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Article

Critical Assessment of Land Use Land Cover Dynamics Using Multi-Temporal Satellite Images

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Abstract: An attempt has been made to assess the dynamics of land use land cover change (LULCC) in the study area. LANDSAT-5 TM, IRS-1C LISS III, IRS-P6 LISS III images of 1987, 1997 and 2007, respectively, were digitally classified for land use land cover (LULC) mapping. The dynamics of LULCC critically analyzed for the two time periods 1987–1997 and 1997–2007. The LULCC analyzed in terms of quantity of change and allocation of change. Relative changes; gross gains, gross losses and persistence; net change and swap changes of LULC of the study area examined carefully. The study provided a better understanding of the LULCC pattern. The total change during (1987–1997) was 68.40% and during (1997–2007) was 80.12%. Major exchanges of areas are in between degraded forest and built up land followed by dense forest and degraded forest. Others dominant systematic transitions are: degraded forest to built up land; dense forest to degraded forest; agricultural land to built up; degraded forest to land with or without scrub; land with or without scrub to built up; and in between river and sandy area. The transformation from forest to built up land especially built-up area constitutes a large percentage of the total landscape. The direct beneficiaries of this research will include resource managers and regional planners as well as others scientific community.

Keywords: satellite images; LULC mapping; LULC dynamics; critical analysis of LULCC

1. Introduction

Remote sensing and Geographical Information System (GIS) have emerged as powerful tools to create spatial inventory on natural resources and the state of environment. Remote sensing and GIS, and process-based modeling play crucial roles in spatial and dynamic assessment of an area. Remote sensing methods have great advantages in observation of actual conditions, since such information can be obtained on remote (synoptic view), wide area, non-destructive, and/or real time bases. Furthermore, thanks to the sensor technologies, non-visible signals such as in near infrared, thermal-infrared and microwave wavelength domains can be observed. The GIS is a powerful tool for integration of data and information, for their spatial analysis, and for visual presentations. Some advantages of remote sensing in land use and land cover mapping are; (i) Remote sensing techniques provide reliable, accurate, baseline information for land use and land cover (LULC) mapping, generalized land use and land cover classification for large areas, their delineation and spatial distribution categories, are possible by satellite imagery, because of its synoptic coverage of large areas; (ii) Study on the structure and dynamics of land use is possible because of repetitive coverage of the same area; (iii) Monitoring the land use for optimal use on long term basis is possible by remote sensing techniques; multispectral multi-temporal imagery enhances land use information; (iv) Land use mapping both by visual interpretation and computer based digital image processing analysis is possible by remote sensing technique; (v) Land use maps can be prepared more speedily, accurately and economically by remote sensing techniques; and (vi) Land use maps thus prepared will form a basic input in planning and management decisions. Some significances of land use and land cover mapping are: (i) To form and implement land and policies regarding existing and future land use, (ii) Planning, management and monitoring of natural resources, and (iii) LULC is an input parameter in many fields as geology, hydrology, demography, environment *etc.* The study of land use land cover changes (LULCC) is very important to have proper planning and utilization of natural resources and their management [1]. The land use and land cover change plays an important role in global environmental change. Accurate and up-to-date land cover change information is necessary to understand both human causes and environmental consequences of such changes [2]. Land use land cover changes also affect climate change in the long term [3]. It contributes significantly to earth-atmosphere interactions and biodiversity loss, and is a major factor in sustainable development and human responses to global change. Inventory and monitoring of land use/land cover changes are indispensable aspects of further understanding of change mechanism and modeling the impact of change on environment and associated eco-systems at different scales [4–6]. There has been a growing trend in the development of change detection techniques using remote sensing data to assess the land use land cover changes. Various methods have been developed to compare multi-temporal signatures, and are reviewed by Singh, 1989 and Jensen, 1996 [7,8]. Post-classification comparison examines the changes over time between various thematic land cover categories (e.g., forest, grassland, agriculture) [7]. In this study, the dynamics of land use land cover change of the study area was critically analyzed for the two time

periods (1987–1997 and 1997–2007). Land use land cove maps prepared from satellite images of 1987, 1997 and 2007 and the dynamics of land use land cover change of the study area was critically analyzed using post classification comparison methods. The direct beneficiaries of this LULCC research will include two distinct groups: (i) resource managers at the local, regional and state levels of government, and (ii) regional as well as urban planners who want better urban planning in broader social and economic settings.

2. Study Area and Data Used

The study area comprises part of Brahmaputra River basin spreading over an area about 413.94 km², which is parts of Kamrup Metropolitan district in the state of Assam, India and located between 26°02'04" to 26°14'27" north latitudes and 91°33'01" to 91°51'41" east longitudes covering parts of Brahmaputra River basin and foothill zone of lower Meghalaya hills with elevation ranging from 49.5 m to 638 m above mean sea level but average altitude of the Guwahati city area is 54 m (above MSL) (Figure 1).

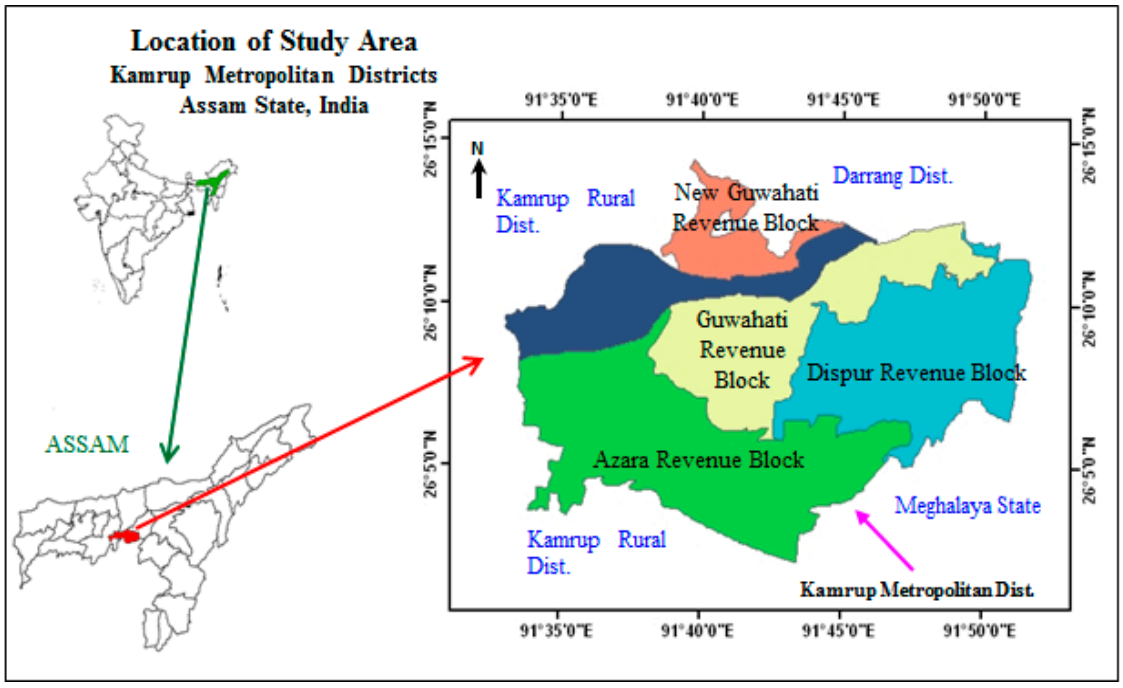

Figure 1. Location of study area [9].

Digital satellite data of Landsat-5 TM image acquired on 26 December 1987, IRS-1C LISS III image acquired on 5 March 1997, IRS-P6 LISS III image acquired on 14 December 2007 has been used for this study. Properties of the satellite data used in the study shows in Table 1 and Figure 2 shows satellite images for the study area. Other than satellite data, Survey of India (SOI) topographic sheet No. 72N/12 and 72N/16 at 1:50,000 scales along with master plan prepared by Guwahati Metropolitan Development Authority (GMDA) also have been used for this study. Data from Guwahati Metropolitan Development Authority (GMDA), Guwahati Municipal Corporation (GMC), Kamrup Metropolitan District - National Informatics Centre (NIC) have been also used (Table 2).

Table 1. Details of satellite data used in the study [9].

Satellite	Sensor	Path/Row	Data Acquired	Spatial Resolution (Meters)	Spectral Band	Data Sources
LANDSAT-5	TM	136/042 (WRS-2 footprints)	26-12-1987	30 (120 m–thermal (B 6))	B 1 (blue): 0.45–0.52 µm B 2 (green): 0.52–0.60 µm B 3 (red): 0.63–0.69 µm B 4 (NIR): 0.76–0.90 µm B 5 (SWIR): 1.55–1.75 µm B 6 (thermal IR):10.4–12.5 µm B 7 (Mid–Infrared): 2.08–2.35 µm	GLCF *- Earth Science Data Interface
IRS-1C	LISS-III	110/53	05-03-1997	23.5 (70 m–B5 (SWIR))	B 2 (green): 0.52–0.59 µm B 3 (red): 0.62–0.68 µm B 4 (NIR): 0.77–0.86 µm B 5 (SWIR): 1.55–1.70 µm	NRSC
IRS-P6 (Resourcesat-1)	LISS-III	110/53	14-12-2007	23.5	B 2 (green): 0.52–0.59 µm B 3 (red): 0.62–0.68 µm B 4 (NIR): 0.77–0.86 µm B 5 (SWIR): 1.55–1.70 µm	NRSC

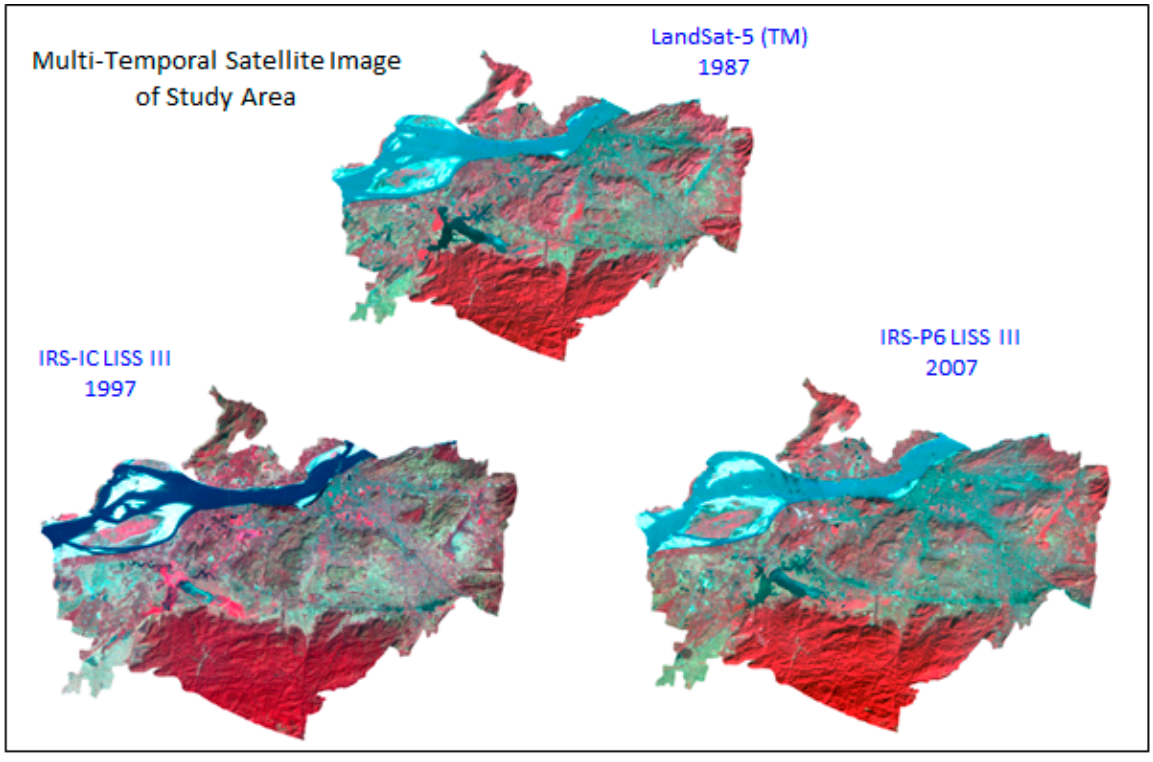

Figure 2. Satellite images of study area [9].

Table 2. Others data used in the study [9].

Data	Data Sources	Scale
Topographic Sheet No. 72N/12 and 72N/16	Survey of India (SOI)	1:50,000
Master Plan of Guwahati	Guwahati Metropolitan Development Authority (GMDA)	1:25,000
	Guwahati Metropolitan Development Authority (GMDA)	
Maps	Guwahati Municipal Corporation (GMC)	
	Kamrup Metropolitan District—National Informatics Centre (NIC)	-
IKONOS, QUICKBIRD Satellite Images	www.earth.google.com	

Note: The *Global Land Cover Facility* (*GLCF*) is a NASA-funded member of the Earth Science Information Partnership at the University of Maryland, providing free satellite images to users all over world.

3. Methodology

3.1. Preparation of Land Use Land Cover (LULC) Map

The methodology adopted to prepare the LULC maps from satellite images in this study involves following phases: pre-processing of satellite images, development of a classification scheme, formation of training dataset, spectral separability analysis, satellite images classification and accuracy assessment (Figure 3). The image dataset used in this study consists of Landsat-5 TM images of December 1987, IRS-1C images of March 1997 and IRS-P6 images of December 2007. Only images acquired in December and March months (winter season) were considered. The available images were selected based on the absence of cloud cover. When multi-date images from different sources are used, different atmospheric and terrain conditions may cause variations in data. Therefore, radiometric corrections including atmospheric correction were applied in this study. After radiometric correction, geometric correction was applied to the images. For accurate change detection, an accurate geometric registration is needed. The IRS-1C images of 1997 and IRS-P6 images of 2007 were rectified (geometrically corrected) with reference to the orthorectified Landsat satellite image of 1987 with two-order polynomial transformation and more than 14 ground control points (GCPs—mainly road junctions) to further improve the georeferencing accuracy. All images were resampled using Nearest Neighbor resampling method with a root mean square error of less than ±0.5 pixels per image to a 23.5 m resolution with the UTM coordinate system (zone 46, WGS 84 datum system). To classify satellite images, first of all a suitable classification scheme for the study area is needed. Therefore, for this study modified (modified from NRSA classification system for India and classification scheme adopted for European Commission sponsored Brahmatwin projects) classification scheme (level II) is adopted for different categories of LULC (Table 3). As supervised classification technique has been used for this study, it requires a priori knowledge of the number of classes, as well as knowledge concerning statistical aspects of the classes. Areas of visually homogeneous spectral response were chosen (10–12 training set for per class) well distributed all over images as AOI (area of interest) and added to the spectral signature editor. Limited pre-classification ground truth (using GPS) helped to select the training samples. The pre-classification ground truth was conducted on 14 December 2007, the same date when satellite collected the images for the study area. In the classification, the signature separability functions were used to examine the quality of training sites and class signature, before performing the classification. The separability cell array presents the results of one of the classifications

for Landsat data of 1987, with range of values (from 1931.08 to 2000, where the average divergence is 1965.54) in the band combinations of band 2 (green: 0.52–0.60 µm), band 3 (red: 0.63–0.69 µm), band 4 (NIR: 0.76–0.90 µm) combination. IRS-1C LISS III of 1997 show the range of divergence values from 1903.02 to 2000 in the band 2 (green: 0.52–0.59 µm), band 3 (red: 0.62–0.68 µm), band 4 (NIR: 0.77–0.86 µm) combination. IRS-P6 LISS III of 2007 shows the range of divergence values from 1922.02 to 2000 in the band 2 (green: 0.52–0.59 µm), band 3 (red: 0.62–0.68 µm), band 4 (NIR: 0.77–0.86 µm) combination. Therefore, combination of band 2 (green), band 3 (red) and band 4 (near infra-red) was the most useful for classification purposes for the time series data (*i.e.*, 1987, 1997, and 2007). For this study, supervised maximum likelihood classifier is used to classify of all satellite images. The land use and land cover types derived from digital image classification validate with data obtained from limited post-classification ground verification and using high-resolution Google earth images.

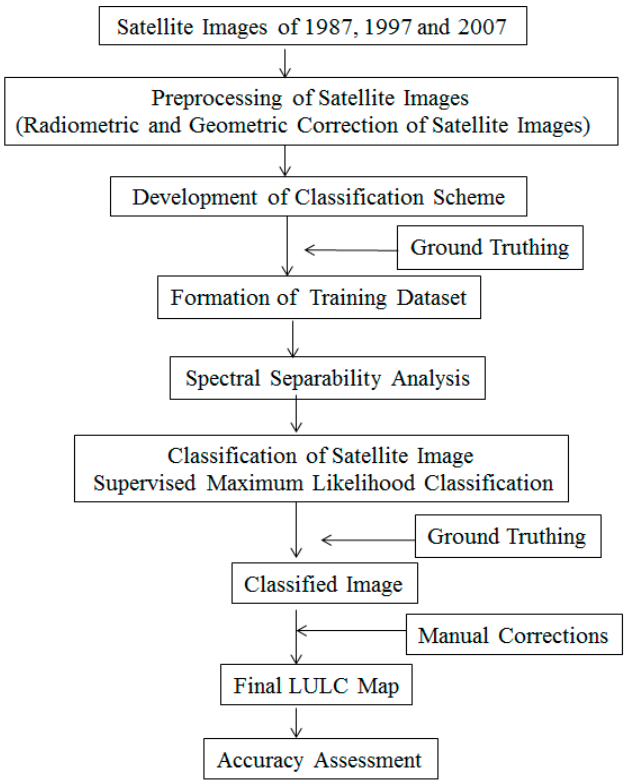

Figure 3. Flowchart shows methodology adopted for LULC mapping [9].

3.2. Quantity of Land Use Land Cover Change (LULUC)

The quantity of LULCC for each category was analyzed in terms of relative changes, gross gains, gross losses and persistence. The LULC maps were overlaid to produce a matrix that provides the LULC areas by categorical transition between 1987 and 1997 and between 1997 and 2007. The off-diagonal entries comprise proportions of the landscape that experienced transition from one category to a different category, while the diagonal entries indicate persistence of categories. The row totals at the right denote the proportion of the landscape by LULC category in 1987 and the column totals at the bottom denote the proportion of landscape by category in time 1997. On other hand, row

totals at the right denote the proportion of the landscape by LULC category in 1997 and the column totals at the bottom denotes the proportion of landscape by category in 2007.

Table 3. Levels and LULC classes considered for classification.

Level I	**Level II**
1. Built up Land	1.1. Built up Land
2. Agricultural Land	2.1. Agricultural Crop Land
	2.2. Agricultural Fallow Land
	2.3. Plantations
3.Forest	3.1. Dense Forest
	3.2. Degraded Forest
4.Waste Land	4.1. Land with or without Scrub
	4.2. Marshy/Swampy
	4.3. Waterlogged Area
	4.4. Sandy Area (River Bed)
5. Water Bodies	5.1. River/Stream
	5.2. Lake/Reservoir/Pond/Tank
6. Others	6.1. Open Land
	6.2. Aquatic Vegetation

3.2.1. Relative Changes of LULC

The relative changes (areas of before LULC—areas of later LULC) derive of different land use and land cover category in each period (1987–1997 and 1997–2007).

3.2.2. Gross Gains, Gross Losses and Persistence of LULC

The cross tabulation matrix of between 1987–1997 and 1997–2007 is extended to derive the gross gains and gross losses by categories. The gross gain for each category is derived by subtracting the persistence from the column total, while the gross loss is computed by subtracting the persistence from the row total [10].

3.2.3. Net Change and Swap Change of LULC

LULCC in terms of the net change and swap change are derived from the extended cross tabulation matrix. The total change for a category is the sum of its gross gain and gross loss. The net change for a category is the difference between the gross gain and gross loss, *i.e.*, difference between the row total and the column total for a given category in the matrix. The swap change for a category is the total change minus the net change for the category [10].

3.3. Allocation of Land Use Land Cover Change (LULUC)

When LULC maps of two years are overlaid, the spatial distribution of change can be visualized. The gain, loss and persistence for each category are derived to assess where the changes have taken place. The change maps with the gains; losses and persistence were laid over the map of the region in order to compute the gains, losses and persistence within the study area.

4. Results and Discussions

4.1. Results of Land Use Land Cover Classification

The quantitative results and spatial distribution of land use and land cover assessment based on digital classification of satellite images for three different years 1987, 1997 and 2007 are shows in Table 4 and Figure 4. Each LULC map (1987, 1997 and 2007) contains 14 LULC classes, *i.e.*, built up land, agricultural crop land, agricultural fallow land, plantation, dense forest land, degraded forest land, land with or without scrub, marshy/swampy land, waterlogged area, sandy area, river, lakes/reservoirs/ponds, open land, aquatic vegetation area. The land use and land cover types derived from digital image classification was validated. The overall accuracy of the LULC maps of 1987, 1997 and 2007 are 84.77%, 85.55% and 87.50%, respectively, at a confidence level of 95%. Overall Kappa statistics for 1987, 1997 and 2007 are 0.8011, 0.8111 and 0.8363, respectively.

Table 4. Area statistics of LULC.

Sl. No.	Class Name	1987		1997		2007	
		Area (Km²)	% of Area	Area (Km²)	% of Area	Area (Km²)	% of Area
1.	Built up Land	60.54	14.63	102.4	24.73	141.35	34.14
2.	Agricultural Crop Land	25.91	6.26	5.99	1.45	7.17	1.73
3.	Agricultural Fallow Land	48.27	11.66	34.08	8.23	25.12	6.07
4.	Plantations	1.38	0.33	3.68	0.89	3.35	0.81
5.	Dense Forest	86.26	20.84	80.56	19.46	74.84	18.08
6.	Degraded Forest	83.48	20.17	76.95	18.59	60.31	14.57
7.	Land with or without Scrub	9.48	2.29	24.82	6	23.78	5.74
8.	Marshy/Swampy	13.42	3.24	10.26	2.48	6.82	1.65
9.	Water Logged Area	3.57	0.86	1.86	0.45	1.52	0.37
10.	Sandy Area (River Bed)	14.83	3.58	16.08	3.88	15.92	3.85
11.	River/Stream	37.27	9	32.51	7.85	33.42	8.07
12.	Lake/Reservoir/Pond/Tank	7.99	1.93	6.05	1.46	6.59	1.59
13.	Open Land	13.8	3.33	7.28	1.76	6.97	1.68
14.	Aquatic Vegetation	7.78	1.88	11.46	2.77	6.82	1.65
Total		413.98	100.00	413.98	100.00	413.98	100.00

4.1.1. Quantity of Land Use Land Cover (LULC)

The quantitative results of land use and land cover assessment based on digital classification of satellite images for three different years 1987, 1997 and 2007 are shows in Table 4. Each LULC map (1987, 1997 and 2007) contains 14 LULC classes, *i.e.*, built up land, agricultural crop land, agricultural fallow land, plantation, dense forest land, degraded forest land, land with or without scrub, marshy/swampy land, waterlogged area, sandy area, river, lakes/reservoirs/ponds, open land, aquatic vegetation area. The total study area is about 413.98 km^2 and LULC map of 1987 shows that nearly 86.26 km^2 (20.84%) of the study area is covered by dense forest followed by degraded forest 83.48 km^2 (20.17%), built up land 60.59 km^2 (14.63%), agricultural fallow land 48.27 km^2 (11.66%), river/stream 37.27 km^2 (9.00%), agricultural crop land 25.91 km^2 (6.26%). In 1987, forestland (dense forest and degraded forest) was 169.74 km^2 (41.01%), dominant in the study area followed by

agricultural land (if we combined agricultural cropland and agricultural fallow land) at 74.18 km² (17.92%) and then built up area at 60.51 km² (14.62%).

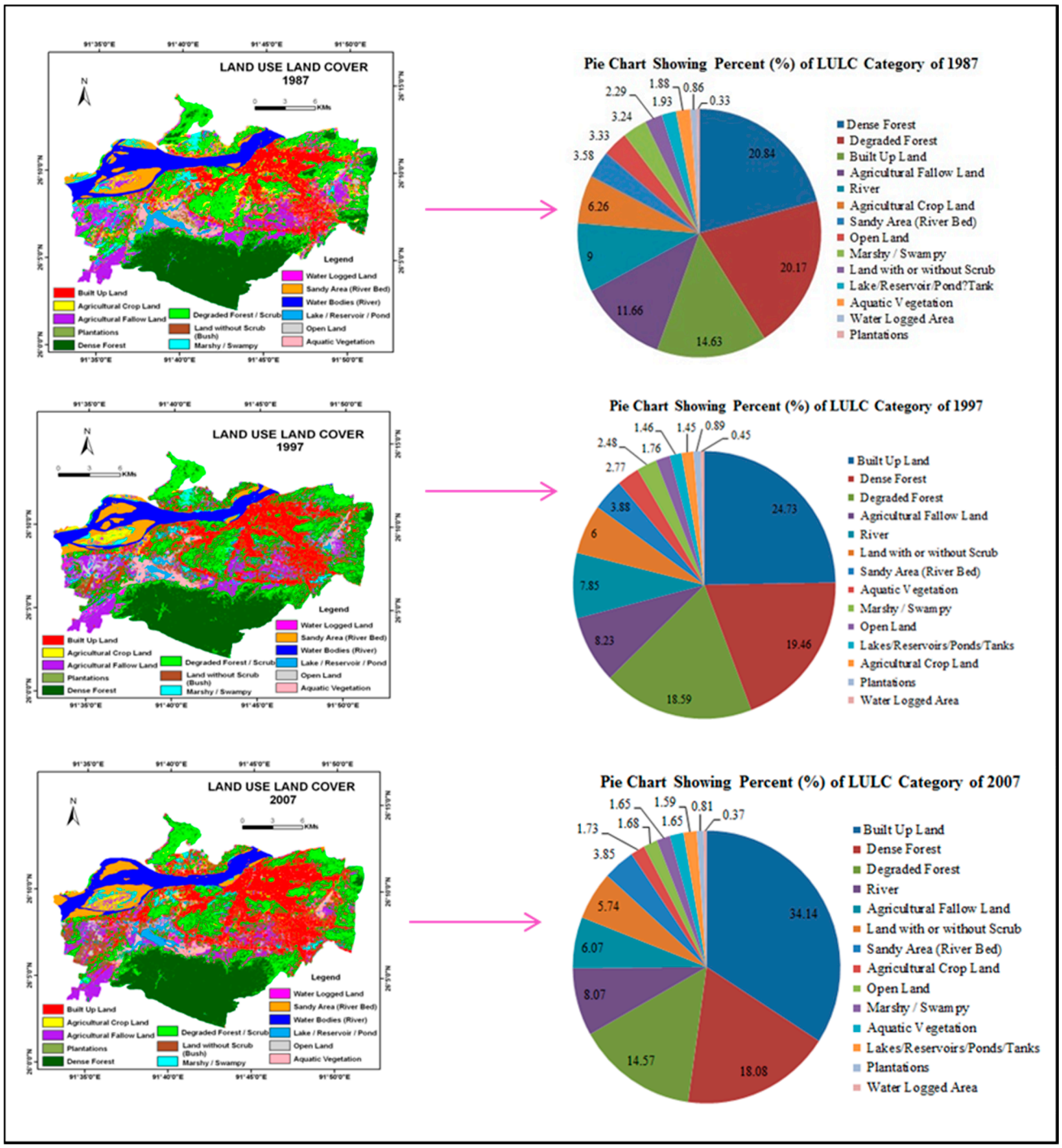

Figure 4. Allocation of LULC and percent (%) of LULC of 1987, 1997 and 2007 [9].

LULC map of 1997 shows that nearly 102.4 km² (24.73%) of the study area is covered by built up land followed by dense forest 80.56 km² (19.46%), degraded forest 76.95 km² (18.59%), agricultural fallow land 34.08 km² (8.23%), river/stream 32.51 km² (7.85%), land with or without scrub 24.82 km² (6%). If we look carefully at built up area, it is the highest area occupied class in 1997 dense forest 80.56 km² (19.46%) followed by degraded forest 76.95 km² (18.59%). But if we look carefully combined dense forest and degraded forest as forest land, it is 157.51 km² (38.05%) and is the

dominant LULC in the study area in 1997 followed by built up area 80.56 km^2 (19.46%) and agricultural land (agricultural cropland and agricultural fallow land) 40.07 km^2 (9.68%).

The classified LULC map of 2007 shows 141.35 km^2 (34.14%) of the study area is occupied by built up land followed by dense forest 74.84 km^2 (18.08%), degraded forest 60.31 km^2 (14.57%), river/stream 33.42 km^2 (8.07%), agricultural fallow land 25.12 km^2 (6.07%), land with or without scrub 23.78 km^2 (5.74%). LULC map of 1997 also shows built up land as dominant an individual LULC class among the all LULC classes followed by dense forest 74.84 km^2 (18.08%), degraded forest 60.31 km^2 (14.57%).

4.1.2. Allocation of Land Use Land Cover (LULC)

The spatial distribution (allocation) of land use and land cover based on digital classification of satellite images for three different years between 1987, 1997 and 2007 are shows in Figure 4. The built up land mainly lies on the south bank of Brahmaputra River, within the twin township of Guwahati and Dispur—the capital of Assam state, India. Forests occupy about 20.84%, 19.46% and 18.08% of study area in 1987, 1997, and 2007, respectively, and are mainly concentrated in the hills and Piedmont zone. The majority of mapped forest area lies within the reserve forest boundaries. Degraded forest mainly mapped in the adjacent area of forest and near the built up area. LULC map shows land used for agricultural purposes mainly found in outskirt of built up land. The fallow land also mainly confined in the near agricultural cropland. The plantation mainly within the city constitutes. Land with or without Scrub mainly confined in near degraded forest. The Brahmaputra River flowing through middle of the study area, occupied nearly 9%, 7.85%, 8.07% of study area, respectively, in three years. Sandy areas are found mainly within the river channel. The main lake (Deepor Beel) situated in middle of study area just outside of city or built up area. Marshy/swampy land mainly demarcated in lake area and also in the southeast and southwest parts of study area. Aquatic vegetation concentrated mainly within near the lake area.

4.2. Changes in Quantity of LULC

The quantity of LULCC for each category was found in terms of the following relative changes, gross gains, gross losses and persistence.

4.2.1. Relative Changes in Quantity of LULC

The area statistics of LULC and relative changes of two time periods, *i.e.*, between 1987 and 1997 and 1997 and 2007 are shown in Tables 5 and 6, respectively. Correlation between relative changes of two time periods are positive, where $R^2 = 0.638$ (Figure 5). It established that relative changes of two time periods are relatively strong correlated; the trends of relative changes between the time periods between 1987 and 1997 and 1997 and 2007 are slightly different from one time period to another time period.

Table 5. Area statistics and relative changes of each land use and land cover changes category between 1987 and 1997.

Sl.	Class Name	1987		1997		Relative Change between 1987 and 1997	
		Area (Km²)	% of Area	Area (Km²)	% of Area	Area in Km²	Area in %
1.	Built up Land	60.54	14.63	102.4	24.73	41.86	10.12
2.	Agricultural Crop Land	25.91	6.26	5.99	1.45	−19.92	−4.82
3.	Agricultural Fallow Land	48.27	11.66	34.08	8.23	−14.19	−3.42
4.	Plantations	1.38	0.33	3.68	0.89	2.3	0.55
5.	Dense Forest	86.26	20.84	80.56	19.46	−5.7	−1.33
6.	Degraded Forest	83.48	20.17	76.95	18.59	−6.53	−1.58
7.	Land with or without Scrub	9.48	2.29	24.82	6	15.34	3.7
8.	Marshy/Swampy	13.42	3.24	10.26	2.48	−3.16	−0.76
9.	Water Logged Area	3.57	0.86	1.86	0.45	−1.71	−0.41
10.	Sandy Area (River Bed)	14.83	3.58	16.08	3.88	1.25	0.28
11.	River/Stream	37.27	9	32.51	7.85	−4.76	−1.17
12.	Lake/Reservoir/Pond/Tank	7.99	1.93	6.05	1.46	−1.94	−0.47
13.	Open Land	13.8	3.33	7.28	1.76	−6.52	−1.58
14.	Aquatic Vegetation	7.78	1.88	11.46	2.77	3.68	0.89
Total		413.98	100.00	413.98	100.00	0.0	0.0

Table 6. Area statistics and relative changes of each land use and land cover changes category between 1997 and 2007.

Sl.	Class Name	1997		2007		Relative Change between 1997 and 2007	
		Area (Km²)	% of Area	Area (Km²)	% of Area	Area in Km²	Area in %
1.	Built up Land	102.4	24.73	141.35	34.14	38.95	9.41
2.	Agricultural Crop Land	5.99	1.45	7.17	1.73	1.18	0.28
3.	Agricultural Fallow Land	34.08	8.23	25.12	6.07	−8.96	−2.16
4.	Plantations	3.68	0.89	3.35	0.81	−0.33	−0.08
5.	Dense Forest	80.56	19.46	74.84	18.08	−5.72	−1.38
6.	Degraded Forest	76.95	18.59	60.31	14.57	−16.64	−3.98
7.	Land with or without Scrub	24.82	6	23.78	5.74	−1.04	−0.27
8.	Marshy/Swampy	10.26	2.48	6.82	1.65	−3.44	−0.82
9.	Water Logged Area	1.86	0.45	1.52	0.37	−0.34	−0.08
10.	Sandy Area (River Bed)	16.08	3.88	15.92	3.85	−0.16	−0.04
11.	River/Stream	32.51	7.85	33.42	8.07	0.91	0.21
12.	Lake/Reservoir/Pond/Tank	6.05	1.46	6.59	1.59	0.54	0.11
13.	Open Land	7.28	1.76	6.97	1.68	−0.31	−0.09
14.	Aquatic Vegetation	11.46	2.77	6.82	1.65	−4.64	−1.11
Total		413.98	100	413.98	100	0.0	0.0

4.2.2. Gross Gain, Gross Loss, and Persistence in Quantity of LULC

The area statistics of each LULC category and relative changes of different LULC category in each period (1987–1997 and 1997–2007) is shown in Tables 5 and 6. These tables give useful information about the quantity of each category, but they do not offer any details concerning individual transitions between different 14 categories Therefore, overlaying the 1987 map with the 1997 map and then the 1997 map with the 2007 map produced two matrices which are, respectively, presented in Tables 7 and 8. Each matrix has a total column at the right that gives the stock of each category at the initial time, and a total row at the bottom that gives the stock of each category at the subsequent time. Furthermore, the matrix for each time interval shows the flow of each category by presenting a column of gross losses

and a row of gross gains. These extended cross tabulation matrix is to show the gross gains and gross losses by category for the periods between 1987–1997 and 1997–2007.

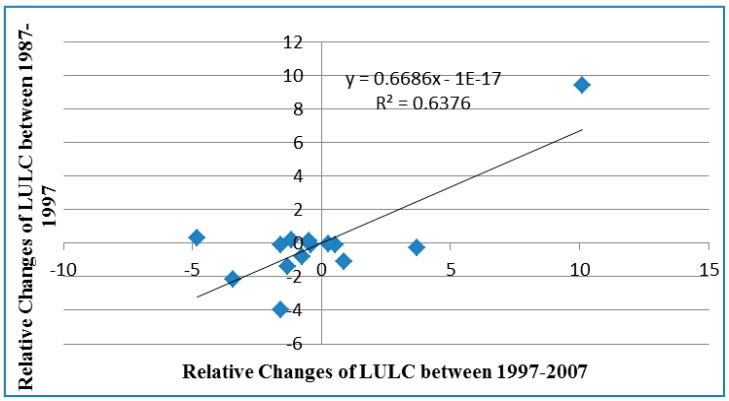

Figure 5. Correlation between relative changes of LULC in 1987–1997 and relative changes of LULC in 1997–2007.

The transition matrices of 1987–1997 and 1997–2007 LULC maps are shown in Tables 7 and 8, wherein Table 7 the rows display the results of the LULC categories of 1987 and the columns display those of the categories of 1997. In Table 8, the rows display the results of the LULC categories of 1997 and the columns display those of the categories of 2007. The traditional transition matrix would have had only the total change without the last column (gross loss) and the last row (gross gain), while this extended transitional matrix has the last column indicating gross loss by category and the last row indicates gross gain by category in the landscape during the 1987 and 2007.

Statistics of landscape persistence and components (gains and losses) of change in terms of percent of study area in the time periods 1987–1997 and 1997–2007 is shown in Tables 9 and 10, respectively. Between 1987 and 1997, the gain is highest for built up land 10.42% followed by degraded forest 8.04%. Between 1987 and 1997, loss is highest for degraded forest 9.62% followed by agricultural fallow land 6.44%, agricultural crop land 5.80%. The gain is highest in between 1997 and 2007 for built up land as 10.12% followed by degraded forest 5.5%. The loss is highest in between 1997 and 2007 for degraded forest as 9.48%. If we look ranking gain loss matrix of 1987–1997 and 1997–2007, degraded forest experiences the largest loss in both time intervals and built up experiences the largest gain in both time intervals. Others important gain experiences by degraded forest, land with or without scrub, agricultural fallow land, sandy area (river bed), marshy/swampy in both time periods. Others important losses experiences by agricultural fallow land followed by agricultural crop land, dense forest, open land, marshy/swampy in 1987–1997 time intervals and land with or without scrub followed by agricultural fallow land, dense forest, marshy/swampy in 1997–2007 time intervals. So, other than degraded forest agricultural land (fallow and crop), dense forest, land with or without scrub, open land and marshy-swampy are the important category, which experienced important losses in both time intervals (1987–1997 and 1997–2007). The persistence of the landscape is 59.94% between 19871997 time period and 65.8% between 1997–2007 time periods. In other words, about 40.06% of the study area exhibited transition from one category to a different category during 1987–1997 and about 34.20% of the study area exhibited transition from one category to a different category during 1997–2007.

Table 7. Losses and gains, respectively. Light sky shows persistence 1 of categories 2, while pink and ash colors show major changes (in between 1987–1997).

LULC in 1997	LULC in 1987														Total 1997	Gross Gain
	Built up Land	Agricultural Crop Land	Agricultural Fallow Land	Plantations	Dense Forest	Degraded Forest/ Scrub	Land with or without Scrub	Marshy/ Swampy	Water Logged Area	Sandy Area (Riverbed)	River/ Stream	Lake/ Reservoir/ Pond/ Tank	Open Land	Aquatic Vegetation		
Built up Land	14.33	1.75	2.30	0.03	0.05	3.65	0.66	0.48	0.11	0.12	0.08	0.08	0.98	0.12	24.75	10.42
Agricultural Crop Land	0.00	0.46	0.40	0.00	0.00	0.07	0.00	0.15	0.00	0.33	0.01	0.00	0.01	0.00	1.44	0.98
Agricultural Fallow Land	0.00	0.71	5.21	0.00	0.01	0.69	0.19	0.36	0.14	0.14	0.00	0.03	0.60	0.15	8.23	3.02
Plantations	0.11	0.09	0.04	0.16	0.01	0.34	0.03	0.04	0.01	0.01	0.00	0.00	0.02	0.01	0.89	0.73
Dense Forest	0.00	0.06	0.05	0.03	17.71	1.52	0.03	0.03	0.00	0.00	0.00	0.01	0.02	0.01	19.48	1.77
Degraded Forest	0.06	1.65	1.29	0.06	2.82	10.54	0.56	0.48	0.08	0.05	0.04	0.11	0.66	0.16	18.58	8.04
Land with or without Scrub	0.00	0.98	0.94	0.01	0.19	2.31	0.61	0.11	0.03	0.02	0.00	0.06	0.48	0.25	5.99	5.38
Marshy/Swampy	0.03	0.21	0.40	0.00	0.01	0.45	0.05	0.52	0.02	0.44	0.12	0.02	0.12	0.08	2.48	1.96
Water Logged Area	0.00	0.01	0.10	0.00	0.00	0.08	0.00	0.12	0.10	0.00	0.00	0.01	0.01	0.02	0.45	0.35
Sandy Area (River Bed)	0.00	0.04	0.02	0.00	0.00	0.01	0.00	0.10	0.02	1.73	1.94	0.00	0.01	0.00	3.87	2.14
River/Stream	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.29	0.01	0.71	6.80	0.00	0.00	0.00	7.85	1.05
Lake/Reservoir/ Pond/Tank	0.02	0.03	0.07	0.02	0.00	0.10	0.01	0.21	0.09	0.01	0.00	0.64	0.03	0.22	1.46	0.82
Open Land	0.05	0.12	0.70	0.00	0.01	0.16	0.05	0.16	0.12	0.02	0.01	0.03	0.29	0.03	1.76	1.47
Aquatic Vegetation	0.02	0.11	0.12	0.01	0.00	0.24	0.09	0.18	0.11	0.00	0.00	0.94	0.10	0.84	2.77	1.93
1997 Total	14.63	6.26	11.65	0.34	20.81	20.16	2.29	3.24	0.86	3.59	9.02	1.93	3.34	1.88	100.00	40.06
Gross Loss	0.30	5.80	6.44	0.18	3.10	9.62	1.68	2.72	0.76	1.86	2.22	1.29	3.05	1.04	40.06	

Table 8. Losses and gains, respectively. Light sky shows persistence 1 of categories 2, while pink and ash colours shows major changes (in between 1997-2007).

	LULC in 1997															
LULC in 2007	**Built Up Land**	**Agricultural Crop Land**	**Agricultural Fallow Land**	**Plantations**	**Dense Forest**	**Degraded Forest**	**Land with or without Scrub**	**Marshy/ Swampy**	**Water Logged Area**	**Sandy Area (Riverbed)**	**River/ Stream**	**Lake/ Reservoir/ Pond/ Tank**	**Open Land**	**Aquatic Vegetation**	**Total 1997**	**Gross Gain**
Built Up Land	24.05	0.14	1.97	0.39	0.24	4.30	1.41	0.50	0.06	0.08	0.05	0.15	0.53	0.30	34.17	10.12
Agricultural Crop Land	0.01	0.53	0.17	0.03	0.05	0.40	0.17	0.14	0.01	0.10	0.00	0.02	0.01	0.09	1.73	1.20
Agricultural Fallow Land	0.03	0.34	3.49	0.02	0.02	0.57	0.52	0.36	0.03	0.08	0.00	0.05	0.42	0.13	6.07	2.58
Plantations	0.02	0.02	0.05	0.21	0.11	0.22	0.11	0.01	0.01	0.00	0.00	0.02	0.00	0.03	0.81	0.60
Dense Forest	0.00	0.00	0.00	0.00	16.99	1.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	18.07	1.08
Degraded Forest	0.14	0.04	0.67	0.13	1.80	9.08	2.02	0.27	0.09	0.01	0.00	0.05	0.10	0.17	14.58	5.50
Land with or without Scrub	0.07	0.05	1.07	0.07	0.16	1.93	1.25	0.26	0.13	0.02	0.00	0.16	0.27	0.29	5.73	4.48
Marshy/Swampy	0.04	0.06	0.09	0.02	0.04	0.39	0.07	0.33	0.05	0.28	0.13	0.07	0.04	0.05	1.66	1.33
Water Logged Area	0.00	0.00	0.04	0.00	0.01	0.09	0.05	0.01	0.02	0.03	0.03	0.02	0.03	0.03	0.37	0.35
Sandy Area (River Bed)	0.01	0.11	0.06	0.00	0.00	0.02	0.01	0.28	0.00	1.88	1.45	0.01	0.01	0.00	3.84	1.96
River/Stream	0.04	0.13	0.06	0.00	0.00	0.05	0.01	0.19	0.00	1.41	6.18	0.00	0.00	0.00	8.07	1.89
Lake/Reservoir/ Pond/Tank	0.02	0.00	0.04	0.00	0.01	0.08	0.03	0.02	0.01	0.00	0.00	0.63	0.03	0.70	1.57	0.94
Open Land	0.31	0.02	0.45	0.01	0.02	0.25	0.15	0.08	0.01	0.00	0.00	0.03	0.26	0.08	1.67	1.41
Aquatic Vegetation	0.01	0	0.08	0.01	0.01	0.15	0.16	0.03	0.04	0	0.00	0.24	0.03	0.90	1.66	0.76
1997 Total	24.76	1.45	8.23	0.89	19.45	18.56	6.00	2.48	0.45	3.88	7.86	1.46	1.76	2.77	100	34.20
Gross Loss	0.71	0.92	4.74	0.68	2.46	9.48	4.75	2.15	0.43	2.00	1.68	.83	1.50	1.87	34.20	

Table 9. Statistics of landscape persistence and components (gains and losses) of change in terms of percent of study area in the time periods 1987–1997.

Land Use/ Land Cover Class	Persistence	Gain	Loss	Total Change (Gain + Loss)	Value of Net Change (Gain − Loss)	Absolute Value of Net Change (Gain − Loss)	Swap (Total Change—Absolute Value of Net Change)
Built up Land	14.33	10.42	0.30	10.72	10.12	10.12	0.60
Agricultural Crop Land	0.46	0.98	5.80	6.78	−4.82	4.82	1.96
Agricultural Fallow Land	5.21	3.02	6.44	9.46	−3.42	3.42	6.04
Plantations	0.16	0.73	0.18	0.91	0.55	0.55	0.36
Dense Forest	17.71	1.77	3.10	4.87	−1.33	1.33	3.54
Degraded Forest	10.54	8.04	9.62	17.66	−1.58	1.58	16.08
Land with or without Scrub	0.61	5.38	1.68	7.06	3.7	3.7	3.36
Marshy/Swampy	0.52	1.96	2.72	4.68	−0.76	0.76	3.92
Water Logged Area	0.1	0.35	0.76	1.11	−0.41	0.41	0.70
Sandy Area (River Bed)	1.73	2.14	1.86	4.00	0.28	0.28	3.72
River/Stream	6.8	1.05	2.22	3.27	−1.17	1.17	2.10
Lake/Reservoir/Pond/Tank	0.64	0.82	1.29	2.11	−0.47	0.47	1.64
Open Land	0.29	1.47	3.05	4.52	−1.58	1.58	2.94
Aquatic Vegetation	0.84	1.93	1.04	2.97	0.89	0.89	2.08
Total	59.94	40.06	40.06	80.12	0.0	31.08	49.04

Table 10. Statistics of landscape persistence and components (gains and losses) of change in terms of percent of study area in the time periods 1997–2007.

Land use/ Land Cover Class	Persistence	Gain	Loss	Total Change (Gain + Loss)	Value of Net Change (Gain − Loss)	Absolute Value of Net Change (Gain − Loss)	Swap (Total Change—Absolute Value of Net Change)
Built ip Land	24.05	10.12	0.71	10.83	9.41	9.41	1.42
Agricultural Crop Land	0.53	1.2	0.92	2.12	0.28	0.28	1.84
Agricultural Fallow Land	3.49	2.58	4.74	7.32	–2.16	2.16	5.16
Plantations	0.21	0.6	0.68	1.28	–0.08	0.08	1.2
Dense Forest	16.99	1.08	2.46	3.54	–1.38	1.38	2.16
Degraded Forest	9.08	5.5	9.48	14.98	–3.98	3.98	11
Land with or without Scrub	1.25	4.48	4.75	9.23	–0.27	0.27	8.96
Marshy/Swampy	0.33	1.33	2.15	3.48	–0.82	0.82	2.66
Water Logged Area	0.02	0.35	0.43	0.78	–0.08	0.08	0.7
Sandy Area (River Bed)	1.88	1.96	2	3.96	–0.04	0.04	3.92
River/Stream	6.18	1.89	1.68	3.57	0.21	0.21	3.36
Lake/Reservoir/ Pond/Tank	0.63	0.94	0.83	1.77	0.11	0.11	1.66
Open Land	0.26	1.41	1.5	2.91	–0.09	0.09	2.82
Aquatic Vegetation	0.9	0.76	1.87	2.63	–1.11	1.11	1.52
Total	65.8	34.2	34.2	68.4	0.0	20.02	48.38

4.2.3. Net Change and Swap Changes in Quantity of LULC

The exhibited transition from one category to a different category is about 40.06% area of total LULC and 34.20% area of total LULC, respectively, during 1987–1997 and 1997–2007. Overall (total) change is more during 1987–1997 as compared to 1997–2007. The overall (total) change during 1987–1997 is 80.12% area of total LULC and during 1997–2007 is 68.40% area of total LULC (Figure 6).

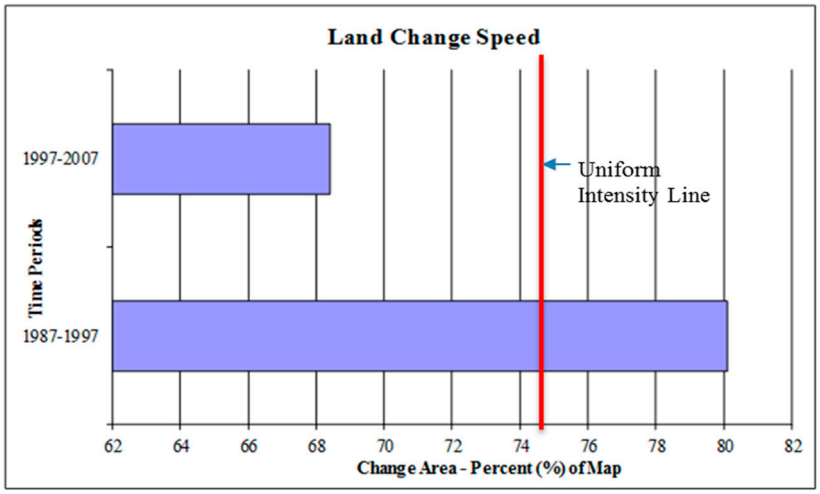

Figure 6. Land change speed (rate of change) in between 1987 and 1997 and 1997 and 2007.

A gross gain of one category is always accompanied by a gross loss of another category, so the total gross gain is equivalent to the total gross loss in a landscape, which is 40.06% in 1987–1997 time period and 34.2% in between 1997–2007. Between 1987–1997, degraded forest is the most highest category in terms of total gross gains and gross losses (17.66%), since it accounts for 8.04% points of the total gross gain and for 5.21% points of the total gross losses, followed by agricultural fallow land since it accounts for 3.02% points of the total gross gain and for 9.62% points of the total gross losses and total gain and loss 9.46%. while built up land is the highest gained LULC since it accounts for 10.42% points of the total gross gain and for only 0.30% points of the total gross losses, but there is a high proportion (10.72%) of total gain loss components of change for built up land ,we considered only the net change, the bulk of change in built up land would have been overlooked, which could have led to the wrong conclusion that built up is one of the more dynamic categories after degraded forest. Thus both swap and net changes are important to understand the total change in a landscape. This is in agreement with the finding of Pontius *et al*. [10] who stated that accounting for only net change could lead to a bias of dramatically underestimating the total change. While the sum of gross gain and gross loss indicates the total change, the difference between the gross gain and gross loss for a category is the net change for the given category. The difference between the total change and net change is the amount of swap change (Tables 11 and 12). Figure 7 shows the intensity of gross gain and gross loss of each LULC category between 1987 and 1997 and Figure 8 shows the intensity of gross gain and gross loss of each LULC category between 1987 and 1997.

Table 11. Ranking, % of gains, losses and persistence's of LULC category between 1987 and 1997.

Land Use/Land Cover Class	Gain	Land Use/Land Cover Class	Loss	Land Use/Land Cover Class	Total Change (Gain+ Loss)	Land Use/Land Cover Class	Persistence
Built up Land	10.42	Degraded Forest	9.62	Degraded Forest	17.66	Dense Forest	17.71
Degraded Forest	8.04	Agricultural Fallow Land	6.44	Built Up Land	10.72	Built Up Land	14.33
Land with or without Scrub	5.38	Agricultural Crop Land	5.8	Agricultural Fallow Land	9.46	Degraded Forest	10.54
Agricultural Fallow Land	3.02	Dense Forest	3.1	Land with or without Scrub	7.06	River/Stream	6.8
Sandy Area (River Bed)	2.14	Open Land	3.05	Agricultural Crop Land	6.78	Agricultural Fallow Land	5.21
Marshy/Swampy	1.96	Marshy/Swampy	2.72	Dense Forest	4.87	Sandy Area (River Bed)	1.73
Aquatic Vegetation	1.93	River/Stream	2.22	Marshy/Swampy	4.68	Aquatic Vegetation	0.84
Dense Forest	1.77	Sandy Area (River Bed)	1.86	Open Land	4.52	Lake/Reservoir/Pond/Tank	0.64
Open Land	1.47	Land with or without Scrub	1.68	Sandy Area (River Bed)	4	Land with or without Scrub	0.61
River/Stream	1.05	Lake/Reservoir/Pond/Tank	1.29	River/Stream	3.27	Marshy/Swampy	0.52
Agricultural Crop Land	0.98	Aquatic Vegetation	1.04	Aquatic Vegetation	2.97	Agricultural Crop Land	0.46
Lake/Reservoir/Pond/Tank	0.82	Water Logged Area	0.76	Lake/Reservoir/Pond/Tank	2.11	Open Land	0.29
Plantations	0.73	Built Up Land	0.3	Water Logged Area	1.11	Plantations	0.16
Water Logged Area	0.35	Plantations	0.18	Plantations	0.91	Water Logged Area	0.1
Total	40.06		40.06		80.12		59.94

Table 12. Ranking, % gains, losses and persistence's of LULC category between 1997 and 2007.

Land Use/Land Cover Class	Gain	Land Use/Land Cover Class	Loss	Land Use/Land Cover Class	Total Change (Gain + Loss)	Land Use/Land Cover Class	Persistence
Built up Land	10.12	Degraded Forest	9.48	Degraded Forest	14.98	Built Up Land	24.05
Degraded Forest	5.5	Land with or without Scrub	4.75	Built Up Land	10.83	Dense Forest	16.99
Land with or without Scrub	4.48	Agricultural Fallow Land	4.74	Land with or without Scrub	9.23	Degraded Forest	9.08
Agricultural Fallow Land	2.58	Dense Forest	2.46	Agricultural Fallow Land	7.32	River/Stream	6.18
Sandy Area (River Bed)	1.96	Marshy/Swampy	2.15	Sandy Area (River Bed)	3.96	Agricultural Fallow Land	3.49
River/Stream	1.89	Sandy Area (River Bed)	2	River/Stream	3.57	Sandy Area (River Bed)	1.88
Open Land	1.41	Aquatic Vegetation	1.87	Dense Forest	3.54	Land with or without Scrub	1.25
Marshy/Swampy	1.33	River/Stream	1.68	Marshy/Swampy	3.48	Aquatic Vegetation	0.9
Agricultural Crop Land	1.2	Open Land	1.5	Open Land	2.91	Lake/Reservoir/Pond/Tank	0.63
Dense Forest	1.08	Agricultural Crop Land	0.92	Aquatic Vegetation	2.63	Agricultural Crop Land	0.53
Lake/Reservoir/Pond/Tank	0.94	Lake/Reservoir/Pond/Tank	0.83	Agricultural Crop Land	2.12	Marshy/Swampy	0.33
Aquatic Vegetation	0.76	Built Up Land	0.71	Lake/Reservoir/Pond/Tank	1.77	Open Land	0.26
Plantations	0.6	Plantations	0.68	Plantations	1.28	Plantations	0.21
Water Logged Area	0.35	Water Logged Area	0.43	Water Logged Area	0.78	Water Logged Area	0.02
Total	34.2		34.2		68.4		65.8

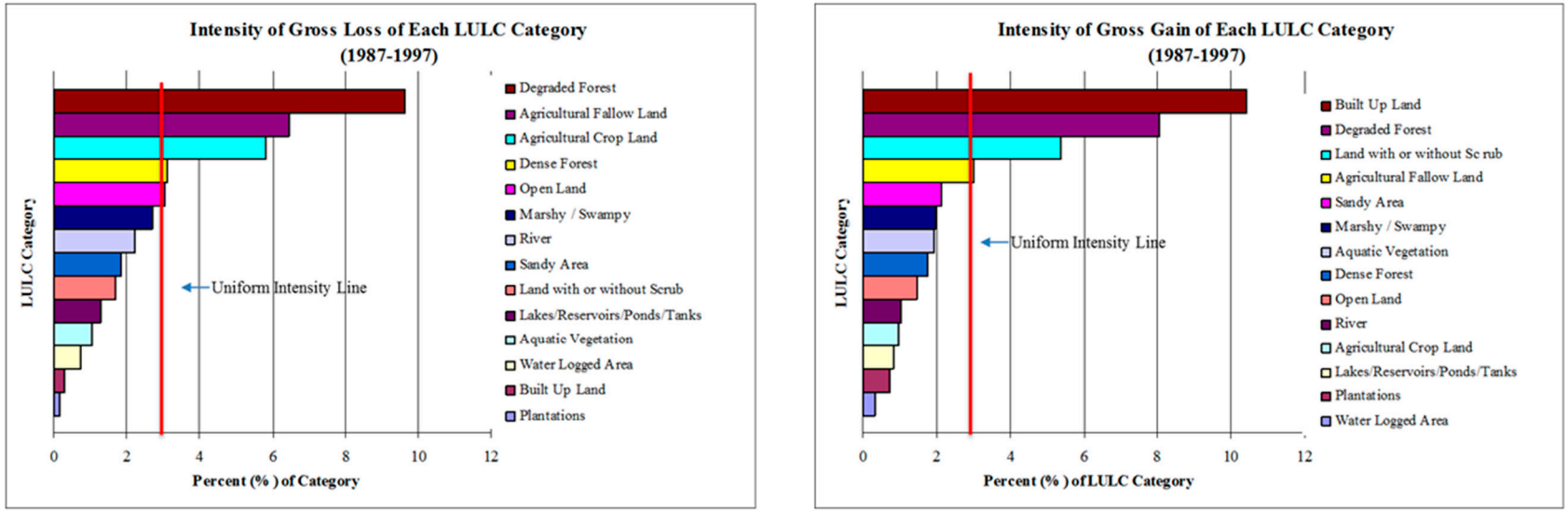

Figure 7. Intensity of gross gain and gross loss of each LULC category in between 1987 and 1997.

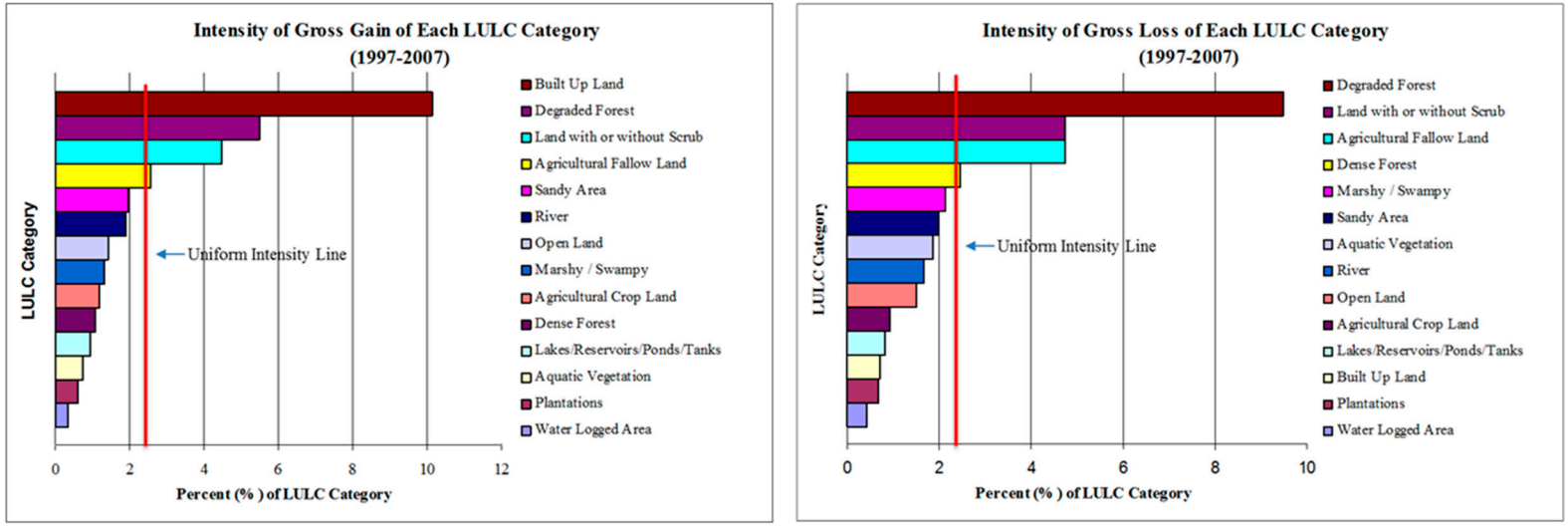

Figure 8. Intensity of gross gain and gross loss of each LULC category in between 1997 and 2007

According to swap change (Table 13) between 1987–1997, degraded forest exhibits net change on 17.66% of the study area and swapping change on about 16.08% of the study area clearly indicating most dynamic LULC in 1987–1997, followed by agricultural fallow land (6.04% swapping). According to swap change (Table 13) in 1997–2007 time periods, degraded forest (11%) is also most dynamic LULC followed land with or without scrub (8.96%). Degraded forest is the most dynamic category in terms of swap change followed by agricultural fallow land, land with or without scrub, marshy/swampy, open land, sandy area (river bed), river/stream of the study area in last 20 years accounting period in both time points (1987–1997 and 1997–2007).

Table 13. Ranking of swap rate between different time periods.

Swap Ranking between 1987 and 1997		Swap Ranking between 1997 and 2007	
Swap	**LULC Class**	**LULC Class**	**Swap**
16.08	Degraded Forest	Degraded Forest	11
6.04	Agricultural Fallow Land	Land with or without Scrub	8.96
3.92	Marshy/Swampy	Agricultural Fallow Land	5.16
3.72	Sandy Area (River Bed)	Sandy Area (River Bed)	3.92
3.54	Dense Forest	River/Stream	3.36
3.36	Land with or without Scrub	Open Land	2.82
2.94	Open Land	Marshy/Swampy	2.66
2.1	River/Stream	Dense Forest	2.16
2.08	Aquatic Vegetation	Agricultural Crop Land	1.84
1.96	Agricultural Crop Land	Lake/Reservoir/Pond/Tank	1.66
1.64	Lake/Reservoir/Pond/Tank	Aquatic Vegetation	1.52
0.7	Water Logged Area	Built up Land	1.42
0.6	Built Up Land	Plantations	1.2
0.36	Plantations	Water Logged Area	0.7

4.3. Changes in Allocation of LULC

Persistence and changes of LULC between 1987 and 1997 are shown in Figure 9, while persistence and changes of LULC between 1997 and 2007 are shown in Figure 10. Figures 11 and 12 show gross loss of each LULC category during 1987–1997 and 1997–2007, respectively. Figures 13 and 14 show gross gain of each LULC category during 1987–1997 and 1997–2007, respectively. Figure 15 shows gains, losses and persistence of each LULC category during 1987–1997. Figure 16 also shows gains, losses and persistence of each LULC category during 1997–2007.

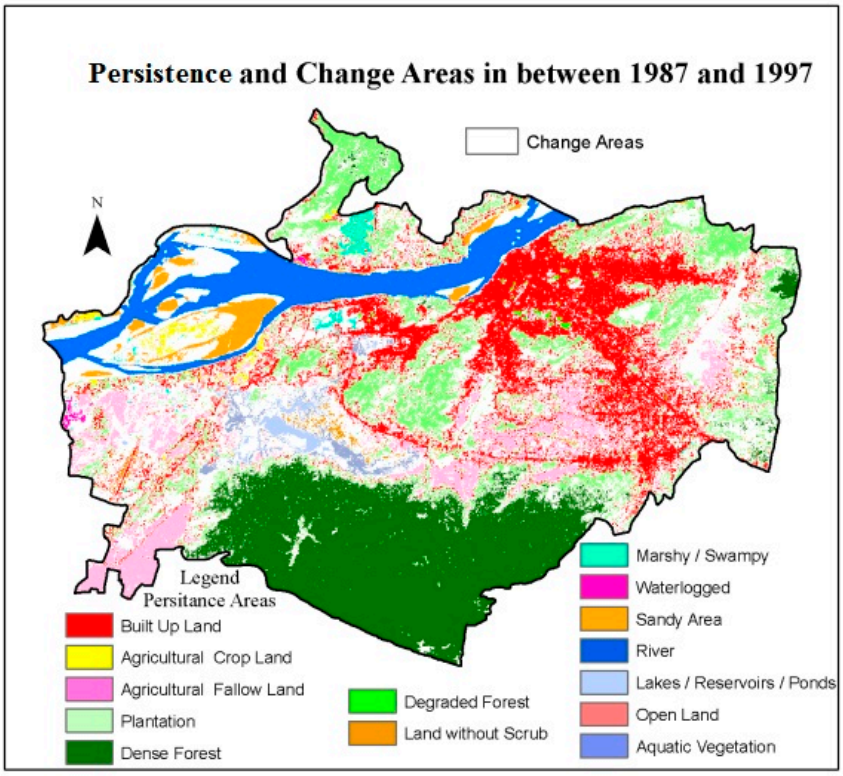

Figure 9. Persistence and change areas between 1987 and 1997.

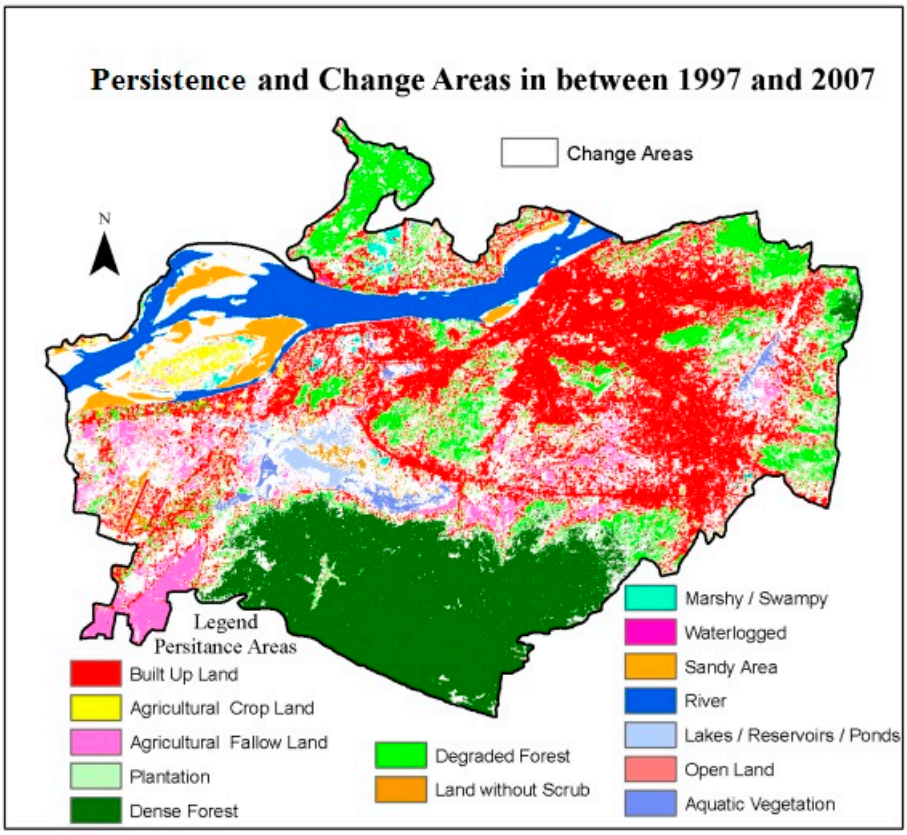

Figure 10. Persistence and change areas between 1997 and 2007.

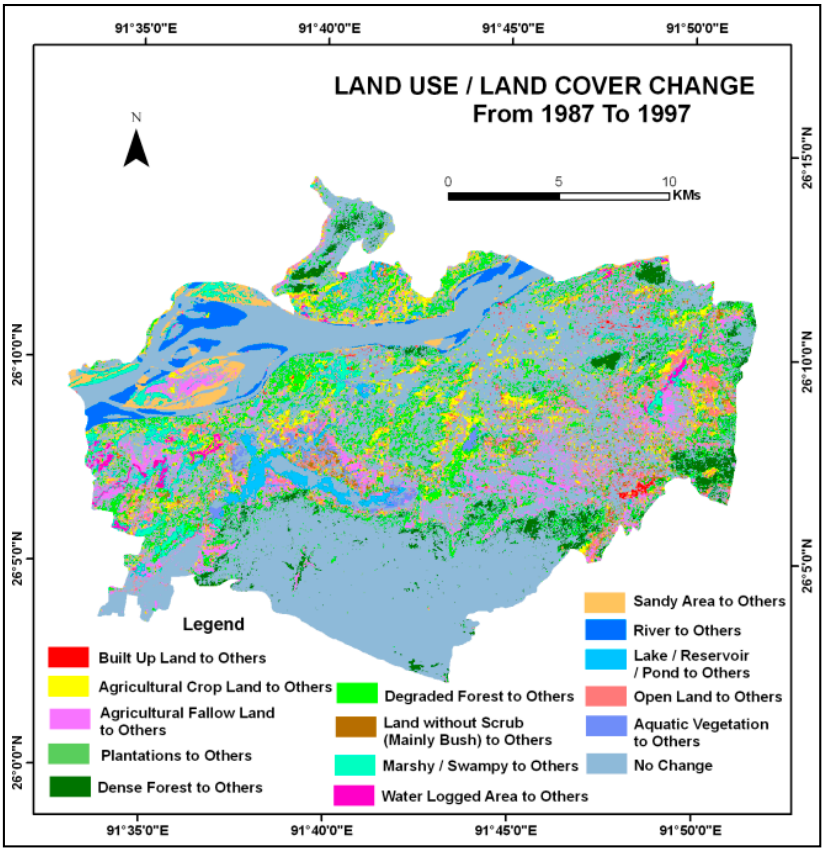

Figure 11. Gross loss of each LULC category during 1987 and 1997.

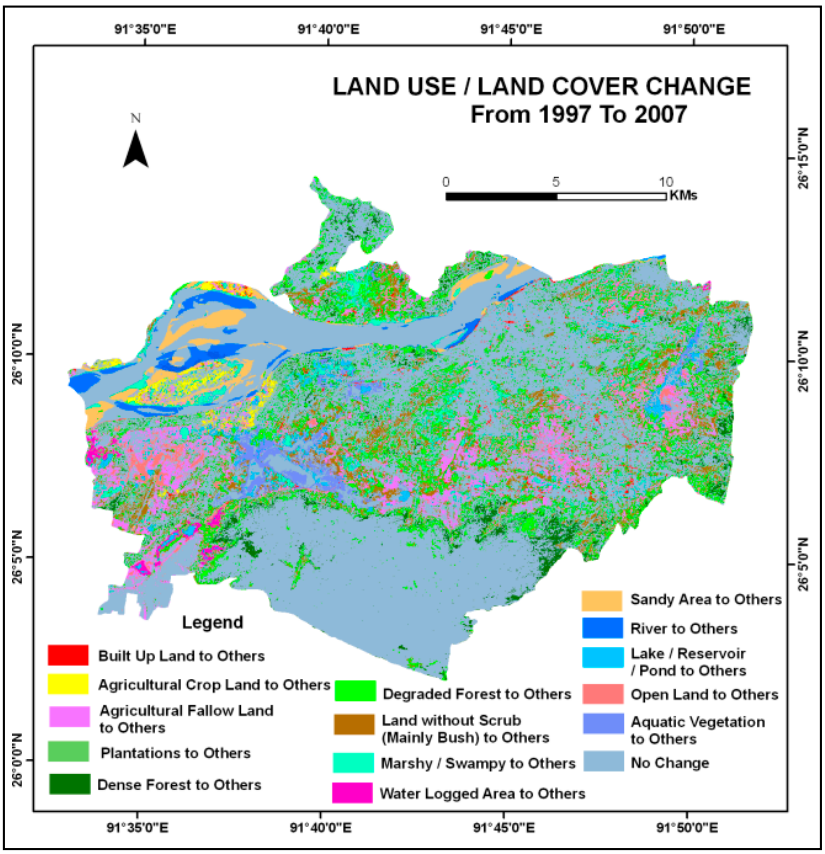

Figure 12. Gross loss of each LULC category during 1997 and 2007.

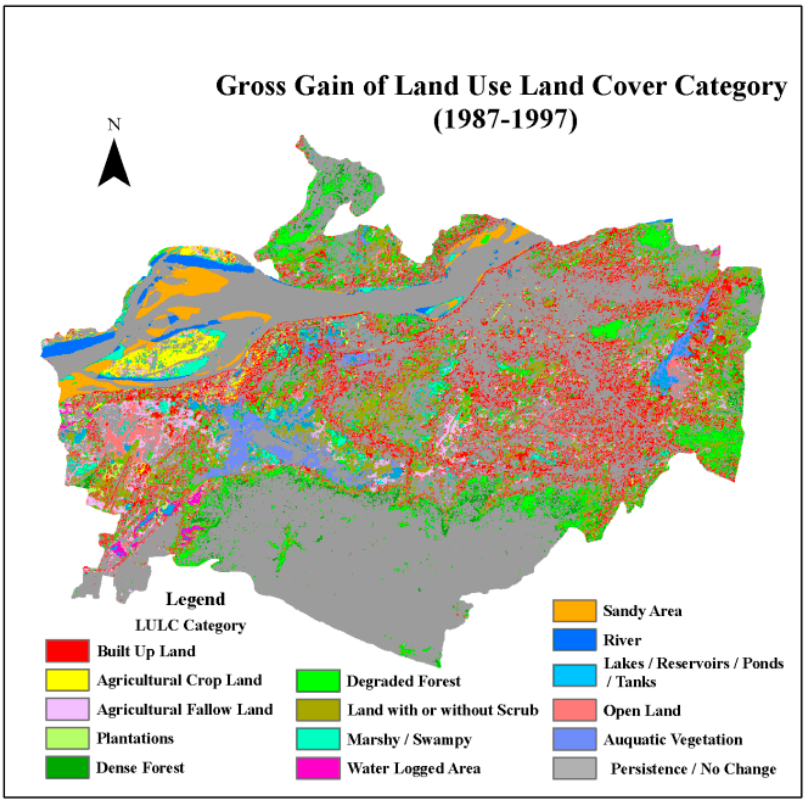

Figure 13. Gross gain of each LULC category during 1987 and 1997.

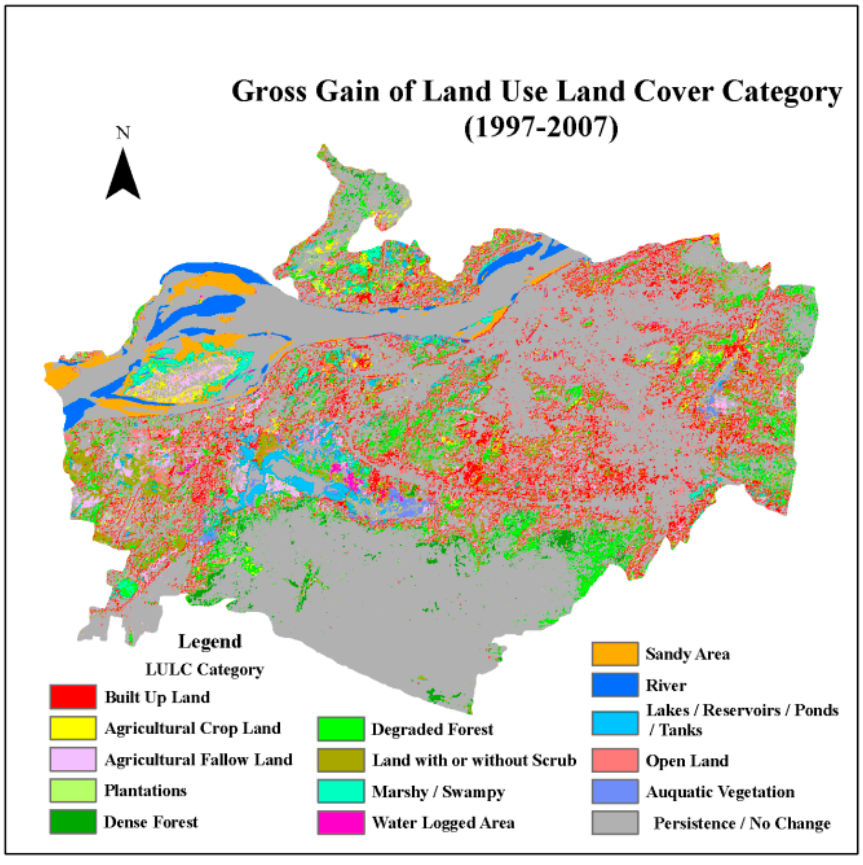

Figure 14. Gross gain of each LULC category during 1997 and 2007.

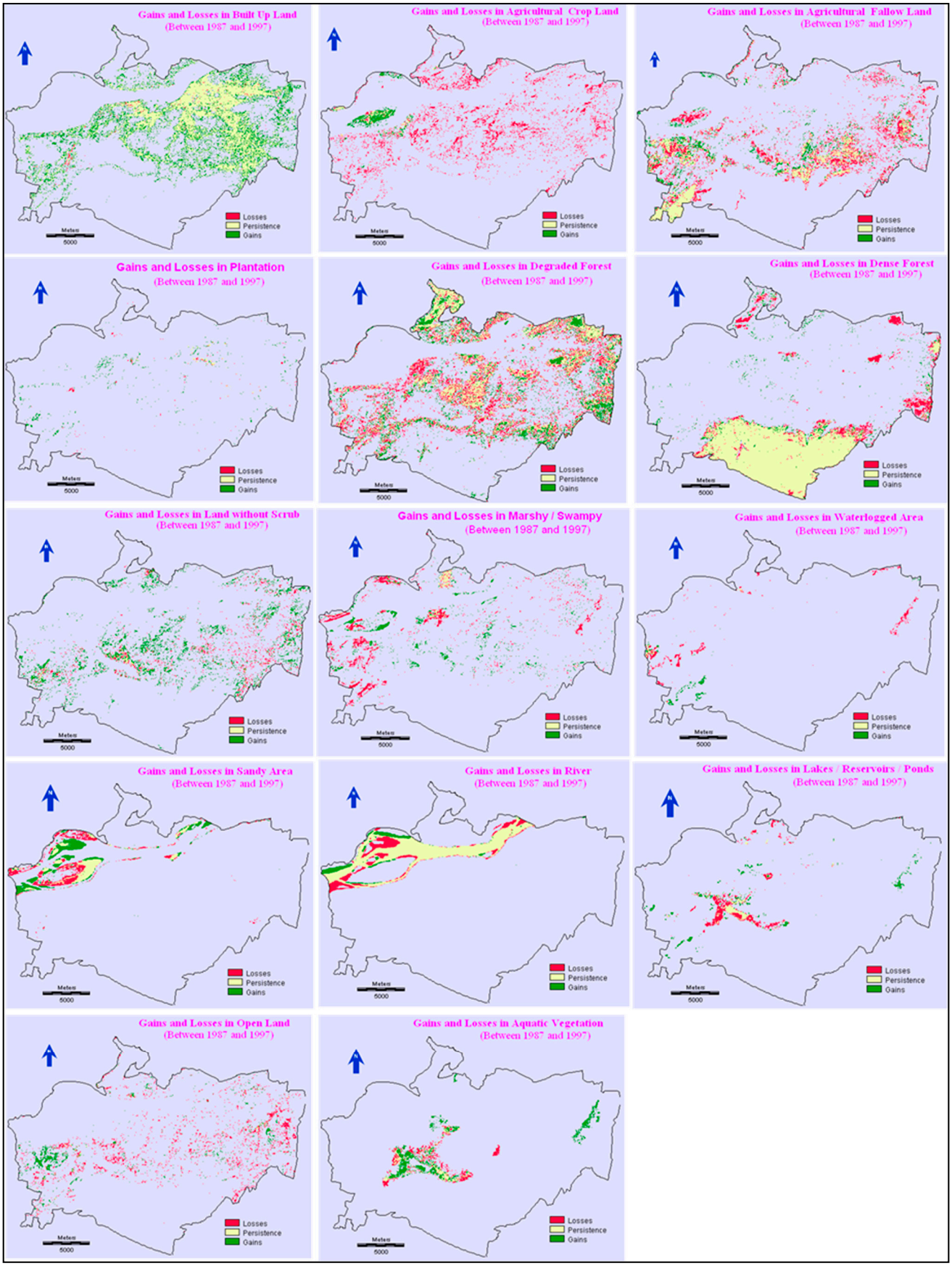

Figure 15. Gains, losses and persistence of each LULC category in time periods 1987–1997.

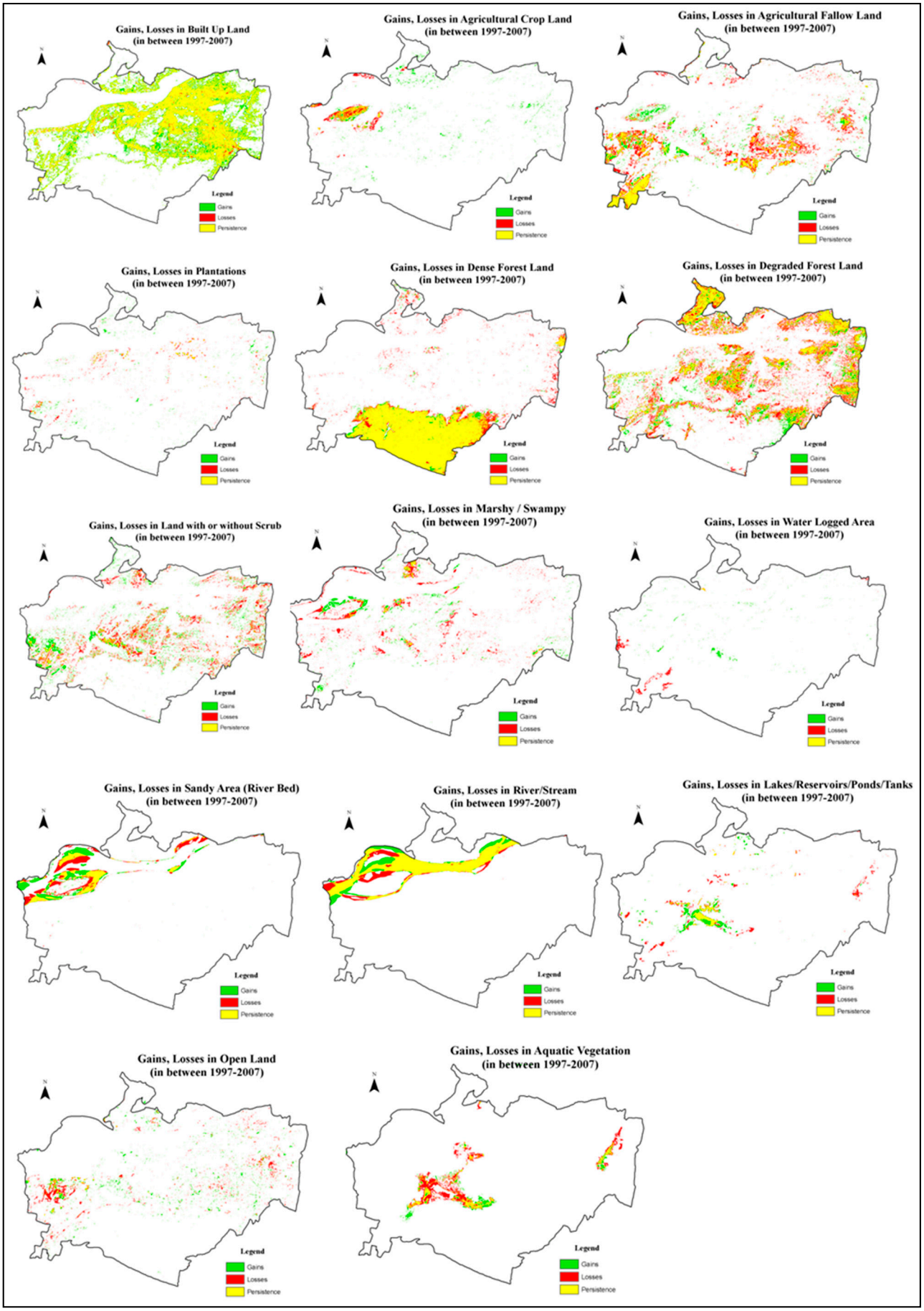

Figure 16. Gains, losses and persistence of each LULC category in time periods 1997–2007.

As expected the Built up expansion is mainly in the outskirts of the existing built-up, *i.e.*, expansion of Guwahati city and other built up areas for both time periods due to mainly rapid urbanization in Guwahati Metropolitan areas. The gain of built up land within surrounding the existing built up land is mainly in degraded forest, agricultural land and land with or without scrub area. The gain in Built-up is more than the loss in all over the study area for both time periods. It has happened due to rapid conversion of degraded forestland, agricultural land and land with or without scrub to built up land within the study area between 1987 to 2007. Degraded forestland decreased due to transformation to built up land and land with or without scrub. Interestingly, agricultural land and land with or without scrub also finally converted to built up land due to rapid increased population in Guwahati city and surrounding areas. Local Lake-Reservoir-Pond-Tank, open land has also been converted to built up land. Lake (Deepor beel) and marshy or swampy land (*i.e.*, near Deepor beel protected land) converted to built up land also. Forestland is mainly converted to degraded forest, and then degraded forest is converted to land with or without scrub and agricultural land, then land with or without scrub and agricultural land converted to built up land. The substantial exchanges of areas and allocation of change in both time periods (1987–1997 and 1997–2007) are nearly similar as above. Another major transition is found river-stream to sandy area or in riverbed (1.94%) between 1987–2007. The river stream is slightly decreased by 1.94% area mainly occupied by sandy area caused by deposition of river. Plantation land somehow increased due to awareness of advocacy of the concept of social forestry by government.

There are substantial exchanges of areas during 1987–1997 found between degraded forests and built up land; agricultural cropland as well as agricultural fallow land and built up land; dense forest and degraded forest. The prominent transitions are from degraded forest to built up land (3.65%). These are followed by both agricultural crop and agricultural fallow land converting to built up land (1.75% and 2.30%, respectively). The other prominent transitions are from dense forest to degraded forest (2.82%) and degraded forest to land with or without scrub (2.31%). Another major transition was found in river/stream during 1987–1997 to sandy area or in riverbed (1.94%). Similarly to between 1987–1997 time periods, there are substantial exchanges of areas during 1997–2007 between degraded forests and built up land; agriculture fallow land and built up land; dense forest and degraded forest. Others substantial exchanges of areas during 1997–2007 found between land with scrub and built up land; agricultural fallow land and land with or without scrub. The prominent transitions are from degraded forest to built up land (4.30%). These are followed by both agricultural fallow land and land with scrub converting to built up land (1.97% and 1.41%, respectively). The other prominent transitions are from dense forest to degraded forest (1.80%); degraded forest and agricultural fallow land to land with or without scrub (1.93% and 1.07%, respectively).

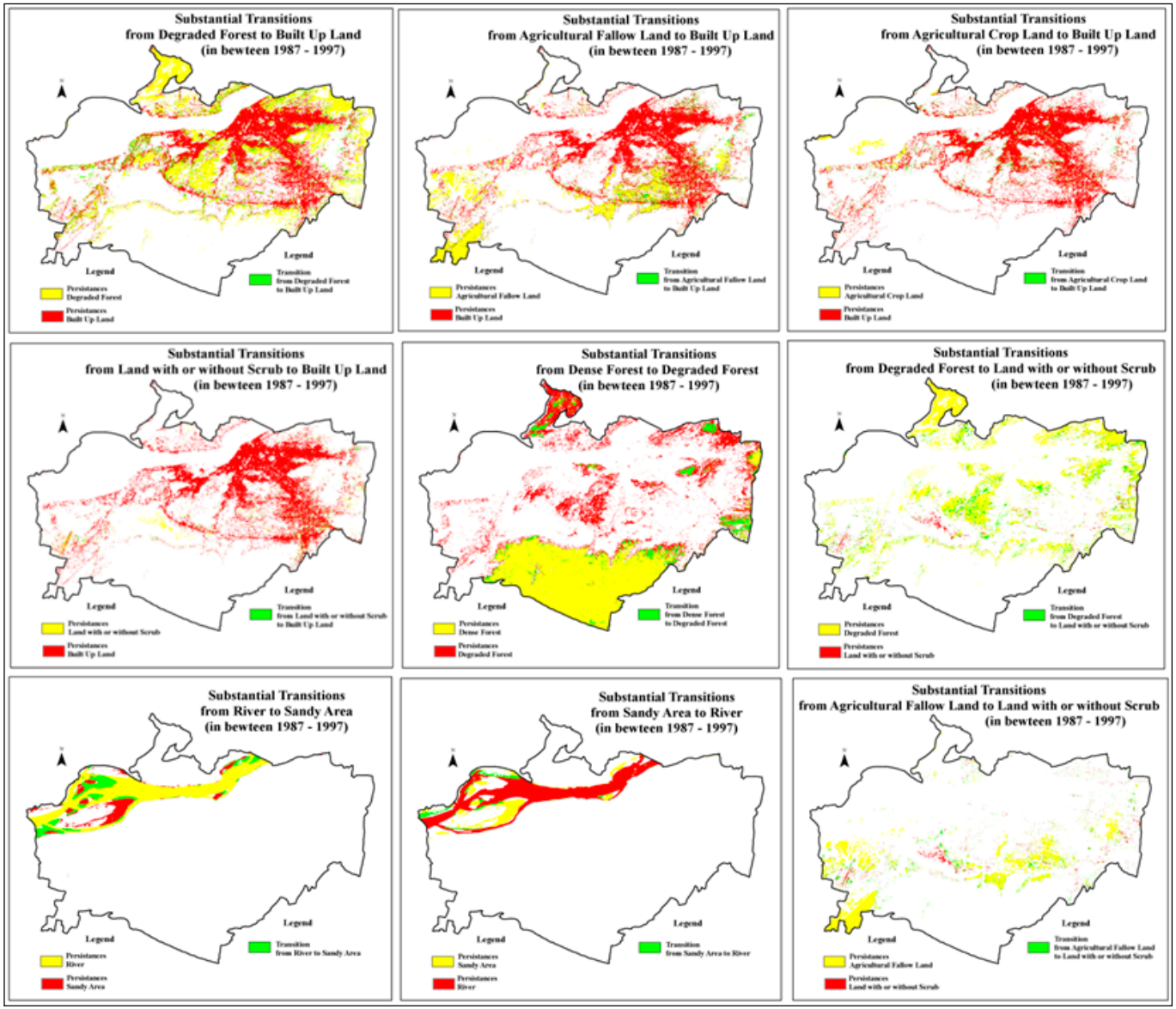

Figure 17. Substantial transitions between different LULC during 1987–1997.

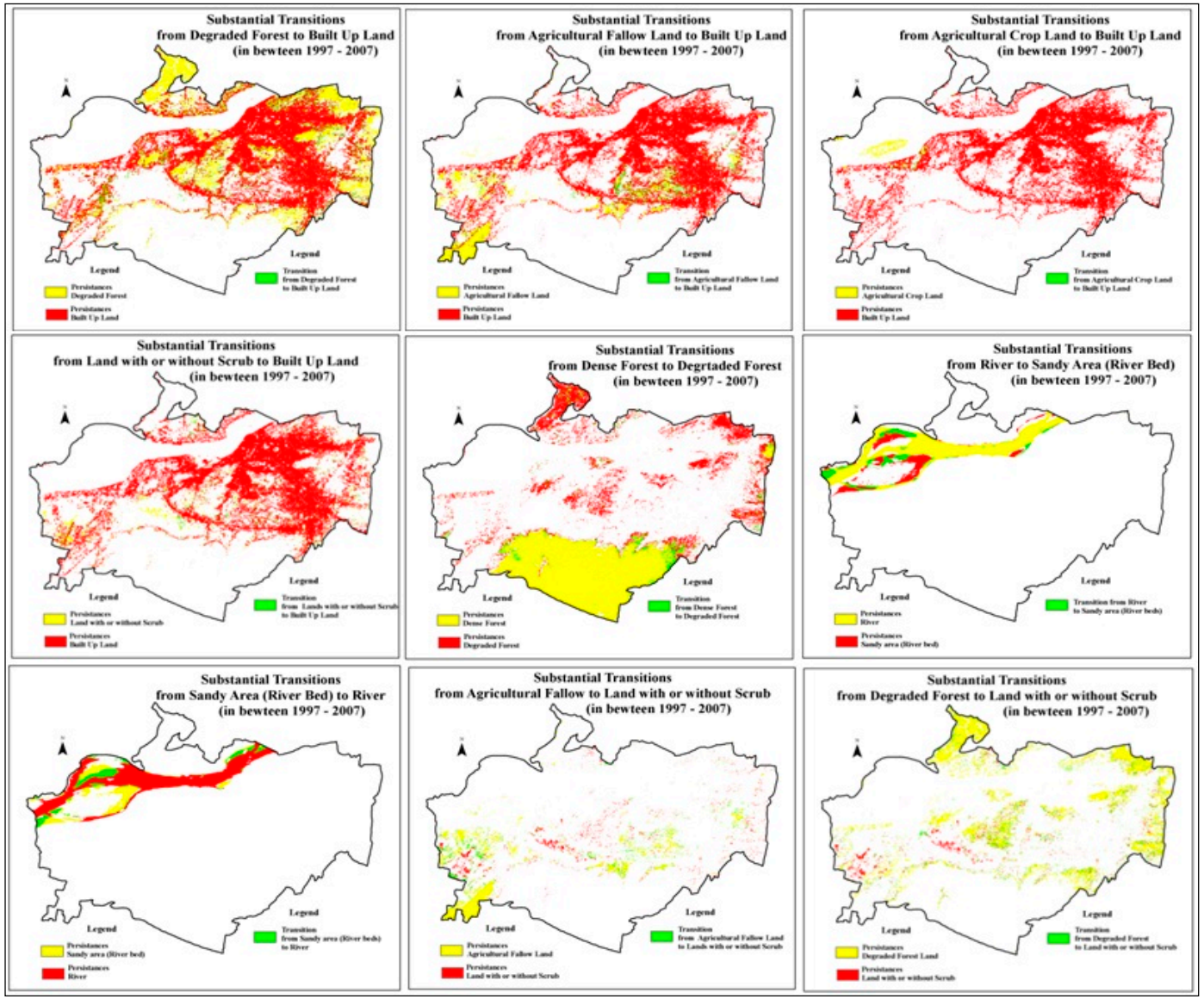

Figure 18. Substantial transitions between different LULC during 1997–2007.

Another major transition we found in 1997–2007 is river/stream to sandy area or in river bed and vice versa (1.41% and 1.45%, respectively). Therefore substantial exchanges of areas in both periods (1987–1997 and 1997–2007) are nearly similar. In other words, the trends of major exchanges between LULC categories are nearly similar. Table 14 and Figures 17 and 18 clearly show major substantial exchanges between LULC categories during (1987–1997 and 1997–2007). Degraded forest experienced the greatest amount of gross loss to land with or without scrub between 1987 and 1997 compare to between 1997 and 2007. Land with or without scrub experienced the greatest amount of gross loss to built up land after 1997. However, it was found that there are small transitions between other LULC categories in both time periods.

Table 14. Substantial exchanges/prominent transitions between LULC categories.

LULC		Time Periods	
Change from	Change to	1987–1997	1997–2007
Degraded Forest	Built up	3.65%	4.30%
Agricultural Fallow Land	Built up	2.30%	1.97%
Agricultural Crop Land	Built up	1.75%	0.14%
Dense	Degraded	2.82%	1.80%
Degraded Forest	Land with or without Scrub	2.31%	0.16%
Land with or without Scrub	Built up	0.66%	1.41%
River	River Bed	1.94%	1.45%
River Bed (Sandy Area)	River	-	1.41%
Agricultural Fallow Land	Land with or without Scrub	-	1.07%

5. Conclusions

This study analyzed remotely sensed observations to measure and characterize the changes of the land use land cover (LULC). The dynamics of LULC analysis was done for the study area. This study examined changes among several categories between 1987–1997 and 1997–2007 in the study area and the results show that the annual speed of changes was slower during 1987–1997 than during 1997–2007. About 34.20% (during 1987–1997) and 40.06% (during 1997–2007) of the study area exhibited transition from one category to a different category. The total change during (1987–1997) is 68.40% and during (1997–2007) is 80.12%. There are substantial exchanges of areas between degraded forest and built up land. The other prominent transitions are dense forest to degraded forest. The dominant systematic transitions are: degraded forest to built up land; dense forest to degraded forest; agricultural land to built up; degraded forest to land with or without scrub; land with or without scrub to built up; and in between river and sandy area. These transitions are probably due to increased land values caused by the growing socio-economic activities and population growth in the Capital city Guwahati-Dispur. During both the periods, Degraded Forest has the highest total gains and gross losses means most dynamic LULC categories followed by Agricultural Fallow Land, Land with or without Scrub, Sandy Area (River Bed), River/Stream, Dense Forest, Open Land, Marshy/Swampy. Interestingly, built up is nearly lowest category in terms of total gross gains and gross losses because its gains more area compare to gross losses. The largest transitions are exchanges between degraded forests and built up land followed by dense forest to degraded forest. Other major transition are in between agricultural land (crop as well as fallow) to built up; degraded forest to land with or without

scrub; land with or without scrub to built up; river (stream) to sandy area (river bed); agricultural fallow land to land with or without scrub. Built-up gain occurs mainly in the outskirt of existing Built up land in degraded forests, agricultural (crop as well as fallow) land and land with or without scrub. Dense forest loss is occurring mainly in degraded forest. Built-up experiences a consistently large intensity of gains since 1987 in all time periods, built-up has expanded into degraded forests, agricultural area; but since 1997 built-up has also expanded into land with or without scrub. The overarching conclusion in this study is that when only the net changes are used, the bulk of changes accruing from swap changes would have missed. Additionally, when analysis is done based on the traditional transitional matrix, we would have focused only on the larger categories and missed the systematic transitions in the landscape. It is inferred that LULC patterns in the area are generally controlled by agro-climatic conditions, ground water potential and hosts of other factors like irrigation facilities, soil characteristics, socio-economic status and demography. Deeper explanation of the driving factors of LULC dynamics will be the subject of future study. Finally, it can be suggested that the transformation from forest to built up land especially built-up area constitutes a large percentage of the total landscape, but it contributes a substantial ecological footprint and thus increase in built-up areas needs to be considered in the realm of environmental monitoring and sustainability. This study is a systematic description of LULC landscape dynamics for the study area in a developing country. The present research will provide a better understanding of the land use and land cover change pattern. The direct beneficiaries of this research will include two distinct groups: (1) resource managers at the local, regional and state levels of government, and (2) regional as well as urban planners who want better urban planning in broader social and economic settings

Author Contributions

Md. Surabuddin Mondal (corresponding author) had the original idea for the study, carried out the analyses and drafted the manuscript. Drafted manuscript has been revised and approved (the final manuscript) by all authors (Nayan Sharma, Martin Kappas and P. K. Garg).

Conflicts of Interest

The authors declare no conflict of interest.

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