

Land Use/Land Cover (LULC) Dynamics in a Semi-Arid Watershed in Eastern Rajasthan, India Using Geospatial Tools

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Abstract

Land use/land cover (LULC) change analysis has become a unique approach in determining the extent of degradation of natural resources within a given period of time. Remote sensing and GIS techniques have proved to be efficient tools for mapping and analyzing LULC changes over the last few decades. LULC change analysis has been carried out in Ruparel watershed which is situated in Alwar district, Eastern Rajasthan, India, based on visual image interpretation and change detection analysis of multi-temporal satellite data pertaining to IRS-P6 LISS III data of 2004 (Path-Row 95:52), IRS-P6 LISS III of 2014 (Path-Row 95:52) and IRS-R2A LISS III data of 2021. Visual image interpretation led to the delineation of 13 LULC classes using ArcGIS 10.5 software and include categories such as cultivated land, fallow land dense forest, open forest, degraded forest, open scrub, gullied/ravenous land, settlement/built-up land, River/waterbody, dry waterbody/dry river, plantation, barren/rocky/stony waste, and stone quarry. Results of the analysis depict significant LULC changes that have taken place in the area from 2004 to 2021. LULC categories such as cultivated land and settlement/built-up land have reported major changes in terms of their increase with 56.42 km² (4.63%) and 31.9 km² (2.63%) respectively primarily because of an increase in population. Likewise, the dense forest has reported a decrease of 33.78 km² (2.78%) in its area and has been converted into degraded forest *i.e.*, 32.04 km² (2.64%) and open forest 2.85 km² (0.24%) due to increased human exploitation of forest resources and mining activities taking place within the forested area. The study area needs the immediate attention of policymakers and stakeholders as the study area being part of the National Capital Region (NCR) will see excessive in-migration of the population in coming years which will further deplete the precious resources in the area.

Keywords

Land Use/Land Cover, Ruparel Watershed, Change Detection Analysis, Remote Sensing and GIS

1. Introduction

Land use/land cover (LULC) change analysis has become an important aspect in monitoring the impact of both the natural as well as anthropogenic activities on natural resources within a given period of time. LULC pattern of a region is the outcome of both natural and socio-economic factors as well as their utilization by man in time and space [1]. Spatio-temporal LULC change analysis is used to study the changes that are brought as a result of the spatial variability in the distribution of land and water resources and the alterations due to human interactions with various ecological systems. With the rapid and uncontrolled expansion of population, there has been a significant change in land cover particularly the conversion of forestland into agricultural land to supply the never-ending food demand of the growing population. “Land cover” generally refers to the biophysical features which are present on the earth’s surface, whereas the term “Land use” refers to the human activities associated with these features. Even though both the terms land use and land cover are very often used interchangeably, there is a clear distinction between the two. Land cover signifies the spatial distribution of various land cover classes on the earth’s surface and can be directly estimated qualitatively as well as quantitatively by remote sensing whereas, land use and its changes necessitate the integration of natural and social scientific methods to assess which human activities are occurring in different parts of the landscape, even when the land cover appears to be the same [2]. Changes in LULC help in understanding the changing dynamics of the land surface over a certain period of time which thereby helps in managing natural resources for sustainable development. LULC change involves the quantitative changes in the areal extent *i.e.*, increase or decrease of a given type of land use and land cover respectively [3].

LULC analysis is the most commonly used method for proper planning and management of natural resources however knowledge of the existing state of the landscape, its change and spatial distribution are some of the important factors which are pre-requisite for planning [4]. Application of remote sensing data has widely been acknowledged for gathering and monitoring LULC changes due its repeated and synoptic coverage capabilities, besides Geographic Information System (GIS) allows the integration of multiple data sets for detailed analysis. Remote sensing coupled with GIS possess immense potential in getting valuable information using multi-temporal, spectral and cost-effective data, for mapping, monitoring and assessing changes at landscape level. Recent studies on LULC analysis in India using remote sensing and GIS techniques have been carried out

by [5]-[15]. The present study has been carried out to analyze the land use/land cover changes in Ruparel watershed of Alwar district, Eastern Rajasthan, India from using multi-temporal remote sensing data of 2004, 2014 and 2021.

2. Study Area

Ruparel watershed is situated in Alwar district, Eastern Rajasthan, India and covers a geographical area of 1215.76 km². The watershed is bounded between 27°10'N to 27°54'N latitudes and 76°16'E and 76°45'E longitudes (**Figure 1**). The maximum and minimum elevation encountered in the study area is 732 m and 231 m above mean sea level respectively. Slope varies from 0° to 60° and has been categorized into three classes of equal intervals *i.e.*, gentle (0° to 20°), moderate (20° to 40°) and steep (40° to 60°). The study area has an undulating topography of Aravalli hills in the form of rocky and precipitous hills which almost run parallel. The Aravalli hills are low in the north and east of the study area but rise boldly and abruptly on the south-western side presenting an almost impassable wall of rock whereas Quaternary fertile Alluvial plains occupy the eastern side of the watershed. The study area has semi-arid climate with hot summers and cold winters and is mainly rainfed with fairly good monsoonal rainfall with mean annual rainfall of 555.13 mm and maximum and minimum temperatures recorded 47°C and 0.76°C respectively. Agriculture is the main occupation, and the major crops grown are Mustard, bajra, wheat, gram, arhar and ground nuts. The area is primarily drained by Ruparel River and its tributaries which originates from Udainath hills in Thanagazi tehsil of Alwar district, flows eastwards and finally terminates in the adjoining Bharatpur district of Rajasthan. Entisols and Inceptisols are the two major soil groups present, representing gravelly sandy loam, sand, loamy sand, sandy loam, fine sand, loam, and sandy clay loam textures.

3. Data Sources and Methodology

Survey of India toposheets (54A/6, 54A/7, 54A/8, 54A/10, 54A/11 and 54A/12) on 1:50,000 were mosaicked in order to demarcate watershed boundary and was further used for the generation of base map. The toposheets were scanned, clipped, georeferenced and then registered to UTM projection (WGS-84, zone 43) in ArcGIS 10.5 environment. The watershed boundary of the Ruparel watershed was delineated by taking slope, spot height, first order channels and drainage flow directions into consideration.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM data of 30 m resolution downloaded from USGS explorer was used to prepare the elevation and slope maps of the watershed. Standard Geocoded False Color Composite (FCC) of Indian Remote Sensing satellite IRS-P6 LISS III (Linear Imaging Self Scanning) data of 2004 (Path-Row: 95:52) (**Figure 2(a)**), IRS-P6 LISS III data of 2014 (Path-Row: 95:52) (**Figure 2(b)**) and IRS-R2A LISS III data of 2021 (Path-Row: 95:52) (**Figure 2(c)**) acquired from National Remote

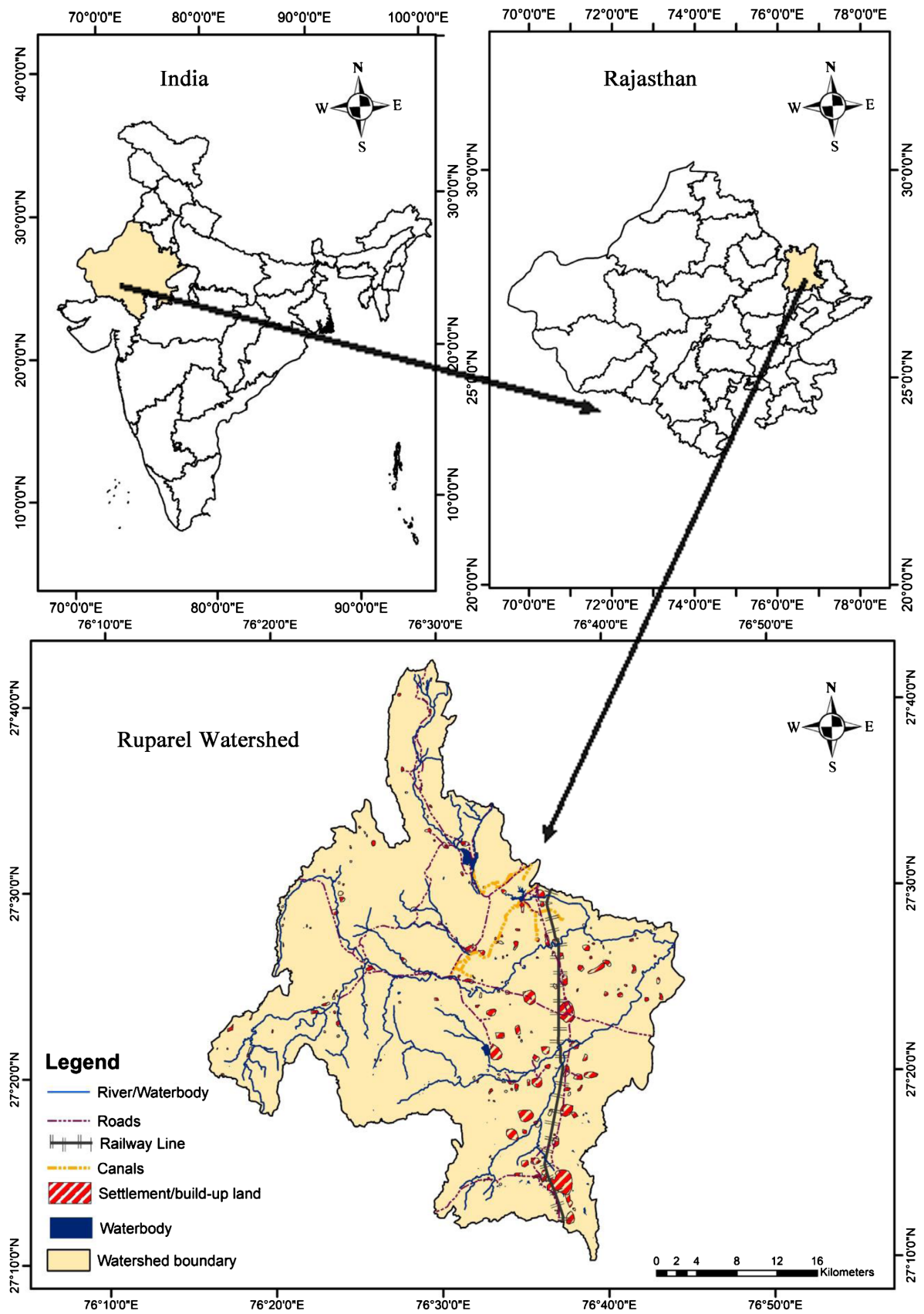


Figure 1. Location map of the study area.

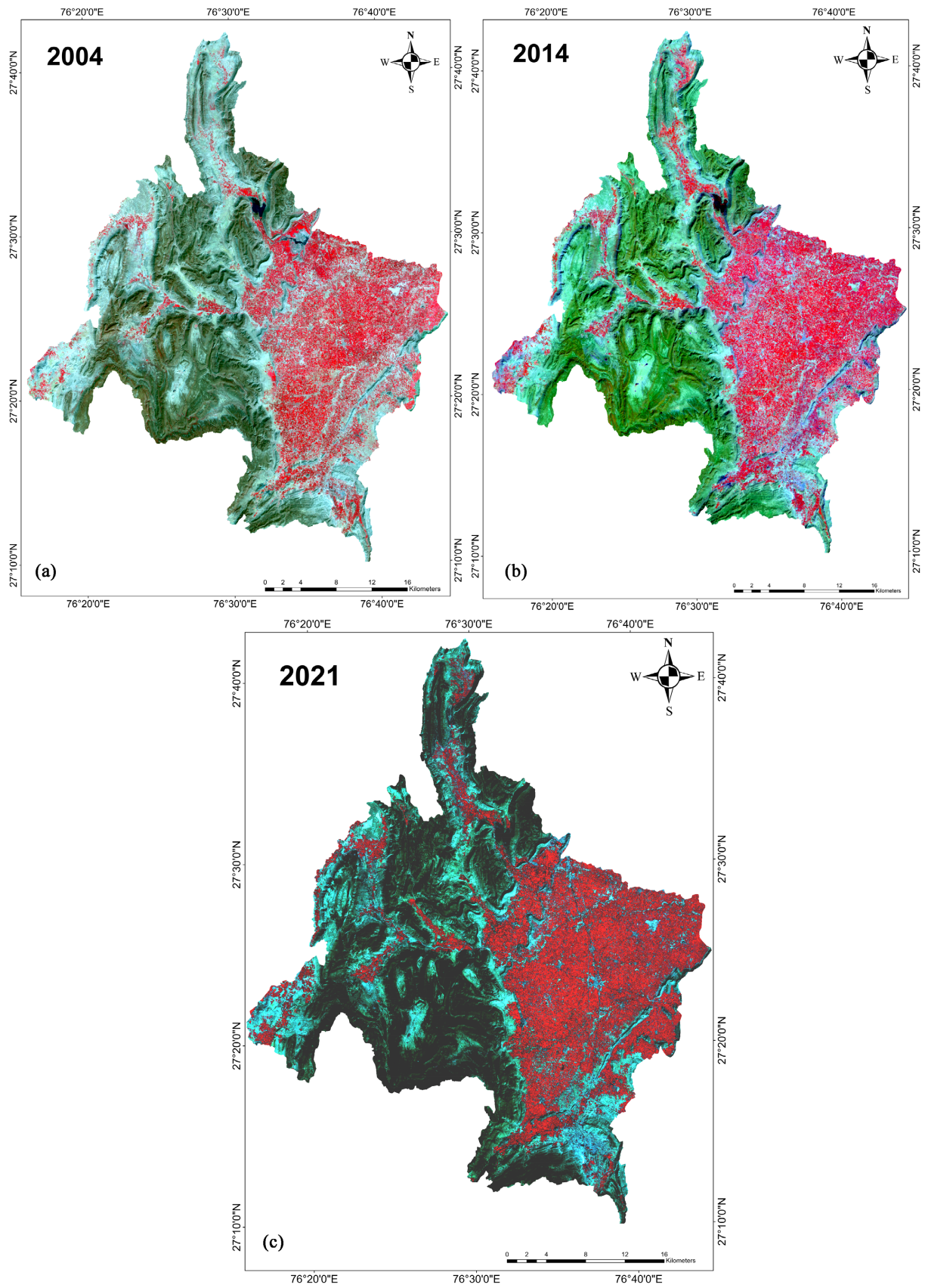


Figure 2. Multi-temporal satellite data of (a) IRS-P6 LISS III 2004; (b) IRS-P6 LISS III 2014; (c) IRS-R2A LISS III 2021.

Sensing Centre (NRSC) Hyderabad were utilized for land use/land cover mapping, analysis and change detection. Ground truthing and collection of secondary data from published and unpublished sources was done to further supplement the study. For the assessment and evaluation of LULC change, methods such as visual image interpretation and change analysis were used. Visual interpretation of satellite data on the basis of photographic and geotechnical elements such as tone, texture, shape, size, pattern and association were used to delineate 13 LULC classes namely, cultivated land, fallow land dense forest, open forest, open scrub, degraded forest, plantation, gullied/ravenous land, barren/rocky/stony waste, river/waterbody, dry waterbody/dry river, settlement/build-up land and stone quarry. LULC maps were prepared in ArcGIS 10.5 software and each LULC category was assigned a unique polygon id and subsequently area under each category was computed both in square kilometers and percentage. For change analysis either image to image or map to map comparison can be used [16]. However, in the present study map to map comparison has been used as it provides detailed and precise information of land use/land cover change as compared to image-to-image comparison. Land use and land cover analysis for the period 2004 to 2014, 2014 to 2021 and 2004 to 2021 was done and the results were then compared to determine the extent of change of each land use/land cover category in Ruparel watershed.

The LULC statistics derived from 2004, 2014 and 2021 satellite data were analysed at sub-watershed level, to assess the changes at micro-level. The whole watershed was demarcated into 17 sub-watersheds and LULC changes were computed at sub-watershed level.

4. Results and Discussion

4.1. Spectral Characteristics of LULC Classes

Based on visual image interpretation and extensive field knowledge each land use/land cover has been successfully recognized and delineated on standard geocoded FCCs of satellite data. Cultivated land is identified on the FCC satellite data bright red to red tone, smooth texture, regular to sub-regular boundary and well-shaped pattern and is mainly confined to the central and eastern parts of the study area, whereas fallow land displays light tone, medium texture, irregular boundary and non-contiguous pattern and is found in proximity to cultivated land throughout the study area. Dense forest exhibits dark green to light red tone, medium texture, scattered pattern and irregular outline and its association with physiographic high relief zones in the study area whereas open forest shows green tone, coarse texture, irregular outline and contiguous to non-contiguous pattern. Open scrub displays whitish cyan to greenish tone, irregular boundary outline, scattered pattern and coarse texture whereas plantation shows dark red tone, medium texture, scattered pattern and is found in association with cultivated land in the study area. Degraded forest displays light greenish to cyan tone, coarse texture and non-contiguous pattern with an irregular boundary.

Gullied/ravenous land is identified by its light to bright cyan tone, very coarse to coarse texture, associated with dendritic to sub-dendritic pattern of lower stream order and is mainly found along the banks of Ruparel River suggesting gully erosion in the study area. Barren/rocky/stony waste is interpreted by its light green tone, coarse to medium texture, linear pattern and is defined by sharp and well-defined boundary. River/Waterbody is identified by its black tone due to the absorption of incoming infra-red radiation, have smooth texture and well-defined boundary outline where as dry waterbody is recognized on FCC by its light tone which is due to the presence of sand smooth texture and has a linear pattern and an irregular boundary. Settlement/built-up land is distinguished by its cyan blue tone, coarse texture, checkered pattern and regular to irregular outline with a close proximity to cultivated and fallow land in the watershed. Stone quarry is marked by its whitish cyan tone, rough and uneven texture, scattered pattern with variable size and shape, depressed topography, and lack of any vegetation or land use activity (**Figure 3**).

4.2. Land Use/Land Cover Analysis

4.2.1. Land Use/Land Cover Analysis (2004)

IRS P6 LISS III data of 2004 was used as a baseline data to carry out LULC mapping in the study area and the analysis suggests that dense forest is the most dominant land cover category which occupies an area of 391.12 km² (32.17%) of

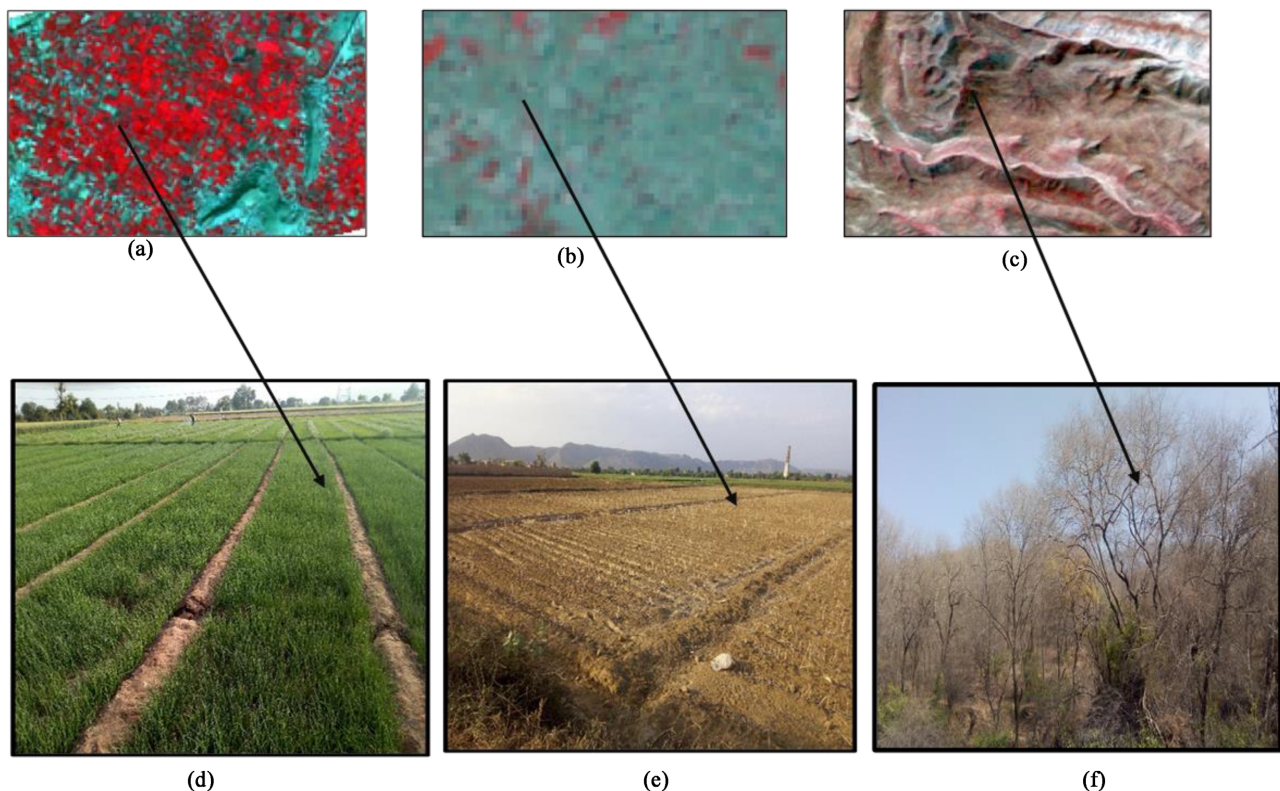


Figure 3. Spectral signatures of LULC (a) Cultivated land; (b) Fallow land; (c) Dense Forest and their corresponding field photographs (d), (e) and (f).

the total watershed area and is found in the western, northern and southern parts of the watershed. Cultivated land is the second dominant LULC category occupying an area of 295.9 km² (24.33%) and is spread throughout the watershed. Fallow land occupies an area of 182.95 km² (15.04%) of the total watershed area and is present in association with cultivated land throughout the study area. Open scrub is spread over an area of 140.53 km² (11.55%) and is confined to the southern, western, north-western and northern parts of the watershed. Degraded forest covers an area of 77.23 km² (6.35%) whereas Open Forest is spread over an area of 35.49 km² (2.91%) of the total watershed area. Barren/rocky/stony waste occupies an area of 28.05 km² (2.31%) and is found in the eastern, southern and western parts of the watershed. Gullied/Ravenous land is found along the course of Ruparel River in the central, eastern and western parts of the watershed and covers an area of 25.5 km² (2.09%). Settlement/build-up land occupies an area of 22.78 km² (1.87%) of total watershed area. River/waterbody covers an area of 4.89 km² (0.4%) whereas dry river/dry waterbody covers an area of 6.09 km² (0.5%) of total watershed area (**Table 1**).

4.2.2. Land Use/Land Cover Analysis (2014)

LULC analysis of IRS P6 LISS III data of 2014 suggests that dense forest is the dominant land cover category which covers an area of 372.26 km² (30.61%) and occupies the physiographic uplands in the northern, southern and western parts

Table 1. LULC statistics and change detection during 2004-2014-2021 period based on IRS data.

| LULC Categories | 2004 | | 2014 | | 2021 | | Change | | | | | |
|--------------------------|-------------------------|------------|-------------------------|------------|-------------------------|------------|-------------------------|----------|-------------------------|----------|-------------------------|----------|
| | | | | | | | 2014-2004 | | 2021-2014 | | 2021-2004 | |
| | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) |
| Cultivated land | 295.9 | 24.34 | 342.02 | 28.13 | 352.32 | 28.97 | 46.12 | 3.79 | 10.3 | 0.84 | 56.42 | 4.63 |
| Fallow land | 182.95 | 15.05 | 135.13 | 11.11 | 101.1 | 8.32 | -47.82 | -3.94 | -34.03 | -2.79 | -81.85 | -6.73 |
| Dense forest | 391.12 | 32.17 | 372.26 | 30.62 | 357.34 | 29.39 | -18.86 | -1.55 | -14.92 | -1.23 | -33.78 | -2.78 |
| Open forest | 35.49 | 2.92 | 33.24 | 2.73 | 32.64 | 2.68 | -2.25 | -0.19 | -0.6 | -0.05 | -2.85 | -0.24 |
| Degraded forest | 77.23 | 6.35 | 96.2 | 7.91 | 109.27 | 8.99 | 18.97 | 1.56 | 13.07 | 1.08 | 32.04 | 2.64 |
| Open scrub | 140.53 | 11.56 | 136.94 | 11.26 | 135.89 | 11.18 | -3.59 | -0.3 | -1.05 | -0.08 | -4.64 | -0.38 |
| Plantation | 4.71 | 0.39 | 8.39 | 0.7 | 13.49 | 1.11 | 3.68 | 0.31 | 5.1 | 0.41 | 8.78 | 0.72 |
| Gullied/Ravenous land | 25.5 | 2.09 | 21.85 | 1.8 | 17.65 | 1.45 | -3.65 | -0.29 | -4.2 | -0.35 | -7.85 | -0.64 |
| Barren/Rocky/Stony waste | 28.05 | 2.31 | 28.26 | 2.32 | 28.26 | 2.32 | 0.21 | 0.01 | – | – | 0.21 | 0.01 |
| River/Waterbody | 4.89 | 0.4 | 5.15 | 0.42 | 4.4 | 0.36 | 0.26 | 0.02 | -0.75 | -0.06 | -0.49 | -0.04 |
| Dry Waterbody/Dry River | 6.09 | 0.5 | 5.29 | 0.44 | 7.76 | 0.64 | -0.8 | -0.06 | 2.47 | 0.2 | 1.67 | 0.14 |
| Settlement/Built up Land | 22.78 | 1.87 | 30.14 | 2.48 | 54.68 | 4.5 | 7.36 | 0.61 | 24.54 | 2.02 | 31.9 | 2.63 |
| Stone quarry | 0.52 | 0.04 | 0.89 | 0.07 | 0.96 | 0.08 | 0.37 | 0.03 | 0.07 | 0.01 | 0.44 | 0.04 |
| Total | 1215.76 | 100 | 1215.76 | 100 | 1215.76 | 100 | | | | | | |

of the watershed. The agricultural land covers an area of 478.96 km² (39.39%) of the total watershed area. Out of which cultivated land covers an area of 342.02 km² (28.13%) and fallow land is spread over an area of 135.13 km² (11.11%). Open scrub is spread over an area of 136.94 km² (11.26%) whereas Degraded Forest covers an area of 96.2 km² (7.91%) of total watershed area. Open forest covers an area of 33.24 km² (2.73%) and Settlement/built-up land occupies an area of 30.14 km² (2.47%) of the total watershed area. The rest *i.e.*, 69.83 km² (5.74%) of the watershed area is occupied by LULC categories such as barren/rocky/stony waste, gullied/ravenous land, plantation, dry river/dry waterbody, river/waterbody and stone quarry (**Table 1**).

4.2.3. Land Use/Land Cover Analysis (2021)

IRS-R2A LISS III geocoded FCC data of 2021 has been used as the third and most recent data set for LULC mapping. LULC analysis of 2021 data set suggests that dense forest covers an area of 357.34 km² (29.39%) of the total watershed area and has remain the most dominant land cover category throughout the assessment period 2004-2021. Cultivated land is still the second most dominant LULC category and constitutes 352.32 km² (28.97%) whereas Fallow land covers an area 101.1 km² (8.31%) of total watershed area. Open forest is spread over an area of 32.64 km² (2.68%) and settlement /built-up land covers an area of 54.68 km² (4.49%) of total watershed area. The rest *i.e.*, 54.87 km² (4.51%) of the total watershed area is covered by LULC categories such as barren/rocky/stony waste, gullied/ravenous land, plantation, dry waterbody/dry river, river/waterbody and stone quarry (**Table 1**).

4.3. LULC Change Detection Analysis

Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times [16]. LULC Change detection analysis involves the use of multitemporal datasets to quantitatively analyse changes in LULC classes [17]. Change detection method is useful in different applications such as LULC analysis, monitoring of shifting cultivation, study of changes in vegetation phenology, seasonal changes in crop production, crop stress detection, disaster monitoring, and other environmental changes [18]. LULC change detection methods are broadly divided into Pre-classification change detection method and post-classification change detection method. The former classification method analyses transformed images from two different dates and produces change vs. no change maps without identifying the nature of the changes [19] [20] whereas the post-classification method not only locates changes, but also offers “from-to” change information, reducing the challenge imposed by sensor and atmospheric condition variations [21] [22] [23]. Land use/land cover maps for the year 2004, 2014 and 2021 (**Figures 4(a)-(c)**) were generated from three satellite data sets and the changes under each land use/land cover category were computed both in area and percentage (**Table 1**). The analysis suggests that dense forest and the cultivated land are the dominant

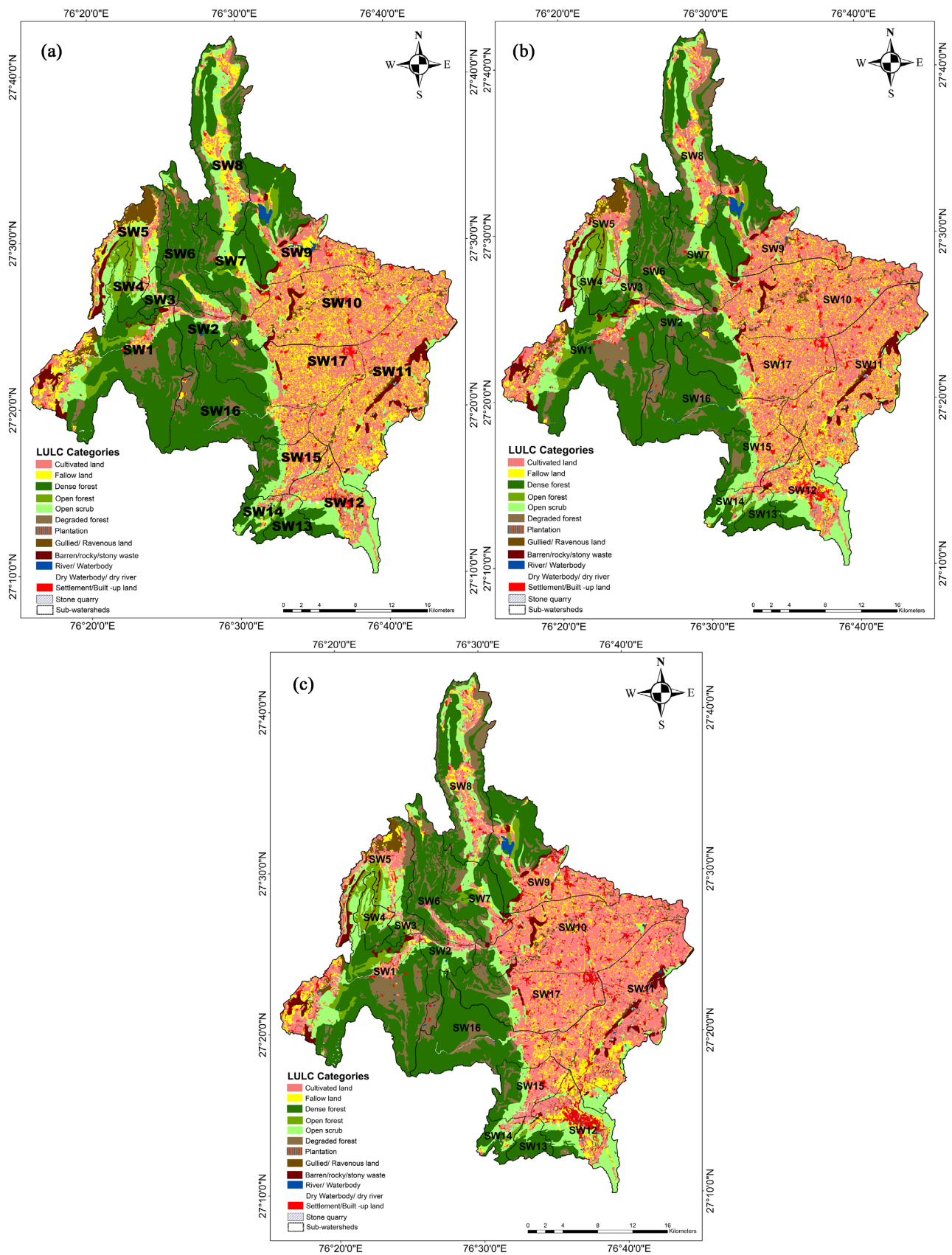


Figure 4. Land use/land cover map derived from (a) IRS-P6 LISS III 2004; (b) IRS-P6 LISS III 2014; (c) IRS-R2A LISS III 2021.

LULC in the study area from the period 2004 to 2021. Major changes in land use/land cover can be seen in (Figure 5) when comparing the land use/land cover maps from 2004, 2014 and 2021 as well as their corresponding statistics which are discussed as under.

4.3.1. LULC Cover Change Detection (2004 to 2014)

LULC statistics generated from the comparative analysis of LULC data for the period 2004-2014 suggests that cultivated land has increased from 295.9 km² (24.33%) from 2004 to 342.02 km² (28.13%) in 2014, suggesting a total gain of 46.12 km² (3.79%) from 2004 to 2014. Increase in area under cultivated land is possibly due to good monsoonal rain in the preceding years which has led to reduction in fallow land by 47.82 km² (3.93%). Dense forest has reduced by 18.86 km² (1.56%) *i.e.*, from 391.12 km² (32.17%) in 2004 to 372.26 km² (30.61%) in 2014. Additionally, there has been degradation of dense forest which has increased by 18.97 km² (1.56%). Area under open forest has decreased from 35.49 km² (2.91%) in 2004 to 33.24 km² (2.73%) in 2014. Open scrub has also decreased in its areal extent from 140.53 km² (11.55%) to 136.94 km² (11.26%) in 2014. However, plantation has shown a total increase of 3.68 km² (0.31%) from 2004 to 2014. Gullied/Ravenous land has shown a reduction of 25.5 km² (2.09%) from 2004 to 21.85 km² (1.79%) in 2014 whereas settlement/build-up land has reported a total expansion of 7.36 km² (0.61%) *i.e.*, from 22.78 km² (1.87%) in 2004 to 30.14 km² (2.47%) from 2004 to 2014. River/Waterbody has increased from 4.89 km² (0.4%) in 2004 to 5.15 km² (0.43%) in 2014 whereas dry waterbody/dry river shows an overall decrease of 0.8 km² (0.06%) during 2004 to 2014. Stone quarry has increased from 0.52 km² (0.04%) from 2004 to 0.89 km² (0.07%) in 2014, registering an increase of 0.37 km² (0.03%) from 2004 to 2014.

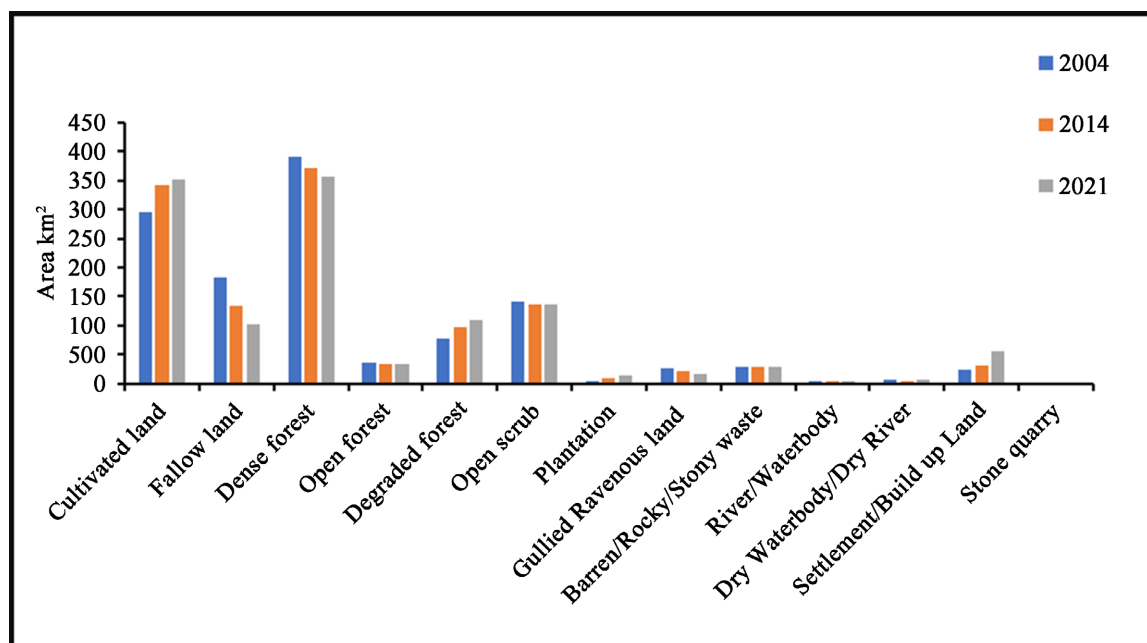


Figure 5. Changes in LULC categories during 2004 - 2021 period.

The major changes in LULC from 2004 to 2021 are seen in cultivated land, plantation, stone quarry, river/waterbody and settlement/build-up land (**Table 1**).

4.3.2. LULC Change Detection (2014 to 2021)

Comparative analysis of LULC data for the period 2014–2021 suggests that cultivated has reported a total gain of a total gain of 10.3 km² (0.84%) *i.e.*, from 342.02 km² (28.13%) in 2014 to 352.32 km² (28.97%) in 2021 with fallow land showing a reduction of 4.03 km² (2.79%). Dense forest has further reduced in its areal extent *i.e.*, 14.92 km² (1.22%) which has led to an overall increase of 13.07 km² (1.07%) in degraded forest. Open forest and open scrub have reported a total decrease of 0.6 km² (0.04%) and 1.05 km² (0.08%) respectively. However, plantation has further reported an increase of 5.1 km² (0.41%) *i.e.*, from 8.39 km² (0.69%) in 2014 to 13.49 km² (1.1 %) in 2021. Gullied/ravenous land has decreased from 21.85 km² (1.79%) in 2014 to 17.65 km² (1.45%) in 2021 whereas settlement/build-up land has shown further expansion of 24.54 km² (2.01%) *i.e.*, from 30.14 km² (2.47%) in 2014 to 54.68 km² (4.49%) in 2021. River/waterbody has shown a decline in its areal extent from 5.15 km² (0.43%) in 2014 to 4.4 km² (0.36%) in 2021 whereas dry waterbody/dry river has shown an increase from 5.29 km² (0.43%) in 2014 to 7.76 km² (0.63%) in 2021. Stone quarry has also reported an increase of 0.07 km² (0.01%) *i.e.*, from 0.89 km² (0.07%) in 2014 to 0.96 km² (0.07%) in 2021. Cultivated land, plantation, settlement/build-up land, dry waterbody, dry river and stone quarry are the land use/land cover categories which has reported significant changes during 2014 to 2021 (**Table 1**).

4.3.3. LULC Change Detection (2004 to 2021)

LULC statistics generated from the comparative analysis of LULC data for the period 2004 to 2021 suggests that cultivated land has shown an overall increase of 56.42 km² (4.64%) *i.e.*, from 295.9 km² (24.33%) in 2004 to 352.32 km² (28.97%) in 2021 whereas as fallow land has further reported a reduction of 81.85 km² (6.73%) *i.e.*, from 182.95 km² (15.04%) in 2004 to 101.1 km² (8.31%) in 2021. Dense forest has also reported a decrease of 33.78 km² (2.77%) in its areal extent *i.e.*, from 391.12 km² (32.17%) in 2004 to 357.34 km² (29.39%) in 2021 which has further led to an increase of 32.04 km² (2.63%) in degraded forest 77.23 km² (6.35%) in 2004 to 109.27 km² (8.98 %) in 2021. Open forest and open scrub have reported a total decrease of 2.85 km² (0.23%) and 4.64 km² (0.38%) from 2014 to 2021 respectively. Plantation has further increased in its areal extent from 8.78 km² (0.72%) *i.e.*, from 4.71 km² (0.38%) in 2004 to 13.49 km² (1.1 %) in 2021 whereas gullied/ravenous land has reported an overall decrease of 7.85 km² (0.64%) in its areal extent. Settlement/build-up land has also shown an expansion of 22.78 km² (1.87%) in 2004 to 54.68 km² (4.49%) in 2021 whereas River/Waterbody has reported a total decrease of 0.49 km² (0.06%) in its areal extent from 4.89 km² (0.4%) in 2004 to 4.4 km² (0.36%) in 2021. Dry waterbody/dry river has shown a total increase of 1.67 km² (0.13%) from 6.09 km² (0.5%) in 2004 to 7.76 km² (0.63%) in 2021. Stone quarry has also reported an

overall increase of 0.44 km² (0.03%) from 0.52 km² (0.04%) in 2004 to 0.96 km² (0.07%) in 2021. The significant changes during 2004 to 2021 are seen in cultivated land, plantation, settlement/build-up land, dry waterbody/dry river and stone quarry (**Table 1**).

The comparative change analysis suggests that the area under cultivated land has increased due to increase in monsoonal rainfall in the previous years and groundwater use which has led to decrease in fallow land. Dense forest has decreased and has been converted into degraded forest and at places into open forest mainly due to anthropogenic activities. Open scrub has reported decrease mainly due its conversion into agricultural land *i.e.*, cultivated land and fallow land in the study area. Area under river/waterbody has reported decrease and has been converted into dry waterbody/dry river, since the river/waterbodies receive highest rainfall only in the monsoonal season and usually remain dry throughout the year. Settlement area has increased due to increase in population and the migration of people from other areas for employment, as the study area is a part of National Capital Region (NCR).

4.4. Sub-Watershed Wise Key Changes in LULC Categories (2004 to 2021)

Comparative analysis of LULC data at sub-watershed level for 2004-2021 (**Table 2**) suggests significant changes which are discussed as under:

- Cultivated land has increased in its area extent in 12 sub-watersheds except SW12 and SW14. The maximum is reported from SW10 *i.e.*, 16.36 km² (11.4%) followed by SW8, SW11, SW17 and SW1. This increase is attributed to the increase in rainfall and soil conservation measures.
- Fallow land has shown decline in 15 sub-watersheds except SW12 and SW13. The maximum decline in fallow land is reported from SW10 *i.e.*, 23.05 km² (16.1%) followed by SW11, SW17, SW8 and SW9.
- Dense forest show reduction in its area in 15 sub-watersheds, except SW10 and SW14. The maximum reduction is reported from SW8 *i.e.*, 6.87 km² (6.5%) followed by SW1, SW17, SW6, SW7 and SW16.
- Degraded forest has reported an increase in its area from all sub-watersheds barring one (SW11), where SW8 shows maximum increase followed by SW8, SW1, SW17, SW7 and SW6.
- Open scrub has reduced in its area in 13 sub-watersheds with SW8 *i.e.*, 2.18 km² (2.06%) showing maximum decline followed by, SW14, SW17, SW6 and SW10.
- Settlement/built-up land has reported increase from all the seventeen sub-watersheds and is attributed to increasing population and demand for housing. The maximum increase in settlement/built-up land from is reported from SW10 *i.e.*, 6.4 km² (4.47%) followed by SW11, SW12 and SW9.

5. Conclusion

The present study in Ruparel watershed using multi-temporal data aimed at

Table 2. LULC statistics at sub-watershed level based on 2004, 2014 and 2021, IRS data.

| LULC categories | LULC 2004 | | LULC 2014 | | LULC 2021 | | LULC Change Analysis | | | | | |
|--------------------------|-------------------------|------------|-------------------------|------------|-------------------------|------------|-------------------------|----------|-------------------------|----------|-------------------------|----------|
| | | | | | | | 2014-2004 | | 2021-2014 | | 2021-2004 | |
| | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) | Area (km ²) | Area (%) |
| SW1 | | | | | | | | | | | | |
| Cultivated land | 13.05 | 8.43 | 18.58 | 12.01 | 17.64 | 11.4 | 5.53 | 3.58 | -0.94 | -0.61 | 4.59 | 2.97 |
| Fallow land | 11.79 | 7.62 | 6.76 | 4.37 | 7.41 | 4.79 | -5.03 | -3.25 | 0.65 | 0.42 | -4.38 | -2.83 |
| Dense forest | 77.28 | 49.94 | 70.83 | 45.77 | 70.56 | 45.59 | -6.45 | -4.17 | -0.27 | -0.18 | -6.72 | -4.35 |
| Open forest | 10.11 | 6.53 | 10.54 | 6.81 | 8.71 | 5.63 | 0.43 | 0.28 | -1.83 | -1.18 | -1.4 | -0.9 |
| Degraded forest | 16.39 | 10.59 | 20.76 | 13.41 | 21.87 | 14.13 | 4.37 | 2.82 | 1.11 | 0.72 | 5.48 | 3.54 |
| Open scrub | 13.27 | 8.57 | 14.49 | 9.36 | 14.9 | 9.63 | 1.22 | 0.79 | 0.41 | 0.27 | 1.63 | 1.06 |
| Plantation | 0.07 | 0.05 | 0.32 | 0.21 | 0.57 | 0.37 | 0.25 | 0.16 | 0.25 | 0.16 | 0.5 | 0.32 |
| Gullied/Ravenous land | 4.18 | 2.7 | 3.31 | 2.14 | 2.54 | 1.64 | -0.87 | -0.56 | -0.77 | -0.5 | -1.64 | -1.06 |
| Barren/Rocky/Stony waste | 5.95 | 3.84 | 5.95 | 3.84 | 5.95 | 3.84 | - | - | - | - | - | - |
| River/Waterbody | 0.38 | 0.25 | 0.54 | 0.35 | 0.38 | 0.25 | 0.16 | 0.1 | -0.16 | -0.1 | - | - |
| Dry Waterbody/Dry River | 0.64 | 0.41 | 0.48 | 0.31 | 0.84 | 0.54 | -0.16 | -0.1 | 0.36 | 0.23 | 0.2 | 0.13 |
| Settlement/Build up Land | 1.65 | 1.06 | 2.2 | 1.42 | 3.39 | 2.19 | 0.55 | 0.36 | 1.19 | 0.77 | 1.74 | 1.13 |
| Total | 154.76 | 100 | 154.76 | 100 | 154.76 | 100 | | | | | | |
| SW2 | | | | | | | | | | | | |
| Cultivated land | 1.89 | 6.03 | 2.18 | 6.95 | 2.01 | 6.41 | 0.29 | 0.92 | -0.17 | -0.54 | 0.12 | 0.38 |
| Fallow land | 0.83 | 2.65 | 0.19 | 0.61 | 0.35 | 1.12 | -0.64 | -2.04 | 0.16 | 0.51 | -0.48 | -1.53 |
| Dense forest | 17.18 | 54.8 | 16.57 | 52.85 | 16.11 | 51.39 | -0.61 | -1.95 | -0.46 | -1.46 | -1.07 | -3.41 |
| Degraded forest | 7.24 | 23.09 | 8.42 | 26.85 | 7.56 | 24.11 | 1.18 | 3.76 | -0.86 | -2.74 | 0.32 | 1.02 |
| Open scrub | 3.11 | 9.92 | 2.93 | 9.35 | 4.11 | 13.11 | -0.18 | -0.57 | 1.18 | 3.76 | 1 | 3.19 |
| Plantation | 0.01 | 0.03 | 0.05 | 0.16 | 0.06 | 0.2 | 0.04 | 0.13 | 0.01 | 0.04 | 0.05 | 0.17 |
| River/Waterbody | 0.24 | 0.77 | 0.26 | 0.82 | 0.22 | 0.7 | 0.02 | 0.05 | -0.04 | -0.12 | -0.02 | -0.07 |
| Dry Waterbody/Dry River | 0.47 | 1.5 | 0.34 | 1.08 | 0.34 | 1.08 | -0.13 | -0.42 | - | - | -0.13 | -0.42 |
| Settlement/Build up Land | 0.38 | 1.21 | 0.41 | 1.31 | 0.59 | 1.88 | 0.03 | 0.1 | 0.18 | 0.57 | 0.21 | 0.67 |
| Total | 31.35 | 100 | 31.35 | 100 | 31.35 | 100 | | | | | | |
| SW3 | | | | | | | | | | | | |
| Cultivated land | 0.95 | 7.49 | 1.38 | 10.9 | 1.18 | 9.31 | 0.43 | 3.41 | -0.2 | -1.59 | 0.23 | 1.82 |
| Fallow land | 0.64 | 5.05 | 0.35 | 2.76 | 0.33 | 2.6 | -0.29 | -2.29 | -0.02 | -0.16 | -0.31 | -2.45 |
| Dense forest | 6.24 | 49.25 | 5.72 | 45.15 | 6.12 | 48.3 | -0.52 | -4.1 | 0.4 | 3.15 | -0.12 | -0.95 |
| Open forest | 0.64 | 5.05 | 0.76 | 6 | 0.66 | 5.21 | 0.12 | 0.95 | -0.1 | -0.79 | 0.02 | 0.16 |
| Degraded forest | 1.35 | 10.66 | 1.54 | 12.15 | 1.57 | 12.4 | 0.19 | 1.49 | 0.03 | 0.25 | 0.22 | 1.74 |
| Open scrub | 2.65 | 20.92 | 2.71 | 21.39 | 2.44 | 19.26 | 0.06 | 0.47 | -0.27 | -2.13 | -0.21 | -1.66 |

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|--------------------------|--------------|------------|--------------|------------|--------------|------------|-------|-------|-------|-------|-------|-------|
| Plantation | – | – | – | – | 0.01 | 0.08 | – | – | 0.01 | 0.08 | 0.01 | 0.08 |
| River/Waterbody | – | – | 0.08 | 0.63 | 0.01 | 0.08 | 0.08 | 0.63 | –0.07 | –0.55 | 0.01 | 0.08 |
| Dry Waterbody/dry river | 0.15 | 1.18 | 0.07 | 0.55 | 0.18 | 1.42 | –0.08 | –0.63 | 0.11 | 0.87 | 0.03 | 0.24 |
| Settlement/Build up Land | 0.04 | 0.32 | 0.05 | 0.39 | 0.16 | 1.26 | 0.01 | 0.07 | 0.11 | 0.87 | 0.12 | 0.94 |
| Stone quarry | 0.01 | 0.08 | 0.01 | 0.08 | 0.01 | 0.08 | – | – | – | – | – | – |
| Total | 12.67 | 100 | 12.67 | 100 | 12.67 | 100 | | | | | | |
| SW4 | | | | | | | | | | | | |
| Cultivated land | 0.58 | 2.84 | 0.69 | 3.38 | 0.56 | 2.75 | 0.11 | 0.54 | –0.13 | –0.63 | –0.02 | –0.09 |
| Fallow land | 0.29 | 1.42 | 0.09 | 0.44 | 0.17 | 0.83 | –0.2 | –0.98 | 0.08 | 0.39 | –0.12 | –0.59 |
| Dense forest | 6.11 | 29.95 | 6.36 | 31.18 | 5.23 | 25.64 | 0.25 | 1.23 | –1.13 | –5.54 | –0.88 | –4.31 |
| Open forest | 7.62 | 37.35 | 6.85 | 33.58 | 7.97 | 39.07 | –0.77 | –3.77 | 1.12 | 5.49 | 0.35 | 1.72 |
| Degraded forest | – | – | – | – | 0.55 | 2.69 | 0 | 0 | 0.55 | 2.69 | 0.55 | 2.69 |
| Open scrub | 5.54 | 27.16 | 6.12 | 30 | 5.46 | 26.77 | 0.58 | 2.84 | –0.66 | –3.23 | –0.08 | –0.39 |
| Plantation | – | – | 0.01 | 0.04 | 0.03 | 0.15 | 0.01 | 0.04 | 0.02 | 0.11 | 0.03 | 0.15 |
| River/Waterbody | 0.03 | 0.15 | 0.03 | 0.15 | 0.06 | 0.29 | – | – | 0.03 | 0.14 | 0.03 | 0.14 |
| Dry Waterbody/dry river | 0.05 | 0.25 | 0.05 | 0.25 | 0.07 | 0.34 | – | – | 0.02 | 0.09 | 0.02 | 0.09 |
| Settlement/Build up Land | 0.18 | 0.88 | 0.2 | 0.98 | 0.3 | 1.47 | 0.02 | 0.1 | 0.1 | 0.49 | 0.12 | 0.59 |
| Total | 20.4 | 100 | 20.4 | 100 | 20.4 | 100 | | | | | | |
| SW5 | | | | | | | | | | | | |
| Cultivated land | 6.94 | 11.49 | 11.61 | 19.22 | 12.23 | 20.25 | 4.67 | 7.73 | 0.62 | 1.03 | 5.29 | 8.76 |
| Fallow land | 6.48 | 10.73 | 4.18 | 6.92 | 4.18 | 6.92 | –2.3 | –3.81 | – | – | –2.3 | –3.81 |
| Dense forest | 5.47 | 9.05 | 4.49 | 7.43 | 4.26 | 7.05 | –0.98 | –1.62 | –0.23 | –0.38 | –1.21 | –2 |
| Open forest | 7.69 | 12.73 | 6.89 | 11.41 | 7.42 | 12.28 | –0.8 | –1.32 | 0.53 | 0.87 | –0.27 | –0.45 |
| Degraded forest | 3.89 | 6.44 | 4.93 | 8.16 | 4.89 | 8.1 | 1.04 | 1.72 | –0.04 | –0.06 | 1 | 1.66 |
| Open scrub | 13.89 | 23 | 13.41 | 22.2 | 13.51 | 22.36 | –0.48 | –0.8 | 0.1 | 0.16 | –0.38 | –0.64 |
| Plantation | 0.15 | 0.24 | 0.22 | 0.36 | 0.33 | 0.55 | 0.07 | 0.12 | 0.11 | 0.19 | 0.18 | 0.31 |
| Gullied/Ravenous land | 10.07 | 16.67 | 8.55 | 14.15 | 7.39 | 12.23 | –1.52 | –2.52 | –1.16 | –1.92 | –2.68 | –4.44 |
| Barren/Rocky/Stony waste | 4.66 | 7.71 | 4.66 | 7.71 | 4.66 | 7.71 | – | – | – | – | – | – |
| River/Waterbody | 0.06 | 0.1 | 0.22 | 0.36 | 0.12 | 0.2 | 0.16 | 0.26 | –0.1 | –0.16 | 0.06 | 0.1 |
| Dry Waterbody/dry river | 0.59 | 0.98 | 0.29 | 0.48 | 0.33 | 0.55 | –0.3 | –0.5 | 0.04 | 0.07 | –0.26 | –0.43 |
| Settlement/Build up Land | 0.52 | 0.86 | 0.96 | 1.58 | 1.09 | 1.8 | 0.44 | 0.72 | 0.13 | 0.22 | 0.57 | 0.94 |
| Total | 60.41 | 100 | 60.41 | 100 | 60.41 | 100 | | | | | | |
| SW6 | | | | | | | | | | | | |
| Cultivated land | 2.31 | 3.97 | 3.81 | 6.55 | 3.96 | 6.81 | 1.5 | 2.58 | 0.15 | 0.26 | 1.65 | 2.84 |
| Fallow land | 2.18 | 3.75 | 1.19 | 2.05 | 1.26 | 2.16 | –0.99 | –1.7 | 0.07 | 0.11 | –0.92 | –1.59 |

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|--------------------------|---------------|------------|---------------|------------|---------------|------------|-------|-------|-------|-------|-------|-------|
| Dense forest | 38.84 | 66.77 | 37.36 | 64.23 | 34.89 | 59.97 | -1.48 | -2.54 | -2.47 | -4.26 | -3.95 | -6.8 |
| Open forest | 0.04 | 0.07 | – | – | | | -0.04 | -0.07 | – | – | -0.04 | -0.07 |
| Degraded forest | 9.83 | 16.9 | 11.28 | 19.39 | 13.25 | 22.78 | 1.45 | 2.49 | 1.97 | 3.39 | 3.42 | 5.88 |
| Open scrub | 4.28 | 7.36 | 3.51 | 6.03 | 3.42 | 5.87 | -0.77 | -1.33 | -0.09 | -0.16 | -0.86 | -1.49 |
| Plantation | 0.02 | 0.03 | 0.24 | 0.41 | 0.24 | 0.41 | 0.22 | 0.38 | – | – | 0.22 | 0.38 |
| Gullied/Ravenous land | – | – | – | – | 0.21 | 0.36 | – | – | 0.21 | 0.36 | 0.21 | 0.36 |
| River/Waterbody | 0.06 | 0.1 | 0.13 | 0.22 | 0.07 | 0.12 | 0.07 | 0.12 | -0.06 | -0.1 | 0.01 | 0.02 |
| Dry Waterbody/dry river | 0.25 | 0.43 | 0.24 | 0.41 | 0.25 | 0.43 | -0.01 | -0.02 | 0.01 | 0.02 | – | – |
| Settlement/Build up Land | 0.36 | 0.62 | 0.41 | 0.71 | 0.62 | 1.07 | 0.05 | 0.09 | 0.21 | 0.36 | 0.26 | 0.45 |
| Total | 58.17 | 100 | 58.17 | 100 | 58.17 | 100 | | | | | | |
| SW7 | | | | | | | | | | | | |
| Cultivated land | 3.19 | 6.08 | 4.18 | 7.97 | 5.25 | 10.01 | 0.99 | 1.89 | 1.07 | 2.04 | 2.06 | 3.93 |
| Fallow land | 3.29 | 6.28 | 2.33 | 4.44 | 1.06 | 2.02 | -0.96 | -1.84 | -1.27 | -2.42 | -2.23 | -4.26 |
| Dense forest | 28.95 | 55.22 | 27.41 | 52.28 | 25.07 | 47.82 | -1.54 | -2.94 | -2.34 | -4.46 | -3.88 | -7.4 |
| Open forest | 2.97 | 5.66 | 2.66 | 5.07 | 2.06 | 3.93 | -0.31 | -0.59 | -0.6 | -1.14 | -0.91 | -1.73 |
| Degraded forest | 4.77 | 9.1 | 6.76 | 12.9 | 9.1 | 17.36 | 1.99 | 3.8 | 2.34 | 4.46 | 4.33 | 8.26 |
| Open scrub | 8.16 | 15.56 | 7.66 | 14.61 | 8.15 | 15.54 | -0.5 | -0.95 | 0.49 | 0.93 | -0.01 | -0.02 |
| Plantation | 0.05 | 0.09 | 0.21 | 0.4 | 0.18 | 0.34 | 0.16 | 0.31 | -0.03 | -0.06 | 0.13 | 0.25 |
| Barren/Rocky/Stony waste | 0.46 | 0.88 | 0.46 | 0.88 | 0.46 | 0.88 | – | – | – | – | – | – |
| River/Waterbody | 0.02 | 0.04 | 0.07 | 0.13 | 0.08 | 0.15 | 0.05 | 0.09 | 0.01 | 0.02 | 0.06 | 0.11 |
| Dry Waterbody/dry river | – | – | – | – | 0.02 | 0.04 | – | – | 0.02 | 0.04 | 0.02 | 0.04 |
| Settlement/Build up Land | 0.57 | 1.09 | 0.69 | 1.32 | 1 | 1.91 | 0.12 | 0.23 | 0.31 | 0.59 | 0.43 | 0.82 |
| Total | 52.43 | 100 | 52.43 | 100 | 52.43 | 100 | | | | | | |
| SW8 | | | | | | | | | | | | |
| Cultivated land | 10.02 | 9.47 | 18.9 | 17.86 | 18.37 | 17.36 | 8.88 | 8.39 | -0.53 | -0.5 | 8.35 | 7.89 |
| Fallow land | 16.04 | 15.15 | 8.55 | 8.08 | 7.1 | 6.71 | -7.49 | -7.07 | -1.45 | -1.37 | -8.94 | -8.44 |
| Dense forest | 42.52 | 40.19 | 36.15 | 34.17 | 35.65 | 33.69 | -6.37 | -6.02 | -0.5 | -0.48 | -6.87 | -6.5 |
| Degraded forest | 14.22 | 13.44 | 20.39 | 19.27 | 22.17 | 20.95 | 6.17 | 5.83 | 1.78 | 1.68 | 7.95 | 7.51 |
| Open scrub | 21.39 | 20.22 | 19.44 | 18.37 | 19.21 | 18.16 | -1.95 | -1.85 | -0.23 | -0.21 | -2.18 | -2.06 |
| Plantation | – | – | 0.29 | 0.27 | 0.45 | 0.43 | 0.29 | 0.27 | 0.16 | 0.16 | 0.45 | 0.43 |
| River/Waterbody | 0.17 | 0.16 | 0.45 | 0.43 | 0.21 | 0.2 | 0.28 | 0.27 | -0.24 | -0.23 | 0.04 | 0.04 |
| Dry Waterbody/dry river | 0.54 | 0.51 | 0.34 | 0.32 | 0.74 | 0.7 | -0.2 | -0.19 | 0.4 | 0.38 | 0.2 | 0.19 |
| Settlement/Build up Land | 0.91 | 0.86 | 1.3 | 1.23 | 1.91 | 1.8 | 0.39 | 0.37 | 0.61 | 0.57 | 1 | 0.94 |
| Total | 105.81 | 100 | 105.81 | 100 | 105.81 | 100 | | | | | | |

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|--------------------------|---------------|------------|---------------|------------|---------------|------------|--------|-------|--------|-------|--------|--------|
| SW9 | | | | | | | | | | | | |
| Cultivated land | 27.49 | 26.77 | 31.06 | 30.26 | 30.68 | 29.89 | 3.57 | 3.49 | -0.38 | -0.37 | 3.19 | 3.12 |
| Fallow land | 13.44 | 13.09 | 8.98 | 8.75 | 7.15 | 6.96 | -4.46 | -4.34 | -1.83 | -1.79 | -6.29 | -6.13 |
| Dense forest | 37.53 | 36.56 | 38.32 | 37.32 | 36.3 | 35.36 | 0.79 | 0.76 | -2.02 | -1.96 | -1.23 | -1.2 |
| Open forest | 4.02 | 3.92 | 3.31 | 3.22 | 3.57 | 3.48 | -0.71 | -0.7 | 0.26 | 0.26 | -0.45 | -0.44 |
| Degraded forest | 3.6 | 3.51 | 3.73 | 3.63 | 3.89 | 3.8 | 0.13 | 0.12 | 0.16 | 0.17 | 0.29 | 0.29 |
| Open scrub | 6.48 | 6.31 | 6.43 | 6.26 | 7.16 | 6.97 | -0.05 | -0.05 | 0.73 | 0.71 | 0.68 | 0.66 |
| Plantation | 0.89 | 0.87 | 1.69 | 1.65 | 1.69 | 1.65 | 0.8 | 0.78 | 0 | 0 | 0.8 | 0.78 |
| Gullied/Ravenous land | 0.93 | 0.91 | 0.56 | 0.55 | 0.57 | 0.55 | -0.37 | -0.36 | 0.01 | 0 | -0.36 | -0.36 |
| Barren/Rocky/Stony waste | 2.53 | 2.46 | 2.53 | 2.46 | 2.53 | 2.46 | - | - | - | - | - | - |
| River/Waterbody | 3.1 | 3.01 | 2.38 | 2.32 | 1.91 | 1.86 | -0.72 | -0.69 | -0.47 | -0.46 | -1.19 | -1.15 |
| Dry Waterbody/dry river | 0.01 | 0.01 | 0.01 | 0.01 | 0.16 | 0.16 | - | - | 0.15 | 0.15 | 0.15 | 0.15 |
| Settlement/Build up Land | 2.49 | 2.43 | 3.49 | 3.4 | 6.85 | 6.67 | 1 | 0.97 | 3.36 | 3.27 | 4.36 | 4.24 |
| Stone quarry | 0.15 | 0.15 | 0.17 | 0.17 | 0.2 | 0.19 | 0.02 | 0.02 | 0.03 | 0.02 | 0.05 | 0.04 |
| Total | 102.66 | 100 | 102.66 | 100 | 102.66 | 100 | | | | | | |
| SW10 | | | | | | | | | | | | |
| Cultivated land | 75.68 | 52.84 | 85.46 | 59.67 | 92.04 | 64.26 | 9.78 | 6.83 | 6.58 | 4.59 | 16.36 | 11.42 |
| Fallow land | 41.86 | 29.23 | 30.35 | 21.2 | 18.81 | 13.13 | -11.51 | -8.03 | -11.54 | -8.07 | -23.05 | -16.1 |
| Dense forest | 4.34 | 3.03 | 4.55 | 3.18 | 4.52 | 3.16 | 0.21 | 0.15 | -0.03 | -0.02 | 0.18 | 0.13 |
| Open forest | 0.2 | 0.14 | 0.02 | 0.01 | | | -0.18 | -0.13 | -0.02 | -0.01 | -0.2 | -0.14 |
| Degraded forest | 1.43 | 1 | 1.51 | 1.05 | 1.66 | 1.16 | 0.08 | 0.05 | 0.15 | 0.11 | 0.23 | 0.16 |
| Open scrub | 5.35 | 3.74 | 4.65 | 3.24 | 4.82 | 3.36 | -0.7 | -0.5 | 0.17 | 0.12 | -0.53 | -0.38 |
| Plantation | 0.56 | 0.39 | 1.19 | 0.83 | 1.33 | 0.93 | 0.63 | 0.44 | 0.14 | 0.1 | 0.77 | 0.54 |
| Gullied/Ravenous land | 4.46 | 3.11 | 5.04 | 3.52 | 3.95 | 2.76 | 0.58 | 0.41 | -1.09 | -0.76 | -0.51 | -0.35 |
| Barren/Rocky/Stony waste | 3.94 | 2.75 | 3.94 | 2.75 | 3.94 | 2.75 | - | - | - | - | - | - |
| River/Waterbody | 0.2 | 0.14 | 0.21 | 0.15 | 0.38 | 0.27 | 0.01 | 0.01 | 0.17 | 0.12 | 0.18 | 0.13 |
| Dry Waterbody/dry river | 0.98 | 0.68 | 0.92 | 0.64 | 1.15 | 0.8 | -0.06 | -0.04 | 0.23 | 0.16 | 0.17 | 0.12 |
| Settlement/Build up Land | 4.22 | 2.95 | 5.38 | 3.76 | 10.62 | 7.42 | 1.16 | 0.81 | 5.24 | 3.66 | 6.4 | 4.47 |
| Total | 143.22 | 100 | 143.22 | 100 | 143.22 | 100 | | | | | | |
| SW11 | | | | | | | | | | | | |
| Cultivated land | 79.18 | 51.21 | 85.67 | 55.41 | 88.88 | 57.48 | 6.49 | 4.2 | 3.21 | 2.07 | 9.7 | 6.27 |
| Fallow land | 45.13 | 29.19 | 37.68 | 24.37 | 26.49 | 17.13 | -7.45 | -4.82 | -11.19 | -7.24 | -18.64 | -12.06 |
| Open scrub | 10.86 | 7.02 | 10.66 | 6.9 | 10.36 | 6.7 | -0.2 | -0.12 | -0.3 | -0.2 | -0.5 | -0.32 |
| Plantation | 0.71 | 0.46 | 1.74 | 1.13 | 4.93 | 3.19 | 1.03 | 0.67 | 3.19 | 2.06 | 4.22 | 2.73 |
| Gullied/Ravenous land | 4.06 | 2.62 | 2.86 | 1.86 | 2.37 | 1.54 | -1.2 | -0.76 | -0.49 | -0.32 | -1.69 | -1.08 |

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|--------------------------|---------------|------------|---------------|------------|---------------|------------|-------|-------|-------|-------|-------|--------|
| Barren/Rocky/Stony waste | 9.21 | 5.95 | 9.21 | 5.95 | 9.21 | 5.95 | – | – | – | – | – | – |
| River/Waterbody | 0.27 | 0.17 | 0.3 | 0.19 | 0.52 | 0.34 | 0.03 | 0.02 | 0.22 | 0.15 | 0.25 | 0.17 |
| Dry Waterbody/dry river | 0.9 | 0.58 | 0.95 | 0.61 | 1.23 | 0.79 | 0.05 | 0.03 | 0.28 | 0.18 | 0.33 | 0.21 |
| Settlement/Build up Land | 4.11 | 2.66 | 5.03 | 3.25 | 10.1 | 6.53 | 0.92 | 0.59 | 5.07 | 3.28 | 5.99 | 3.87 |
| Stone quarry | 0.19 | 0.12 | 0.52 | 0.33 | 0.53 | 0.34 | 0.33 | 0.21 | 0.01 | 0.01 | 0.34 | 0.22 |
| Total | 154.62 | 100 | 154.62 | 100 | 154.62 | 100 | | | | | | |
| SW12 | | | | | | | | | | | | |
| Cultivated land | 19.2 | 30.88 | 15.89 | 25.56 | 10.85 | 17.45 | –3.31 | –5.32 | –5.04 | –8.11 | –8.35 | –13.43 |
| Fallow land | 8.09 | 13.01 | 9.65 | 15.52 | 10.04 | 16.15 | 1.56 | 2.51 | 0.39 | 0.63 | 1.95 | 3.14 |
| Dense forest | 6.65 | 10.7 | 6.72 | 10.81 | 6.03 | 9.7 | 0.07 | 0.11 | –0.69 | –1.11 | –0.62 | –1 |
| Degraded forest | – | – | – | – | 0.56 | 0.9 | – | – | 0.56 | 0.9 | 0.56 | 0.9 |
| Open scrub | 22.12 | 35.58 | 21.69 | 34.88 | 21.64 | 34.81 | –0.43 | –0.7 | –0.05 | –0.07 | –0.48 | –0.77 |
| Plantation | 1.76 | 2.83 | 1.76 | 2.83 | 2.94 | 4.73 | 0 | 0 | 1.18 | 1.9 | 1.18 | 1.9 |
| Gullied/Ravenous land | 0.46 | 0.74 | 0.52 | 0.84 | 0.17 | 0.27 | 0.06 | 0.1 | –0.35 | –0.57 | –0.29 | –0.47 |
| Barren/Rocky/Stony waste | 0.26 | 0.42 | 0.26 | 0.42 | 0.26 | 0.42 | – | – | – | – | – | – |
| River/Waterbody | 0.04 | 0.06 | 0.07 | 0.11 | 0.1 | 0.16 | 0.03 | 0.05 | 0.03 | 0.05 | 0.06 | 0.1 |
| Dry Waterbody/dry river | 0.4 | 0.64 | 0.42 | 0.68 | 0.55 | 0.88 | 0.02 | 0.04 | 0.13 | 0.2 | 0.15 | 0.24 |
| Settlement/Build up Land | 3.16 | 5.08 | 5.16 | 8.3 | 9.01 | 14.5 | 2 | 3.22 | 3.85 | 6.2 | 5.85 | 9.42 |
| Stone quarry | 0.03 | 0.05 | 0.03 | 0.05 | 0.02 | 0.03 | – | – | –0.01 | –0.02 | –0.01 | –0.02 |
| Total | 62.17 | 100 | 62.17 | 100 | 62.17 | 100 | – | 0.01 | – | – | – | 0.01 |
| SW13 | | | | | | | | | | | | |
| Cultivated land | 1.07 | 6.75 | 1.14 | 7.2 | 0.96 | 6.06 | 0.07 | 0.45 | –0.18 | –1.14 | –0.11 | –0.69 |
| Fallow land | 0.31 | 1.96 | 0.27 | 1.71 | 0.42 | 2.65 | –0.04 | –0.25 | 0.15 | 0.94 | 0.11 | 0.69 |
| Dense forest | 10.37 | 65.51 | 10.37 | 65.51 | 10.11 | 63.87 | – | – | –0.26 | –1.64 | –0.26 | –1.64 |
| Open forest | 0.78 | 4.93 | 0.84 | 5.31 | 0.82 | 5.18 | 0.06 | 0.38 | –0.02 | –0.13 | 0.04 | 0.25 |
| Degraded forest | – | – | – | – | 0.3 | 1.9 | 0 | 0 | 0.3 | 1.9 | 0.3 | 1.9 |
| Open scrub | 3.08 | 19.46 | 2.79 | 17.63 | 2.73 | 17.25 | –0.29 | –1.83 | –0.06 | –0.38 | –0.35 | –2.21 |
| Gullied/Ravenous land | 0.05 | 0.32 | | | | | –0.05 | –0.32 | – | – | –0.05 | –0.32 |
| Barren/Rocky/Stony waste | – | – | 0.21 | 1.32 | 0.21 | 1.32 | 0.21 | 1.32 | – | – | 0.21 | 1.32 |
| River/Waterbody | 0.01 | 0.06 | 0.04 | 0.25 | 0.02 | 0.13 | 0.03 | 0.19 | –0.02 | –0.12 | 0.01 | 0.07 |
| Dry Waterbody/dry river | 0.07 | 0.44 | 0.05 | 0.32 | 0.13 | 0.82 | –0.02 | –0.12 | 0.08 | 0.5 | 0.06 | 0.38 |
| Settlement/Build up Land | 0.08 | 0.51 | 0.11 | 0.69 | 0.12 | 0.76 | 0.03 | 0.18 | 0.01 | 0.07 | 0.04 | 0.25 |
| Stone quarry | 0.01 | 0.06 | 0.01 | 0.06 | 0.01 | 0.06 | – | – | – | – | – | – |
| Total | 15.83 | 100 | 15.83 | 100 | 15.83 | 100 | | | | | | |

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| SW14 | | | | | | | | | | | | |
| Cultivated land | 1.28 | 7.54 | 1.21 | 7.13 | 1.73 | 10.19 | -0.07 | -0.41 | 0.52 | 3.06 | 0.45 | 2.65 |
| Fallow land | 0.7 | 4.12 | 0.46 | 2.71 | 0.44 | 2.6 | -0.24 | -1.41 | -0.02 | -0.11 | -0.26 | -1.52 |
| Dense forest | 7.6 | 44.78 | 8.28 | 48.79 | 8.3 | 48.91 | 0.68 | 4.01 | 0.02 | 0.12 | 0.7 | 4.13 |
| Open forest | 1.12 | 6.6 | 1.09 | 6.42 | 1.09 | 6.42 | -0.03 | -0.18 | - | - | -0.03 | -0.18 |
| Degraded forest | - | - | - | - | 0.05 | 0.29 | 0 | 0 | 0.05 | 0.29 | 0.05 | 0.29 |
| Open scrub | 5.8 | 34.18 | 5.49 | 32.35 | 4.53 | 26.69 | -0.31 | -1.83 | -0.96 | -5.66 | -1.27 | -7.49 |
| Plantation | - | - | 0.03 | 0.18 | 0.04 | 0.24 | 0.03 | 0.18 | 0.01 | 0.06 | 0.04 | 0.24 |
| Gullied/Ravenous land | 0.12 | 0.71 | - | - | | | -0.12 | -0.71 | - | - | -0.12 | -0.71 |
| River/Waterbody | 0.03 | 0.18 | 0.01 | 0.06 | - | - | -0.02 | -0.12 | -0.01 | -0.06 | -0.03 | -0.18 |
| Dry Waterbody/dry river | 0.08 | 0.47 | 0.13 | 0.77 | 0.33 | 1.94 | 0.05 | 0.3 | 0.2 | 1.17 | 0.25 | 1.47 |
| Settlement/Build up Land | 0.13 | 0.77 | 0.16 | 0.94 | 0.3 | 1.77 | 0.03 | 0.17 | 0.14 | 0.83 | 0.17 | 1 |
| Stone quarry | 0.11 | 0.65 | 0.11 | 0.65 | 0.16 | 0.94 | - | - | 0.05 | 0.29 | 0.05 | 0.29 |
| Total | 16.97 | 100 | 16.97 | 100 | 16.97 | 100 | | | | | | |
| SW15 | | | | | | | | | | | | |
| Cultivated land | 10.86 | 27.06 | 11.24 | 28.02 | 12.67 | 31.58 | 0.38 | 0.96 | 1.43 | 3.56 | 1.81 | 4.52 |
| Fallow land | 5.42 | 13.51 | 4.9 | 12.21 | 3.32 | 8.28 | -0.52 | -1.3 | -1.58 | -3.93 | -2.1 | -5.23 |
| Dense forest | 12.9 | 32.15 | 11.66 | 29.06 | 11.94 | 29.76 | -1.24 | -3.09 | 0.28 | 0.7 | -0.96 | -2.39 |
| Degraded forest | 2.39 | 5.96 | 3.39 | 8.45 | 3.12 | 7.78 | 1 | 2.49 | -0.27 | -0.67 | 0.73 | 1.82 |
| Open scrub | 6.89 | 17.17 | 7.16 | 17.85 | 6.66 | 16.6 | 0.27 | 0.68 | -0.5 | -1.25 | -0.23 | -0.57 |
| Plantation | 0.02 | 0.05 | 0.05 | 0.12 | 0.13 | 0.32 | 0.03 | 0.07 | 0.08 | 0.2 | 0.11 | 0.27 |
| Gullied/Ravenous land | 0.3 | 0.75 | 0.24 | 0.6 | 0.05 | 0.12 | -0.06 | -0.15 | -0.19 | -0.48 | -0.25 | -0.63 |
| River/Waterbody | 0.12 | 0.3 | 0.08 | 0.2 | 0.05 | 0.12 | -0.04 | -0.1 | -0.03 | -0.08 | -0.07 | -0.18 |
| Dry Waterbody/dry river | 0.28 | 0.7 | 0.29 | 0.72 | 0.44 | 1.1 | 0.01 | 0.02 | 0.15 | 0.38 | 0.16 | 0.4 |
| Settlement/Build up Land | 0.92 | 2.3 | 1.07 | 2.67 | 1.71 | 4.26 | 0.15 | 0.37 | 0.64 | 1.59 | 0.79 | 1.96 |
| Stone quarry | 0.02 | 0.05 | 0.04 | 0.09 | 0.03 | 0.07 | 0.02 | 0.04 | -0.01 | -0.02 | 0.01 | 0.02 |
| Total | 40.12 | 100 | 40.12 | 100 | 40.12 | 100 | | | | | | |
| SW16 | | | | | | | | | | | | |
| Cultivated land | 8.02 | 8.9 | 8.77 | 9.73 | 8.93 | 9.91 | 0.75 | 0.83 | 0.16 | 0.18 | 0.91 | 1.01 |
| Fallow land | 4.75 | 5.27 | 3.87 | 4.3 | 3.46 | 3.84 | -0.88 | -0.97 | -0.41 | -0.46 | -1.29 | -1.43 |
| Dense forest | 65.46 | 72.65 | 63.66 | 70.65 | 62.56 | 69.43 | -1.8 | -2 | -1.1 | -1.22 | -2.9 | -3.22 |
| Open forest | 0.09 | 0.1 | 0.08 | 0.09 | 0.1 | 0.11 | -0.01 | -0.01 | 0.02 | 0.02 | 0.01 | 0.01 |
| Degraded forest | 8.42 | 9.35 | 9.96 | 11.05 | 10.64 | 11.81 | 1.54 | 1.7 | 0.68 | 0.76 | 2.22 | 2.46 |
| Plantation | 0.27 | 0.3 | 0.22 | 0.24 | 0.23 | 0.26 | -0.05 | -0.06 | 0.01 | 0.02 | -0.04 | -0.04 |
| Gullied/Ravenous land | 0.12 | 0.13 | 0.14 | 0.16 | 0.08 | 0.09 | 0.02 | 0.03 | -0.06 | -0.07 | -0.04 | -0.04 |

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| River/Waterbody | 0.07 | 0.08 | 0.19 | 0.21 | 0.16 | 0.18 | 0.12 | 0.13 | −0.03 | −0.03 | 0.09 | 0.1 |
| Dry Waterbody/dry river | 0.45 | 0.5 | 0.44 | 0.49 | 0.62 | 0.69 | −0.01 | −0.01 | 0.18 | 0.2 | 0.17 | 0.19 |
| Settlement/Build up land | 0.5 | 0.55 | 0.55 | 0.61 | 1.12 | 1.24 | 0.05 | 0.06 | 0.57 | 0.63 | 0.62 | 0.69 |
| Total | 90.1 | 100 | 90.1 | 100 | 90.1 | 100 | | | | | | |
| SW17 | | | | | | | | | | | | |
| Cultivated land | 34.19 | 36.35 | 40.25 | 42.79 | 44.38 | 47.18 | 6.06 | 6.44 | 4.13 | 4.39 | 10.19 | 10.83 |
| Fallow land | 21.71 | 23.08 | 15.33 | 16.3 | 9.11 | 9.68 | −6.38 | −6.78 | −6.22 | −6.62 | −12.6 | −13.4 |
| Dense forest | 23.68 | 25.17 | 23.81 | 25.31 | 19.69 | 20.93 | 0.13 | 0.14 | −4.12 | −4.38 | −3.99 | −4.24 |
| Open forest | 0.21 | 0.22 | 0.2 | 0.21 | 0.24 | 0.26 | −0.01 | −0.01 | 0.04 | 0.05 | 0.03 | 0.04 |
| Degraded forest | 3.7 | 3.93 | 3.53 | 3.75 | 8.09 | 8.6 | −0.17 | −0.18 | 4.56 | 4.85 | 4.39 | 4.67 |
| Open scrub | 5.71 | 6.07 | 5.58 | 5.93 | 4.59 | 4.88 | −0.13 | −0.14 | −0.99 | −1.05 | −1.12 | −1.19 |
| Plantation | 0.2 | 0.21 | 0.37 | 0.4 | 0.33 | 0.35 | 0.17 | 0.19 | −0.04 | −0.05 | 0.13 | 0.14 |
| Gullied/Ravenous land | 0.75 | 0.8 | 0.63 | 0.67 | 0.32 | 0.34 | −0.12 | −0.13 | −0.31 | −0.33 | −0.43 | −0.46 |
| Barren/Rocky/Stony waste | 1.04 | 1.11 | 1.04 | 1.11 | 1.04 | 1.11 | − | − | − | − | − | − |
| River/Waterbody | 0.09 | 0.09 | 0.09 | 0.09 | 0.11 | 0.12 | − | − | 0.02 | 0.03 | 0.02 | 0.03 |
| Dry Waterbody/dry river | 0.23 | 0.24 | 0.27 | 0.29 | 0.38 | 0.4 | 0.04 | 0.05 | 0.11 | 0.11 | 0.15 | 0.16 |
| Settlement/Build up Land | 2.56 | 2.72 | 2.97 | 3.15 | 5.79 | 6.15 | 0.41 | 0.43 | 2.82 | 3 | 3.23 | 3.43 |
| Total | 94.07 | 100 | 94.07 | 100 | 94.07 | 100 | | | | | | |

mapping and monitoring land use/land changes from 2004 to 2021. The results of the analysis show significant LULC changes especially under dense forest, cultivated land, degraded forest and settlement/build-up land. Cultivated land and settlement/build-up land have reported major changes in terms of their increase during 2004-2021 with 56.42 km² (4.63%) and 31.9 km² (2.63%) respectively. Ruparel watershed, an agriculturally dominant area, has seen an increase in cultivated land due to the conversion of fallow land and open scrub into cropland as a result of good rainfall received during the south-west monsoon in previous years and groundwater use. As the study area is part of the National Capital Region (NCR), an increase in settlement/built-up land implies an increase in population, owing primarily to migration from other areas. Dense Forest has decreased by 33.78 km² (2.78%), causing degradation, which has led to its conversion in degraded forest by 32.04 km² (2.64%) and open forest 2.85 km² (0.24%) as a result of natural and anthropogenic activities. Fallow land has also reduced in its areal extent by 81.85 km² (6.73%). Open scrub and river/waterbody have also noticed change in terms of decrease in their areal extent. The present study emphasizes that remote sensing and GIS technique are the efficient and proper tools in monitoring land use/land cover change dynamics. The quantification of LULC change in Ruparel watershed will be helpful for planning, management and effective utilization of natural resources and will help policy makers, stake

holders and government organization to take necessary steps for conservation of resources at the sub-watershed level.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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