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Urban Expansion Occurred at the Expense of Agricultural Lands in the Tarai Region of Nepal from 1989 to 2016

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Abstract: Recent rapid urbanization in developing countries presents challenges for sustainable environmental planning and peri-urban cropland management. An improved understanding of the timing and pattern of urbanization is needed to determine how to better plan urbanization for the near future. Here, we describe the spatio-temporal patterns of urbanization and related land-use/land-cover (LULC) changes in the Tarai region of Nepal, as well as discuss the factors underlying its rapid urban expansion. Analyses are based on regional time-series Landsat 5, 7 and 8 image classifications for six years between 1989 and 2016, representing the first long-term observations of their kind for Nepal. During this 27-year period, gains in urban cover and losses of cultivated lands occurred widely. Urban cover occupied 221.1 km^2 in 1989 and increased 320% by 2016 to a total 930.22 km^2. Cultivated land was the primary source of new urban cover. Of the new urban cover added since 1989, 93% was formerly cultivated. Urban expansion occurred at moderately exponential rates over consecutive observation periods, with nearly half of all urban expansion occurring during 2006–2011 (305 km^2). The annual rate of urban growth during 1989–1996 averaged 3.3% but reached as high as 8.09% and 12.61% during 1996–2001 and 2011–2016, respectively. At the district level, the rate of urban growth and, by extension, agricultural loss, were weakly related to total population growth. Variability in this relationship suggests that concerted urban-growth management may reduce losses of agricultural lands relative to historic trends despite further population growth and urbanization. Urbanization and LULC change in the Tarai region are attributable to significant inter-regional migration in a context of poor urban planning and lax policies controlling the conversion and fragmentation of peri-urban cultivated lands. Urban expansion and farmland loss are expected to continue in the future.

Keywords: Land-use/land cover; urbanization; remote sensing; Tarai; Nepal

1. Introduction

Land-use/land cover (LULC) change is a dynamic process [1] and plays a pivotal role in global environmental change [2,3], ecological deterioration [4], loss of biodiversity, and the transformation of local climates [5] and natural landscapes [6]. Urbanization, a cumulative phenomenon [7], is among the most important anthropogenic activities impacting LULC change [8] and is increasingly prominent and accelerating across the 'Global South' [9]. Approximately 55% of the world's urban population resides in the Asia-Pacific region [10], and this proportion is expected to increase. From 2014 to 2050, urban populations are expected to grow by 404 million in India and 292 million in China, with a further 212 million in Nigeria, such that 66% of the world's population would be urban dwellers [9]. By 2030, the extent of urban cover is correspondingly predicted to expand significantly across South-east Asia, as well as West Africa, South America and Central Africa [11]. Much of the new urban area is expected to come from agricultural areas surrounding urban centers, typically situated in prime agricultural areas. The loss of these areas to urban expansion has broad implications for LULC and sustainable development generally as demographic pressures mount [12]. The conversion of natural habitats to agriculture is one of the greatest drivers of global change [13], and an increased rate of loss of agricultural lands to urban expansion could compound such changes via feedbacks centered on food insecurity and agricultural incursions into intact natural areas. Virtually all population growth culminating in the projected 11.2 billion global population of 2100 will occur in the Global South [14], where social disruption due to recent spikes in agricultural commodity prices has been concentrated [15]. Increasing food prices would be compounded if the agricultural production of smallholders in developing countries were to decline due to higher fertilizer prices, as may be occurring presently.

Globally, land use change is increasing due to urbanization and it is one of the major challenge for policy makers and planners [16]. Mass rural–urban migration has arguably been a defining characteristic of many regions of the Global South over the last three decades, reflecting in turn growing rural–urban economic inequalities [9] as well as the increasing economic aspirations of the rural poor. The pace and scale of this migration has markedly reshaped the nature of urban growth and planning and hence LULC, locally and regionally [17,18]. Globally, the tremendous urban growth experienced in the last century [19] in East–South-east Asia, home to low-income and lower-middle income countries, has resulted in rapid urbanization due to well-established trends of rapid industrialization, economic growth and globalization [20].

Developing countries in South-east Asia with emerging economies [21] are amongst the most rapidly urbanizing. For example, Cambodia, Laos, Myanmar and Vietnam experienced increases in urban populations ranging from 9% to 35% between 1980 and 2012. Nepal has a relatively lower rate of urbanization with a shorter history, but it has similarly experienced rapid urbanization in the last two decades [22]. Many factors contribute to urban growth in Nepal including population growth and domestic inter-regional migration, highly uneven economic development, and government policies favoring urban-centric economic growth [23–27]. The ongoing reclassification of select rural areas as urban areas [28] has also enhanced aggregate measures of urban growth, arguably at the expense of understanding precise roles and the relative importance of such socio-economic factors in Nepal. The percentage of the national population residing in urban areas in Nepal increased 14-fold between 1952 and 2015, from 2.9% to 40.5% [29]. In comparison, the national population increased less than three-fold over the same period [26]. Nepal is particularly vulnerable to agriculture-to-urban conversion because only 28% of its land is suitable for cultivation [30] and almost all of this land is already cultivated and proximate to growing urban centers [31].

The Tarai region of Nepal, the focus of this study, typifies many of the challenges and dynamics of urbanizing regions in the Global South. The region, which hosts one third of Nepal's cultivated and managed lands [31], commenced urbanizing with the eradication of malaria in 1958 [32] and state-sponsored resettlement and rural land-consolidation programs targeting Hill people between the mid-1950s and late 1980s (e.g., Rapti Valley Development Project, Nepal resettlement company) [33]. Internal migration to the region also increased rapidly after the establishment of democracy in Nepal in 1951 [25], and increased again following the restoration of democracy in 1990 and attendant patterns of urban-centric economic development and migration to the Tarai region is largely driven by a belief that the region promises economic opportunities and improved living standards, such that most migrants to Tarai originate in other, largely upland regions of the country [26]. Earlier migrants tended to practice subsistence peri-urban agriculture to supplement meager urban incomes, and later migrants were naturally attracted to existing settlements, such that emerging urban settlements are largely unplanned and have developed over prime agricultural lands.

Notwithstanding limited localized studies of urban sprawl around individual Nepalese urban centers [18,22,29,34–39], there have been no large scales analyses of Nepalese urban expansion and its implications for land-cover change and agricultural production. In response, this article observes long-term trends in urbanization in the Tarai region and highlights associated underlying socio-economic factors. Special attention is given to the proportion of cultivated area converted to urban cover over time as well as underlying relationships between regional urban population growth and urban expansion over cultivated lands.

2. Methods

On-ground field assessment to monitor and model LULC change in large areas is often not practical, whereas the use of remote sensing and GIS tools can be quite effective [40,41]. Spatio-temporal observations using remote sensing and GIS techniques [42] allow researchers to obtain time-sensitive data to analyze LULC change in urbanizing contexts [43] and project future land-use change [44,45].

This study used satellite-image analysis to describe LULC trends associated with urbanization in the Tarai region of Nepal. Some 42 Landsat scenes for six years between 1986 and 2016 were classified in order to observe aerial exchanges between urban cover and other land uses/covers in the study area.

2.1. Study Area

Nepal comprises three geographical regions, namely the High Mountains, Mid Hills and the Tarai region, the latter of which defines our study region. The Tarai region is a fertile low-lying region of Nepal (Figure 1). The region comprises 20 districts with total area of 33,485 km^2, which constitutes 23% of the national area. The region has a humid tropical and sub-tropical climate with summer temperatures ranging from 32 °C to 35 °C and winter temperatures ranging from 8 °C to 15 °C, with an average annual rainfall of 270 mm. Tarai has experienced remarkable population growth in recent decades, more than doubling over 1981–2011 from 6.5 million inhabitants (44% of the national population) to 13.3 million (50.3%).

2.2. Data, Processing and Analysis

A total of 42 surface reflectance (SR) Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Image (OLI) scenes were classified for 1989, 1996, 2001, 2006, 2011, 2016 for the Tarai region to observe aerial exchanges between urban cover and other land uses (Table 1). All Landsat scenes were obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov) (Table 1). Landsat SR data underwent post-production processing entailing geometric rectification, atmospheric correction and other processing (for more details, http://landsat.usgs.gov/CDR_LSR.php), rendering data suitable for scientific analysis [29,40,46,47] The SR data product includes quality assessment (QA) bands used here to identify and omit pixels with snow, clouds and cloud shadows. Geometric accuracy was verified for all satellite images, which were projected to the UTM projection (datum WGS 1984). All Landsat data products (TM and ETM) were generated by the Landsat Ecosystem Disturbance Adoptive Processing System (LEDAPS) established by NASA [48]. Landsat SR Code (LaSRC) was employed to generate the Landsat 8 OLI-SR data [49]. Almost all scenes were nearly free of clouds and all have 30-m spatial resolution. Landsat ETM+ data with the Scan Line Corrector-off (SLC-off) error after May 2003 were used only where Landsat TM scenes were unavailable and overlay operations had filled the no-data gaps in the these ETM+ scenes (Table 1).

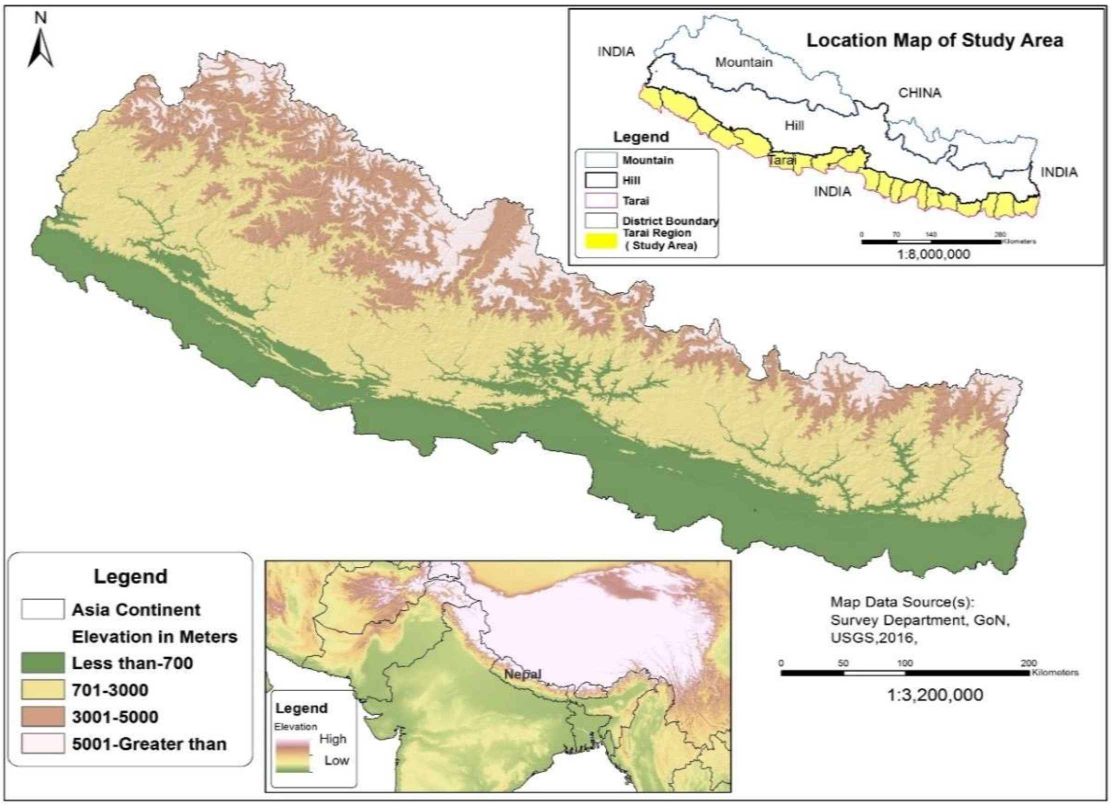

Figure 1. Elevation model of Nepal and location of the study area.

Table 1. Dates of the Landsat Time series 5, 7 and 8 images (Landsat 5, hereafter Thematic Mapper (TM); Landsat 7, hereafter Enhanced Thematic Mapper Plus (ETM+); (Landsat 8, hereafter Operational Land Image (OLI).

Path/Row	1989 (TM)	1996 (TM)	2001 (ETM+)	2006 (TM)	2011 (TM)	2016 (OLI)
139/42	4 December	23 December	29 December	19 December	31 January	13 January
140/041	9 November	30 December	17 October	10 December	7 February	18 October
140/042	9 November	12 November	17 October	10 December	7 February	18 October
141/041	18 December	18 October	24 October	30 October	29 January	25 October
142/041	7 November	10 November	31 October	5 October	19 October	22 March
143/041	14 November	17 November	25 December	2 March	26 October	23 October
144/040	22 February	9 January	3 March	1-March-ETM+ (SLC, OFF)	7 March	17 February

All Landsat scenes were mosaicked, temporally 'stacked', subset by district boundary, and analyzed using ENVI for 19 out of 20 districts comprising the Tarai study area (Figure 1). The LULC data for the 20th district (Jhapa) was derived from a previous study [29]. District boundaries were buffered by five kilometers when sub-setting a scene for classification.

The maximum likelihood (ML) classifier algorithm [18,50–52] was employed to classify the Landsat data into various land-use/cover classes for each of the six years of observation. The ML approach is one of the classical parametric statistical classifiers and is widely used for LULC classification [53]. Several studies have also evaluated alternative, recently-developed machine-learning algorithms for land-cover classification, such as support vector machine (SVM) methods [54], decision trees (DT) [55], and random-forest models (RF) [56,57]. Schneider [55] observed that the DT and SVM classifiers outperformed the ML classifier in the context of highly dynamic land-cover change and 'fuzzy' multi-signal classes around the Chinese cities of Chengdu, Xi'An, and Kunming. Nonetheless, we employed the ML classifier here due to its broad familiarity [18,50–52], relatively moderate data requirements, and appropriateness for our study context. Indeed, the accuracy of our ML classification accuracy was reasonably high (Section 2.6), and far in excess of the ML accuracy observed in urban areas by Schneider [55]. Nonetheless, we highlight that alternative remote-sensing classifiers might potentially observe subtler and/or relatively localized LULC dynamics additional to those captured here.

A review of the peer-reviewed and 'grey' literature (e.g., government and donor-agency reports) [18,24,25,27–29,37,38,58–60] was undertaken to identify recurrently occurring factors shaping urbanization in the Nepalese Tarai region [26]. Attention focused on socio-economic factors, including those whose relevance was regularly indicated by specific empirical metrics but which, nonetheless, often escape direct observation and quantification in Nepal. The review was also inclusive of assessments of various major national pride projects [61,62] and other long- and short-term infrastructure-development projects [63] that have spurred land-cover change in formerly exclusively rural areas.

2.3. Extraction of Land-Use/Land-Cover (LULC)

The land-cover classification scheme developed by Anderson et al., 1976 [64] (Table 2) was adopted here, defining eight land-use/cover classes: urban (built-up), cultivated land, vegetation (dense forest, scattered forest, shrub, and grass), barren land, sand area, water body, swamp area and tea plantations (Table 2). LULC transitions rates for the periods 1989–1996, 1996–2001, 2001–2006 and 2006–2011 and 2011–2016 were subsequently derived from the Landsat classifications.

Table 2. Land-cover classification scheme.

Land Cover Types	Description
Urban/Built up (U/B)	Urban and rural settlements, commercial areas, industrial areas, construction areas, traffic, airports, public service area (e.g., school, college, hospital)
Cultivated land (CL)	Wet and dry crop lands, orchards
Vegetation cover (VC)	Evergreen broad leaf forest, deciduous forest, scattered forest, low density sparse forest, degraded forest, mix of trees and other natural grass covers
Barren land (BL)	Cliffs/small landslide, bare rocks
Sand cover (SC)	Sand area, other unused land, river bank
Water body (WB)	River, lake/pond, canal, reservoir and swamp area
Swamp/Wetland area (WA)	Swamp land/and with a permanent mixture of water and marsh
Tea farming (TF)	Tea plantation

2.4. Transition Analysis of LULC

After classifying the Landsat imagery, the LULC cross-tabulation function of TerrSet software (clarklabs.org, Clark lab, Worcester, MA, USA) was used to quantify the aerial exchanges between each land-use/cover category, both for individual observation periods of the time series (1989–1996, 1996–2001, 2001–2006, 2006–2011 and 2011–2016) and the larger, inclusive period 1986–2016. These land-cover change data for each individual observation period were further analyzed using LULC statistics to identify the detailed LULC trajectories of the study area.

2.5. Measuring Urban Expansion Rate

The urban expansion growth rate of the study area was measured by calculating the total new urban area for each time period and determining an annual rate of change.

$$\text{UER} = (U_{t1} - U_{t0})/(T_1 - T_0) \times 100 \quad (1)$$

where UER is the urban expansion rate (km^2/year), U is urban area in km^2 between t_1 and t_2 years.

2.6. Accuracy Assessment

Land-cover classifications were validated against 4235 randomly sampled reference points. These randomly sampled reference points were stratified by district and land-use class, with 35 points sampled per LULC class per district (e.g., 6 districts have 7 classes, 5 districts have 5 classes, and 8 districts have 6 classes). The numbers of sample points per district varied between 175 and 245 since the spatial distribution of sample points were determined by the distribution of land cover categories amongst the 19 districts. The accuracy assessment information data for the 20th ditrict, Jhapa, was derived from an earlier study [29]. For the validations of the Landsat classifications for 1989, 1996 and 2001, 2006, 2011 and 2016, the land cover classes of the reference points were visually interpreted using contemporary high-resolution Google Earth images or retrospective field assessments realized in 2014, 2015 and 2016 using the Global Positioning System (GPS). GPS ground truth data were collected mainly in the urban areas and the periphery of road networks. Google Earth images for multiple dates, topographical maps published by the Survey Department of the Government of Nepal in 1995 at 1:25,000 scale [65] were also used as ground references to validate the earlier classifications of the time series. The study area occupied almost flat land and land-cover classes were easily identified in the reference data.

3. Results

3.1. Land-Use/Land-Cover Change of Tarai, 1989 to 2016

Across all 20 districts and years in our time series of classifications, the overall classification accuracy ranged between 80% and 88%. The minimum accuracy of 80% was for Mahottrai district in 1989, and the maximum classification accuracy of 88% was for Morang district in 2016. For the 'urban areas' and 'cultivated lands' classes of particular interest in this study, their user's accuracies were not less than 80% for all districts and all years. For each district and year in the time series, the supplementary information provides producer's and user's accuracies for each class as well as overall classification accuracy (S1).

The most pronounced LULC changes in Tarai region between 1989 and 2016 were the rapid increase in urban (built/up) cover (+420%) and associated decrease in cultivated lands (−4%) (Tables 3 and 4, and Figure 2a–e). Urban area spanned 221 km^2 in 1989 and increased to 930 km^2 by 2016. Of the total urban expansion of 709 km^2, 658 km^2 or 93% occurred over cultivated lands alone according to the land-cover transition map for 1989–2016. The remaining area of new urban cover of 2016 derived from lands that were forest (41.48 km^2) or sandy areas (30.13 km^2) in 1989 (Table 3). Direct land-cover transitions for each successive observation period (Tables 5–9) generally tracked these overall trends for 1989–2016 as do the gross gains and losses of land-cover classes by district and period (Figure S2) given that new urban areas were sourced nearly exclusively from cultivated lands.

Table 3. Land-use/land-cover (LULC) classes of the Tarai region, by year, 1989–2016 (km^2 and percent).

Class	1989		1996		2001		2006		2011		2016	
LULC	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
U/B	221.1	0.66	272.36	0.81	382.66	1.14	486.1	1.45	792.59	2.37	930.22	2.78
CL	16,670	49.78	16,733	49.97	16,597.9	49.57	16,431	49.07	16,130.17	48.17	16,000.86	47.78
VC	14,100	42.11	14,041	41.93	14,043.3	41.94	14,081	42.05	14,025.17	41.88	14,091.05	42.08
BL	90.96	0.27	76.88	0.23	83.9	0.25	85.19	0.25	88.39	0.26	60.98	0.18
SC	1712	5.11	1822	5.44	1853.91	5.54	1887	5.64	1905.76	5.69	1799.19	5.37
WB	669.6	2.00	519.55	1.55	500.71	1.50	488.4	1.46	514.36	1.54	580.58	1.73
TF	22.26	0.07	20.38	0.06	23.1	0.07	26.58	0.08	28.96	0.09	22.52	0.07
Total	33,485	100	33,485	100.00	33,485.4	100.00	33,485	100.00	33,485.4	100.00	33,485.4	100.00

Notes: LULC shorthand names are as per Table 2.

Table 4. Rate of land-cover change in the Tarai region, by land-cover class and period (km^2/year).

	1989–1996	**1996–2001**	**2001–2006**	**2006–2011**	**2011–2016**	**1989–2016**
U/B	51.23	110.3	103.43	306.5	137.63	709.09
CL	63.45	−135.39	−167.29	−300.39	−129.31	−668.93
VC	−58.94	2.25	38.12	−56.22	65.88	−8.91
BL	−14.08	7.02	1.29	3.2	−27.41	−29.98
SC	110.22	31.94	33.33	18.52	−106.57	87.44
WB	−150	−18.84	−12.36	26.01	66.22	−88.97
Tea	−1.88	2.72	3.48	2.38	−6.44	0.26

Notes: LULC shorthand names are as per Table 2.

Table 5. Spatiotemporal transition of LULC, 1989–1996.

Year				**1996**				
	LULC	**U/B**	**CL**	**VC**	**BL**	**SA**	**WB**	**TF**
1989	**U/B**	**218.13**	1.05	0.00	0.00	0.11	1.81	0.00
	CL	46.00	**16,449.44**	100.75	0.04	50.84	20.40	2.62
	VC	3.54	143.64	**13,868.39**	0.52	71.29	12.49	0.13
	BL	0.00	1.11	15.20	**72.65**	1.43	0.57	0.00
	SC	3.45	89.69	44.89	3.64	**1490.32**	80.01	0.00
	WB	1.21	44.36	12.18	0.03	208.00	**403.77**	0.00
	TF	0.00	4.14	0.44	0.00	0.05	0.00	**17.63**

Notes: LULC shorthand names are as per Table 2.

Table 6. Spatiotemporal transition of LULC, 1996–2001.

Year				**2001**				
	LULC	**U/B**	**CL**	**VC**	**BL**	**SA**	**WB**	**TF**
1996	**U/B**	**267.35**	4.21	0.02	0.00	0.70	0.07	0.00
	CL	104.90	**16,350.67**	135.93	1.17	115.05	22.24	3.21
	VC	4.91	153.46	**13,816.06**	9.00	46.70	10.70	0.35
	BL	0.00	0.03	2.38	**73.04**	1.30	0.10	0.00
	SC	3.91	69.21	82.03	0.49	**1557.98**	108.41	0.08
	WB	1.56	19.67	6.73	0.20	132.17	**359.20**	0.00
	TF	0.04	0.69	0.15	0.00		0.04	**19.46**

Notes: LULC shorthand names are as per Table 2.

Table 7. Spatiotemporal transition of LULC, 2001–2006.

Year				**2006**				
	LULC	**U/B**	**CL**	**VC**	**BL**	**SA**	**WB**	**TF**
2001	**U/B**	**377.34**	3.73	0.24	0.00	1.16	0.16	0.03
	CL	98.04	**16,293.22**	142.65	0.06	25.48	32.81	4.83
	VC	4.86	102.49	**13,869.45**	2.42	45.91	17.92	0.13
	BL	0.00	0.05	1.10	**82.20**	0.51	0.04	0.00
	SC	4.59	24.24	60.82	0.40	**1661.31**	103.25	0.06
	WB	1.25	5.89	6.55	0.12	152.62	**334.21**	0.10
	TF	0.09	1.38	0.19	0.00	0.01	0.00	**21.44**

Notes: LULC shorthand names are as per Table 2.

Table 8. Spatiotemporal transition of LULC, 2006–2011.

Year		2011						
	LULC	U/B	CL	VC	BL	SA	WB	TF
2006	U/B	**480.01**	4.24	0.06	0.00	1.50	0.30	0.01
	CL	279.25	**15,957.04**	100.89	0.12	61.00	29.10	3.83
	VC	20.15	102.35	**13,862.19**	4.60	75.45	16.17	0.08
	BL	0.00	0.06	1.97	**82.92**	0.12	0.12	0.00
	SC	10.60	51.87	52.35	0.31	**1656.73**	114.66	0.48
	WB	2.40	14.17	7.22	0.05	110.23	**354.00**	0.08
	TF	0.19	1.48	0.33	0.00	0.04	0.07	**24.47**

Notes: LULC shorthand names are as per Table 2.

Table 9. Spatiotemporal transition of LULC, 2011–2016.

Year		2016						
	LULC	U/B	CL	VC	BL	SA	WB	TF
2011	U/B	**783.15**	6.85	0.10	0.00	1.30	0.65	0.04
	CL	130.02	**15,806.95**	82.48	0.33	78.37	31.63	0.21
	VC	8.02	90.54	**13,892.76**	3.28	24.19	6.58	0.00
	BL	0.00	0.93	26.14	**55.98**	4.81	0.53	0.00
	SC	7.58	68.62	73.29	0.76	**1599.95**	155.30	0.01
	WB	1.56	20.70	16.26	0.25	90.24	**385.90**	0.00
	TF	0.03	6.27	0.03	0.00	0.36	0.00	**22.25**

Notes: LULC shorthand names are as per Table 2.

Rates of urban expansion have increased exponentially in the Tarai region since 1989 (Figure 2a,b). During 1989–1996, urban area increased at an annual rate of 3.3%, or 51.23 km^2, of which 89.79% occurred over cultivated land. In the subsequent period, 1996–2001, the rate of urban expansion more than doubled to 8.1%, adding 110.3 km^2 new urban area, now with 95% of this derived from cultivated lands. The rate of urban expansion dropped slightly to 5.4% during 2001–2006, although the extent of new urban cover was comparable to the preceding period, and 95% of new urban area was again sourced from cultivated lands. In the next period of 2006–2011 the rate of expansion more than doubled again to 12.6%, with 91% of the 306 km^2 of new urban area sourced from cultivated lands. Urban expansion rates have again subsided for the current period of 2011–2016, to 3.5%, though the absolute area of new urban cover (137 km^2) and the degree to which it is sourced from cultivated lands (94.5%) remains comparable to earlier periods (Figure 4). The spatial distribution of this urban expansion from year to year describes a highly dispersed pattern of growth whereby smaller urban centers grew equally to larger regional centers (Figure 4a–e). District-level urban-growth and other LULC statistics are available in the online supplementary information document (S3).

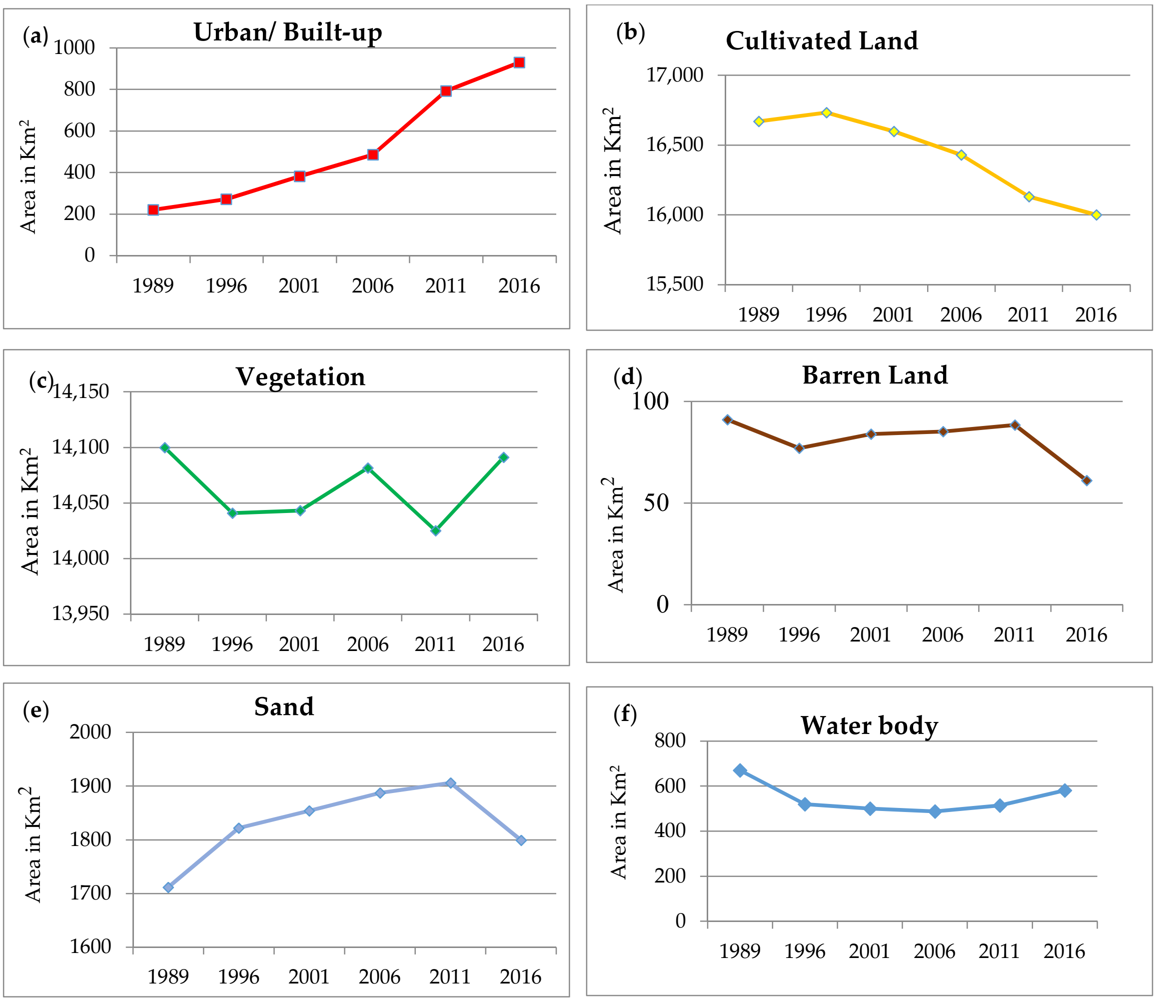

Figure 2. Land-cover change in the Tarai region 1989–2016, by land-cover class, (**a**) urban /built-up (**b**) cultivated land (**c**) vegetation (**d**) barren land, (**e**) sand (**f**) Water body.

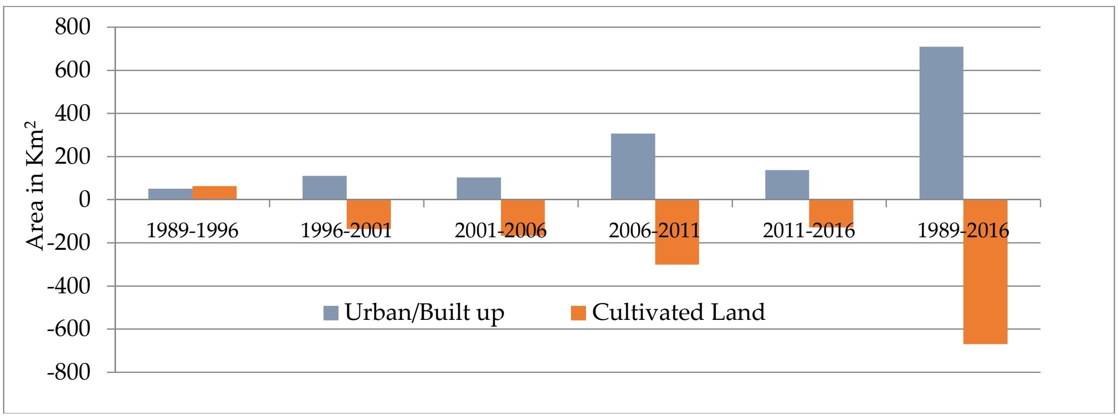

Figure 3. Gain and loss of urban area and cultivated land during 1989–2016, Tarai region, by period of observation.

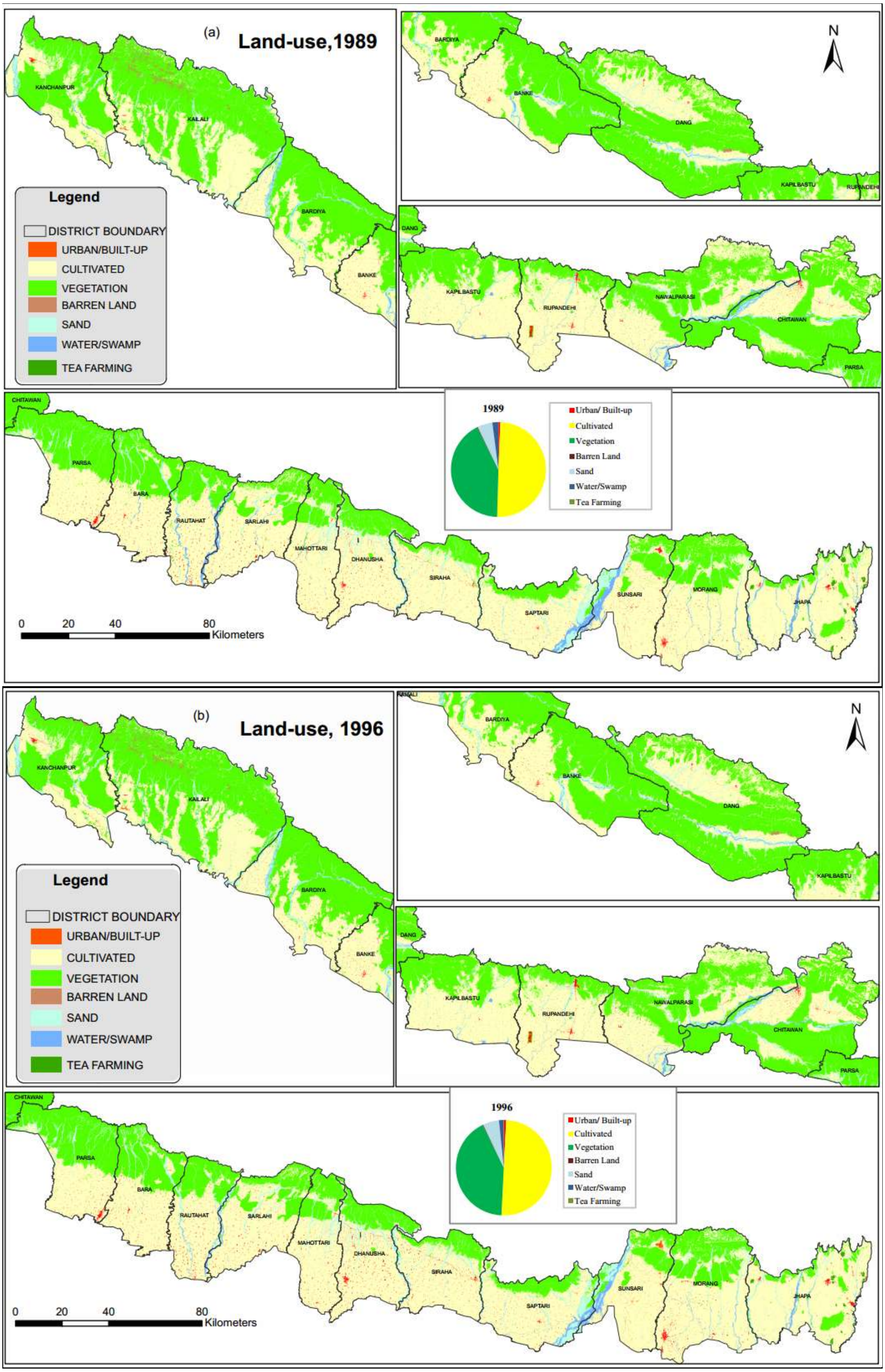

Figure 4. *Cont.*

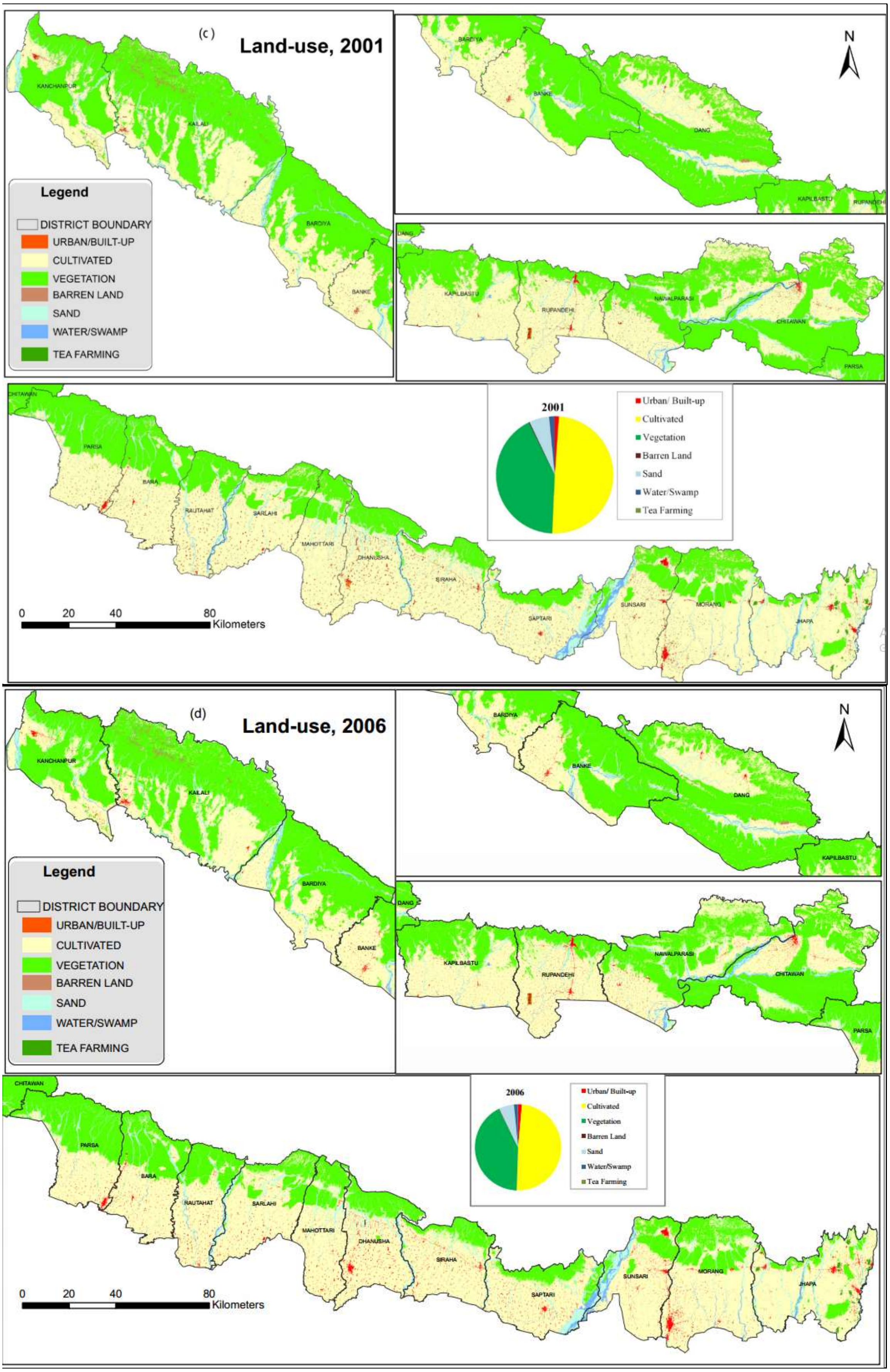

Figure 4. *Cont.*

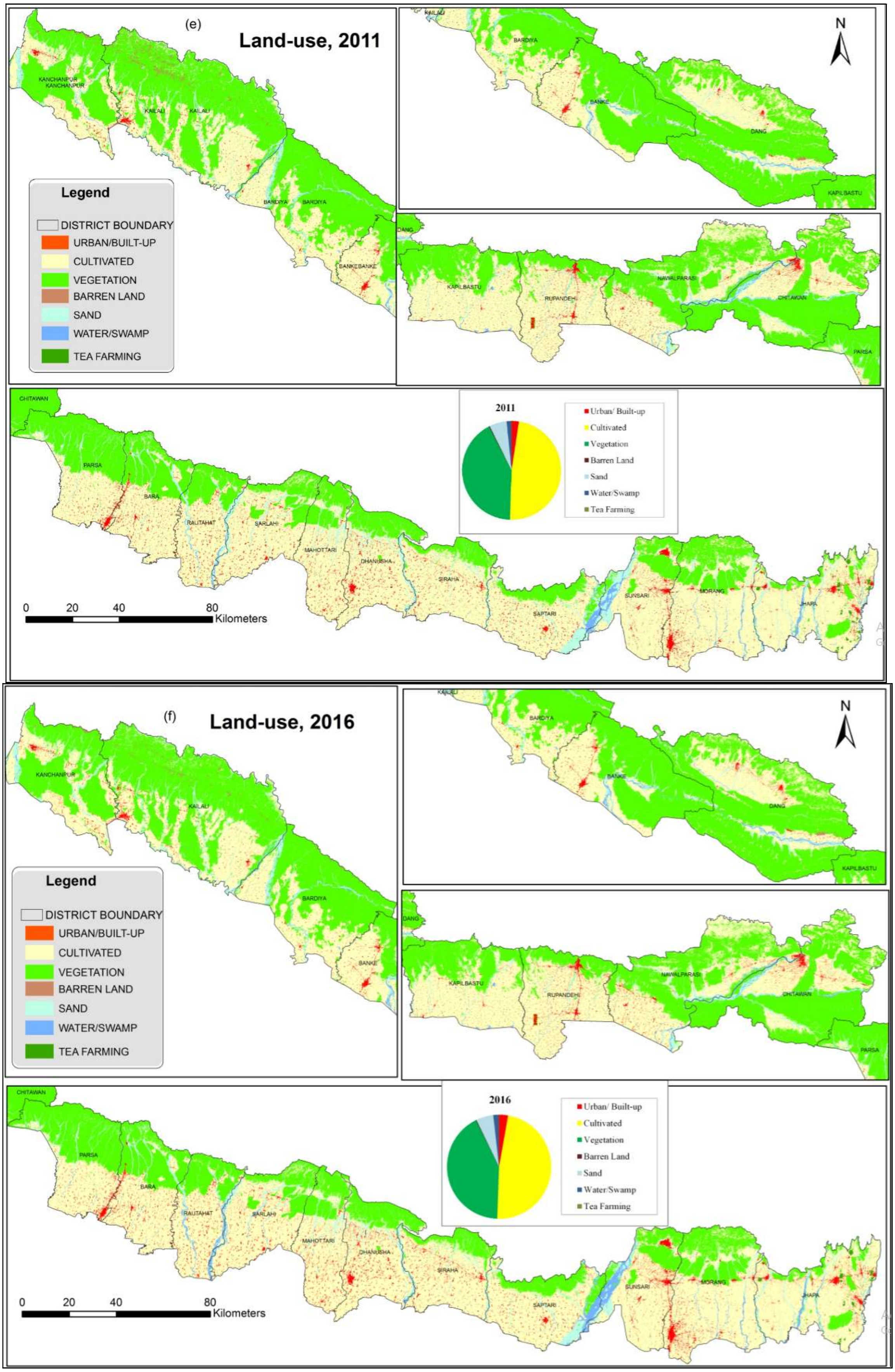

Figure 4. (**a**) LULC-1989; (**b**) LULC-1996; (**c**) LULC-2001; (**d**) LULC-2006; (**e**) LULC-2011; (**f**) LULC-2016.

3.2. Urban Growth and Loss of Cultivated Land

The 20 districts in Tarai experienced a consistent relationship between urban growth, agricultural loss, and population growth between 1989 and 2016, albeit with appreciable variability. This variability may reflect variations in spatio-temporal patterns of urban cover and expansion amongst the districts. Spatially, the districts variously assumed agglomerative, linear, and 'mottled' patterns of urban expansion (Figure 4), depending in part on their varying respective patterns of road development.

At the district level, the overall relationship between urban growth and agricultural loss over 1989–2016 was linear (Figure 5). This does not conflict with the moderately exponential rate of land-cover change observed at the regional scale (Figure 2), which reflects aerial trends, but it does affirm that agricultural land was the prime source of new urban cover generally. The relationship between urban and agricultural change at the district level is similarly linear across all individual periods of the time series, notwithstanding the fact that earlier periods, characterized by relatively low urban growth rates, are characterized by weaker, more variable relationships (Figure 5). The pattern of urban and agricultural change by district and period in Figure 5 affirms the aforementioned observations of steadily increasing regional rates of change while also highlighting the variable and temporally irregular nature of the urban–agricultural relationships at the local level, via the lack of overlap between data points for 2006–2011 and those of other periods. Inter-district variability in the urban–agricultural relationship probably also reflects differences between flood-prone districts (Bardiya, Nawalparasi, Sarlahi, Saptari, Sunsari and Jhapa (the outlier agriculture loss value for Jhapa district during 1996–2001 (at −71 km^2) was omitted from Figure 5 for the sake of graphical interpretability) and others, as cultivated areas in the former districts are frequently transformed into sandy river embankments due to seasonal flooding.

At the district level, the contribution of total population growth to urban growth and, by extension, to local agricultural loss, appears more uncertain. The relationship between population growth and urban growth was highly variable over 1989–2011 at the district scale (Figure 6), precluding reliable generalizations. This regional variability in the relationship between population growth and urban growth highlights the potential for urban-growth management to achieve more consistently reduced rates of urban expansion and agricultural loss despite continued population growth.

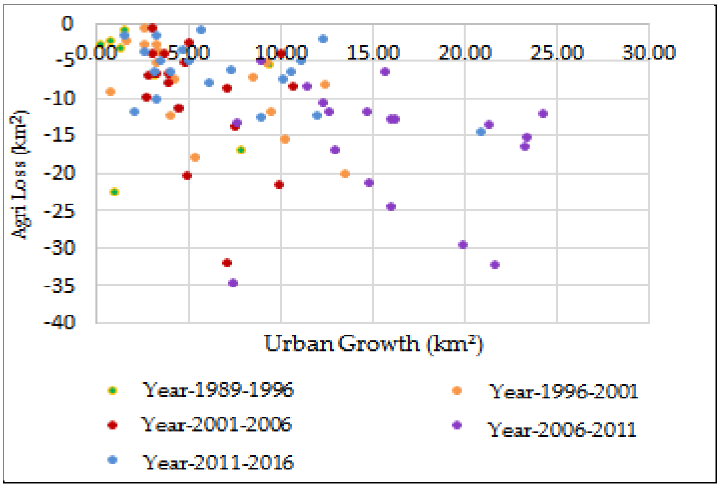

Figure 5. Urban gain and agricultural loss, by district and period, Tarai region, 1989–2016. Each data point represents a single district for a single period of observation.

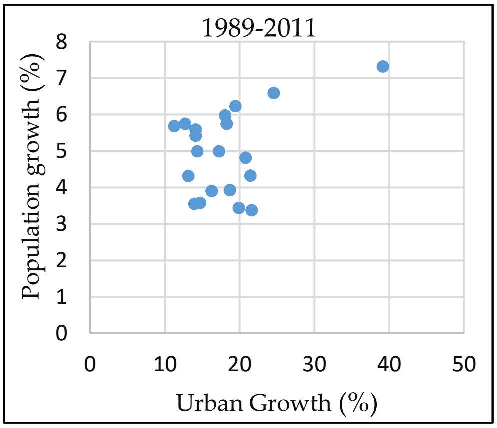

Figure 6. Urban growth and population growth, by district, Tarai region, 1989–2011. Each data point represents a single district for 1989–2011. Population was enumerated for 1991–2011.

Notwithstanding the aforementioned variability amongst the districts, urban growth rates at the district scale evidence an increasing trends over the time series, consistent with the regional-scale observations (Figure 2a). While no district in Tarai experienced annual rates of urban growth of >10% between 1989 and 1996, seven districts (Jhapa, Morang, Saptari, Kapilbastu, Nawalparasi, Rupandehi and Kanchanpur) exceeded this rate between 1996 and 2001, as did three others (Kapilbastu, Kailali and Dang) between 2001 and 2006 (Supplementary information S4). By the subsequent period 2006–2011, 16 out of 20 districts had annual urban growth rates of >10%, and a single district (Dang) maintained such a rate between 2011 and 2016.

4. Discussion and Conclusions

In a context of rapid population growth in the Nepalese Tarai region, we observed extensive increases in urban area, corresponding rapid decreases in cultivated lands, and fluctuating but generally constant areas of forest/shrub and tea plantations since 1989. Between 1989 and 2016, urban area increased from 221.13 km^2 (0.66% of the region) to 930.22 km^2 (2.78%) while cultivated land decreased from 16,670 km^2 to 16,000.86 km^2, with losses occurring on relatively fertile lands.

Urban grown patterns in Tarai have implications for long-term national food security. Tarai's districts are the principal agricultural producers of Nepal. For example, Kapilbastu, Rupandehi, Nawalparasi, Morang and Jhapa districts are the most productive nationally in terms of rice production. Similarly, Dang, Chitwan and Jhapa districts are specialized areas dedicated to maize, while Kapilbastu, Rupandehi, Bara, Parsa and Dhanusa are integral to national wheat production [30]. Our analysis observes a notable decline in cultivated areas in these districts due to urban expansion, spurred by inter-regional migration and associated localised population growth. Regionally, the pattern of urban grown is characterised more by spatial dispersion than concentration in major urban centers. The implications of this particular pattern are not yet clear. Conceivably, such a pattern may promote land speculation and agricultural land fragmentation more broadly than alternative, more concentrated growth patterns.

In the case of Tarai, inter-regional immigration is the largest single contributor to urban growth and, by extension, the loss of agricultural lands. The percentage of immigrants in Tarai originally from other regions ranged between 70–92% during 1971–2011, and Tarai region now contains 50.3% of the national population and rural to urban migration was 33.4% [26]. Mass migration to Tarai's urban areas was heavily encouraged by the decade-long civil conflict and political upheaval, which began in 1996 and peaked in 2001 [28]. This conflict was most acute in poorer, peripheral, upland regions due to their strategic utility for insurgents [66], encouraging urban migration [23]. As national conflict subsided in 2006, economic development quickly gained momentum [29] and ultimately facilitated a land-market boom and regional or district-level development activities. Post-conflict development has done little to ameliorate the regional imbalance of poverty and development that provoked and sustained the civil conflict [66]. Indeed, inter-regional disparities have likely intensified in the interim. Some 34% of non-farm employment opportunities nationally are concentrated in eastern Tarai (Jhapa, Morang, Sunsari, Saptari and Siraha districts) and central Tarai alone (Dhanusa, Mahottrai, Sarlahi, Rautahat, Bara, Parsa and Chitwan districts) [58]. Similarly, some 81% of all industries nationally are situated in 10 Tarai districts, with the bulk of these industries (827) situated in only five districts (Morang, Bara, Rupandehi, Chitwan and Parsa) [67]. Clearly, beyond localized urban-growth management and land-use zonation in Tarai, the prevention of agricultural loss due to urban growth in Tarai will require national development programmes focused on Nepal's poorer regions to entice would-be economic migrants to remain. Previous studies [29,34–36,59,68] have similarly reported the loss of highly fertile agricultural lands in the different part of Nepal due to urbanization and population pressure, suggesting that our regional observations capture a general trend that is likely to continue, and even intensify, in the absence of any intervention to the contrary.

The weak relationship between total population growth and urban expansion and, by extension, agricultural loss at the district level highlights a significant untapped potential for improved urban planning. To date, numerous policies and legislation seeking to regulate land use and urban development have proven ineffective due to a lack of long-term strategy [58]. Furthermore, the designation of municipalities (urban centers) for management as such is often politically motivated, while functional criteria relevant to urban-area designations are often disregarded. Total population size is overemphasized and well-established measures of urbanization, such as demographic density, settlement contiguity and occupational structure, are afforded less importance [28,58]. Thus, the number of urban centers (i.e., metropolitan, sub-metropolitan and municipalities) in Tarai has risen to 149 in 2017, from just 5 in 1952/54, with 57% of the total national urban population residing therein [69], yet in many respects they are characterized as more rural than urban [58]. The preservation of cultivated land in the course of urbanization will ultimately require significant improvements in local-level institutional capacity for land-use monitoring, zoning and enforcement [29].

This article presents the first, long-term, regional-scale evaluation of urban expansion and losses of cultivated land in Nepal. As such, it presents lessons and implications for urbanization at the national scale as well as for countries facing similar issues as Nepal. Its findings assert that current, poorly controlled urbanization and land-cover changes seriously undermine sustainable urban development in Nepal. The prime farm lands in the Tarai districts are threatened by land fragmentation and dispersed urban development, driven chiefly by inter-regional migration. To address these perils, the study appeals for integrated, long-term, national development and land-use strategies to balance Nepal's conflicting economic, demographic and environmental trends.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/5/1341/s1. Table S1: LULC classification accuracy. Figure S2: distribution of urban growth and loss of cultivated land; Table S3: district level LULC statistics. Table S4: district level urban growth rate.

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