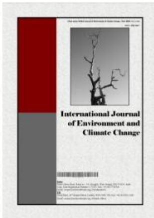

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Assessment of Dynamic Land System in Nilgiri Biosphere Reserve Using MODIS Derived Temporal Data Sets during 2001 to 2018

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Nilgiri Biosphere Reserve (NBR) is one of the largest protected ecologically sensitive areas in India. This study examined the land use/land cover (LULC) changes in NBR for past 18 years from 2001 to 2018 to figure out the LULC changed within a protected area using datasets in 2001, 2010, and 2018 with the help of pertinent geospatial techniques. MODIS Land Cover Type Product (MCD12Q1) accuracy was quantitatively analyzed based on ground truth data and Google Earth imagery. Validation of data were assessed using and overall 635 locations for its accuracy assessment. The obtained kappa coefficient of 0.75, denotes the classification has moderate accuracy. The results showed that in the past 18 years, woody savannas and grasslands were reduced by 299.47 sq.km and 155.32 sq.km respectively. The areas of croplands and cropland/natural vegetation mosaics were also increased by 34.84 sq.km and 54.41 sq.km, respectively. These results showed anthropogenic influences through agricultural practices within the NBR buffer zones. The mixed forests were increased by 266.01 sq.km. One of the significant changes was seen in closed shrublands, which were absent in 2018, that covered 1.50 sq.km in 2001. In addition, A gradual decrease in the area were noticed in woody savannas. From the

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outcomes, it is recommended that the LULC classes that cover minimal area may be unstable, so measures should be taken for their conservation. The study proved the usefulness of MODIS land cover type data in monitoring large areas periodically for quick decision-making.

Keywords: MODIS; Nilgiri Biosphere Reserve (NBR); geospatial technology; LULC; change detection; Kappa statistics.

1. INTRODUCTION

Land use and land cover (LULC) changes from the last two decades are accelerating due to human activities [1]. The LULC map showcases land use and land cover, in which land cover relates to the type of feature present on the surface of the earth, and land use relates to the human activity or economic function associated with a specific piece of land [2]. LULC classification is the process of categorization of similar features into predefined classes. LULC classification and mapping play a significant role in planning, management, monitoring, and policy-making programs at local, regional, and national levels [3,4]. The application of LULC data is vast in fields such as hydrology, natural resource management, wildlife habitat studies, urban studies, routing and logistics planning, disaster studies, and change analysis.

LULC classification and change detection of forest areas through temporal analysis have a significant role since they can identify how forest area change occurs due to natural and anthropogenic activities [5]. The Nilgiri Biosphere Reserve (NBR) is an international biosphere reserve situated in South India in the Western Ghats and Nilgiri hills. The LULC change analysis in 18 years from 2001 to 2018 can provide the changes in each land use/land cover class either in expansion or in declination.

The LULC data has been retrieved from remote sensing images over the past ten years [6]. Satellite imageries are available in different spatial resolutions, bandwidths, and spectral regions, which can be used based on the purpose and are processed and interpreted to get information about the LULC of an area [7,8,9]. Remote sensing data has become more accepted due to its cost-effective and multi-temporal availability, even in inaccessible areas to humans [10]. The remote sensing datasets coupled with Geographic Information System (GIS) make the information more sensible.

Multispectral imageries are commonly used due to their availability and processing ease. Several multispectral satellite missions provide the land cover classified image itself, making the change analysis much faster and easier [11]. Moderate Resolution Imaging The Spectroradiometer (MODIS) is a satellite instrument that can cover the whole earth in two days [12]. MODIS land cover type product (MCD12Q1) provides a suite of science data sets (SDSs) that map the land cover at 500m spatial resolution [13].

The sustainable development of land change detection requires accurate, intensive, and regular analysis [14]. So, pixel-wise accuracy assessment is mandatory to avoid errors in LULC data, which can be checked by comparing ground truth data [15]. Several statistical methods are in use for quantitative accuracy assessment. Cohen's Kappa coefficient is the most commonly used method to check the correctness of LULC. It is common due to its simplicity and accuracy. The comprehensive use of remote sensing and statistical analysis will be helpful for the change detection of NBR precisely.

This study aimed to analyze the land cover changes in NBR in 18 years using MODIS data. The primary objectives of the study are (a) to estimate the LULC of NBR, (b) to identify the changes in LULC in 18 years, and (c) to check the accuracy of the LULC of 2018 with ground truth data using the kappa coefficient.

2. MATERIALS AND METHODS

2.1 Study Area

The Nilgiri Biosphere Reserve (NBR) is the largest protected forest in India, situated in the southern part of the country. The NBR spreads across Kerala, Tamil Nadu, and Karnataka and is a part of the Western Ghats. It includes six national parks: Aralam, Mudumalai, Mukurthi, Nagarhole, Bandipur, and Silent Valley. The wildlife sanctuaries within NBR are Wayanad, Karimpuzha, and Sathyamangalam. Tribal groups like the Badagas, Todas, Kotas, Irullas, Kurumbas, Paniyas, Adiyans, Edanadan Chettis, Allar, Malayans, etc., are native to the reserve [15].

The area was constituted as NBR by UNESCO in September 1986 under the Man and Biosphere Programme. NBR is India's first biosphere reserve and is rich in flora and fauna. Fauna includes over 100 species of mammals, 370 species of birds, 80 species of reptiles, about 39 species of fish, 31 amphibians, and 316 species of butterflies. Flora includes about 3,300 species of flowering plants, among which 133 are endemic to the reserve. Out of the 175 species of orchids found in the NBR, eight are endemic. 80% of the flowering plants in the Western Ghats occur in NBR. The major vegetational types present at NBR are tropical evergreen forests, Montane sholas and grasslands, moist deciduous forests, semi-evergreen forests, dry deciduous forests, and thorn forests [16].

Bhavani, Moyar, Kabani, Chaliyar, and Punampuzha are the major rivers with their major catchment area as NBR. The annual rainfall of the NBR ranges from 500 mm to 7000 mm, with temperatures ranging from 0°C during winter to 41°C during summer.

The study area has an area of 6189.78 sq.km (Fig. 1). Out of the total area, 2537.6 sq.km. comes under Tamil Nadu, 1455.4 sq.km. under Kerala and 1527.4 sq.km. under Karnataka states. The NBR lies between 10°50’N and 12°16’N latitude and 76°00’E to 77°15’E longitude.

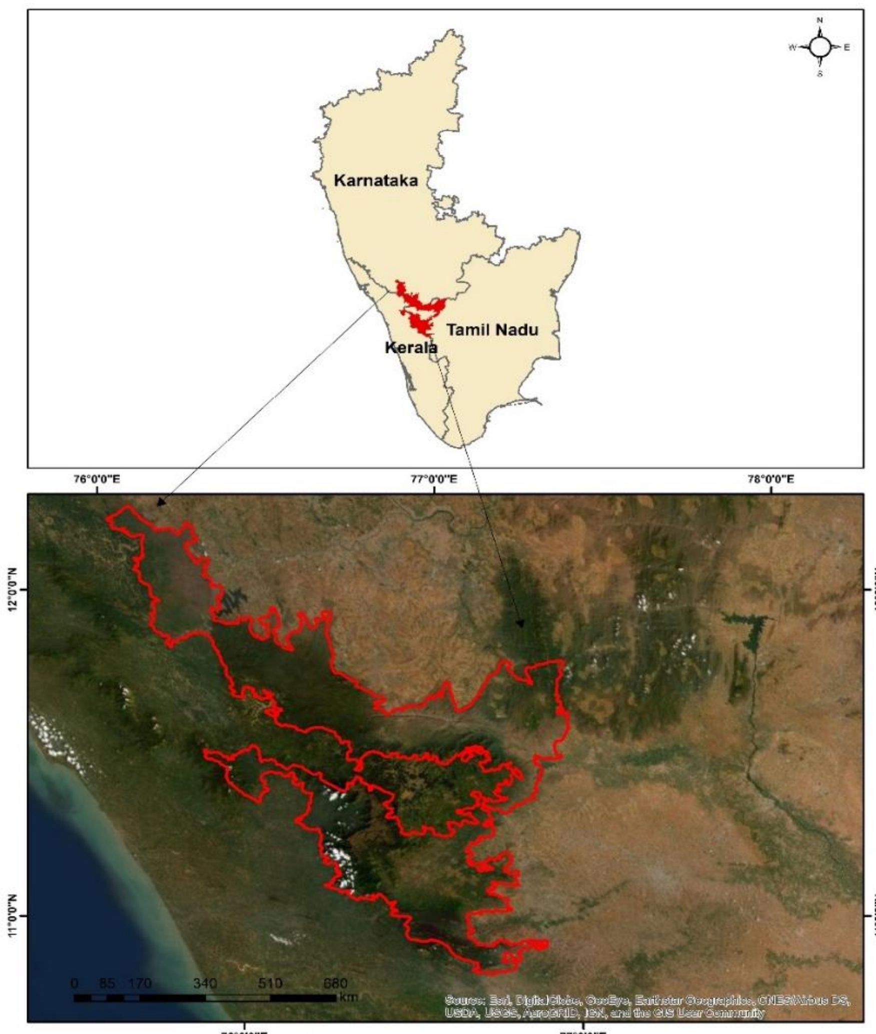

Fig.1. Study area map

2.2 MODIS Land Cover Type Product (MCD12Q1)

In the present study MODIS Land Cover Type Product (MCD12Q1) was used for the LULCC analysis. The product results from supervised classification of spectro-temporal features of the Moderate Resolution Imaging Spectroradiometer (MODIS). It provides global maps of land cover with a 500m spatial resolution that can be used directly without pre-processing. The product was downloaded from USGS Earth Explorer [17] for 2001, 2010, and 2018. As the study area comes in biosphere category, we used the IGBP data product of pre-processed MODIS for the present study. In addition, We took the tritemporal data sets for the years 2001, 2010 and 2018 by the mere assumption that most of the anthropogenic interventions happened during the said period.

3. METHODOLOGY

3.1 LULC Classification Used

MODIS Land Cover Type Product MCD12Q1 user guide provides International Geosphere-Biosphere Programme (IGBP) legend and class descriptions as in Table 1.

The flow chart of the methodology followed in the study is shown in Fig. 2.

Table 1. MCD12Q1 International Geosphere-Biosphere Programme (IGBP) legend and class descriptions

Name	Value	Description
Evergreen Needleleaf Forests	1	Dominated by evergreen conifer trees (canopy >2 m). Tree cover >60%
Evergreen Broadleaf Forests	2	Dominated by evergreen broadleaf and palmate trees (canopy >2 m). Tree cover >60%
Deciduous Needleleaf Forests	3	Dominated by deciduous needleleaf (larch) trees (canopy >2 m). Tree cover >60%
Deciduous Broadleaf Forests	4	Dominated by deciduous broadleaf trees (canopy >2 m). Tree cover >60%
Mixed Forests	5	Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy >2 m). Tree cover >60%
Closed Shrublands	6	Dominated by woody perennials (1-2 m height) >60% cover
Open Shrublands	7	Dominated by woody perennials (1-2 m height) 10-60% cover
Woody Savannas	8	Tree cover 30-60% (canopy >2 m)
Savannas	9	Tree cover 10-30% (canopy >2 m)
Grasslands	10	Dominated by herbaceous annuals (<2 m)
Permanent Wetlands	11	Permanently inundated lands with 30-60% water cover and >10% vegetated cover
Croplands	12	At least 60% of area is cultivated cropland
Urban and Built-up Lands	13	At least 30% impervious surface area including building materials, asphalt, and vehicles
Cropland/Natural Vegetation Mosaics	14	Mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation
Permanent Snow and Ice	15	At least 60% of area is covered by snow and ice for at least 10 months of the year
Barren	16	At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation
Water Bodies	17	At least 60% of area is covered by permanent waterbodies
Unclassified	255	Has not received a map label because of missing inputs

Source: User Guide to Collection 6 MODIS Land Cover (MCD12Q1 and MCD12C1) Product [18]

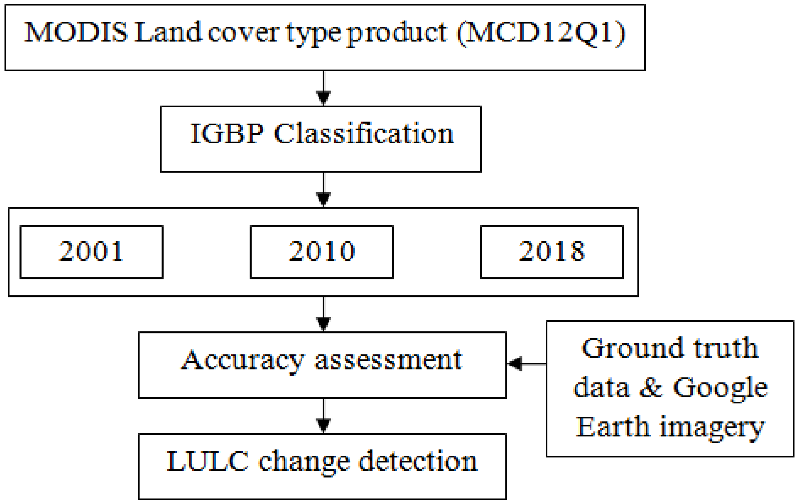

Fig. 2. Flow chart of the methodology

3.2 Data Collection and Accuracy Assessment

Accuracy assessment is a method to check the correctness of the analysis by using ground truth data and Google Earth imagery [19,20]. Cohen's Kappa coefficient is a statistical method used in this study for accuracy assessment. The Kappa coefficient indicates the extent of agreement between the frequencies of two sets of data collected on two different occasions [21]. It is determined by using a confusion matrix, which is also called an error matrix. The validation data was collected for 635 locations from the field and Google Earth images and assessed. Through the confusion matrix, the relationship between classified and reference data is evaluated. The data is obtained from the user (eq.1) and producer (eq.2) values, respectively.

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User accuracy = $$\frac{Number\ of\ correctly\ classified\ pixels}{total\ classified\ pixels} \times 100 \quad (1)$$

Producer accuracy = $$\frac{Number\ of\ correctly\ classified\ pixels}{total\ reference\ pixels} \times 100 \quad (2)$$

Overall accuracy (eq.3) is the correctness in the classification of the full LULC output, which is derived by combining both producer and user accuracy. The Kappa coefficient is calculated using eq.4.

Overall accuracy = $$\frac{Total\ number\ of\ correctly\ classified\ pixels}{Total\ reference\ or\ classified\ pixels} \times 100 \quad (3)$$

Kappa coefficient, $$k = \frac{N\sum_{i=1}^{r} x_{ii-\sum_{i=1}^{r}} x_{i+}.x_{+i}}{N^2-\sum_{i=1}^{r} x_{i+}.x_{+i}} \quad (4)$$

where,

Xii = Sum of diagonal input of error matrix;
$Xi +$ = Sum of row I of error matrix;
$X + I$ = Sum of column I of error matrix;
N = No. of elements in error.

Landis and Koch [21] suggested a classification of strength for the Kappa accuracy values and the categories of range was as following: k < 0.00: poor; k ∈ [0.00, 0.20]: slight; k ∈ [0.21, 0.40]: fair; k ∈ [0.41, 0.60]: moderate; k ∈ [0.61 − 0.80]: substantial; k ∈ [0.81 − 1.00]: almost perfect.

4. RESULTS AND DISCUSSION

4.1 LULC Classification in 2001

The NBR LULC classifications were done with the MODIS MCQ12Q1 data product for the years 2001, 2010, and 2018. In 2001, the most significant area covered by woody savannas was 1682.85 sq.km. they were followed by the classes of evergreen broadleaf forests by 1291.44 sq.km, deciduous broadleaf forests by 911.95 sq.km, grasslands by 821.14 sq.km, savannas by 679.48 sq.km, mixed forests by 479.51 sq.km, croplands by 237.25 sq.km, and cropland/natural vegetation mosaics by 74.83 sq.km. The remaining classes contributed to an area of 11.32 sq.km. Fig. 3 shows the LULC of NBR in 2001.

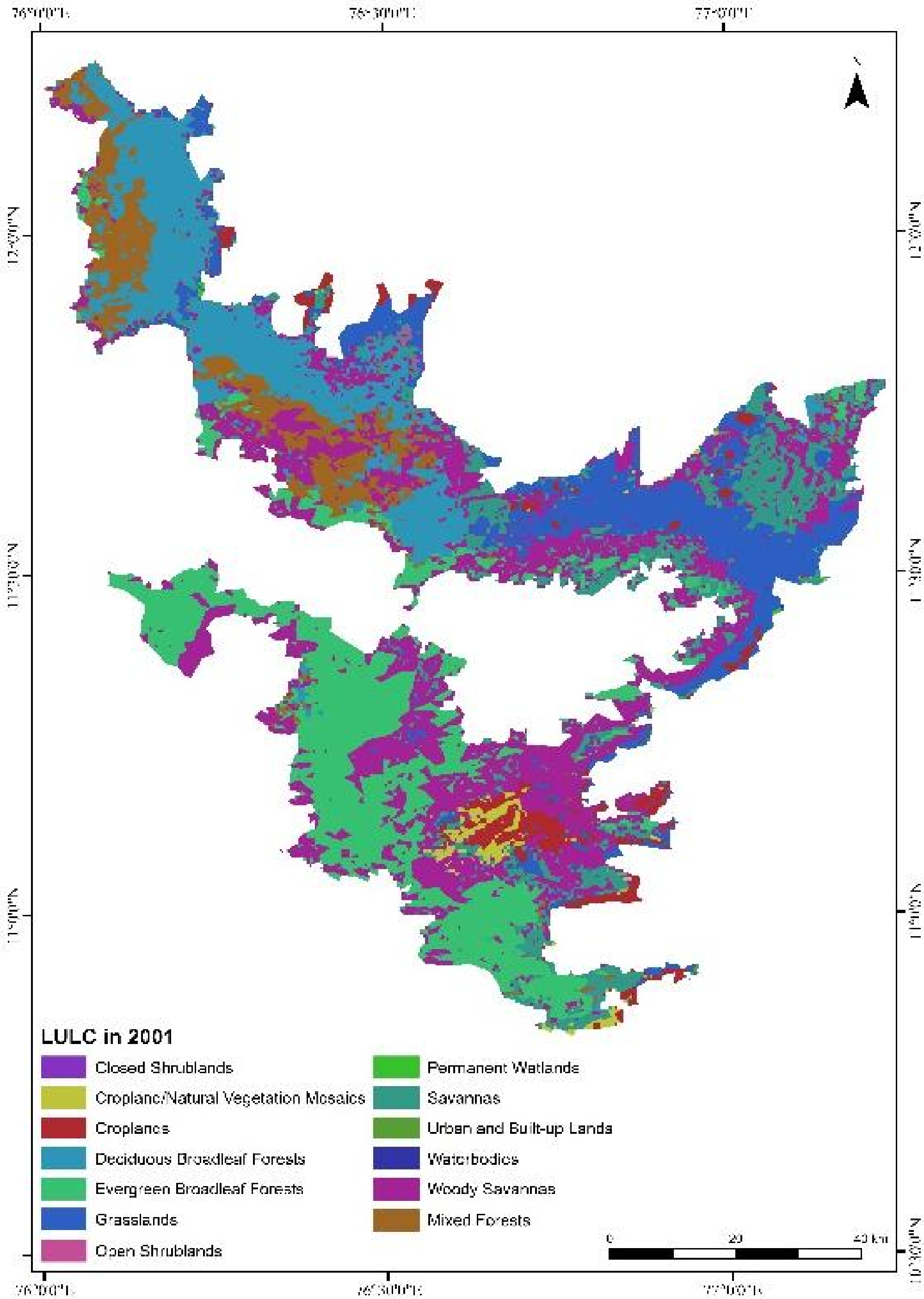

Fig. 3. LULC of NBR in 2001

4.2 LULC Classification in 2010

In 2010, the woody savannas consisted of 1575.40 sq.km. Areas of other classes are woody savannas with 1347.03 sq.km evergreen broadleaf forests with 1347.03 sq.km deciduous broadleaf forests with 856.66 sq.km, mixed forests with 802.08 sq.km, grasslands with 765.37 sq.km, savannas with 516.28 sq.km, croplands with 218.79 sq.km, and cropland/natural vegetation mosaics with 93.79 sq.km. The remaining classes altogether contributed to an area of 14.38 sq.km. The LULC of NBR in 2018 is shown in Fig. 4.

4.3 LULC Classification in 2018

In 2018, the woody savannas themselves contributed to an area of 1383.95 sq.km followed by evergreen broadleaf forests with 1337.81 sq.km, deciduous broadleaf forests with 1010.95 sq.km, mixed forests with 745.52 sq.km, grasslands with 665.82 sq.km, savannas with 638.99 sq.km, croplands with 272.12 sq.km, and cropland/natural vegetation mosaics with 129.24 sq.km. The remaining classes, except closed shrublands, provided an area of 5.38 sq.km. The closed shrublands were absent in 2018. The LULC of NBR in 2018 is given in Fig. 5.

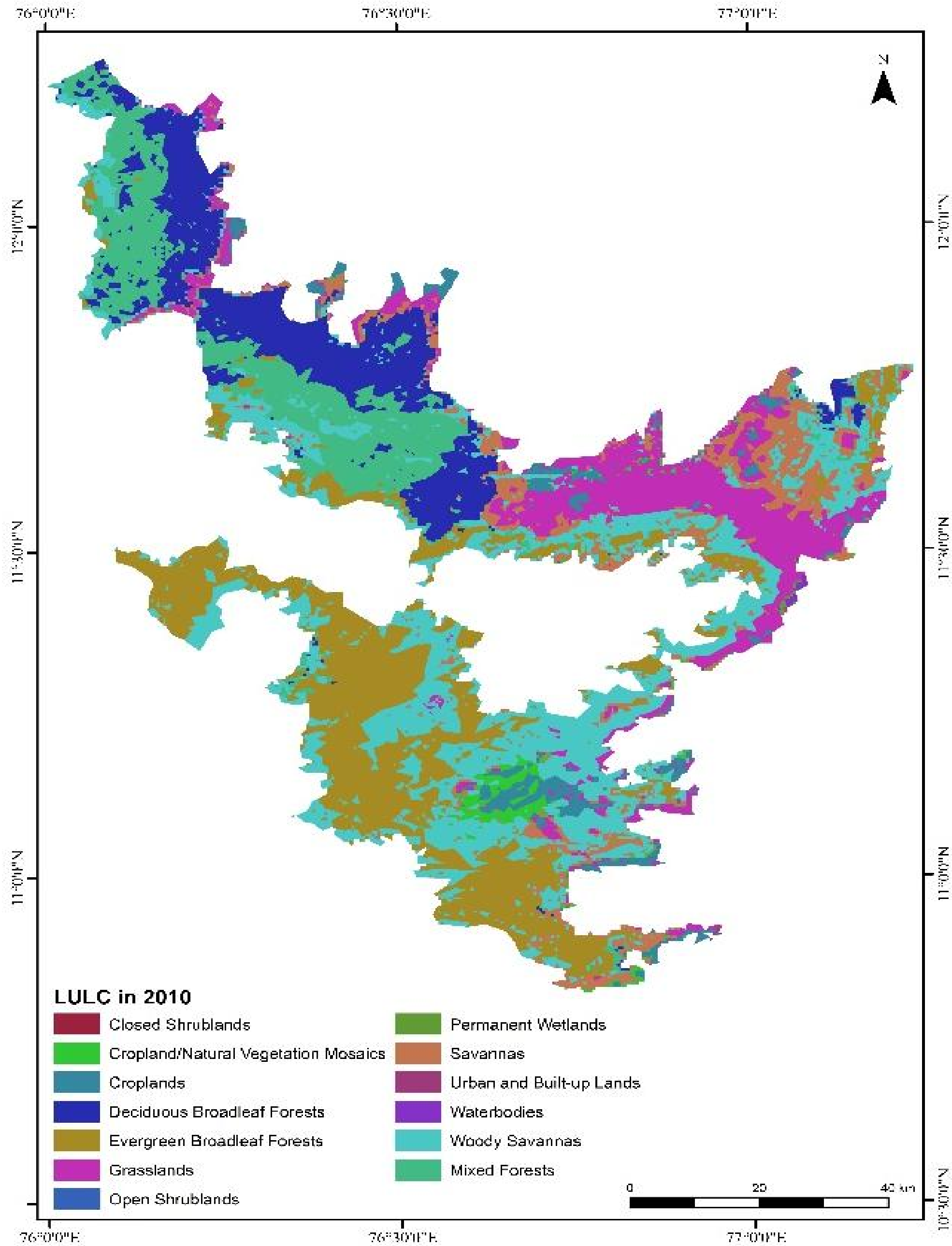

Fig. 4. LULC of NBR in 2010

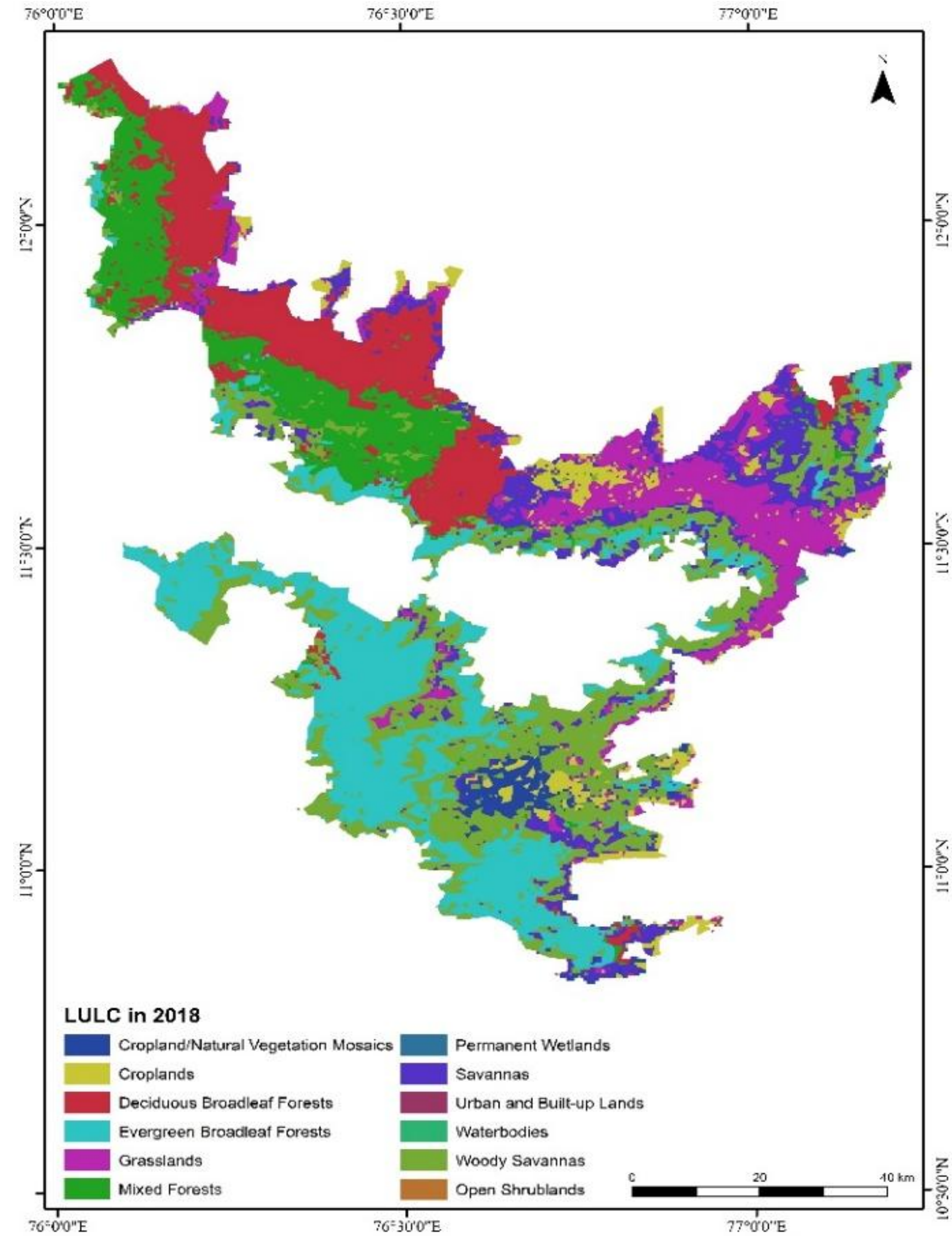

Fig. 5. LULC of NBR in 2018

4.4 Accuracy Assessment of the LULC Classifications

The accuracy of the LULC classes in 2018 was checked, and the details are provided in Table 2. The data was collected from 635 locations, of which data from 450 locations were collected by field verification, and the remaining data for 185 locations were collected from Google Earth imagery. Fig. 6 shows the locations of sample points in NBR. In the accuracy check of LULC, 0.75 is obtained as a kappa coefficient. As per the classification of the strength of Kappa accuracy by Landis and Koch in 1977, the LULC accuracy class comes under moderate.

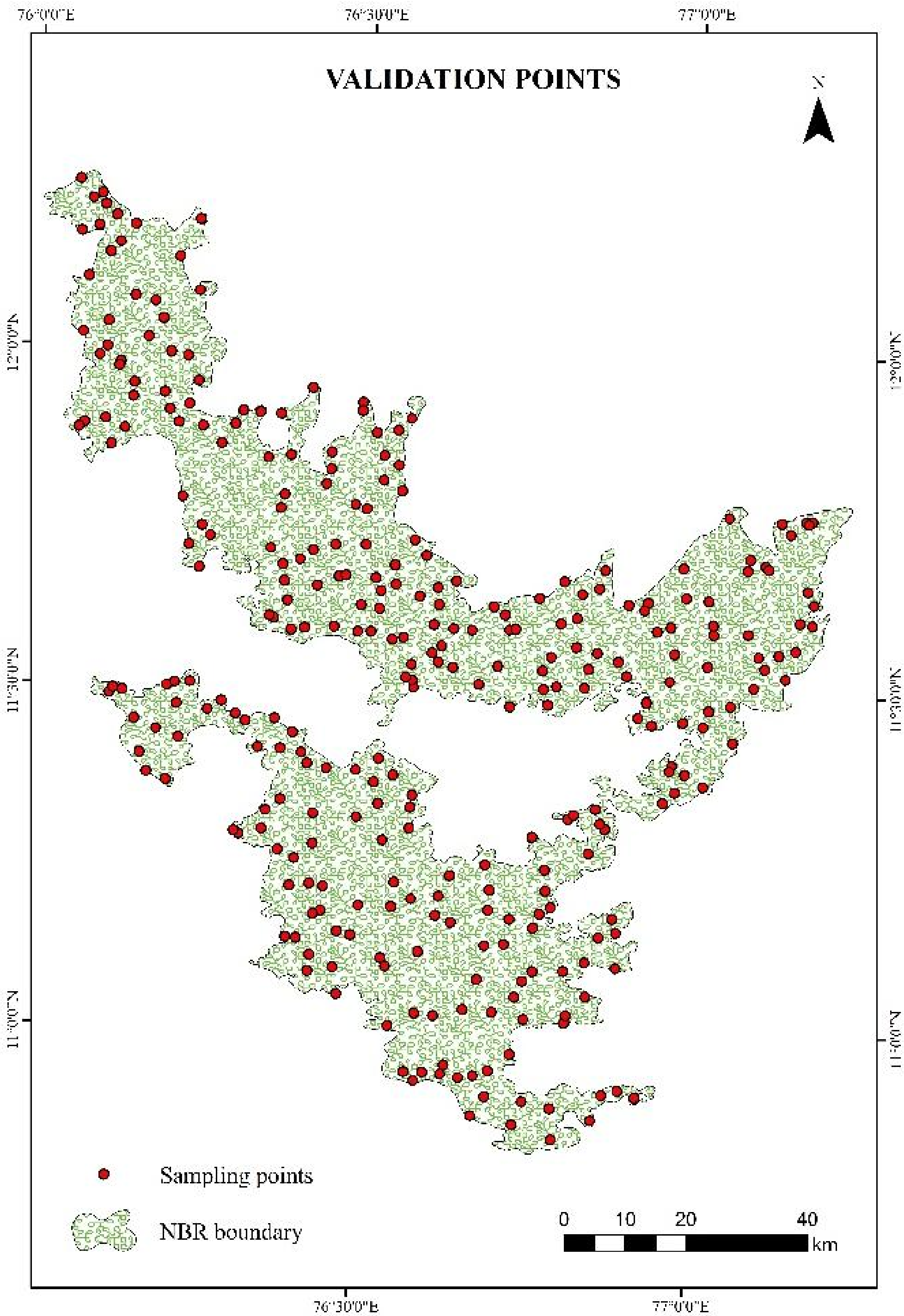

Fig. 6. Validation points for accuracy assessment in the study area

4.5 LULC Change Detection Analysis

The land cover changes in 18 years were analyzed concerning the classifications, and the results were quantified. The results showed some expansion and declination in areas of classified land covers. The year-wise comparison is discussed in the below sessions, and the quantitative details are given in Table 3.

Table 2. Accuracy evaluation of classification

Classes	Producer's accuracy (%)	User's accuracy (%)
Evergreen Broadleaf Forests	83.33	90.91
Deciduous Broadleaf Forests	76.19	84.21
Mixed Forests	70.27	77.61
Open Shrublands	71.70	77.55
Woody Savannas	77.94	70.67
Savannas	77.50	65.43
Grasslands	81.40	71.43
Permanent Wetlands	89.66	86.67
Croplands	74.55	77.36
Urban and Built-up Lands	90.63	76.32
Cropland/Natural Vegetation Mosaics	54.35	51.02
Water Bodies	90.63	90.63

Overall accuracy: 76.85%; Kappa statistics: 0.75

4.6 LULC Change during 2001 and 2010

In 2001, woody savannas constituted 27.19% of the total area of NBR, which was followed by evergreen broadleaf forests (20.86%), deciduous broadleaf forests (14.73%), grasslands (13.27%), and savannas (10.98%). The remaining classes have minor contributions to the LULC that altogether covered 5.21% of the total area. In 2010, LULC classes were distributed as 25.45% of woody savannas, 21.76% of evergreen broadleaf forests, 13.84% of deciduous broadleaf forests, and 12.37% of grasslands. In a period of 10 years from 2001 to 2010, the largest change in area occurred in mixed forest with an increase of 322.57 sq.km, viz. 5.21%. The decrease in the area has been seen in classes like woody savannas at 107.45 sq.km, savannas at 163.2 sq.km, grasslands at 55.77 sq.km, and open shrubs at 4.24 sq.km. The area of minor classes like waterbodies and permanent wetlands has increased slightly within 10 years. The cropland area was decreased by 18.46 sq.km and the cropland/natural vegetation mosaics were increased by 18.96 sq.km within the period. The LULC class conversions can be visible through these results, for which human activities are the major reason, because these classes come within the buffer zones of NBR. Fig. 7 represents the LULC change in NBR from 2001 to 2010.

4.7 LULC Change during 2010 and 2018

The LULC change from 2010 to 2018 was also analyzed with the MODIS data. One of the significant changes was the absence of closed shrublands in 2018, contained in an area of 0.64 sq.km in 2010. The area of woody savannas in 2018 became 22.35% from 25.45% of the total area, which was the major reduction among all classes by 192.02 sq.km. Other classes where the area reduction occurred are grasslands and mixed forests, with an area of 99.55 sq.km and 56.56 sq.km' respectively. The areas of some LULC classes were increased within eight years, such as deciduous broadleaf forests by 154.29 sq.km, savannas by 122.71 sq.km, cropland by 53.33 sq.km, and cropland/natural vegetation mosaics by 35.45 sq.km. The increase of cropland and cropland/natural vegetation mosaics can be considered human activities within the protected area. Fig. 8 signifies the LULC change of NBR from 2010 to 2018.

4.8 LULC Change during 2001 and 2018

In a period of 18 years from 2001 to 2018, a change in the areas of LULC classes of the NBR occurred. An important observation was that the closed shrubs with an area of 1.50 sq.km in 2001 became absent in 2018. This observation points out that classes with little areas become more vulnerable to extinction and reveal the importance of monitoring LULC classes even in protected areas.

The significant change in area was seen in the woody savannas by 299.47 sq.km and an increase in mixed forests by 266.01 sq.km. Other classes that have increased the area in 18 years are deciduous broadleaf forests, cropland/natural vegetation mosaics, evergreen broadleaf forests, croplands, water bodies, and urban and built-up lands by 99, 54.41, 46.37, 34.84, 01.35, and 0.04 sq.km' respectively. The classes that have decreased the area are grasslands, savannas, open shrublands, and permanent wetlands by 155.32, 40.49, 5.31, and 0.52 sq.km. The areas of cropland and cropland/natural vegetation mosaics were increased in the period, which indicates human involvement within the buffer zones of the NBR through agricultural practices. Fig. 9 displays the LULC change of NBR from 2001 to 2018.

The percentage-wise change in areas between 2001, 2010, and 2018 is graphically represented in Fig. 10. The main observation from Fig. 9 is a gradual decrease in the areas of woody savannas and grasslands. It shows the importance of continuous monitoring of this LULC class to analyze the area reduction and its trend. A noticeable increase in the area occurred in the mixed forests in 2018 compared with 2001. It can also be seen that the deciduous broadleaf forest area also increased in 2018 compared with previous years. The savannas also improved in the area in 2018 than in 2010. These area increases could be a factor in the reduction in the area of woody savannas.

4.9 Discussion

The study of land use and land cover is crucial for the sustainable monitoring of ecosystems. However, the studies on assessment of dynamic land system in Nilgiri Biosphere Reserve as with other similar studies in the Western Ghats viz., [22-25] reported a drastic reduction in the forest land use land cover and high level of landscape dynamism for the subsequent period of their study via geospatial tools. In the presenst study, an increase and decrease in the water bodies were obvious between the three time period of the study and an increase in the two time period. Similarly, Kushawaha [26] observed a marginal increase in the water body in his study. Contrarily, Bilyaminu et al., [22] reported decrease in the water bodies despite the dam construction in their study area and attributed it to the fluctuation in temperature and precipitation of the study area . Torahi and Rai [27] have a similar view on water bodies fluctuation in their study. Unsustainable forest management activities such as unscientific fire control measures, human activities, exploitation, and conversion of forest land use could be the reason for the major changes in many land-use systems in the present studies. The land use and land cover of the forest ecosystem of shendurney WLS were recently studied by Bilyaminu et al., [22] and reported significant changes in the land use of the forest ecosystems during the study period. They recommended that the human activities within the forest, which were considered the major driving forces, should be monitored periodically to protect the fragile ecosystem.

Similar to this study, Sulla-Menashe et al., [28] described improvements in the algorithm and resulting map data sets implemented in the global land cover type products of MODIS collection 6. Unlike the collection 5 product, which were based on the 17 classes of International Geospehere - Biosphere Programme (IGBP) legend, the Collection 6 algorithm used the hierarchical classification model where the classes included in each level of the hierarchy reflect structured distinctions between land cover properties. However, they concluded that in comparison to Collection 5, the Collection 6 product includes less area mapped as forests, open shrublands, and cropland/natural vegetation mosaics and more area mapped as woodlands and grasslands, among other changes. Moreover, the primary FAO-land cover classification system (LCCS) layer of the Collection 6 product has an overall accuracy of 73.6 percent. According to the accuracy assessment, and the amount of spurious land cover change has been significantly reduced in Collection 6 compared to Collection 5. (1.6 percent in C6 and 11.4 percent in C5).

Anthropogenic activities are one of the most important components of global change in land-use and land-cover (LULCC). In the present study also, human activities were considered the major factor for the land use land cover change of the study area. This is in agreement with [22,29]. The overall classification accuracy of the present study was reported as 76.85 percent which is higher than 73.5 percent reported by Sulla-Menashe et al., [28] and lower than reported by Salovaara et al., [30]. The Kappa accuracy as 0.75 higher than 0.62 reported by [30]. This study used MODIS derived temporal data sets from 2001 to 2018 to assess the dynamics in land use land cover change patterns of the Nilgiri Biosphere Reserve, to provide an accurate cost-effective means of mapping and analyzing the changes in LULC over time which can be used as important information in land management and policy decisions.

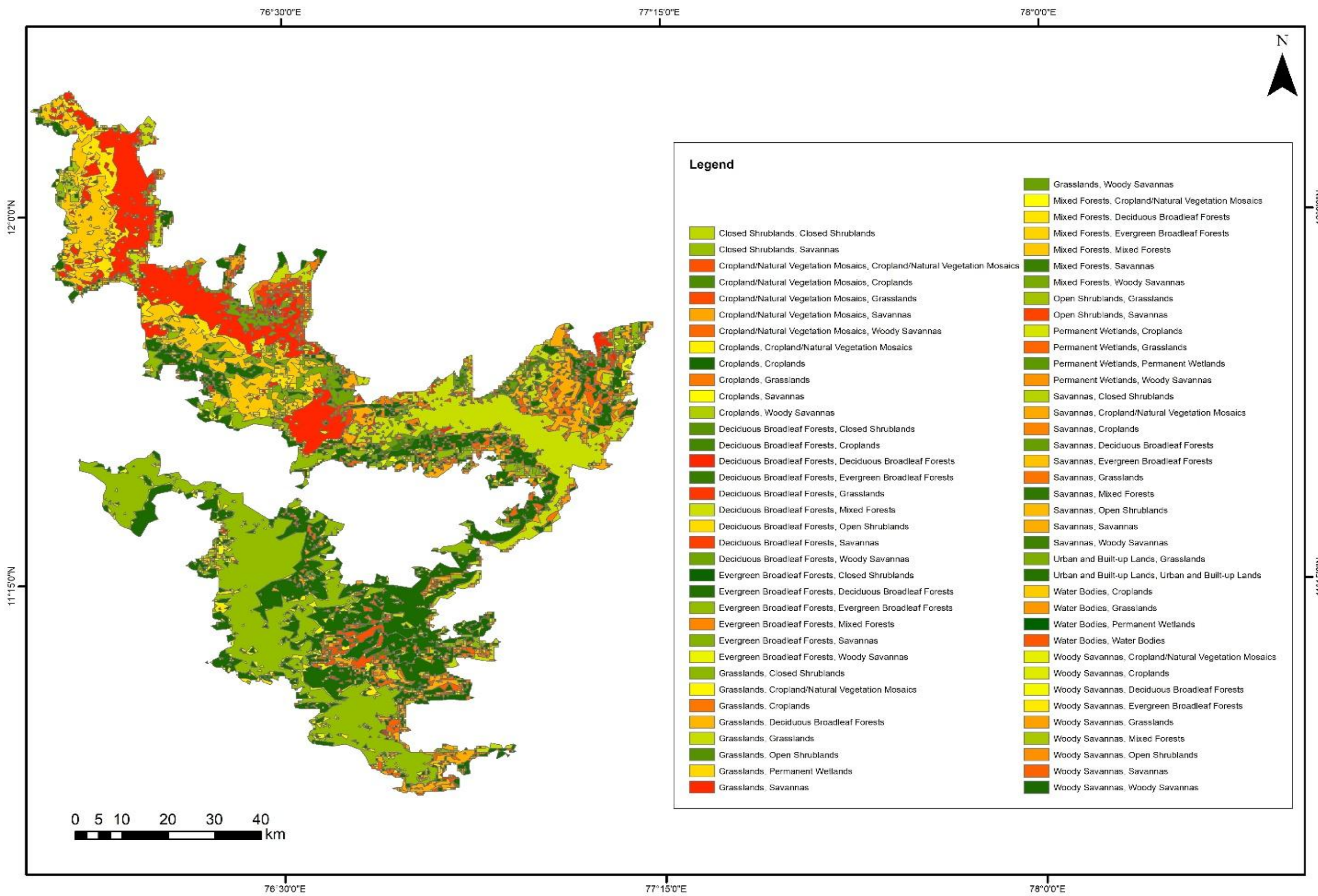

Fig. 7. LULC change during 2001 to 2010

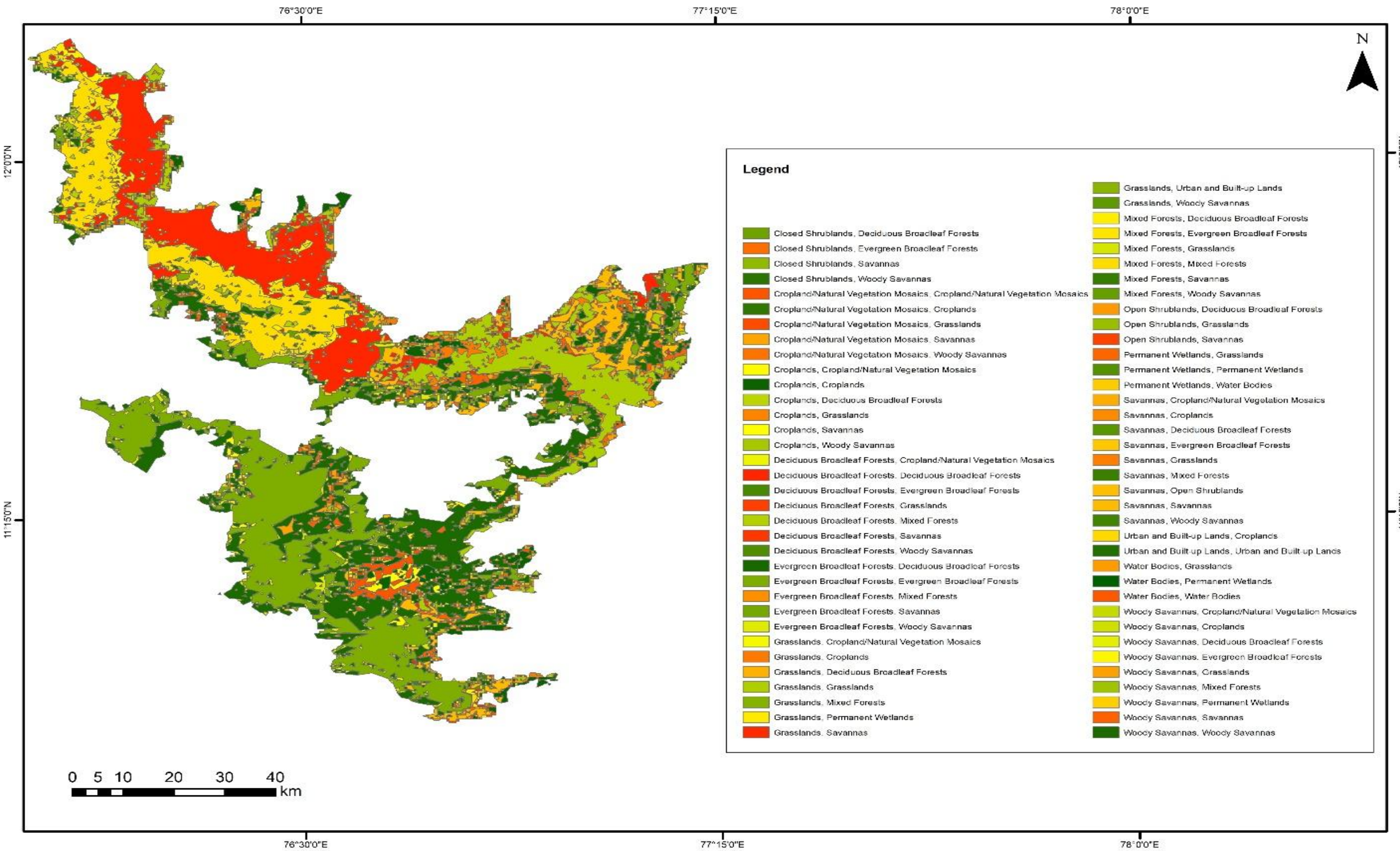

Fig. 8. LULC change during 2010 to 2018

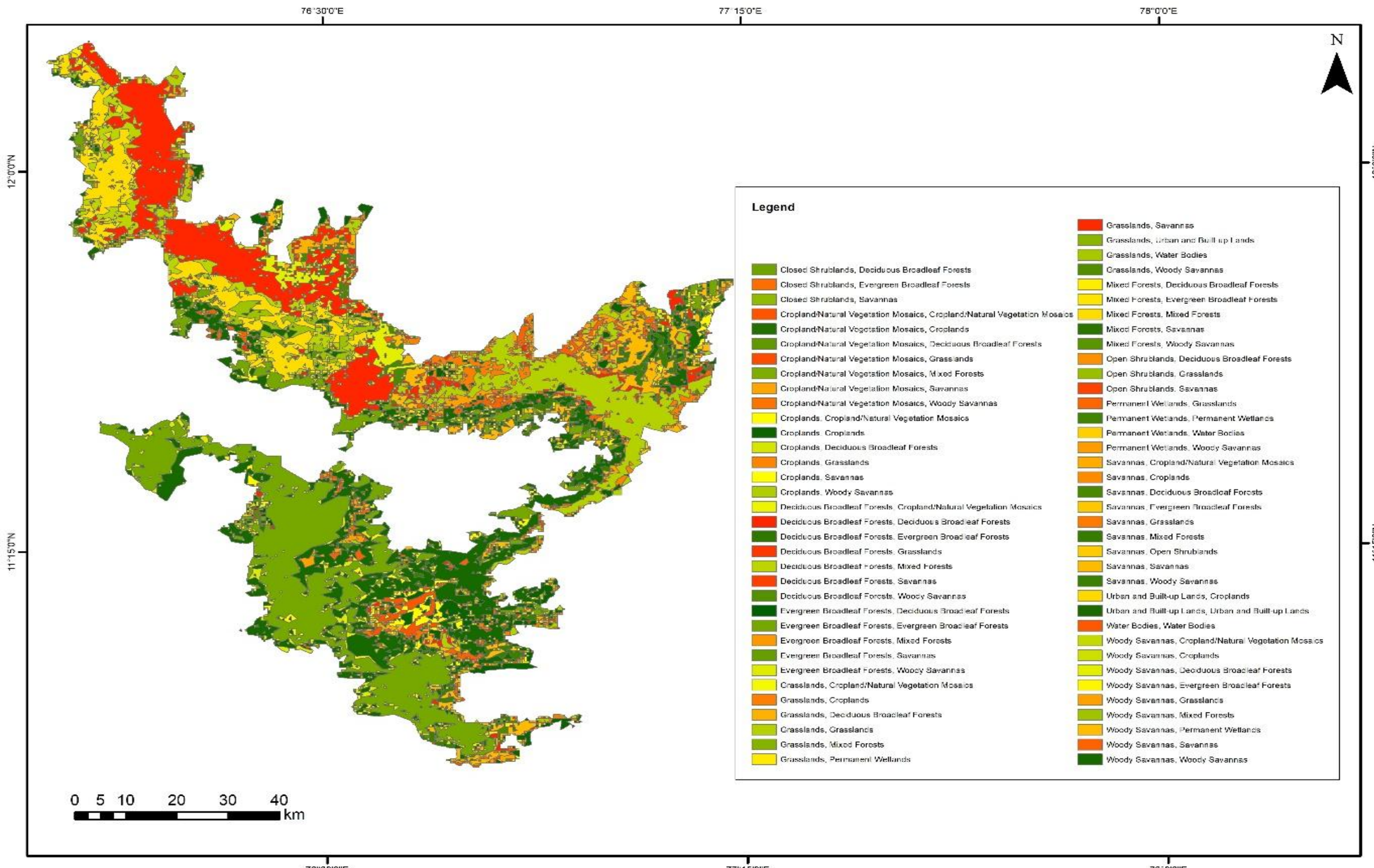

Fig. 9. LULC change during 2001 to 2018

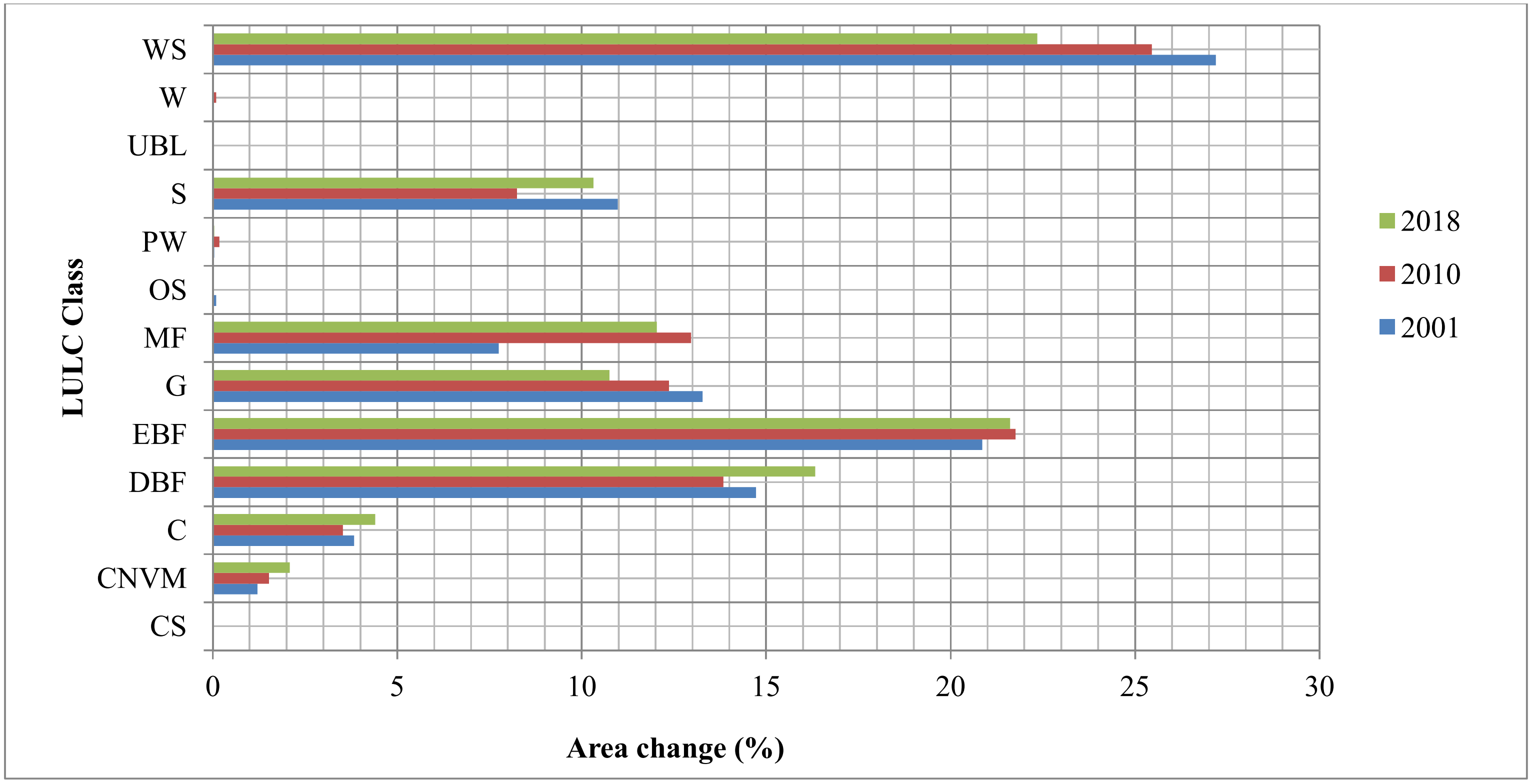

Fig. 10. LULCC per classes in percentage

Table 3. Comparison of areas of NBR based on LULC classes during the years 2001, 2010, and 2018

LULC Classes	**Area (sq.km.)**			**Area changes in sq.km. between**		
	2001	**2010**	**2018**	**2001-2010**	**2010-2018**	**2001-2018**
Closed Shrublands (CS)	1.50	0.64	-	-0.86	-0.64	-1.50
Cropland/Natural Vegetation Mosaics (CNVM)	74.83	93.79	129.24	18.96	35.45	54.41
Croplands (C)	237.25	218.79	272.12	-18.46	53.33	34.84
Deciduous Broadleaf Forests (DBF)	911.95	856.66	1010.95	-55.29	154.29	99.00
Evergreen Broadleaf Forests (EBF)	1291.44	1347.03	1337.81	55.59	-9.22	46.37
Grasslands (G)	821.14	765.37	665.82	-55.77	-99.55	-155.32
Mixed Forests (MF)	479.51	802.08	745.52	322.57	-56.56	266.01
Open Shrublands (OS)	5.46	1.22	0.15	-4.24	-1.07	-5.31
Permanent Wetlands (PW)	2.74	5.64	2.22	2.90	-3.42	-0.52
Savannas (S)	679.48	516.28	638.99	-163.20	122.71	-40.49
Urban and Built-up Lands (UBL)	1.49	1.53	1.53	0.04	0.00	0.04
Waterbodies (W)	0.13	5.35	1.48	5.22	-3.87	1.35
Woody Savannas (WS)	1682.85	1575.40	1383.95	-107.45	-192.02	-299.47
Total	**6189.78**	**6189.78**	**6189.78**	**-**	**-**	**-**

5. CONCLUSION

This study was conducted to analyze the effectiveness of MODIS land cover type product (MCD12Q1) to figure out the land use/land cover change in NBR during 2001 to 2018. The study also checked the accuracy of the remote sensing data using kappa statistics with ground truth data and Google Earth imagery. It gave moderate accuracy, which proved that the MODIS data is helpful for LULC studies, especially for large and inaccessible areas. Also, the class-wise changes in area of LULC of NBR showed both the trends of expansion as well as reduction. The decrease reveals the importance of monitoring LULC changes in areas of closed shrublands and grasslands. The study also revealed the influence of anthropogenic activities within the buffer zones of the NBR that resulted in the increase in areas for the classes, viz. croplands and cropland/natural vegetation mosaics. Moreover, the study revealed the effectiveness of MODIS data product in LULCC studies that can be readily used and quite helpful in decision making for policy makers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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