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Land use land cover change in National Capital Region of India: a remote sensing & GIS based two decadal spatial-temporal analyses

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Abstract

Appropriate location and operation of the developmental activities across different policy zones of National capital Region of India (NCR), to facilitate mutually productive "Centre - Periphery" relationship, requires detailed spatial-temporal mapping and long term change detection analysis of the regional resources of the study area. Scanning of literature revealed that this is acutely lacking for the study area. Hence, the present investigation was primarily aimed at quantifying the spatial-temporal pattern of the Land Use/ Land Cover Change (LULCC) during last two decades (i.e., 1989 to 2006) in the NCR and identifying the major bio-physical factors governing LULCC through modern geo-spatial techniques. Geo-spatial analysis of the above data showed that the study area experienced a steep (67.4%) increase in its croplands during 1989 to 1998 but relatively a small (5.7%) increase during 1998 to 2006 period. This was also associated with a similar steep increase in its built-up areas, due an increase in its urban population, during the same period. The change detection analysis further showed that 1989-1998, associated with change in croplands, change in built-up, ridge and forest lands, change in water-bodies, water levels and rainfall, change in single/ double cropped areas, change in degraded croplands and change in cropping pattern. With comparison of above results and collected socio-economic data in this region, the impact of changing land use & bio-physical/ economic factors on agricultural profitability were analyzed. The result of this study could thus lead to a detailed and lucid spatial-temporal (quantitative) assessment of the major bio-physical factors governing agricultural business – profitability and the overall food security of the National Capital Region. It is expected that the study would go a long way in facilitating better policy making and developing valid change detection methodologies for the National Capital Region and other similar regions of the country.

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1. Introduction

Land uses are primarily the result of human actions and decisions on land. In fact human activities arising from a multiplicity of social objectives are the immediate source of land cover change. To understand these social objectives one needs to analyze the underlying driving forces that motivate or constrain the associated human activities. Biophysical driving forces and shocks (such as geomorphic processes, global and local climate change/ variability, etc.) are also responsible for changes in land cover and ultimately the land use [1].

During the last two decades there has been a rapid economic and industrial development in Delhi. Delhi, being the National Capital Territory (NCT), is one of the important centers for commerce, trade and industries in northern India. In fact industrial development in Delhi and adjoining areas has emerged in somewhat haphazard and unplanned manner thereby leading to increased population and environmental problems of concern. In fact about 60% of its most productive agricultural land has been transformed into non-agricultural uses. It is estimated that between 1970 – 1971 and 1993-94, industrial units have increased from about 26,000 to 93,000 while net sown area has decreased from 85,000 ha to 46,000 ha [2].In order to take care of these problems, the Government of India carved out an inter-state National Capital Region (NCR) comprising NCT-Delhi (in centre) and the surrounding six districts of Haryana, three districts of Uttar Pradesh and Alwar district of Rajasthan. The prime objective of this regional plan was to locate economic activities associated with large scale population and environmental problems outside the NCT region [3].

The National Capital Region is characterized by a surge of physical and economic growth of Delhi and under-development of the area outside it. This has been changing the land use/ land cover of the National Capital Region with profound regional environmental implications and a concomitant de-stabilization of the rural economy and food demand of the region, as evident from a range of localized studies across many agricultural areas within NCR [4,5,6,7]. Analysis of issues relating NCR revealed that a one-sided "Centre (i.e. NCT, Delhi & other DMAs) - Periphery (i.e. rest of rural parts of NCR)" relationship is the main cause of the ongoing lop-sided developmental activities in the study area [8]. Thus it appears that for promoting growth of NCR, it's "Centre - Periphery" relationship needs to be improved and made mutually productive. This is possible only by minimizing the adverse effects/ hypertrophy of the core on the region's environment, both in terms of the loss of natural amenities as well as the degradation of the natural environment, through appropriate location and operation of the developmental activities.

Appropriate location and operation of the developmental activities across different policy zones of NCR requires detailed spatio-temporal mapping and long term change detection analysis of the regional resources. Scanning of literature revealed that this is acutely lacking for the study area. Hence, the present investigation was primarily aimed at quantifying the spatio-temporal pattern of the Land Use/ Land Cover Change during last two decades (i.e., between1989 – 2006) and identifying the major bio-physical factors governing such change through modern geo-spatial techniques.

2. Material and methods

The National Capital Region (NCR, Figure 1) comprising of 33,578 Km2 area, lies between 27° 03' and 29" 29' North latitude and 76° 07' and 78° 29' East longitude. In general, the region is characterized by semi-arid to arid climatic conditions with three well defined seasons viz., summer (March to June), south west monsoon (July to mid October) and winter (November to February). The summers are hot and associated with temperatures as high as 46 oC while the winters are mild to severe. Most of the rainfall is received during south-west monsoon season. Annual rainfall of this region is highly erratic in both time and space and varies from 500 to 700 mm.

NCR forms part of the most productive agricultural areas of the country. Agriculture is the mainstay (79.52%) of the people of this region with Haryana sub-region recording the highest area (46.70%) under agriculture use. This is closely followed by the Uttar Pradesh (38.11%), Rajasthan (12.60%) and NCT-Delhi (2.59%) sub-regions [8]. Due to the area being drained by four major rivers, most of the NCR is predominantly irrigated (total irrigation requirement: 14,000 MCM, NCRPB, 2005) through a well-developed Yamuna, Ganga and Bhakra-Beas canal network. These canals primarily carry river waters laden with industrial/ domestic effluents [9]. Earlier investigations across many agricultural areas within NCR have shown that due to this the productive potential of these agricultural lands is in threat [4]. A part of the irrigation demand is also met from ground water. Alwar and Gurgaon districts of NCR are primarily ground water irrigated. Open wells, shallow tube wells, gravity wells and deep tube wells are abundant in the areas covered by the alluvium. Most of the ground water occurs in the consolidated rocks, both in confined and semi-confined conditions. Mostly the top water table zone and the deeper semi-confined aquifer have the same static water level surface because of their interconnections. The depth of water table below ground level varies in general between 5-20 meters.

In order to achieve the aforementioned objectives of the present investigation, three pairs of multi-temporal classified images for the Rabi (January-February) and Kharif (August-October) cropping seasons of 1989, 1998 and 2006 were generated through a hybrid unsupervised (ISO data)–supervised (Maximum Likelihood) image classification technique. Error matrices were used to assess the classification accuracy of the classification trials and to select the best classified image for each season of the 1989, 1998 and 2006. To avoid confusion between croplands and scrublands, classification trials having higher cropland and ridge land accuracies but associated with relatively lower overall accuracies or Kappa coefficients were given preference. The so classified images were subjected to a change detection analysis to identify the key bio-physical factors impacting any land use/ land cover change in the National Capital Region.

Other spatial and non-spatial data were also acquired to support the aforementioned analysis. These were acquired at varied available (continuous/ discrete) time scales (ranging from 1986 to 2006) from different national data collecting agencies. Besides Landsat and IRS satellite acquired digital imageries, the spatial data comprised of reference Survey of Indiatopo-sheets, Google Earth images and the administrative boundary, canal/ river/ drain/ road network, ground water depth maps. While the non-spatial data comprised of the district-wise time series statistics on the major land use types; rainfall, crop production/ productivity estimates, cost of production and farm harvest prices for the major food crops and the demography of the study area.

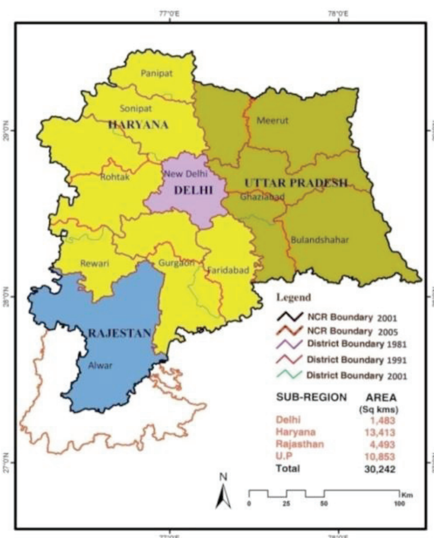

Fig. 1. NCR administrative

3. Results and discussions

3.1. Land use/ cover classification & change detection accuracy

The overall accuracies for the Rabi and Kharif season-classified images (i.e. Trial-8 and Trial-3, respectively) for 1989 were 74.41% and 84.7%, respectively with Kappa statistics of 69.23% and 80.95%. While those for the Rabi and Kharif season -classified images for 1998 were 92.1% (with Kappa = 90.24%) and 76.53% (with Kappa = 71.51%), respectively and for 2006 were 92.86% (with Kappa = 90.92%) and 83.00% (with Kappa = 79.08%), respectively.

A closer inspection of the 2006-Kharif season classified images showed some confusion between the croplands and forests (particularly due to the existence of a sugarcane belt in the north eastern part of the image) and the croplands and scrub lands (particularly in the south western part of the image). Repeated classifications with increased ground truths/ training sites, could not improve the classification accuracy of the 2006-Kharif season image. Thus to increase classification accuracy of the 2006-Kharif season image, the eastern part of the 2006 (raw) Kharif image (comprising Uttar Pradesh) was separated from its western part (comprising Haryana, Delhi and Alwar) and the two parts were classified separately as per the above mentioned "guided clustering" approach after applying the "haze reduction" filter to the consolidated 2006 (raw) Kharif season image. Thereafter the two separately classified parts were mosaiced to create a single 2006-Kharif season (haze free) classified image with improved overall accuracy and Kappa statistics.

As expected, due to haze/ cloud cover in Kharif season images, in general both overall accuracy and Kappa statistics for the Rabi season classified images were higher than those for the Kharif season classified images. The accuracies of individual classes were consistently high, ranging from 57% to 100%. Multiplying the individual classification accuracies gave the expected overall change detection accuracies of 68.53% (Rabi season) and 64.82% (Kharif season) for 1989–1998, 85.52% (Rabi season) and 63.52% (Kharif season) for 1998–2006, and 69.09% (Rabi season) and 70.30% (Kharif season) for 1989–2006.

The accuracy of satellite based land use inventories was also adjudged through a comparison of the classified satellite image based gross and net sown area estimates with their corresponding estimates from independent ground based land use inventories (Table 1).

The results of this analysis, for the base (1989) and the latest (2006) years, showed that the differences between the satellite and ground based estimates for year 1989 were significant while those for the year 2006 were non-significant. It was further observed that the satellite based net and gross sown estimates for 1989 were far lower than those for 2006. Closure inspection of the rainfall data for these years revealed that this trend was realistic and was mainly due to the prevalence of extreme drought conditions (with about 33% below normal rainfall) in the Kharif season of year 1989. However the impact of drought conditions, in 1989, on the ground based net and gross sown area estimates was not evident as these estimates were compiled from the Kharif season of 1988 (with about 25% above normal rainfall) and the (normal) Rabi season of 1989.

Table 1. Comparison of net & gross sown area estimates from satellite classifications and the CMID data

Source -Year	Gross Sown Area	Net Sown Area
Satellite - 1989	16921.9±0.4396 =9483.32 to 24360.8	10419.3 ± 0.4396 =5839 to 14999.6
CMID - 1989	40053.2	25222.4
Satellite - 2006	25840.0 ± 0.22931 = 18266.4 to 33413.64.	14656.9 ± 0.2810 =10538.3 to 18775
CMID - 2006	32906.30	22883.55

3.2. Land use /land cover change and impacting factors

Although land use/ land cover classification maps were generated for both Kharif and Rabi seasons of all three years but due to comparatively lower accuracy of Kharif season classified maps, individual class area and land use / land cover and change statistics were evaluated for only the Rabi-season classified images (Figure 2). These statistics are summarized in tables 2 respectively.

3.2.1. Change in croplands

It could be clearly observed from tables 2 and 3 that from 1989 to 2006, croplands increased approximately 7,986.81 Km2 (76.82%) while the barren lands, ridge (or scrub) lands and water-bodies decreased 5868.96 Km2 (71.76 %), 4759.86 Km2 (39.33 %) and 114.60 Km2 (10.09%), respectively. To further evaluate the results of land cover conversions, matrices of land cover changes from 1989 to 1998, 1998 to 2006, and 1989 to 2006 were also created (Table 3). In this table, unchanged pixels are located along the major diagonal of the matrix. Conversion values were sorted by per cent change and listed in descending order. These results indicate that increases in croplands mainly came from the conversion of the forested (57.11%), ridge/ scrub lands (50%) and barren (45.61%) during the seventeen-year period, 1989-2006 (Table 3). It was further noticed that the croplands encountered a steep (67.4%) increase during 1989 to 1998 but relatively a small (5.7%) increase during 1998 to 2006 period.

Table 2. Summary of land use/ land cover classification area statistics for 1989, 1998 & 2006

Land use	1989 Area (km^2)	(%)	1998 Area (km^2)	(%)	2006 Area (km^2)	(%)	Relative Change (%) 1989-2006
Crop land	10,396.94	30.40	17,399.66	50.87	18,383.75	53.75	76.8
Forest land	1,631.16	4.77	262.02	0.77	3,819.41	11.17	134.2
Water land	147.4227	0.43	1,091.75	3.19	132.55	0.39	-10.1
Built-up land	1,748.19	5.11	3,187.91	9.32	2,216.82	6.48	26.8
Barren land	8,178.79	23.91	9,390.32	27.45	2,309.83	6.75	-71.8
Ridge land	12,101.96	35.38	2,872.73	8.40	7,342.10	21.47	-39.3

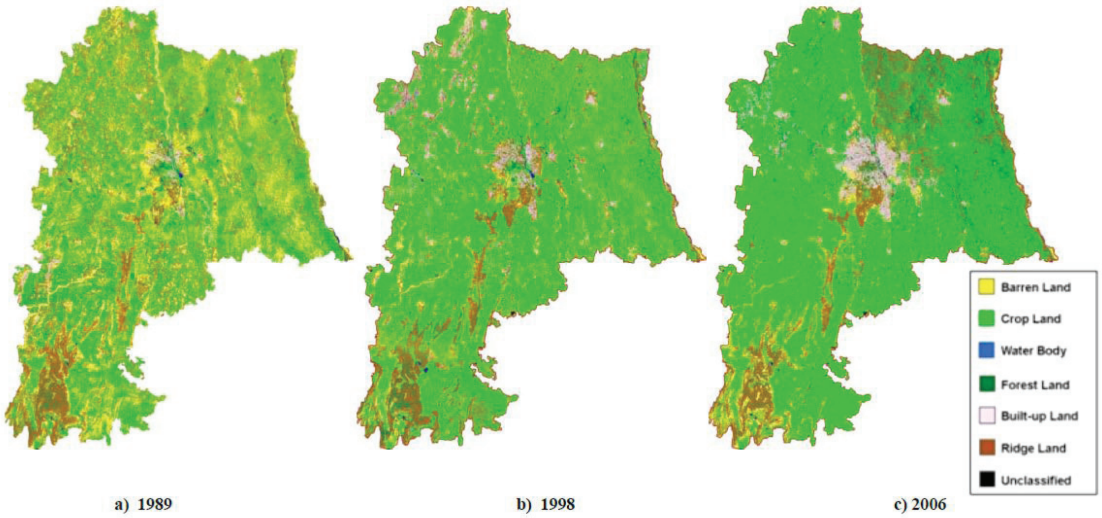

Fig. 2. Rabi season classified images

Table 3. Matrices of land cover and changes (%) from 1989 to 2006

a. 1989 to 1998

	1989					
1998	Crop land	Forest land	Water body	Built-up land	Barren land	Ridge land
Crop land	100	0	0	0	0	0
Forest land	66.3	51.9	11.8	32.7	40.8	47.4
Water land	2.3	13.1	8.9	1.7	1.3	4.0
Built-up land	0.3	0.8	28.7	2.0	0.7	0.7
Barren land	6.5	5.5	10.0	24.8	11.6	8.5
Ridge land	5.3	3.9	13.3	11.9	14.3	7.1
1998 Total	100.0	100.0	100.0	100.0	100.0	100.0
Class Changes	19.4	24.8	27.3	26.9	31.3	32.2
Image Difference	33.7	86.9	71.4	75.2	85.7	67.8

b. 1998 to 2006

	1998					
2006	Crop land	Forest land	Water body	Built-up land	Barren land	Ridge land
Crop land	2.5	3.2	11.1	6.6	20.5	10.7
Forest land	70.4	31.9	11.8	38.2	35.4	37.5
Water land	0.1	1.6	17.4	0.4	0.6	0.3
Built-up land	10.4	25.9	19.8	12.6	8.8	10.9
Barren land	2.9	3.2	14.4	22.0	8.0	7.5
Ridge land	13.7	34.3	25.4	20.3	26.8	33.0
2006 Total	100.0	100.0	100.0	100.0	100.0	100.0
Class Changes	29.6	74.1	82.6	78.0	79.5	67.0
Image Difference	5.7	249.8	-49.5	-30.5	-19.6	-21.8

c. 1989 to 2006

	1989					
2006	Crop land	Forest land	Water body	Built-up land	Barren land	Ridge land
Crop land	2.72	2.474	10.156	8.227	13.275	6.133
Forest land	67.51	57.106	14.539	35.618	45.607	50.067
Water land	0.114	0.364	14.95	0.82	0.354	0.409
Built-up land	11.413	15.171	16.798	11.588	9.074	11.7
Barren land	3.764	4.814	13.246	19.334	8.892	5.471
Ridge land	14.479	20.072	30.311	24.412	22.799	26.221
2006 Total	100	100	100	100	100	100
Class Changes	32.49	84.829	85.05	80.666	86.725	73.779
Image Difference	76.819	134.153	-10.087	26.806	-71.758	-39.331

This was in line with a steep (82.4%) increase in the built-up areas, due an increase in the urban population by about 52.2%[8] during 1989 to 1998 period. It is important to notice that, as against the previous years during which the rural population was lower than the urban population, during 1991-2001 the urban population was about 29.3% more than the rural population. The total growth (26.81%) in built-up (or urban) land use from 1989 to 2006 was contributed by conversion of 8.9% of barren lands, 5.5% of ridge and forest lands and 3.8% of croplands.

3.2.2. Change in built-up, ridge and forest lands

Table 3 further shows that about 4.8% of forest was converted to built-up land between 1989 and 2006, while at the same time, 11.6% of urban/ built-up was converted to forest. These changes may seem to be classification errors, but forested areas are among some of the most sought after areas for developing new housing. Streets and highways were generally classified as urban/ built-up, but when urban tree canopies along the streets grow and expand, the associated pixels may be classified as forest. It may be noticed that the changes from urban or built-up to forest occurred almost entirely near highways and streets. Classification errors may also cause other unusual changes. For example, between 1998 and 2006, 38.2% of built-up land changed to cropland and 13.7% of cropland changed to ridge/ scrub lands. These changes are most likely associated with omission and commission errors in the classified change map. Registration errors and edge effects can also cause apparent errors in the determination of change vs. no-change.

3.2.3. Change in water-bodies, water levels and rainfall

Table 3 shows that during 1989 to 2006 about 13.25% of water-bodies transformed into the built-up lands. However a closer inspection of the spatial distribution of such areas in the water-body change maps revealed that this was mainly due to the misclassification of the dried-up water courses to the built-up or ridge land categories. That there is a general drying up and thus decline of water-bodies (by 10.08%) was evident from a transformation of about 30.31% of water bodies to ridge/ scrub lands during 1989-2006 period. The extent of change in water-bodies may change from year to year due to varying precipitation and temperature. The change detection analysis showed that 1989-1998, associated with above normal to normal rainfalls, was associated with the steepest (77.9%) increase of water bodies in the NCR (Table 3). However, it is worth noticing that most of the water body decline (about 49.5%) occurred during 1998-2006 due to the below normal total annual rainfalls during this period. This was also confirmed by the receding (pre/ post-monsoon) ground water levels due to lowered rainfall and recharge and increased domestic/ industrial water demand because of increased urban population particularly during 1998-2004 period in the study area.

3.2.4. Change in single/ double cropped areas

The single and double cropped area maps and statistics (Table 4) were also generated, from the aforementioned classified images for 1989, 1998 and 2006. 2006. Table 5 illustrate that total cultivated lands changed marginally (0.33 %) between 1989 (36.79% of NCR) and 1998 (36.91% of NCR) but substantially (by about 45.62%) between 1998 and 2006 (with about 54% of NCR cultivated, Figures 3). This was primarily contributed by a progressive exceptional (131.2 %) increase in the Rabi season cropped areas during 1998-2006.

To further evaluate the results of single and double cropped area conversions, change maps and matricesof single and double cropped areas were also created for 1989 to 1998, 1998 to 2006, and 1989 to 2006 periods. These results indicate that, during the seventeen-year period (i.e. 1989-2006, table 6), increases in Rabi season cultivated croplands mainly came from the conversion of the double cropped areas (33%), uncultivated lands (26.3%) and Kharif season cultivated land (24.4%). Table 5 shows that in 1989 about 34.44% of total cultivated area in NCR was double cropped. These double cropped agricultural lands were primarily located around major water sources/ rivers in the study area. During 1989 to 1998, due to extension of in-situ canal system of the study area, the extent of double cropped areas increased (by about 58.3%) and extended to the uncultivated (18.6%) lands. Most of such double cropped areas, obtained from the transformation of the uncultivated lands, were located in the extensive canal network of the study area.

Table 4. Summary of single/ double cropped area statistics for 1989, 1998 and 2006

Cropping Pattern	1989 (Km^2)	(%)	1998 (Km^2)	(%)	2006 (Km^2)	(%)	Relative Change 1989-1998	Relative Change 1998-2006	Relative Change 1989-2006
Double Cropped Land	4335.08	34.44	7194.80	56.99	7455.41	40.55	65.97	3.62	71.98
Rabi Season Single Cropped Land	4792.72	38.08	4277.50	33.88	9887.06	53.78	-10.75	131.14	106.29
Kharif Season Single Cropped Land	3459.03	27.48	1152.51	9.13	1042.13	5.67	-66.68	-9.58	-69.87
Total Cultivated Land	12586.83	100	12624.81	100	18384.6	100	0.30	45.62	46.06

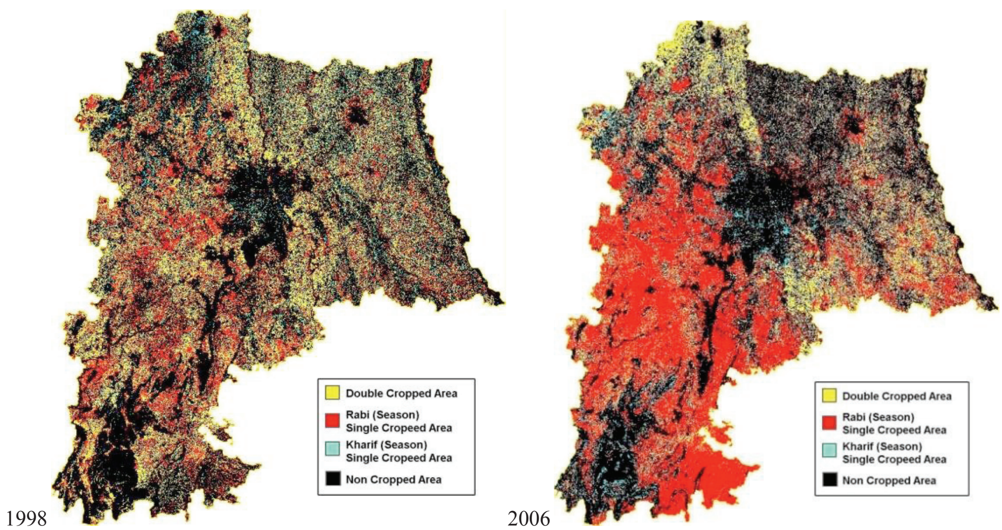

Fig. 3. Spatial distribution of single/ double cropped areas in NCR during 1998

However, due to decreasing total annual rainfalls and increasing urbanization, both double cropped and Kharif season (single) cropped areas suffered a decline of about 12.4 % and 9.6 %, respectively during 1998 - 2006. About 38.1% of the double cropped areas transformed into the uncultivated lands during 1998-2006. In fact the analysis indicated a steep (69.6%) transformation of even the Kharif season (single) cropped areas to the uncultivated lands during 1989-2006. Change detection analysis revealed that these, Kharif season cropped areas transforming into the uncultivated lands, were centered on the highly urbanized/ industrialized areas. Due to normal Rabi season rainfalls such a decline was not associated with the Rabi season cultivated croplands.

3.2.5. Change in degraded croplands

The extent/ type of degraded croplands (Figures4) and their change were also assessed to account for dropping/ stagnant crop yields, particularly during last one decade. The results of degraded cropland statistics and change are presented in Table 5 During last one decade the total degraded lands increased, at a rate of 611.25 Km^{2}per annum, from 5428.38 Km^2 (15.87% of NCR area) to 10,929.55 Km^2 (31.95% of

NCR area). 53.18% of these degraded lands are saline (5813.19 Km^2) with the rest being saline-sodic(25.80%) to sodic (21.01%) in character. Comparison of figures 4 and 3 clearly showthe relation of saline soil area and spatial distribution of Rabi season single cropped area.

3.2.6. Change in cropping pattern

The impact of the changing weather and environmental conditions on the cropping pattern of the study area was also investigated. Analysis of the time series (1980-2006) agricultural production data revealed that, due to the semi-arid climatic conditions (with average annual rainfall of 600 mm); Bajra (with approx. 400,000 ha) during Kharif season and Wheat (with approx. 1250,000 ha) during Rabi season are the dominant crops of the study area. These crops were observed to be predominantly growing on the sandy loam/ loamy sand and relatively more drier and degraded soils of the NCT-Delhi and the southern and the western parts (e.g., Alwar, Rohtak, Rewari, Jhajjar, Gurgaon, Mewat, Faridabad) of the NCR. During last two decades, Wheat cultivated areas increased by about 27% while the Bajra cultivated areas decreased by about 11% respectively. Mustard/ Rapeseed cultivated areas also witnessed an increase of about 700% between 1980 and 2004, with a peak of about 500,000 ha in 1992. Other minor (100,000 - 150, 000 ha) Rabi season cultivated, Barley and Gram, areas also suffered a sharp decline of about 65% since 1980. Rice-Wheat and Sugarcane-Wheat crop rotations were also observed to be practiced particularly in the relatively less semi-arid and canal irrigated Panipat, Sonipat and Bulandshahr and the Baghpat, Meerut and Ghaziabad districts, respectively. Extension of extensive canal system during last one decade (i.e. since 1990) resulted into a 133% increase in the Rice cultivated areas (350,000 ha) and 25% increase in the sugarcane cultivated areas. Thus during last two decades, the study area witnessed a decline in almost all major Kharif season crop cultivating areas, excepting sugarcane.

Table 5. Summary of degraded cropland statistics for 1998 and 2006

Degraded Lands	1998		2006		Relative Change (%)
	Area (Km^2)	%	Area (Km^2)	%	
Saline land	2557.55	7.48	5813.19	17.00	127.30
Low Saline-Sodic Land	1794.27	5.25	1509.47	4.41	-15.87
Moderately Saline-Sodic Land	235.44	0.69	1310.74	3.83	456.72
Sodic (Waterlogged) Land	841.12	2.46	2296.16	6.71	172.99
Total	5428.38	15.87	10929.55	31.95	101.34

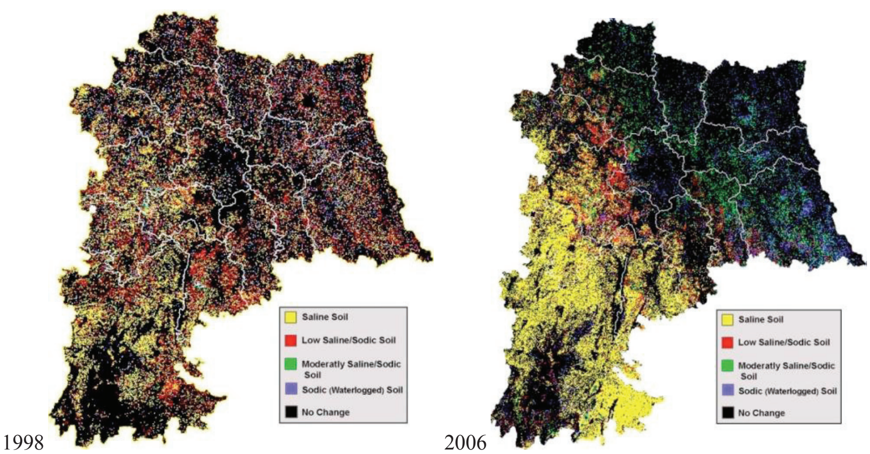

Fig. 4. Classified degraded croplands

3.2.7. Change in irrigation water demand & availability

The impact of decreasing annual rainfalls, receding ground water levels and the study area soil/ topography on the (source independent) available irrigation waters to meet the annual irrigation demand of the study area was also analyzed to show that the annual irrigation demands are about 26.5% higher than the total irrigation waters available in the study area thereby showing that the study area is irrigation starved and that this insufficiency is gradually increasing (28.48%), at an annual rate of 0.31 Km^3, over last one decade.

3.3. Impact of changing land use & bio-physical/ economic factors on agricultural profitability & food grain security

The impact of continuously increasing soil salinity/ sodicity and declining annual rainfall and surface/ ground water levels on the yields of the major crops of the study area were also analyzed. The analysis indicated stagnating/ decreasing crop yields from the increasingly degraded and water starved croplands from year 2001 onwards. The decreasing crop yields were also associated with increasing cost of production and stagnating farm harvest prices thereby leading to a general decrease in the crop B/C ratios and hence the agricultural profitability of the study area.

4. Conclusions

The study could thus lead to a detailed and lucid spatio-temporal (quantitative) assessment of the major bio-physical factors governing land use/ land cover change in the National Capital Region. It is expected that the study would go a long way in facilitating better policy making and developing valid change detection methodologies for the National Capital Region of India.

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