Wetlands are noted to contribute highest to various ecosystem services beneficial for the human being and livelihood.[9,10] These ecosystem services include food, fresh water, raw material, regulating wastewater, pollination, habitat for plants and animals, climate regulation, cultural services which include tourism and recreation, and supporting services like nutrient cycle.[2,11,12] Wetlands also help in maintaining environmental quality and biodiversity and supports to sustain peoples' livelihoods and health.[13] Additionally, wetlands are considered as kidneys of the landscape as they absorb both water and waste induced from natural and anthropogenic activities.[1] It can be identified in urban settings, viz. urban forests, cultivated land, lawns/parks, trees along roads, lakes/reservoirs, and streams.[14,15]

Urban wetlands provide cultural ecosystem services like biodiversity perception, historical & cultural values, medicinal value along with spiritual and recreational value.[16] It also offers most considerable ecological services including water supply, waste management, regulation and control of regional climate and floods.[10,17] Since the beginning of the 20th century 50% of the wetlands have been lost around the word[18] and degradation have occurred in remaining 60% wetland ecosystems.[10,19] The wetlands loss is due to agricultural expansion, urban growth, and unprecedented expansion of infrastructure linked to population growth and increasing consumption. Wetland ecosystems are thus facing enormous pressure and degradation due to rapid urbanization and the absence of proper infrastructural planning.[14,20]

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The bulk of anthropogenic activities utilize the natural resources, impact the environment and lead to LULC change. Urban wetlands are highly sensitive to LULC changes that leads to amend the supply and quality of ecosystem services.[21] Such changes occur at a greater pace in and around the urban wetlands and has eventually caused a high rate of degradation in the wetlands of these regions.[22–24] Therefore, up-to-date information on LULC changes is essential to monitor the wetlands to prevent them from further losses for better environmental management and sustainable planning.[4,25,26] In many studies, remote sensing datasets are used extensively in wetland research to accurately assess LULC change dynamics, wetland mapping, wetland environments, and hydrological process.[27–31] In many studies remote sensing based earth observation datasets are used to determine the LULC changes in Delhi NCR region.[32–35] But very few studies could be found focusing on changing LULC pattern around the wetlands of Delhi NCR region.

Many wetlands are present in and around the capital city of Delhi which are very essential for maintaining the quality of ecosystems. Some wetlands are constructed to check the pollutant load from wastewater and the runoff and help control storm water flows. Some are the remnants of lost water bodies (like Najafgarh Lake). The geographical area of 2556 hectares i.e., 0.86% is identified as wetlands in the study region of Delhi. There are 11 natural lakes and 352 manmade ponds out of the total of 573 water bodies and wetlands in Delhi.[36] Wetlands in urban areas are usually undervalued by people in the vicinity and are used as waste and garbage dumping ground.[14] There is still a dearth of research on the LULC dynamics at spatial and temporal scales in and around the wetland areas in the NCR region and its impact on urban ecosystems. The present study aims to examine the Spatio-temporal LULC dynamics from 1998 to 2018 in and around the selected wetlands of Delhi NCR region of India. Apart from economic uses, thriving biodiversity and providing recreational and spiritual services the wetlands in Delhi are important to check the pollution of Yamuna River, recharging the ground water table, and providing cultural services. The outcomes of this study will contribute to the planning and policy making schemes at space time scale and for the protection and management of wetlands sustainably in such a highly urbanized region.

Materials and Methods

Study Area

The study area consists of nine major wetlands spread in the part of National Capital Region (NCR) of India (Fig. 1). These are: (1) Bhalswa Lake Wetland (BLW); (2) Pusa Hill Forest (PHF); (3)

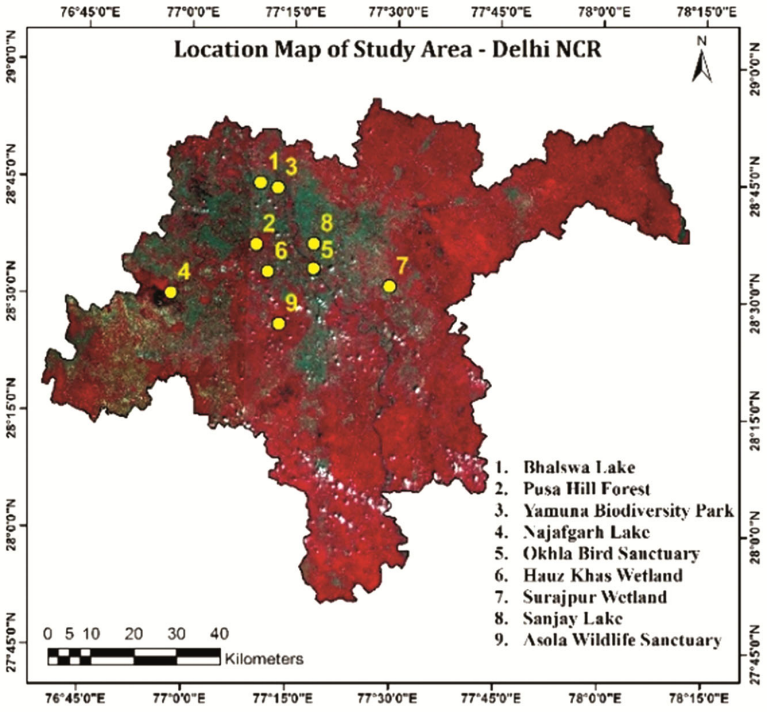

Fig. 1 — Location map of the study area

Table 1 — Description of the datasets used in this work

S. No.	Satellite	Sensor	Spectral Bands	Time of Acquisition	Path / Row	CloudCover
1	Landsat 5	TM	7	March, 1998	146/40; 146/41;147/40	0.3%
2	Landsat 5	TM	7	April, October, 2008	146/40; 146/41; 147/40	4.1%
3	Landsat 8	OLI/TIRS	11	April, May & June, 2018	146/40; 146/41; 147/40	0.2%

Yamuna Biodiversity Park (YBP); (4) Najafgarh Lake (NLW); (5) Okhla Bird Sanctuary (OBS); 6) Hauz Khas Wetland (HKW); (7) Surajpur Wetland (SPW); (8) Sanjay Lake Wetland (SLW); and (9) Asola Wildlife Sanctuary (AWS). The NCR comprises of the National Capital Territory (NCT) of Delhi and fourteen districts of Haryana, eight districts of Uttar Pradesh and two districts of Rajasthan. In the current study only the NCT and four districts namely Gurugram, Faridabad, Gautam Buddha Nagar and Ghaziabad are included as the nine selected wetlands fall within the administrative boundaries of these areas only. The total area covered in this study is 7930 km^2. According to the Census of India (2011), the total population of Delhi NCT is 1,67,87,941, Gurugram is 15,14,085, Faridabad is 18,09,733, Gautam Buddha Nagar is 16,48,115 and Ghaziabad is 16,48,643. Geographically, NCR of Delhi is located between the Himalayas in the north and the Aravalli in the south.

Datasets and Pre-processing

Landsat images of different time periods (1998, 2008 and 2018) have been used to assess the LULC changes (Table 1). The methodology involved the pre-processing, classification, and post-processing of satellite images. A standard supervised classification technique was used for the classification of the satellite images of year 1998, 2008 and 2018 followed by change analysis of the study area. A spatial buffer of 5 km was created around nine selected wetlands and image classification and change analysis was carried out separately around these wetlands.

Methodology

In the first step, Census of India 2011 administrative boundaries are used to delineate the area of interest. The study area is spatially referenced to UTM projection system (zone 43North) with WGS 84 datum. The satellite datasets were processed to correct geometric errors, calibration, and eliminate the present noises. In the second step, False Color Composite (FCC) images were created for each year (1998, 2008 and 2018) using the NIR, Red and Green bands. Brightness and contrast manipulations were done to improve the visual quality of the images. LULC maps are the basic requirement for change detection. To prepare LULC maps, field survey was conducted to collect the training data. A total of 500 location points were collected across different LULC classes. The samples were categorized into five major classes viz., cropland/agriculture, plantation/forest, built-up land, barren land, and water bodies. Subsequently supervised classification was carried out to prepare the final LULC maps using the multi-temporal images of 1998, 2008 and 2018. The classified maps were further validated by using the topo-sheets of Delhi NCR and Google Earth images. Accuracy assessments are performed to examine the overall accuracy of the classification results. LULC change analysis of the study area was carried out by using the temporal outputs produced from three different periods. The change dynamics of LULC for periods (1998 to 2008 and 2008 to 2018) were computed using cross tabulation method.

Results

LULC Change in Delhi NCR

The classified maps of Delhi NCR including five different LULC classes for the years 1998, 2008 and 2018 are given in Fig. 2(a, b & c). The LULC change maps for the period of 1998–2008 and 2008–2018 are shown in Fig. 2(d & e). An enormous change can be observed within a span of 20 years (1998–2018). The area statistics and changes are given in Table 2. In Delhi NCR the cropland/agriculture has been a dominant LULC class, and it has increased from 4688 km^2 (59.12%) in 1998 to 5556 km^2 (70.06%) in 2008. However, it decreased to 5367 km^2 (67.68%) in 2018. Next major LULC class in the region is built-up area, which has also increased its area from 1215 km^2 (15.32%) in 1998 to 1275 km^2 (16.08%) in 2008. It further increased to 1631 km^2 (20.59%) in 2018. Other classes like barren land, plantations and water bodies have depicted a constant decline in area as well as percentage from 1998 to 2018. The largest negative change has occurred in plantation/forest category which declined from 1135 km^2 (14.31%) in 1998 to 477 km^2 (6.02%) in 2018. Barren land has reduced from 786 km^2 (9.91%) in 1998 to 389 km^2 (4.91%) in 2018 whereas the area under water bodies shrunk to 66

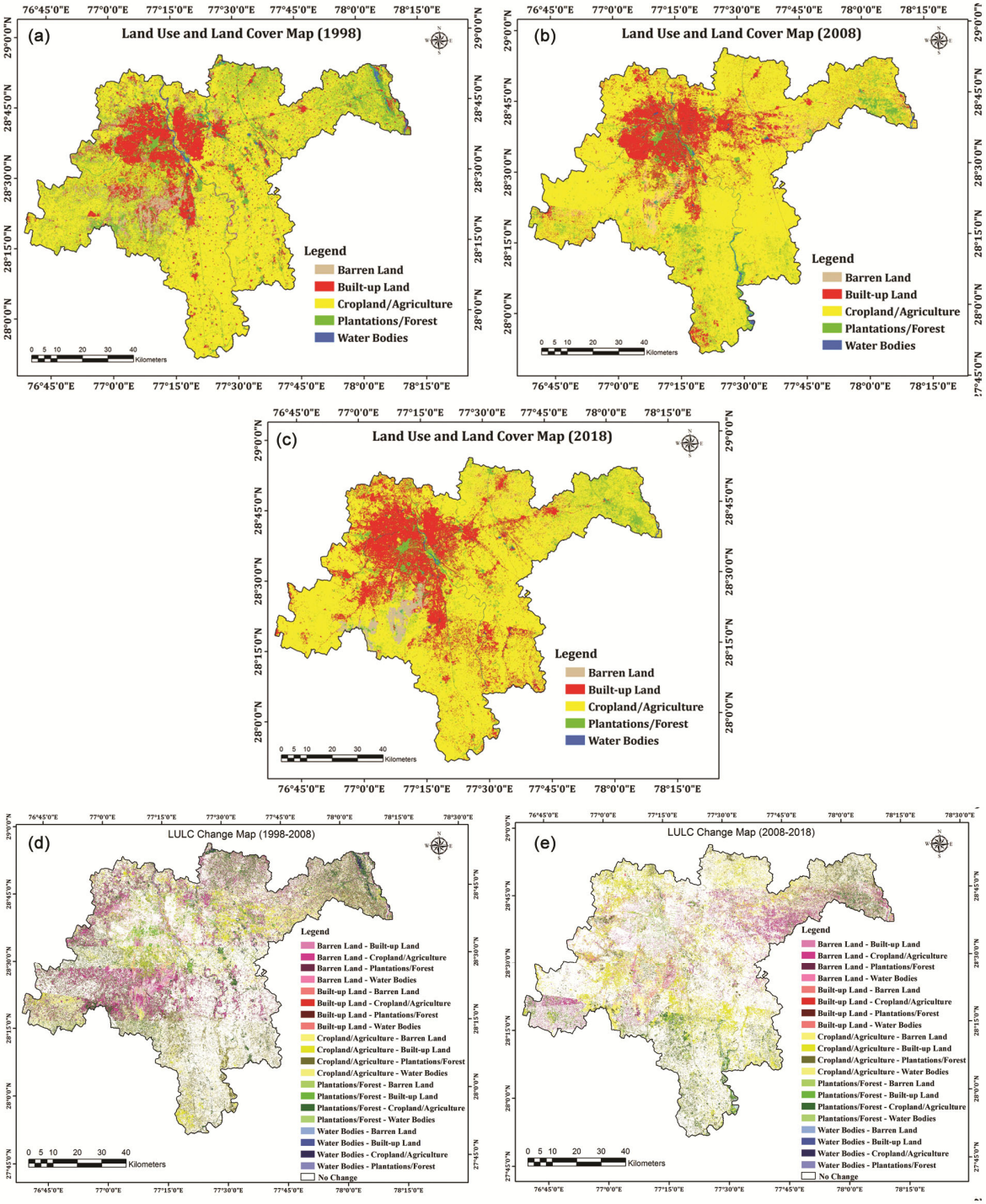

Fig. 2 — The distribution map of Delhi NCR (a) LULC-1998, (b) LULC-2008, (c) LULC-2018, (d) LULC Change map 1998–2008 (e) LULC Change map 2008–2018

km^2 (0.83%) in 2018 from 106 km^2 (1.34%) in 1998.

Accuracy Assessment Results

The accuracy assessment of classified LULC maps is carried out using confusion matrix approach. The user's accuracy (UA), producer's accuracy (PA) and overall accuracy (OA) are the widely used measures of classification results. The accuracy assessment is performed on every classified image. The detailed accuracy results are shown in Table 3.

Table 2 — Area Statistics of LULC categories for years1998, 2008 & 2018 of Delhi NCR

S. No.	LULC class	1998		2008		2018		Change 1998–2008	Change 2008–2018
		Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Changed Area (km^2)	Changed Area (km^2)
1	Barren Land	786	9.91	499	6.29	389	4.91	–287	–110
2	Built-up Land	1215	15.32	1275	16.08	1631	20.57	60	356
3	Cropland/Agriculture	4688	59.12	5556	70.06	5367	67.68	868	–189
4	Plantations/Forest	1135	14.31	512	6.46	477	6.02	–623	–35
5	Water bodies	106	1.34	88	1.11	66	0.83	–18	–22
	Total	7930	100.00	7930	100.00	7930	100.00		

Table 3 — Accuracy assessment results obtained from classified maps of year 1998, 2008, and 2018

LULC Class	Landsat - 5 (1998)		Landsat - 5 (2008)		Landsat - 8 (2018)	
	UA	PA	UA	PA	UA	PA
Water bodies	90.48%	86.36%	90.48%	88.37%	90.91%	86.96%
Cropland/Agriculture	85.71%	82.76%	86.89%	84.13%	86.67%	83.87%
Plantations/Forest	85.53%	78.31%	85.51%	78.67%	84.93%	80.52%
Built-up Land	77.63%	86.76%	79.73%	88.06%	80.82%	86.76%
Barren Land	78.38%	85.29%	79.49%	83.78%	80.00%	86.49%
	Overall Accuracy: 83.28%		Overall Accuracy: 84.21%		Overall Accuracy: 84.48%	
	Kappa = 0.7923		Kappa = 0.8033		Kappa = 0.8083	

LULC Change in and Around Wetlands

To understand the status of wetlands LULC change analysis was undertaken at the nine selected wetlands, taking a buffer of 5 km around each wetland. The results are provided in the following sub-sections.

Bhalswa Lake Wetland (BLW)

The Bhalswa Lake Wetland lies in the northwest part of Delhi NCT. Fig. 3(a-1, a-2 & a-3) depicts the LULC with the 5 km buffer around Bhalswa lake wetland site. The LULC change around the BWL has been tremendous. The built-up area has increased from 36 km^2 in 1998 to 50 km^2 in 2018, an increase of 17.5%. On the other hand the plantation/forest class has declined from 12.5 km^2 in 1998 to 4.75 km^2 in 2018, a decrease of about 10%. The area under water has also shrunk by more than a half from 2.48 km^2 to 0.95 km^2 (Table 4).

Yamuna Biodiversity Park (YBP)

Yamuna Biodiversity Park was developed by Delhi Development Authority (DDA) in association with the University of Delhi's Centre for Environmental Management of Degraded Ecosystems. It is a protected man-made wetland ecosystem situated on the bank of River Yamuna. Fig. 3(b-1, b-2 & b-3) depicts the LULC with the 5 km buffer around Yamuna Biodiversity Park wetland. The area around this wetland is dominated by built-up and cropland (Table 4). The built-up area has been growing from 29 km^2 in 1998 to 33.6 km^2 in 2008, and with a

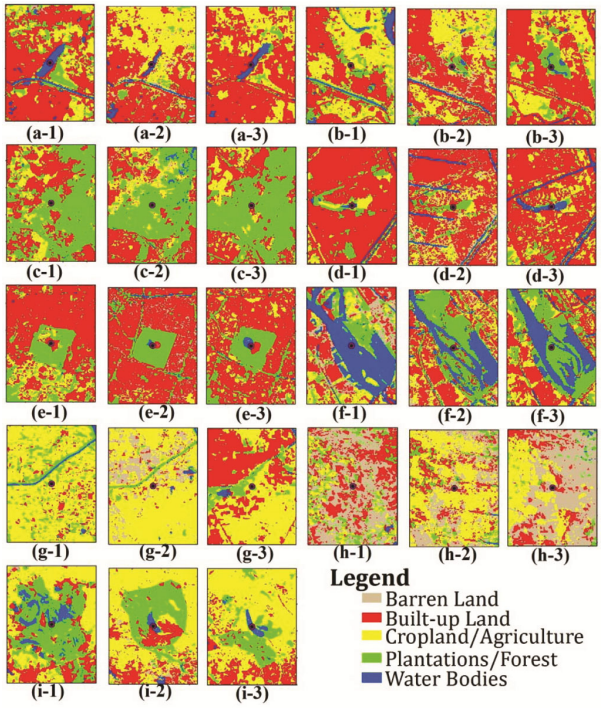

Fig. 3 — Land use land cover change around different Wetland: (a) Bhalswa Lake Wetland (a-1; 1998), (a-2; 2008), (a-3; 2018), (b) Yamuna Biodiversity Park (b-1; 1998), (b-2; 2008), (b-3; 2018), (c) Pusa Hill Forest (c-1; 1998), (c-2; 2008), (c-3; 2018), (d) Sanjay Lake Wetland (d-1; 1998), (d-2; 2008), (d-3; 2018), (e) Hauz Khas Wetland (e-1; 1998), (e-2; 2008), (e-3; 2018), (f) Okhla Bird Sanctuary (f-1; 1998), (f-2; 2008), (f-3; 2018), (g) Najafgarh Lake (g-1; 1998), (g-2; 2008), (g-3; 2018), (h) Asola Wildlife Sanctuary (h-1; 1998), (h-2; 2008), (h-3; 2018), (i) Surajpur Wetland (i-1; 1998), (i-2; 2008), (i-3; 2018)

Table 4 — Change in LULC categories of different years of different Wetland

S. No.	Wetland Name	LULC Class	1998		2008		2018		Change 1998–2008	Change 2008–2018
			Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Changed Area (km^2)	Changed Area (km^2)
1	Bhalswa Lake Wetland	Barren Land	3.47	4.42	4.54	5.78	0.00	0.00	1.07	–4.54
		Built-up Land	36.22	46.12	38.22	48.66	50.02	63.69	2.0	11.8
		Cropland/Agriculture	23.82	30.33	29.31	37.32	22.82	29.06	5.49	–6.49
		Plantations/Forest	12.55	15.98	4.66	5.93	4.75	6.05	–7.89	0.09
		Water bodies	2.48	3.16	1.81	2.30	0.95	1.21	–0.67	–0.86
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
2	Yamuna Biodiversity Park	Barren Land	5.03	6.40	6.18	7.87	0.44	0.56	1.15	–5.74
		Built-up Land	28.97	36.89	33.60	42.78	42.74	54.42	4.63	9.14
		Cropland/Agriculture	25.94	33.03	28.01	35.66	25.93	33.02	2.07	–2.08
		Plantations/Forest	13.60	17.32	7.52	9.57	8.28	10.54	–6.08	0.76
		Water bodies	5.00	6.37	3.23	4.11	1.15	1.46	–1.77	–2.08
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
3	Pusa Hill Forest	Barren Land	1.21	1.54	3.85	4.90	0.00	0.00	2.64	–3.85
		Built-up Land	41.41	52.72	48.32	61.52	44.92	57.19	6.91	–3.4
		Cropland/Agriculture	8.73	11.12	6.90	8.79	10.82	13.78	–1.83	3.92
		Plantations/Forest	26.61	33.88	18.16	23.12	22.54	28.70	–8.45	4.38
		Water bodies	0.58	0.74	1.31	1.67	0.26	0.33	0.73	–1.05
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
4	Sanjay Lake Wetland	Barren Land	4.38	5.58	6.06	7.72	0.00	0.00	1.68	–6.06
		Built-up Land	51.02	64.96	51.14	65.11	46.68	59.43	0.12	–4.46
		Cropland/Agriculture	9.48	12.07	9.10	11.59	15.68	19.96	–0.38	6.58
		Plantations/Forest	8.55	10.89	8.17	10.40	11.99	15.27	–0.38	3.82
		Water bodies	5.11	6.51	4.07	5.18	4.19	5.33	–1.04	0.12
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
5	Hauz Khas Wetland	Barren Land	2.11	2.69	6.42	8.17	1.45	1.85	4.31	–4.97
		Built-up Land	44.53	56.70	52.20	66.46	48.91	62.27	7.67	–3.29
		Cropland/Agriculture	15.11	19.24	6.34	8.07	9.57	12.18	–8.77	3.23
		Plantations/Forest	16.59	21.12	12.99	16.54	18.18	23.15	–3.6	5.19
		Water bodies	0.20	0.25	0.59	0.75	0.43	0.55	0.39	–0.16
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
6	Okhla Bird Sanctuary	Barren Land	3.72	4.74	6.95	8.85	0.03	0.04	3.23	–6.92
		Built-up Land	40.22	51.21	38.83	49.44	37.72	48.03	–1.39	–1.11
		Cropland/Agriculture	19.17	24.41	16.71	21.28	20.32	25.87	–2.46	3.61
		Plantations/Forest	8.60	10.95	11.18	14.23	15.61	19.88	2.58	4.43
		Water bodies	6.83	8.70	4.87	6.20	4.86	6.19	–1.96	–0.01
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
7	Najafgarh Lake	Barren Land	1.98	2.52	6.70	8.53	0.00	0.00	4.72	–6.7
		Built-up Land	7.36	9.37	7.19	9.15	20.04	25.52	–0.17	12.85
		Cropland/Agriculture	55.33	70.45	62.08	79.04	53.45	68.05	6.75	–8.63
		Plantations/Forest	12.61	16.06	1.84	2.34	4.17	5.31	–10.77	2.33
		Water bodies	1.26	1.60	0.73	0.93	0.88	1.12	–0.53	0.15
		Total	78.54	100.00	78.54	100.00	78.54	100.00		
8	Asola Wildlife Sanctuary	Barren Land	31.27	39.81	18.45	23.49	19.61	24.97	–12.82	1.16
		Built-up Land	21.97	27.97	22.29	28.38	29.96	38.15	0.32	7.67
		Cropland/Agriculture	14.02	17.85	27.77	35.36	21.42	27.27	13.75	–6.35
		Plantations/Forest	11.02	14.03	8.23	10.48	6.93	8.82	–2.79	–1.3
		Water bodies	0.26	0.33	1.80	2.29	0.62	0.79	1.54	–1.18
		Total	78.54	100.00	78.54	100.00	78.54	100.00		

(*contd.*)

Table 4 — Change in LULC categories of different years of different Wetland (*contd.*)

S. No.	Wetland Name	LULC Class	1998		2008		2018		Change 1998–2008	Change 2008–2018
			Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Changed Area (km^2)	Changed Area (km^2)
9	Surajpur Wetland	Barren Land	2.02	2.57	4.82	6.14	0.00	0.00	2.8	–4.82
		Built-up Land	11.62	14.80	12.06	15.36	14.03	17.86	0.44	1.97
		Cropland/Agriculture	51.40	65.44	57.50	73.21	60.28	76.75	6.1	2.78
		Plantations/Forest	12.25	15.60	3.78	4.81	3.86	4.91	–8.47	0.08
		Water bodies	1.25	1.59	0.38	0.48	0.37	0.47	–0.87	–0.01
		Total	78.54	100.00	78.54	100.00	78.54	100.00		

dramatic jump to 42.7 km^2 in 2018. The cropland has remained the same (about 26 km^2) in 1998 and 2018, though there was a slight increase to 28 km^2 in 2008. Barren land has declined from 5 km^2 in 1998 to 0.44 km^2 in 2018. Area under plantations has decreased from 13.6 km^2 in 1998 to 8.28 km^2 in 2018 and that of water bodies, 5 km^2 in 1998 to 1.15 km^2 in 2018. Both water bodies and plantation cover has shown a huge decline.

Pusa Hill Forest (PHF)

The wetland of Pusa Hill Forest is situated in the Central Ridge in NCT Delhi Fig. 3(c-1, c-2 & c-3). The area around this wetland is dominated by the built-up land which has increased from about 53% in 1998 to 57% in 2018. Cropland/agriculture class has also shown a positive change whereas the plantations and water bodies have declined. Water bodies have reduced to half from 0.74% area in 1998 to 0.33% in 2018 (Table 4). Clearly, the plantation/forest and water bodies are converted in to built-up and cropland.

Sanjay Lake Wetland (SLW)

Sanjay Lake Wetland is an artificial lake which was developed by Delhi Development Authority in east Delhi in 1970s. Fig. 3(d-1, d-2 & d-3) shows the LULC map of SLW. It is noted that the barren area within the 5 km buffer around this wetland has been converted into other class. The area under barren land had increased from 4.38 km^2 in 1998 to 6 km^2 in 2008, however it has declined to 0 km^2 in 2018. Built-up land and water bodies have declined whereas the cropland and plantations have shown positive changes. Although the percent area of cropland had declined marginally from 1998 to 2008 but in 2018, it has increased by about 8%. Similarly, area under plantations/forest had also declined marginally from 1998 to 2008 but the same increased by about 5% in 2018. The area under water bodies declined to 4 km^2 in 2008 compared to 5.11 km^2 in 1998 but in 2018 the water body has recovered to slightly better position with 5.33% increase. This is the only wetland area where plantations and water bodies have shown a positive change (Table 4).

Hauz Khas Wetland (HKW)

Hauz Khas wetland is situated in the highly urbanized area of south Delhi. It is the largest constructed wetland system in Delhi. The LULC maps for 1998, 2008 and 2018 are given in Fig. 3(e-1, e-2 & e-3). Barren land, built-up and water bodies have shown a decrease from 1998 to 2008 and then an increase from 2008 to 2018. Area under barren land increased to 6.42 km^2 in 2008 from 2.11 km^2 in 1998, and then declined to 1.45 km^2 in 2018, experiencing a net decline of 0.66 km^2 Built-up area increased to 52.20 km^2 in 2008 before falling to 48.9 km^2 in 2018, showing a net increase of 4.38 km^2 from 1998 to 2018. Cropland declined from 15 km^2 in 1998 to 6.34 km^2 in 2008 before slightly increasing to 9.57 km^2 in 2018, witnessing a net area change of −5.54 km^2 from 1998 to 2018. Area under plantations also showed a declining trend from 1998 to 2008 before increasing to 18.18 km^2 showing an overall positive change in area by 1.59 km^2 area under water bodies has increased from 0.20 km^2 in 1998 to 0.59 km^2 in 2008 and further declining to 0.43 km^2 in 2018, showing a net change in area of 0.23 km^2 Built-up, plantations and water bodies have shown a positive change (Table 4).

Okhla Bird Sanctuary (OBS)

Okhla Bird Sanctuary is situated on the Okhla barrage over Yamuna River in Noida, NCR Delhi. LULC maps for the three years are given in Fig. 3(f-1, f-2 & f-3). The area under water bodies has shown a constant declining trend from 6.83 km^2 in 1998 to 4.86 km^2 in 2018. On the other hand, the area under plantations has increased from 8.60 km^2 in 1998 to

11.18 km^2 in 2008 and further to 15.61 km^2 in 2018, showing a net positive change of 4.43 km^2 in three decades. The area under cropland has also slightly increased from 19.17 in 1998 to 20.32 km^2 in 2018. Built-up land has declining from 40.22 km^2 in 1998 to 38.83 km^2 in 2008 and further to 37.72 km^2 in 2018, whereas the barren land increased from 3.72 km^2 in 1998 to 6.95 km^2 in 2008 and then declined to 0.03 km^2 in 2018. Barren land, built-up and water bodies have declined whereas the plantations and cropland has increased (Table 4).

Najafgarh Lake Wetland (NLW)

Najafgarh Lake lies in the southwest Delhi and is an important wetland ecosystem. In Fig. 3(g-1, g-2 & g-3) the LULC for 1998, 2008 and 2018 is depicted. The built-up area around this wetland has dramatically increased from 7.36 km^2 in 1998 to 20 km^2 in 2018, showing an increase of 12.68 km^2 in three decades. All other classes have shown a decline between 1998 and 2018, with plantations declining from 12.61 km^2 in 1998 to 4.17 km^2 in 2018, a decrease of 8.44 km^2. Water bodies have decreased from 1.26 km^2 to 0.88 km^2 within this period. Barren land did not exist in 2018, which were 1.98 km^2 in 1998 and 6.70 km^2 in 2008. Area under agriculture first increased to 62 km^2 in 2008 before declining to 53.45 km^2 in 2018. Water bodies and plantations have decreased in this wetland (Table 4).

Asola Wildlife Sanctuary (AWS)

Asola Wildlife Sanctuary is spread over Gurugram, Faridabad and Delhi. The land use land cover around this wetland is shown in Fig. 3(h-1, h-2 & h-3). The area around the Asola wetland was dominated by the barren land in 1998, occupying 31.27 km^2 of area, followed by built-up land (21.97 km^2), cropland (14.02 km^2), vegetation (11.02 km^2), and water (0.26 km^2). In 2018 built-up dominated the area, followed by cropland, barren land, plantation, and water. Plantations have continuously declined within from 11 km^2 in 1998 to 8.23 km^2 in 2008 and 6.93 km^2 in 2018. On the other hand, built-up area has continuously increased from 21.97 km^2 in 1998 to 22.29 km^2 in 2008 and to 29.96 km^2 in 2018. Water bodies increased from 0.26 km^2in 1998 to 1.8 km^2in 2008 and then declining to 0.62 km^2 in 2018, depicting an overall positive change of 0.36 km^2 (Table 4).

Surajpur Wetland

Surajpur wetland is an urban wetland in Yamuna basin situated in Greater Noida area of NCR Delhi. LULC maps of 1998, 2008 and 2018 are given in Fig. 3 (i-1, i-2 & i-3). Built-up and cropland in the area around Surajpur wetland has shown an increasing trend from 1998 to 2018. The built-up has increased from 11.62 km^2 in 1998 to 12.06 km^2 in 2008 and 14.03 km^2 in 2018. Cropland/agriculture increased from 51.40 km^2 in 1998 to 57.50 km^2 in 2008 and to 60.28 km^2 in 2018. Barren land, plantations and water bodies have decreased within the period of 1998 and 2018. Almost 3/4th of plantation and forest area has vanished within two decades (the area had declined from 12.25 km^2 in 1998 to 3.86 km^2 in 2018). The area under water bodies has reduced to 0.37 km^2 in 2018 from 1.25 km^2 in 1998 (Table 4).

Net Percent Change in Area

Change detection method is used to assess significant differences in classified values in multi-temporal images.[32] Fromto algorithm describes the presence of LULC before and after a quantitative change in the digital image values, on the other hand, the other group of algorithms detect the presence or absence of change.[37] Most LULC changes are complex as the change in area of one class may show no considerable change temporally, but it may have changed in spatial terms. This is true especially of plantations/forest but same can't be true about the built-up area.[32] However, valuable information with respect to LULC change dynamics can be derived from the spatial analysis. The net change in LULC classes from 1998 to 2018 for Delhi NCR and around the wetlands is given in the following sub-heads.

Net Percent LULC Change in Delhi NCR

Net percent change in the study area of Delhi NCR for two decades (1998–2018) are given in Table 2. It is obvious that the built-up and cropland/agriculture has shown tremendous positive change with an increase of 5.25% and 8.56% respectively. Barren land, vegetation and water bodies have declined. For the plantation/forest area the net change is –8.30%, for barren land it is –5% and for water bodies the net change is –0.50%.

The change in different classes over time can be noted from the trend analysis (Fig. 4). Barren land, plantation and water bodies have shown a declining trend with water bodies showing a very high value of R^2= 0.99, followed by barren land (R^2 = 0.94).

Plantations have shown a declining trend as well though the R^2 value is not very high (R^2 = 0.79). On the other hand the built-up area and the cropland have

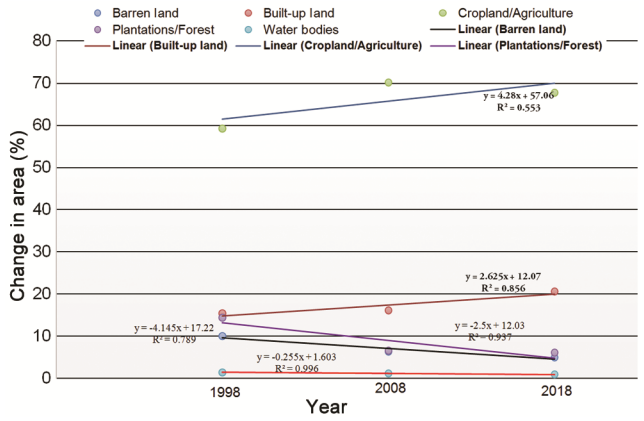

Fig. 4 — Trends of change of LULC classes in Delhi NCR (1998–2018)

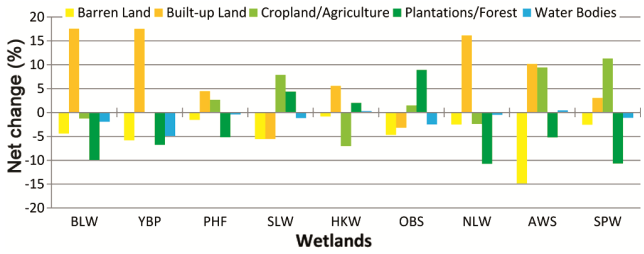

Fig. 5 — Net percent change in LULC classes around wetlands during 1998–2018

both shown an increasing trend with built-up having a high value of R^2 (0.85) compared to cropland (R^2 = 0.55). This reflects the threat posed to plantations and water bodies which are continuously being converted into other classes like cropland and built-up. But it is the built-up area that is encroaching on the other LULC classes in Delhi NCR.

Net Percent Change in Area around Wetlands

The shows (Fig. 5) the net percent change in area of different classes within the 5 km buffer of wetlands. From the Fig. 5 it can observed that the built-up area shows the greatest positive net percent change in six of the nine wetlands. In just two wetlands of Sanjay Lake Wetland and Okhla Bird Sanctuary the built-up area has shown a negative net percent change of –5.53% and –3.18% respectively. Cropland has shown a positive net percent change in five wetlands while threewetlands have shown aperceptible negative change and one, the Yamuna Biodiversity Park, has shown no perceptible change. Plantations/forest has shown a negative net percent change in six wetlands, with Najafgarh experiencing the highest (–10.75%), followed closely by Surajpur wetland (–10.68%) and Bhalswa lake wetland (–9.93%). Yamuna Biodiversity Park, Pusa Hill Forest and Asola Wildlife Sanctuary have witnessed a negative net change of –6.77%, –5.18%, and –5.21% respectively. Three wetlands of Okhla Bird Sanctuary, Sanjay Lake Wetland and Hauz Khas wetland have noted a positive net percent change of +8.93, +4.38 and +2.02 respectively. Water bodies in all but two wetlands have shown a negative net percent change, with highest change observed in Yamuna Biodiversity Park (–4.90%). In two of the wetlands showing negative change, PHF and NLW, the change is imperceptible as is the net positive change in the only two wetlands of AWS and HKW (less than 0.5%). The barren land area has witnessed a negative net percent change in all the wetlands, with AWS observing the highest change (–14.85%) and HKW the lowest (–0.48%).

If we calculate the average net percent change and the net area change around all the wetlands taken together we can see the positive net change in the built-up (+7.3%) and cropland/agriculture (+2.4%). Other classes viz. barren land, plantations and water bodies have shown the net negative change of –4.8%, –3.7% and –1.3% respectively. The net area under built-up has increased by 51.7 km^2 while that of cropland increased by 17.29 km^2 around the wetlands. During the same period, about 26 km^2 of vegetation cover and 9.26 km^2 of water bodies was lost to other LULC classes.

Trends of Various LULC Classes in Wetlands

To understand the land change dynamics of wetlands better trend analysis is done for different LULC classes taking all the wetlands together. The general trends that can be observed is the increase in built-up area and cropland while the area under barren land, plantations and water bodies have shown decreasing trend in all wetlands of Delhi NCR region.

Barren Land

The barren land has shown a high negative change in all wetlands though it is interesting to observe that it has shown a positive change from 1998 to 2008 and then sharp negative changes from 2008 to 2018. Because of this trend the R^2 values of only three wetlands are significant (YBP – R^2 = 0.5711; BLW – R^2 = 0.5344 and SLW – R^2 = 0.49) (Table 5). The plausible explanation is that the vegetation cover is first converted into barren land and then that land is either brought under cultivation or used for built-up purposes.

Built-up Land

The percent area changes under built-up in various wetlands has shown a positive trend from 1998 to

2018, meaning thereby the area under built-up land has increased in all wetlands expect SLW and OBS (Table 5). The high values of R^2 shows the changes are significant. Only PHF and HKW have R^2 value that is insignificant.

Cropland/Agriculture

Cropland/agriculture constitutes a major proportion of area in two wetlands of SPW (76.75%) and NLW (68%), with SPW showing a positive trend since 1998 (R^2 = 0.95) and NLW showing a negative trend with R^2 equal to 0.04 (Table 5). The trend of cropland is significant for only two wetlands viz. SPW and SLW.

Plantation/Forest

Only three wetlands have shown a positive trend viz. SLW, HKW and OBS with OBS depicting significant R^2 value of 0.977. SLW has an R^2 value of

Table 5 — Trend lines of the different LULC classes in various wetlands

S. No.	LULC Classes	Wetland	Change (%)	Trend lines	R^2
1	Barren land	BLW	−4.42	y = −0.2209x + 446.98	0.5344
		YBP	−5.84	y = −0.2922x + 591.7	0.5711
		PHF	−1.54	y = −0.077x + 156.83	0.0944
		SLW	−5.48	y = −0.2788x + 564.34	0.49
		HKW	−0.84	y = −0.042x + 88.605	0.0149
		OBS	−4.43	y = −0.2349x + 476.24	0.2839
		NLW	−2.52	y = −0.1261x + 256.79	0.0827
		AWS	−14.84	y = −7.423x + 44.27	0.6761
		SPW	−2.57	y = −0.1286x + 261.13	0.1741
2	Built-up	BLW	27.47	y = 0.8785x − 1711.3	0.8561
		YBP	17.56	y = 0.8766x − 1715.6	0.9655
		PHF	15.78	y = 0.2235x − 391.55	0.258
		SLW	−5.53	y = −0.2763x + 617.96	0.7293
		HKW	5.57	y = 0.2788x − 498.1	0.3239
		OBS	3.18	y = −0.1592x + 369.14	0.9958
		NLW	16.15	y = 0.8072x − 1606.2	0.7399
		AWS	10.18	y = 0.5087x − 989.89	0.78
		SPW	3.06	y = 0.1534x − 292.07	0.8816
3	Cropland/ Agriculture	BLW	−1.27	y = −0.0637x + 160.07	0.0205
		YBP	−0.01	y = −0.0006x + 35.18	2E−05
		PHF	2.66	y = 0.1331x − 255.95	0.2838
		SLW	7.89	y = 0.3947x − 778.02	0.7042
		HKW	−7.06	y = −0.3527x + 721.36	0.39
		OBS	1.46	y = 0.0732x − 123.16	0.0972
		NLW	−2.40	y = −0.1197x + 312.84	0.0429
		AWS	9.42	y = 0.4711x − 919.14	0.2891
		SPW	11.34	y = 0.5653x − 1063.4	0.9555
4	Plantations/ Forest	BLW	−9.03	y = −0.4966x + 1006.4	0.7413
		YBP	−7.22	y = −0.3387x + 692.55	0.6447
		PHF	−5.16	y = −0.2591x + 548.85	0.2319
		SLW	5..23	y = 0.219x − 427.56	0.6681
		HKW	2.34	y = 0.1012x − 182.98	0.0894
		OBS	9.03	y = 0.4463x − 881.09	0.9773
		NLW	−11.24	y = −0.5373x + 1086.8	0.5546
		AWS	−6.42	y = −0.2604x + 533.95	0.9576
		SPW	−11.38	y = −0.5341x + 1081	0.7428
5	Water bodies	BLW	−1.95	y = −0.0974x + 197.81	0.9949
		YBP	−4.91	y = −0.2451x + 496.14	0.9978
		PHF	−0.41	y = −0.0204x + 41.819	0.0884
		SLW	−1.18	y = −0.0586x + 123.28	0.6536
		HKW	0.30	y = 0.0146x − 28.884	0.3441
		OBS	−2.51	y = −0.1254x + 258.86	0.7538
		NLW	−0.48	y = −0.0242x + 49.795	0.4837
		AWS	1.12	y = 0.0229x − 44.882	0.0499
		SPW	−1.12	y = −0.056x + 113.34	0.7585

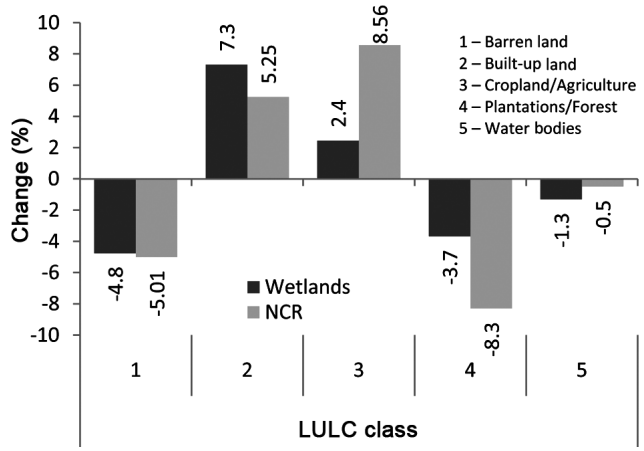

Fig. 6 — Net percent change in LULC in Delhi NCR and wetlands

0.67 while it is insignificant for HKW (R^2 = 0.089) (Table 5). All other wetlands have witnessed a negative trend as far as plantations/forests are concerned of these; AWS, SPW and BLW have significant R^2 values of 0.957, 0.742 and 0.741 respectively.

Water Bodies

The proportion of area under water bodies has also declined in all wetlands except AWS and HKW (Table 5). This trend of decline is significant with R^2 values very high for most of the wetlands. The R^2 is insignificant for the two wetlands showing the positive change (0.34 for HKW and 0.05 for AWS).

Comparison between LULC Change in NCR and Wetlands

A comparison between the LULC change in the NCR and the nine wetlands taken together is given in Fig. 6. It can be noted clearly that the pattern of change is similar. It only differs in the intensity or degree of change. Barren land, plantations and water bodies have shown a net negative change whereas built-up and cropland has depicted a net positive change at both levels. While the net percent change in barren land has been almost same (approximately 5%), the difference is conspicuous in cropland and vegetation. Around wetlands the net percent change of other classes to cropland is +2.4% whereas in the NCR it is +8.56%, a difference of 6.16%. The difference in vegetation is +4.6% with net percent change in wetlands lower (–3.7%) than in NCR (–8.3%). The percent change in built-up around wetlands is higher than the NCR, with values of +7.3% and +5.25% respectively.

Discussion

From the analysis of LULC data for Delhi NCR and nine wetlands it is obvious to note the changes in various classes of LULC around the study region. In the Delhi NCR region the two classes, built-up and cropland, have shown the positive changes. These two categories dominate the landscape. The reason for their increase is the high population growth and rapid urbanization. According to the Census of India, in Delhi NCT the rural area has shrunk from 53.79% in 1991 to 24.9% in 2011 whereas the urban area increased from 46.21% to 75% during the same period. The population increased from 9.4 million in 1991 to 16.7 million in 2011. It is expected to rise to about 30 million in 2021 posing more threat to the sensitive ecosystems like wetlands. The area under plantation has declined by more than half and about 40 km^2 of area under water bodies is lost during these twenty years. These are the two important aspects of wetlands, and together about 700 km^2 of area was converted into cropland. Forested land of 658 km^2 was lost to either built-up area or agriculture, a major part of it was lost from 1998 to 2008 (623 km^2). During the same period almost, equal area was added to the cropland/forest category (679 km^2), thereby depicting a strong negative correlation between agriculture and forest land. Built-up area gained 416 km^2.

There seems to be an intricate relationship between plantation, cropland, and built-up area. From 1998 to 2008 the plantation decreased by 658 km^2 and during the same time the cropland increased by 868 km^2. Since built-up area usually doesn't get converted to cropland or plantations it seems the barren land was also turned in to cropland during this period as an area of 287 km^2 of barren land was converted into other classes, of which a major part seems to have been converted into cropland and the remaining area was brought under the built-up. From 2008 to 2018 the area under cropland has decreased by 189 km^2 and built-up increased by 356 km^2. Plantation and forest decreased by only 35 km^2 while barren land decreased by 110 km^2, showing that the plantation which was converted into agriculture was further converted into the built-up land. Water bodies usually get converted into cropland. The percent change in built-up around the wetlands is higher than NCR. It is a matter of concern as more built-up area around the wetlands means more garbage, more human waste and more degradation that decline the ecosystem services provided by the

wetlands. Landuse modifications diminish the value of ecosystem services.

Water bodies and plantations are the two important elements of wetland ecosystems which are key to attracting the biodiversity and providing other services like recreation etc. Taken together, the 'plantations/forest and water bodies' have witnessed encroachment by cropland and built-up area. Other researches have also shown the increasing trend of built-up in Delhi and NCR.[32] Also agricultural expansion is found to reduce the wetland buffer areas[38] and rapid urban growth and encroachment on wetlands and other water bodies are leading to the reduction of these ecosystems.[39,40] Finally, this study may recommend an alternative LULC plan for urbanization without deteriorating the wetlands present in the study area.

Conclusions

This study spanning over two decades (1998–2018) has brought out the changing LULC dynamics of wetlands in Delhi NCR. Increase in built-up area and the conversion of wetlands into agricultural land have threatened these urban ecosystems which are very essential to provide ecosystem services, directly and indirectly. Management and protection of wetlands is not optional owing to the speedy increase in population and expansion of urban areas in the Delhi NCR. The LULC change analysis has pointed to the loss of wetland area to built-up or agriculture which is going to affect the ecosystem services provided by these wetlands. There is a need to further explore the loss in ecosystem services due to LULC changes in wetlands spread over the Delhi NCR region. Geospatial analysis is an important approach to understand the changing LULC in such a sensitive ecosystem. It needs to be employed for sustaining wetlands so that the ecosystem services they provide are long lasting.

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