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Land Use Change and Wildlife Conservation—Case Analysis of LULC Change of Pench-Satpuda Wildlife Corridor in Madhya Pradesh, India

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Abstract: To the burgeoning population, the tiger reserves of central India have been islanded by human habitation and are interconnected by narrow 'wildlife corridors' for migration of wildlife. Pench-Satpuda wildlife corridor is one such critical wildlife corridor that interconnects the Pench Tiger Reserve and Satpuda Tiger Reserve in central India. Land Use Land Cover (LULC) change of this corridor between April 2002 and April 2019 was analyzed using GIS and Remote Sensing Techniques. The study finds a systematic loss of 10,376.74 ha and 7406.24 ha of dense forests and open forests respectively, thus indicating large scale degradation of the area. The study found that a net area of 2054.60 of dense forests and open forests were diverted for agriculture indicating extensive encroachment of forest land. Water bodies have reduced by 25.41% indicating shrinkage in water bodies in the period under study. The presence of rich coal deposits in the wildlife corridor and operational coal mines in the near vicinity of the wildlife corridor is a matter of serious concern. This study attempts to highlight the importance of long-term sustenance of the Pench-Satpuda wildlife corridor for maintaining the genetic pool of wildlife in the landscape.

Keywords: habitat fragmentation; human-wildlife conflict; land use land cover analysis; Pench-Satpuda corridor; wildlife conservation; wildlife corridor; wildlife migration

1. Introduction

Forests are essential for the earth's life support system and provide a vast variety of benefits as well. These benefits can be classified into 'Direct Use Values', quantifiable in monetary terms such as timber, fuelwood, charcoal, non-timber forest produce (NTFPs), etc., 'Indirect Use Values' such as watershed protection and recharge, carbon storage and sequestration, biodiversity and genetic resource pool, etc., [1] and 'Option Value', the option of utilizing the direct or indirect use values in the future [2]. The global economic value of forest ecosystem goods and services of forests is estimated at $4.7 trillion annually and that of temperate/boreal forests at $894 billion annually [3].

There has been an annual natural forest loss of 10.6 million ha per year globally for the period 1990 to 2000 [4]. Major direct causes of forest clearance and degradation include the expansion of agricultural land, overharvesting of industrial wood, fuelwood and other forest products, and overgrazing. Underlying drivers include poverty, population growth, markets, and trade in forest products, as well as macroeconomic policies [5].

Globally, the forests serve as a repository of carbon and provide a host of direct and indirect benefits, biodiversity being one of the most important benefits so essential for the sustenance of life on this earth. On a regional level, the application of the concept of planetary boundaries assumes even larger significance to assign certain biodiversity-rich areas as inviolate for the conservation of forests as well as the wildlife sustained by them. While on one hand, wild habitats serve as repositories of biological diversity, which is the key element for the process of evolution and sustenance of the gene pool; on the other hand, there is tremendous pressure on these resources for anthropogenic activities such as agriculture and commercial plantations, mining, urbanization, industrialization, and other developmental activities [6,7]. This leads to three interrelated processes: habitat loss, habitat fragmentation, and introduction of new forms of land use [8,9].

Wildlife Corridors can be defined as a linear habitat, embedded in a dissimilar matrix, that connects two or more large blocks of habitat and that is proposed for conservation on the premise that it will enhance or maintain the viability of specific wildlife populations in the habitat blocks [10]. These wildlife corridors serve as "sinks" to allow the wildlife populations to migrate to the "sources", where the population can survive and breed. Together, they provide the habitats upon which the conservation of much of the flora and fauna in developed landscapes ultimately depends [11]. Although corridors may have intrinsic habitat value, their salient wildlife value is that they connect more substantive patches of habitat [12]. The dispersal of populations over distant habitats enhances the chances of survival of species due to a reduction in competition for food and space. If species are not restricted to smaller areas then the localized extinction of a population will not occur due to an outbreak of epidemics as well as natural calamities such as floods or forest fires. In the long run, the chances of extinction of populations due to excessive inbreeding are also reduced [13,14]. The loss of wildlife corridors also results in a steep escalation in human-wildlife conflict [15–17]. Some wildlife corridors are of immense importance as they are crucial for the long-term survival of wildlife, including threatened species such as the Indian tiger (*Panthera tigris*). Such corridors can be termed as "Critical Wildlife Corridors".

India is one of the most biologically diverse countries in the world and with only 2.4 percent of the total land area of the world; the known biological diversity of this country contributes 8 percent to the known global biological diversity [18]. The forest cover of India is estimated at 708,273 km^2, which is 21.54% of the geographical area of the country. While India is endowed with rich natural resources, it is sustaining the second largest human population in the world, a majority of which is largely dependent on the forests for livelihood and sustenance.

The central part of India has rich forest cover and the state of Madhya Pradesh has the largest forest cover in the country [19]. There are several National Parks (an area set aside under the provisions of the Wildlife (Protection) Act, 1972, for conservation of wildlife and its habitat), Tiger Reserves (areas with high population of tigers declared for the conservation of tigers and its habitat and usually includes areas of a National Park), and Wildlife Sanctuaries in this state, the notable ones being the Kanha Tiger Reserve, Satpuda Tiger Reserve, Pench Tiger Reserve, and Panna Tiger Reserve. These three Tiger Reserves, along with the Melghat Tiger Reserve in the neighboring state of Maharashtra forms a large "Protected Area Complex" (Figure 1).

This research paper deals with the landscape level analysis of change in Land Use and Land Cover of the wildlife corridor connecting two important Tiger Reserves in Central India, the Pench Tiger Reserve and Satpuda Tiger Reserve, over a substantial period between 2004 and 2019. This wildlife corridor is the most important corridor of the Central India Protected Area Complex as it is located right in the middle of this complex and the disruption of this corridor will lead to the isolation of genetic resources within the Tiger Reserves located north and south of this wildlife corridor (Figure 1).

It is well established that the understanding of dynamics of LULC (Land Use Land Cover) is crucial for proper land use planning which eventually impacts biological diversity [20–22], but this aspect has not been adequately researched and addressed in Central India. This study aims at covering this research gap by analyzing the development of the wildlife corridors in the case area of Pench-Satpuda. Thus, this study is the first of its kind to analyze the LULC changes and land use planning in this critical wildlife corridor, connecting two important tiger reserves and its implications for the long-term conservation of wildlife in the landscape, and also takes into account potential threats to long-term sustenance of this corridor such as coal mining, deforestation, the encroachment of forest land for agriculture, etc.

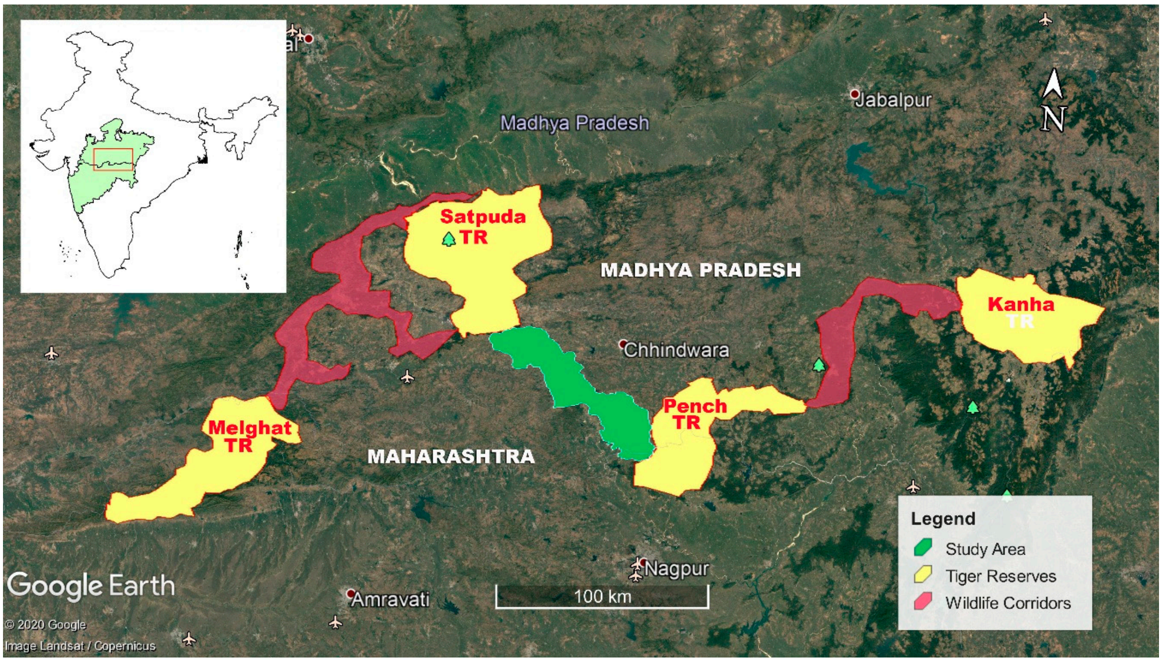


Figure 1. Google Earth image showing the important tiger reserves of central India and their indicative connecting linkages. The area in green wash represents the study area.

1.1. Study Area

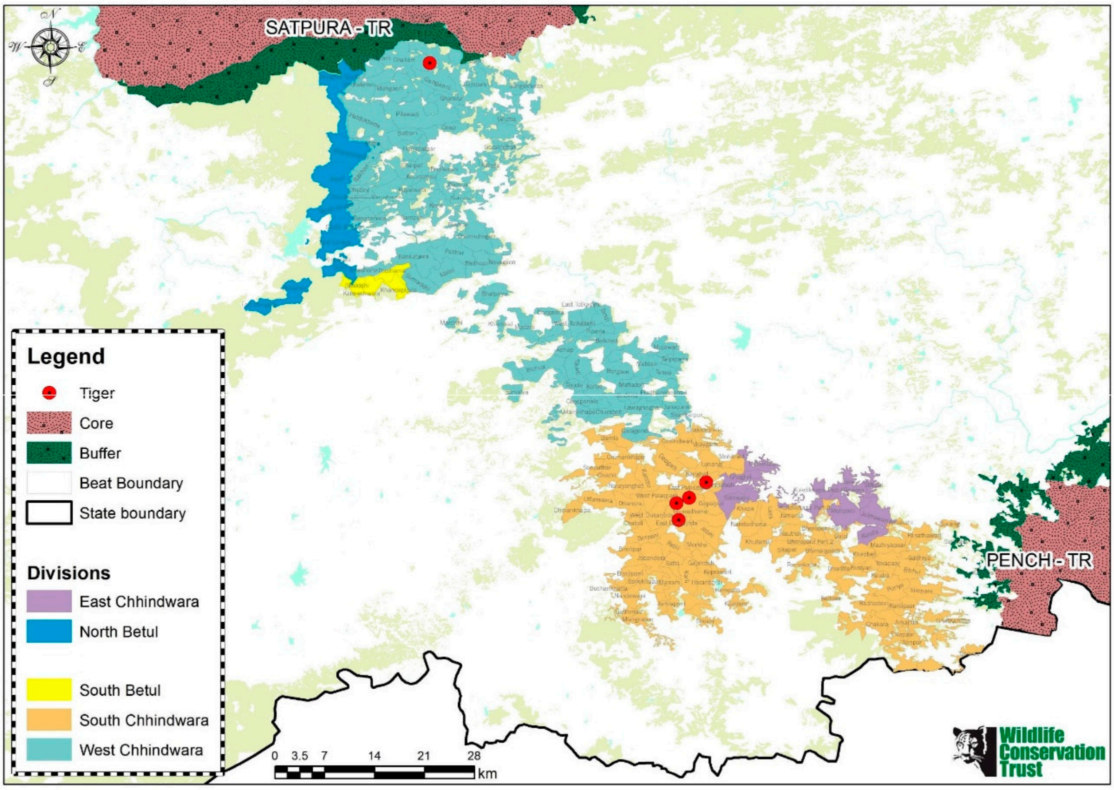
The rich forests of Central India are home to a wide variety of wildlife including the charismatic tiger, leopard, ungulates such as the endemic hard ground barasingha (swamp deer), gaur (Indian Bison), sambhar, cheetal, blackbuck, hog deer, wild boar, primates such as the langur, rhesus monkey, and canids such as the hyena, jackal, etc. These large tracts of forests occur in large isolated patches and are virtually 'islanded' by dense habitation and are connected to other tiger reserves by narrow wildlife corridors.

The study area is comprised of the Pench-Satpuda wildlife corridor (Figure 1). The 2133 km^2 Satpuda Tiger Reserve forms a vital link for spill-over/migrating populations of the 2769 km^2 Melghat Tiger Reserve located in the south-west and the 1180 km^2 Pench Tiger Reserve in the south-east, which eventually connects to the 2052 km^2 Kanha Tiger Reserve. In this way, the Pench-Satpuda wildlife corridor is very vital to the regional movement of wildlife in the area. At the same time, it is a matter of great concern from the point of wildlife conservation that rich coal deposits lie in and around this corridor. Coal is very crucial to the development of a country, and as such, there is pressure for diversion of these rich forest areas for coal mining. Therefore, the loss of the corridor is eventually inevitable unless this corridor, very critical for the movement of wildlife, is preserved in its entirety.

The study area falls between the coordinates 22°05″ N-78°24″ E and 22°41″ N-79°09″ E. Administratively, the area falls in three Forest Divisions namely, East Chhindwara, West Chhindwara, and South Chhindwara. The length of the corridor is roughly 90 km and the average width is about 22 km. It encompasses forest lands, private lands, agriculture, villages, roads, railways, etc. This corridor linkage is extremely precarious with forests intermittently disrupted by agriculture and habitation [23].

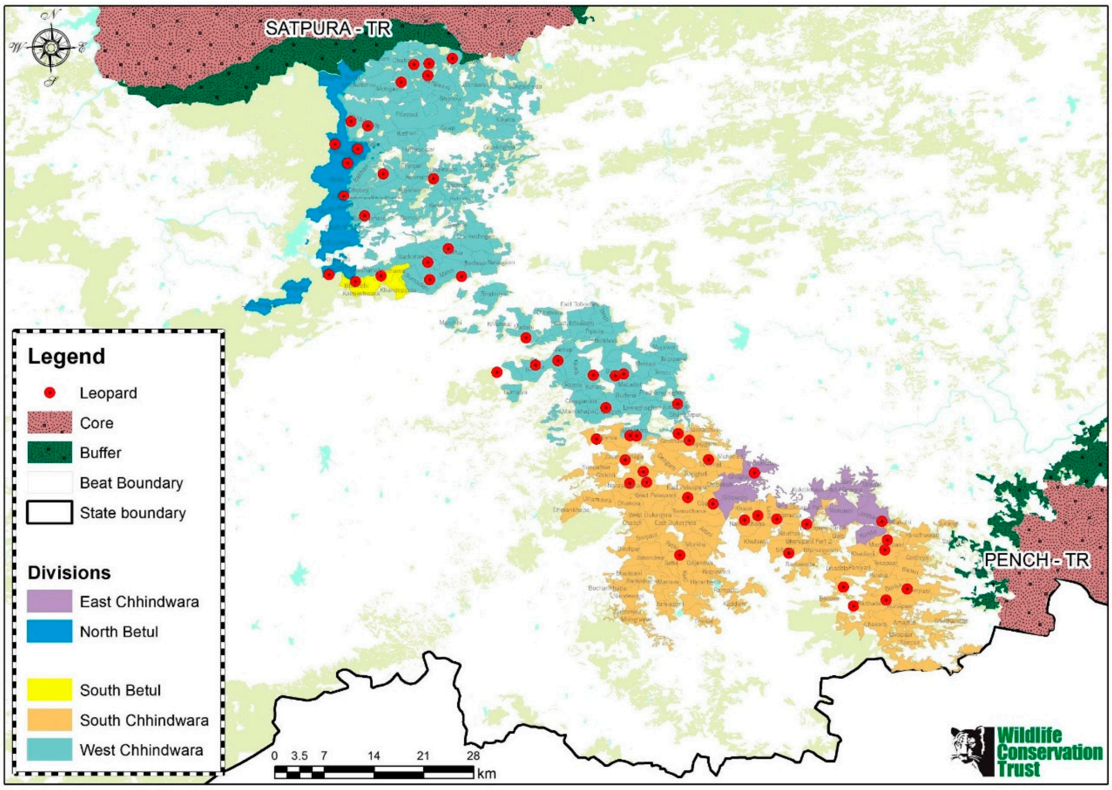
1.2. Viability of the Corridor for Wildlife Movement

The camera trapping studies, undertaken in the study area in 2017 (Figure 2), established that the presence of the tiger has been recorded in the study area only on five occasions. The presence of the leopard is, however, far more abundant than that of the tiger and has been recorded throughout the corridor [24]. Both these maps, as well as camera trapping of other wildlife species, established that the area under study is a viable wildlife corridor and is regularly used by wildlife to migrate between the Pench Tiger Reserve and Satpuda Tiger Reserve. Data of the human kill/injury and cattle depredation available in the records of Forest Department, Madhya Pradesh, for the period 2012–2013 to 2018–2019 reveals a substantial amount of human-wildlife conflict in terms of regrettable human injury/death by tiger, leopard, bear and wild boars, cattle depredation by carnivores and crop-raiding by herbivores have been widely reported at quite a few places in the study area, further confirming the regular presence of wildlife, thus making it an active and viable wildlife corridor [25].



(**a**)

Figure 2. *Cont.*



(**b**)

Figure 2. Source: Joshi and Pariwakam, 2017. Camera trapping photo capture locations of the tiger (**a**) and leopard (**b**) in the study area.

Coincidentally, this area also holds a sizeable reserve of coal, and an entire belt of coal mines exist in Chhindwara district, where the study area lies, and the neighboring Betul district spread over an area of 8056.61 km^2. These coal reserves are all the more important from a coal mining point of view as they hold a considerable reserve of thermal grades of non-coking coal [26]. At present, there are a total of 17 coal mines operational in Chhindwara district (where the study area lies) which includes 6 opencast (OC) mines, 9 underground (UG) mines, and 2 mixed (partly OC and partly UG) mines [27]. However, the production of open cast mines is four times that of the underground mines [28].

The coal mines located in the vicinity of the study area are shown in Figure 3. The Pench-Kanha wildlife corridor overlays a wide-ranging coal belt with promising coal deposits. Active mines exist both to the east and west of the corridor. The Tandsi underground coal mine lies beneath the northern edge of the corridor, while the Nandan and Barkuhi opencast mines are located at a distance of 10.5 km and 15 km respectively. The negative environmental impacts of mining, especially opencast mining, are tremendous and will result in total degradation of the corridor and loss of connectivity in case the area is opened to coal mining.

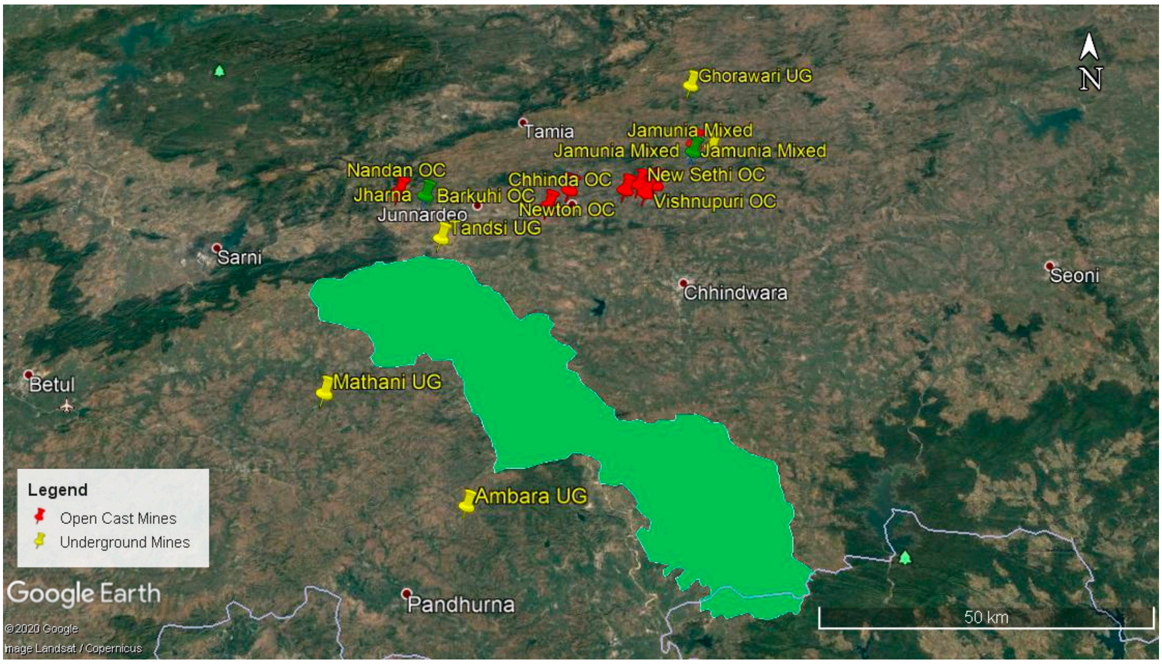


Figure 3. Location of coal mines around the study area.

2. Material And Methods

2.1. Data Sources

The study area encompasses 1520.15 km^2. To analyze the Land Use Land Cover dynamics in the Satpuda-Pench area, satellite images from the public domain USGS Earth were used. It was important to keep into consideration the period of the images to be from the same season of the year to avoid seasonal variation in the images being analyzed for comparison. Hence, images of April 2002 and April 2019 have been used for this study. The details of the images used are given in Table 1 below:

Table 1. Details of images used in the study.

Path and Row	Year 2002 Source: Landsat 7 ETM + Level-1	Year 2019 Source: Landsat 8 OLI/TIRS Level-1
144, 45	23 April	22 April
145, 45	29 March	14 April

2.2. LULC Classification

The study area was classified into six classes of Land Use and Land Cover classification system proposed by Anderson et al. [29]. Since the study mainly focused on wildlife corridors, three classes were based on the density of the forests: ***Dense Forests*** with a density of >0.4, ***Open Forests*** with a density of 0.1–0.4, and ***Scrub Forests*** with a density of <0.1. ***Agriculture*** was taken as the fourth class, as a very substantial part of the study area was under this class. ***Uncultivated Land***, which had a very distinct signature, was taken as a separate class. This class included mostly agricultural land, which was not under cultivation during the period of the study (March–April), but also included barren and uncultivable land. Finally, ***Water Bodies*** was taken as a class which included rivers and their feeder channels, lakes and reservoirs.

2.3. Image Processing

Spectral bands 1 to 7 were used for stacking for both Landsat 7 and Landsat 8 images. The resolution of the images in both cases is 30 m, and hence, accurate results can be obtained. As the study area falls in two satellite images, the corresponding images were mosaicked, and subsequently, a subset of the study area was isolated for the study. Erdas Imagine 2015 was used for image pre-processing, mosaicking, subsetting, classification, and accuracy assessment, and ArcGIS 10.3 was used for the generation of LULC Maps.

2.3.1. Classification of Images

Classification is the process of assigning each pixel into an individual identified class based on a certain set of criteria. For classification, spectral bands 2, 3 and 4 were used for Landsat 7 ETM+ image of 2002, and spectral bands 3, 4 and 5 were used for Landsat 8 OLI/TIRS image of 2019. Supervised classification of the images was carried out using the Maximum Likelihood method and classified images for the years 2002 and 2019 were obtained by assigning desired colors to each of the classes. A total of 180 random points were generated for each of the LULC maps of 2002 and 2019 respectively, using the Stratified Random Sampling Technique. Recoding of the classified images was carried out for the river channels, as dry riverbeds had a spectral signature similar to uncultivated land.

2.3.2. Post Classification Change Detection

Post classification comparison of the separately classified images was carried out and "image difference" image and "highlight change" images were obtained. The LULC change matrix was generated to compare the difference in the LULC classes of the two images under study.

2.4. Accuracy Assessment

Accuracy assessment is the process of validating the generated classified images against a set of reference which is an accurate representation of the actual situation on the ground [30]. Ground truthing was carried out by physical verification of ground control points in the study area. Besides, high-resolution Google Earth data was also used for ground-truthing. The accuracy of each classification was obtained in the form of an error matrix [31,32].

2.5. Magnitude of Change Determination

The magnitude of change represents the change in each LULC class. A positive value indicates an increase in the LULC class size while a negative value indicates a decrease in the same.

The magnitude of change is calculated by the formula:

$$K = I - F \tag{1}$$

The percentage of change (A) is calculated by the formula:

$$A = (I - F)/F \times 100 \tag{2}$$

where:

K = magnitude of change
A = percentage of change
F = first date (2002)
I = reference date (2019).

A flow diagram for the methodology of the study is given in Figure 4.

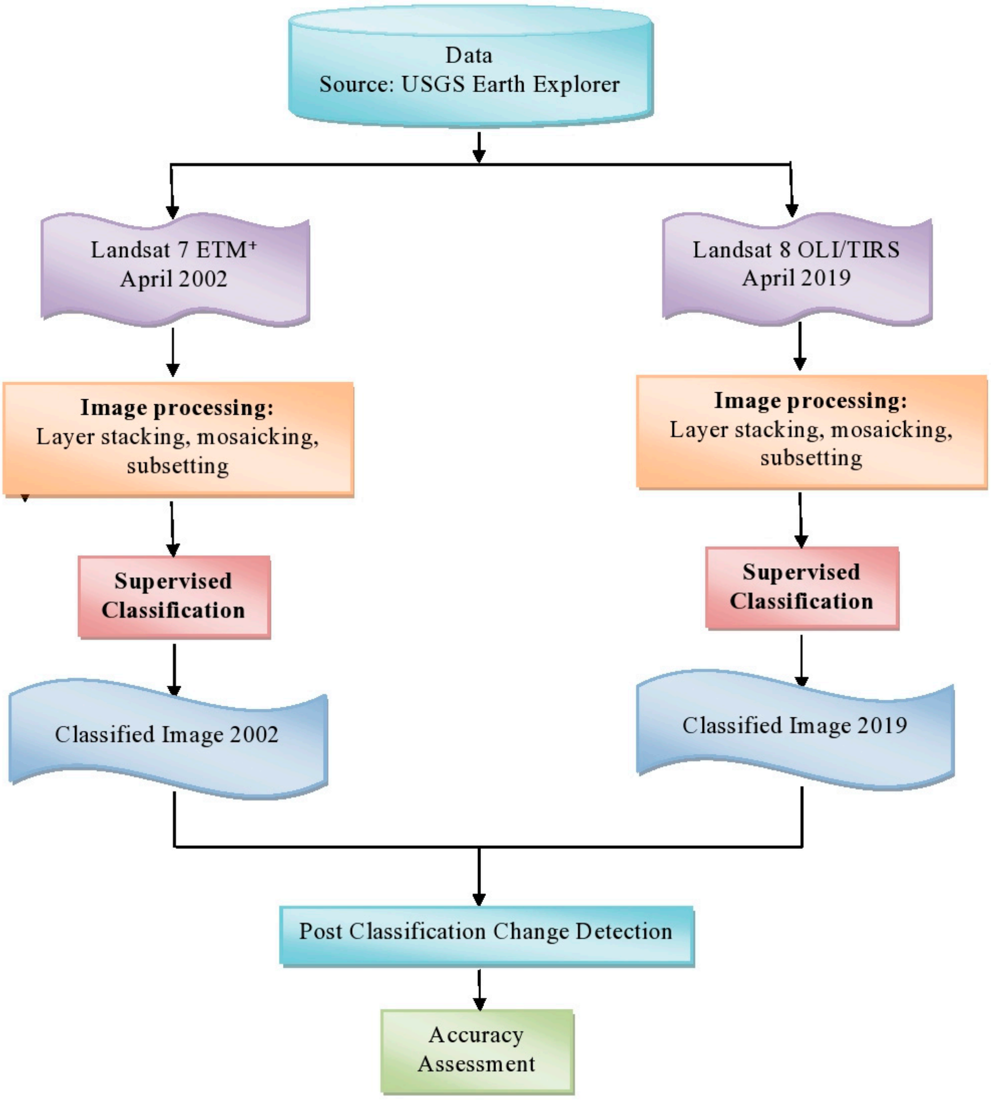


Figure 4. Methodological flow diagram.

3. Results

3.1. Evaluation of LULC Cover Maps

The confusion matrix of the analysis is provided in Table 2. A producer's accuracy of 87.60% and a user's accuracy of 85.42% was obtained for 2002, while a producer's accuracy of 88.04% and user's accuracy of 87.55% was obtained for 2019. Thus, an overall classification accuracy of 85.00% and 86.67% were obtained for 2002 and 2019 respectively.

The conditional Kappa for each LULC class obtained is given in Table 3. An overall Kappa of 0.80 and 0.83 was obtained for 2002 and 2019 respectively.

Table 2. Confusion matrix for 2002 and 2019 images.

Class Name	Reference Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
2002					
Dense Forest	51	54	42	82.35%	77.78%
Open Forest	33	30	27	81.82%	90.00%
Scrub Forest	9	18	9	100.00%	50.00%
Uncultivated Land	21	15	15	71.43%	100.00%
Agriculture	60	57	54	90.00%	94.74%
Water Bodies	6	6	6	100.00%	100.00%
TOTAL	180	180	153		
2019					
Dense Forest	21	24	15	71.43%	62.50%
Open Forest	39	33	27	69.23%	81.82%
Scrub Forest	39	42	36	92.31%	85.71%
Uncultivated Land	12	12	12	100.00%	100.00%
Agriculture	63	63	60	95.24%	95.24%
Water Bodies	6	6	6	100.00%	100.00%
TOTAL	180	180	156		

Table 3. Conditional Kappa for LULC (Land Use Land Cover) classes.

Class Name	2002	2019
Dense Forest	0.69	0.58
Open Forest	0.88	0.77
Scrub Forest	0.47	0.82
Uncultivated Land	1.00	1.00
Agriculture	0.92	0.93
Water	1.00	1.00
Overall Kappa	0.80	0.83

3.2. Land Use Land Cover Change Analysis

The Land Use Land Cover Maps of 2002 and 2013 are given in Figure 5. This map represents the distribution of the six LULC classes taken for the study in the year 2002 and 2019, thus displaying the magnitude of change for each class and the location thereof.

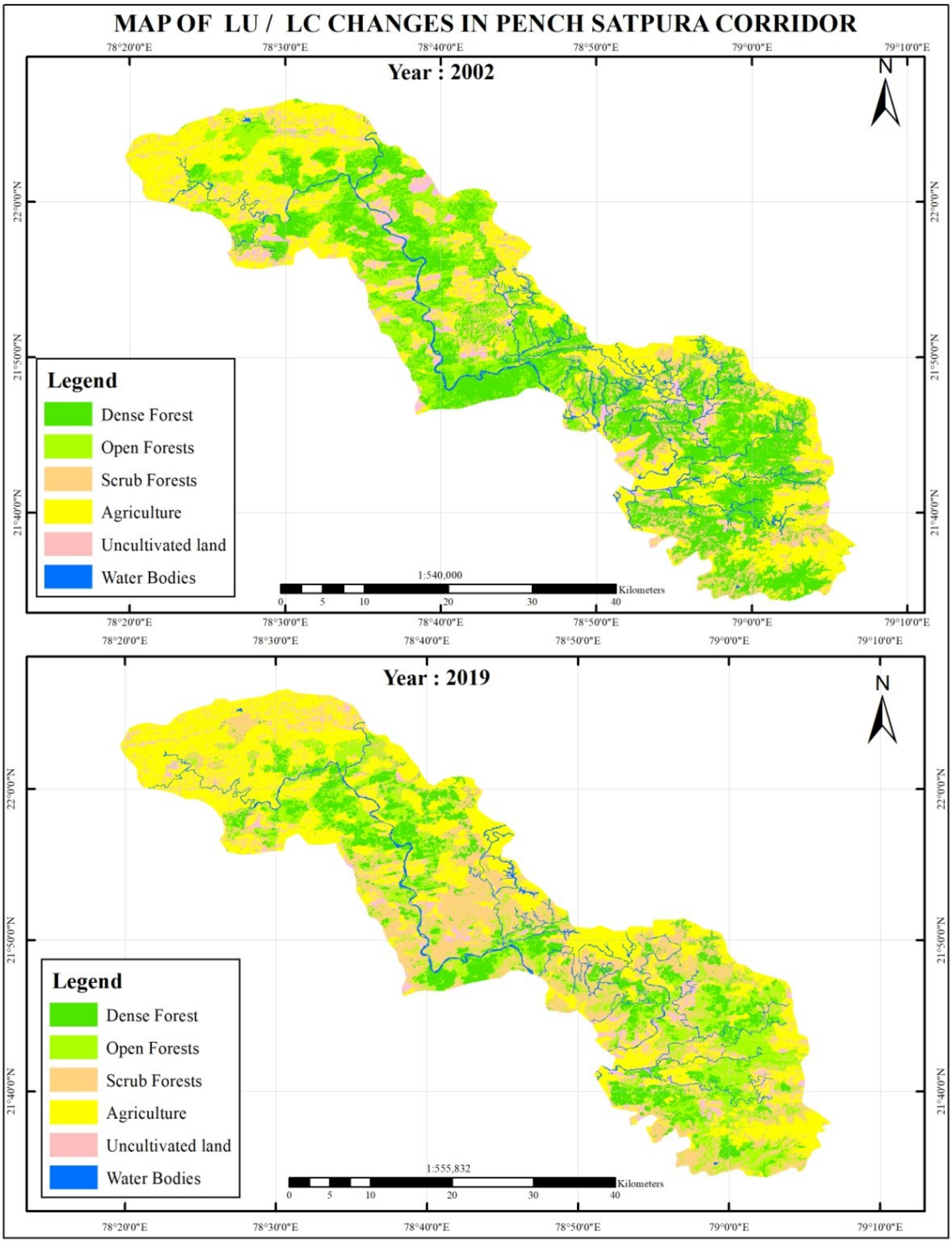


Figure 5. LULC change in Pench-Satpuda wildlife corridor between 2002–2019.

The change in land cover between 2002 and 2019 is provided in Figure 6. This figure depicts areas with an increase or decrease of more than 20%, areas with an increase or decrease of less than 20% and finally, areas where no change has taken place.

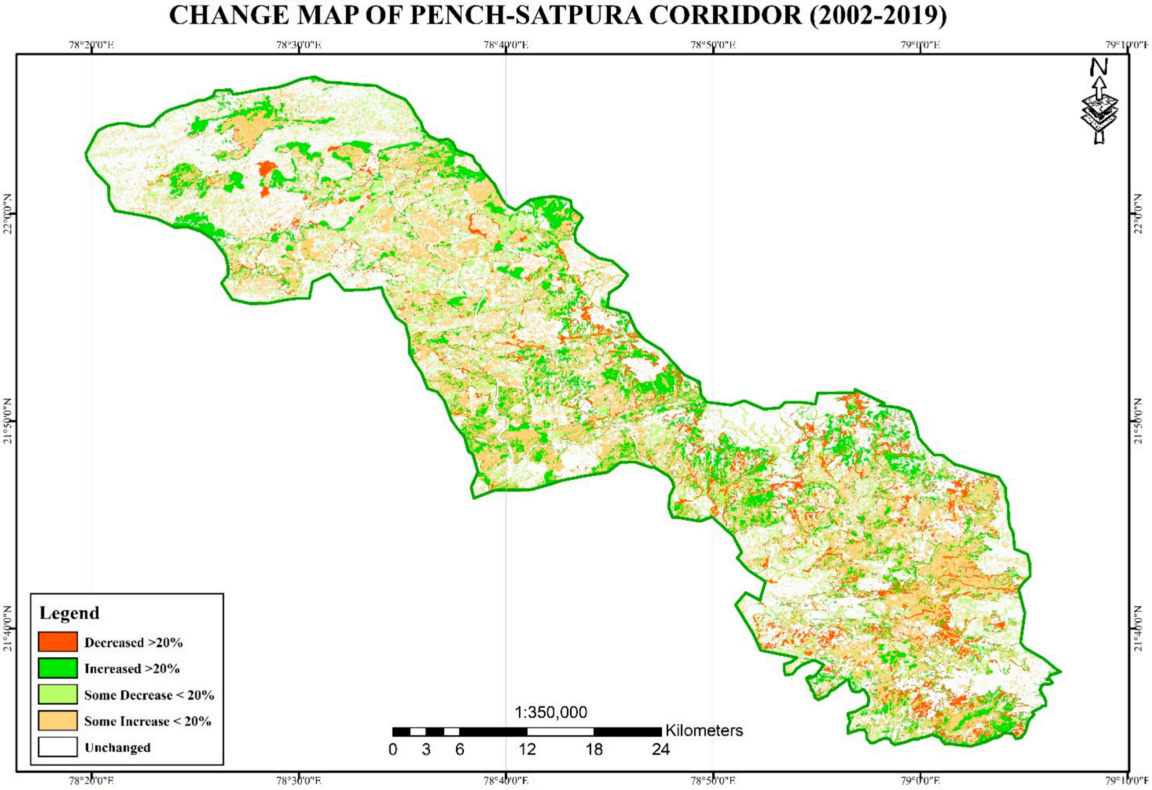


Figure 6. Change Map of Pench-Satpuda wildlife corridor between 2002–2019.

The magnitude and percentage change in LULC classes is presented in Table 4. This table shows the area covered by each class and the corresponding percentage of the total study area for the years 2002 and 2019. The change for each class in the area, as well as the percentage change from 2002 to 2019, is given for each LULC class.

Table 4. Magnitude and percentage change in LULC classes.

Class	AREA CHANGE					
	2002		2019		CHANGE	
	Ha	% Age	Ha	% Age	Ha(4 − 2)	% age(6/2) * 100
1	2	3	4	5	6	7
Dense Forest	46,074.48	30.31	20,767.05	13.66	−25,307.43	−54.93
Open Forest	23,931.29	15.74	27,709.03	18.23	3777.74	15.79
Scrub Forest	13,815.12	9.09	34,667.88	22.81	20,852.75	150.94
Uncultivated Land	13,229.27	8.70	10,489.25	6.90	−2740.02	−20.71
Agriculture	48,947.70	32.20	53,893.42	35.45	4945.72	10.10
Water	6017.29	3.96	4488.53	2.95	−1528.75	−25.41
Total	**152015.15**	**100.00**	**152015.15**	**100.00**	**0.00**	

The LULC change matrix is given in Table 5. This matrix is a cross-tabulation where the area of each LULC class of the given year (2002) has been compared to the area of the LULC classes of the year under comparison (2019). The last column of the matrix shows the percentage change in the area between 2002–2019.

Table 5. LULC change matrix.

	2002								
	LULC Classes	**DF**	**OF**	**SF**	**UL**	**Ag**	**W**	**Total (2019)**	**% Change 2002–2019**
2019	DF	13,236.60	4733.15	1859.96	104.92	442.95	389.47	20,767.05	−121.86
	OF	17,286.60	5673.79	2533.59	206.62	1431.53	576.90	27,709.03	13.63
	SF	12,236.70	9939.83	7884.06	822.00	2664.13	1121.16	34,667.88	60.15
	UL	286.79	221.43	177.39	4247.43	5294.55	261.66	10,489.25	−26.12
	Ag	2309.93	3182.97	1100.31	7658.06	38,332.00	1310.15	53,893.42	9.18
	W	717.86	180.12	259.81	190.25	782.54	2357.95	4488.53	−34.06
	Total (2002)	46,074.48	23,931.29	13,815.12	13,229.27	48,947.70	6017.29	152,015.15	

DF = Dense Forest; OF = Open Forests; SF = Scrub Forests; UL = Uncultivated Land; Ag = Agriculture; W = Water.

The net area change matrix derived from the LULC change matrix is given in Table 6. The total of each column represents the change in each class between 2002 and 2019, while each cell represents the individual change from the class mentioned in the column to the class mentioned in the corresponding row. Positive values indicate the addition of area to a given class while a negative value represents the deletion of the area of a given class.

Table 6. Net area change matrix.

		2002					
	LULC Classes	**Dense Forests**	**Open Forests**	**Scrub Forests**	**Uncultivated Land**	**Agriculture**	**Water**
2019	**Dense Forest**	0.00	12,553.45	10,376.74	181.88	1866.98	328.39
	Open Forest	−12,553.45	0.00	7406.24	14.81	1751.44	−396.78
	Scrub Forest	−10,376.74	−7406.24	0.00	−644.60	−1563.82	−861.35
	Uncultivated Land	−181.88	−14.81	644.60	0.00	2363.51	−71.41
	Agriculture	−1866.98	−1751.44	1563.82	−2363.51	0.00	−527.61
	Water	−328.39	396.78	861.35	71.41	527.61	0.00
	Area Change 2002–2019	−25,307.43	3777.74	20,852.75	−2740.02	4945.72	−1528.75

Dense Forests covered an area of 46,074.48 ha in 2002, which was 30.31% of the study area. By 2019, the dense forest cover was reduced by an area of 25,307.43 ha (−54.93%) to 20,767.05 ha, which now comprised a meager 13.66% of the study area. Thus, there has been a phenomenal reduction in the area of Dense Forests. The LULC change matrix reveals that a net area of 12,553.45 ha of Dense Forests was converted to Open Forests while a net area of 10,376.74 ha was converted to Scrub Forests, thus indicating large-scale degradation of the Dense Forests. A net area of 1866.98 ha of Dense Forest has been converted to Agriculture indicating clearing and illegal encroachment of Dense Forests for cultivation.

Open Forests represent areas with a density of 10–40%. This class covered an area of 23,931.29 ha in 2002 which comprised 15.74% of the study area. The area under this class increased by 15.79%, that is, by an area of 3777.74 ha between 2002 and 2019 to cover an area of 27,709.03 ha, which comprised 18.23% of the study area in 2019. As mentioned in the previous paragraph, the major area gained in this class is by way of degradation of an area of 12,553.45 ha of Dense Forests. At the same time, there has been a net loss of an area of 7406.24 ha from this class to Scrub Forests indicating the degradation of this class of forests as well. A net area of 1751.44 from this class has also been lost to Agriculture, again indicating clearing of Open Forests and illegal encroachment for cultivation.

Scrub Forests, with an area of 13,815.12 ha, covered 9.09% of the study area in 2002. This area under this class increased to 34,667.88 ha in 2019. The magnitude of LULC change in this class over 17 years is 20,852.75 ha and the percentage increase is 150.94%. Due to degradation of the forests, an area of 10,376.74 ha of Dense Forests and 7406.24 ha of Open Forests have been added to this class.

An area of 1563.82 ha has been lost to Agriculture, again indicating illegal encroachment of forest land for cultivation.

Uncultivated Land comprised 8.70% of the study area and covered 13,229.27 ha in 2002. There was a decrease of 2740.02 ha in the area of this class, and the area covered in 2019 was 10,489.25 ha in 2019, which is 6.90% of the study area. The percentage decrease is −20.71%. A major part of this reduction can be attributed to the conversion of an area of 2363.51 ha of Uncultivated Land to Agriculture. An area of 644.60 ha from this class has been converted to scrub forests indicating these areas to have been abandoned at a later stage by the encroachers and subsequent regeneration over such lands.

Agriculture is the largest LULC class covering the maximum area among all classes, both in 2002 and 2019. The area under Agriculture in 2002 was 48,947.70 ha and covered 32.20% of the study area. There was an increase of 10.10% area under agriculture by 4945.72 ha by 2019, and this class now covered an area of 53,893.42 ha and accounted for 35.45% of the study area. This class has gained a net area of 3618.42 ha from the forests (1866.98 ha and 1751.44 ha from Dense Forest and Open Forests respectively) indicating clearing of forest areas for cultivation and illegal encroachment by local communities. An area of 1563.82 ha of Agriculture has been converted to Scrub Forests indicating abandonment of agriculture and subsequent regeneration of such areas. An area of 2363.51 ha has also been added to this class due to the conversion of Uncultivated Land to Agriculture.

Water Bodies form the lifeline, both for the wild animals as well as humans. The area covered by water bodies in 2002 was 6017.29 which constituted 3.96% of the study area. The area under water bodies was reduced by 25.41% by an area of 1528.75 ha by 2019, and the area now covered was 4488.53 ha which constituted 2.95% of the study area. The major loss of an area of 861.35 ha of this class has been lost to Scrub Forests. This indicates drying up of river streams and catchment areas and subsequent regeneration of forests in such areas. An area of 527.61 ha of Water Bodies has been converted to Agriculture which indicates farming activities being taken up along the drying rivers and streams. The shrinkage of water bodies can be directly correlated to the degradation of forest areas.

4. Discussion

Forests harbor immense biodiversity, especially in the tropical regions [33]. The loss of forests has serious consequences as the biodiversity and survival of wildlife is threatened [34,35]. Our study finds large scale deforestation in the study area, which can be attributed mainly to anthropogenic reasons such as illicit felling of timber and conversion of forest land to agriculture. Forests provide food, cover, and shelter, or in other words, a habitat for the survival of wildlife. Loss of, or changes in habitat, are the prime causes of wildlife decline [36]. Besides, depletion of forests also results in an escalation of human-wildlife conflict [37]. Forests act as sponges to absorb rainfall and reduce run-off and there is a direct correlation between forest degradation and reduction in water availability [38]. We have also found that the net area of water bodies has shrunk considerably in the time frame of 17 years of our comparison, and this can be directly correlated with the depletion of the forests in the study area.

Earlier studies carried out in the adjoining Pench-Tadoba Wildlife corridor also found a significant decrease in dense forest cover [39]. Our study finds that the land use of a significant area of forests has been altered to agriculture. The villagers residing in the vicinity of the forests are dependent on the forests for their daily sustenance needs such as firewood, fodder/grazing, and timber, which eventually results in depletion of forest cover and degradation, as substantiated in a study in the Pench-Kanha corridor, neighboring the study area, which found a higher rate of depletion of forests in villages with a higher population as compared to villages with a lower population [40].

A recent study on deforestation due to mining has found that five states of India, including the state of Madhya Pradesh, where the study area lies, that account for 35% of India's forests also produce large amounts of coal and iron [41]. Even though underground mining presumably has zero impact on the surface, studies have found that subsidence from underground coal mining adversely impacts agriculture by creating wet or ponded areas sometimes resulting in crop failure [42] and that the subsidence adversely impacts bulk density, development of surface cracks, the undulation of land and tilting of trees at the edge of the subsided sites [43]. Opencast mining is far more deleterious to the environment and the direct effects of mining activities are removal of topsoil and vegetation and the resulting loss of productivity of farmlands and forests, biodiversity loss, contamination of water bodies and groundwater through leaching, and environmental risks and hazards arising out of overburden dumping. Mining in close vicinity of the Pench-Satpuda wildlife corridor and rich coal deposits is a matter of great concern for long-term sustenance of this corridor. Therefore, the situation calls for future land-use planning that prohibits any form of opencast mining in the area.

Pench-Satpuda corridor is an active wildlife corridor as substantiated by camera trapping studies carried out in 2017 [24]; and many species of ungulates, canids, simians and felines including the charismatic tiger and leopard have found to have been using this wildlife corridor for movement and migration between the Pench Tiger Reserve and Satpuda Tiger Reserve. Degradation and habitat loss in the corridor will render this wildlife corridor unviable, thereby isolating populations, which will adversely impact the genetic diversity of the landscape.

An effective conservation strategy involves obvious complexities and approaches that vary, from science and planning to policy and site-specific measures [44]. As wildlife habitats become increasingly fragmented, conservation of corridors assume paramount importance, and therefore, documenting the loss of connectivity, assessing root causes, and exploring restoration options are priority conservation goals [45]. In the Indian context, wildlife corridors do not have any defined boundaries, nor do the wildlife corridors have any legal recognition as 'important' for wildlife conservation. There is no statutory regulation of developmental activities within such areas despite their established relevance in ecological conservation [46].

5. Conclusions

The Pench-Satpuda wildlife corridor is a very important wildlife corridor of central India and its viability is critical to long-term migration of wildlife in the landscape. The study found large-scale degradation of the forests, shrinkage of water bodies, and an increase in the area under agriculture due to illegal encroachment over forest lands by local communities which might eventually lead to a total disruption of the corridor, in the case of preventive measures not timely taken. Further, the presence of rich coal deposits and the presence of active opencast and underground mines in close vicinity of this wildlife corridor is a matter of great concern for the long-term existence of this critical wildlife corridor. The long-term conservation of wildlife and biodiversity at the regional level is possible only by conserving this critical wildlife corridor.

Based on the findings of the study, the following mitigation measures can be implemented for the betterment and long-term viability of the corridor:

1. Detailed survey and demarcation exercise to identify the boundaries of forests and eviction of illegal encroachers undertaking cultivation on forest lands.
2. Enrichment of the forests through Assisted Natural Regeneration (ANR) or artificial regeneration (gap planting). This will improve the water regime of the area to reduce human-wildlife conflict.
3. Escalating the level of protection of the forests to prevent illegal felling of trees in the wildlife corridor and taking stringent action under the law against those involved in the illicit felling of trees.
4. Scientific management of grasslands for supporting the herbivore population. This will reduce cattle depredation by carnivores.
5. Declaring the Pench-Satpuda wildlife corridor as an absolute "prohibited area" for coal mining, and even underground coal mining should not be allowed under any circumstance.
6. Scientific monitoring of wildlife through systematic studies and other techniques such as camera trapping, presence-absence surveys, and maintaining wildlife sighting registers by the field staff.

7. Necessity of elaboration of alternatives for local communities to prevent illegal encroachment of forests for cultivation in the future. Such plans should be elaborated jointly by the multiple stakeholders including the administration, local people, and scientists.
8. There is a pressing need to introduce a wide information campaign among local communities to reduce human-wildlife conflict, and for reducing the biotic pressures on the forests.

While this research attempts to put into a perspective the degrading Pench-Satpuda wildlife corridor and its implications for long-term conservation of wildlife in the Central Indian landscape, certain aspects need further research. As previously mentioned, other than the camera trapping study undertaken by WCT, and the broad-based tiger estimation survey carried out on a routine basis by the Government of India, hardly any significant studies have been undertaken in this corridor. Thus, there is a huge scope, as well as pressing need to undertake further research in this critical wildlife corridor.

Since wild animals are found outside forest areas, especially in agricultural lands, as it provides a good cover and shelter for them, both herbivore and carnivore presence/absence studies may be carried out to delineate migratory paths of various species within the corridor. Tracking the movement of wildlife through radio collaring or other telemetry studies can be a good option.

The Pench-Satpuda wildlife corridor is human-dominated, and several incidences of human-wildlife conflict have occurred in the past. This includes crop damage by herbivores, cattle depredation of livestock by carnivores, and injury and death caused in humans by wildlife attacks. An analysis of the human-wildlife conflict in the study area will reveal 'hotspots' where countermeasures can be taken to reduce the conflict. This will greatly help in the conservation of wildlife.

Some other aspects that need further investigation are a quantification of the requirement of the local people vis-a-vis the availability of fuelwood and small timber from forest areas; estimation of the extent of poaching or trapping of wildlife; assessing the impact of grazing on grasslands in forests and exposure of wild herbivores to diseases from domestic herbivores, and the potential of ingress of weed species into the tiger reserves from the wildlife corridor.

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