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Assessing anthropogenic disturbance on forest health based on fragment grading in Durgapur Forest Range, West Bengal, India

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Abstract With the increasing degradation and encroachment of natural landscape environmentalists are now highly concerned with declining forest cover as well as increasing forest fragmentation at different scales across the world for last several decades. Considering the major fourfold effect of forest fragmentation i.e., reduction in habitat area, increased number of fragmented habitats, decrease in area coverage of habitat patch and increased number of isolated patches forest fragmentation is recognized as a major threat to forest ecosystems. Indicators of forest fragmentation are thereby gaining gradual importance at national and international environmental programs. But Spatio-temporal change of forest cover using forest fragmentation along with incorporation of population growth and associated anthropogenic intervention, at a micro-spatial scale has become the major thrust area in the present study. Kanksa is one of the few forest dominated block in Barddhaman District mostly affected by the rapid population growth, land use change in terms of increase in irrigated area as well as agricultural land, rapid urbanization in the last three decades. Present study focuses on forest fragmentation and spatio-temporal dynamics of forest cover from the beginning of 1990s up to present using geospatial techniques.

1 Introduction

Human activities play an important role by altering the large forest cover to small fragments. The growing degradation in terms of human-induced forest cover change is a significant research area for landscape ecologists that have raised several issues in the last several decades in the context of the changing global environmental scenario [1–3]. Anthropogenic activities (e.g., land-use change) and resulted stress in terms of deforestation and reduction in forest density are among the major focus of present study in relation to current global climatic disorder as well as concerns of biodiversity [4, 5]. Pressures of human population growth are intensified in this context as well as expanding the area of land-uses, such as agriculture and built-up land, along with urbanization, that create pressure on natural environment in various parts of the earth to meet the demand of population for basic needs of survivals [5, 6]. As a result, such type of spatio-temporal dynamics of land-use have led to decrease in forest cover which further increases the fragmentation of remaining forest lands [7, 8]. But from a conservationist perspective, forest health can be estimated by quantifying different variables, such as the capacity of forests to provide ecosystem services and the capacity for adequate natural reforestation [9].

Forest fragmentation indicates the mechanism through which vast-continuous forest areas are converted into a number of smaller and distinct isolated fragments [10] Fragmentation of such green spaces throughout the world

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can increase the risk of species extinction which ultimately reduces biodiversity [11]. Globally, forest cover markedly diminished over the last several decades through human interferences [12–14]. In pace with global phenomena, India has been continuously facing the problem of forest degradation mainly due to population growth and demand for forest products and its economic earning especially through non-timber forest products [15, 16, 34]. In the state of West Bengal, rapid rate of urbanization and population increase largely affect green space. Therefore, Barddhaman being developed in urbanization and industrialization is not an exception to this scenario. Only 3.94% of the total area of Barddhaman district has remained in the central part of the lateritic tract of Barddhaman as protected forest under the Burdwan and Durgapur Forest Division [17]. Large scale modification of land into mining sector and industrial complex, along with urban expansion specially in and around Durgapur region fragmented the whole green space into different segments which is a greater concern considering the ecological set up of whole region. Therefore, discourse about forest dynamics, its temporal phenology and the extent of fragmentation may be influential factors for eco-friendly forest management [18, 19].

Remote sensing and GIS-based application have become useful tools in examining many issues of human induced forest degradation and fragmentation globally [10, 20–27, 34, 35]. At the landscape level, forest fragmentation has resulted in loss of habitat for some forest-dependent community, reduced connectivity of the remaining green space from all angles, increased inter-patch distance, as well as, increase in edge at the expense of core forest [25, 28–36]. In Indian context, Sahana et al. [37, 38] and Jain et al. [39] studied forest cover dynamics using forest fragmentation approach to monitor spatio-temporal change in the forest health in Physiographic unit such as Song Watershed in northern India as well as in protected forest area of Sariska Tiger reserve respectively and have pointed at the probable anthropogenic disturbance for LULC change as a casual factor of such temporal dynamics in green space.

In the present discussion, with deeper insight, a unique methodology is applied for integrating forest cover change trajectories by forest fragmentation approach, spatial patterns of fragmentation, and lastly forest disturbance which is not included simultaneously with fragmentation by the previous researches. Numerous human activities are responsible for forest disturbances which is associated with fragmentation. Here we have assessed the impact of two major developmental entities in terms of a built up environment as settlement and transport on the dynamics of forest health by proximity measurement in Durgapur Forest Range (DFR) of Barddhaman District in West Bengal using geo-spatial approach. Two specific objectives in this study

are: (1) to assess the spatio-temporal patterns of forest fragmentation in the protected and open forest between 1990 and 2015 and (2) to analyse the factor and degree of disturbances of forest cover change with respect to the impact of built up environment, demographic aspects in terms of settlement and transport as well as population growth factor in DFR.

2 Materials and methods

2.1 Study area

The focused area i.e., the central part of Barddhaman District which occupies an area of 278.4 km². Areas under Kanksa C.D. Block include the total DFR under Burdwan Forest Division of West Bengal, India. The study area is bounded by the Ajay River in the north, girdled by the Damodar River on the south, while the Kunur River flows through the middle part of the study area from west to east. The study area extending from 23°25′N to 23°42′N latitudes and 87°20′E to 87°35′E is located in the Ajay–Damodar interfluves of the district (Fig. 1). In Kanksa
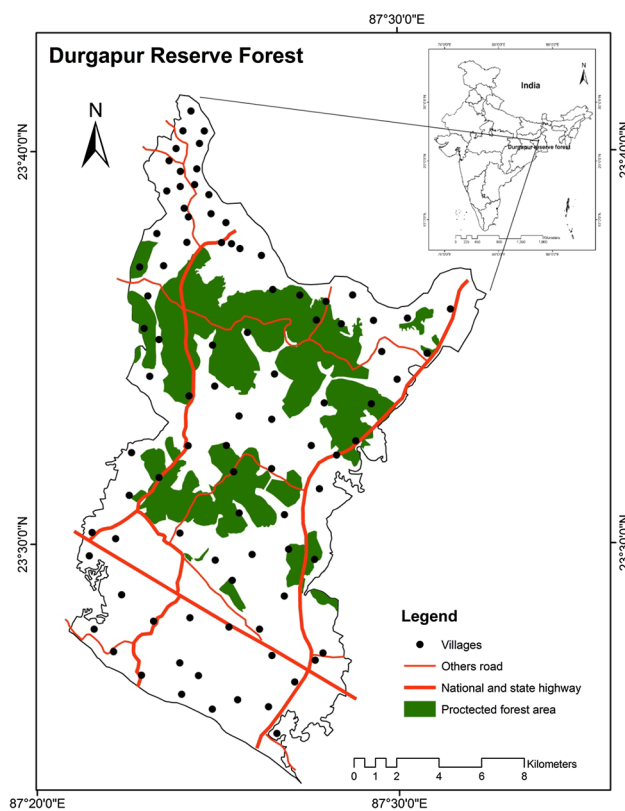

Fig. 1 *Maps* show location of the study are in the eastern part of India and in the state of West Bengal and *green patches* are the protected forest (PF) boundary under Durgapur Forest Range and its association with settlement and road *lines* in *black dots* and *red colours line* respectively. (Color figure online)

Block, 62.4 km^2 area fall under the Protected Forest boundary of DFR. The study area has a mean surface elevation of 50–60 m under the rolling topography with lateritic land and numerous gullies and ravines. The climate is tropical monsoon but morphogenetically belong to 'Tropical Wet-Dry Savanna Region' [40]. The region under the Kanksa block has a population of 1, 78,125 with a population density of 640 per sq km. The spatial variations in the distribution, density composition, migration and growth of population have a direct imprint on the utilization of resources and the levels of development of the region. As a whole, in the study area population growth is very rapid after 1951 but quite steady and slow after 1981. Decadal growth rate was maximum in between 1951 and 1961. In the last two decades (1991–2001) this growth has almost been the same. Till 1991 there was no recorded urban center. But after 2001, Census has accounted seven urbanized tract in terms of Census Town (CTs') in Kanksa. As a result the urban share of population has significantly increased from nil to 20.4% in 2001 and 41.8% in 2011. All these seven census towns have emerged from initially agro-based rural units. These are Kanksa, Debipur, Prayagpur, Arrah, Gopalpur, Bamunara and Amlajora. Three stages of demographic transitions have been identified since independence. These are: (a) Rapid growth of population (1951–1961), (b) Steady growth of population (1961–1981), (c) Period of high growth with definite sign of slowing down (1991–2011). Another important identity of Kanksa is the concentration of tribal population. Though only 10.2% of total population belongs to this category but the spatial pattern of this concentration is quite interesting. Gini's Co-efficient Value (0.59) depicts the uneven distribution of ST population in the study area. There are 21 villages having more than 25% tribal population contiguously found in the northern and central part of the study area mainly around the Durgapur Protected forest. This location is very important as it marks the interaction of man and nature in a forested environment.

2.2 Database

Evaluation of spatio-temporal dynamics in forest cover area has been done by using a set of two Landsat images from two different time point. These two different sensor systems under Landsat series, Landsat TM image of 5th January, 1990 and Landsat 8 (OLI) image of 17th December, 2015, were incorporated as major sources of information for assessing the forest fragmentation under forest health monitoring. Landsat data are more popularly used spaceborne numeric information for green space identification, forest fragmentation and forest habitat degradation studies [41]. USGS (http://earthexplorer.usgs.gov) provides geometrically and radiometrically corrected datasets in terms of satellite images from different time points throughout the globe in GeoTIFF format. The data were collected for this study was nearly cloud free. Nevertheless we used histogram minimum method or dark pixel atmospheric correction method [42] to remove additive effects due to atmospheric scattering for the satellite data. This image processing helps improve surface reflectance values of the images giving better result for assessing vegetation indices. Survey of India (SoI) topographical sheet was used for preparation of base map and delineation of protected and non-protected forest. Focused area under present study (DFR) was judiciously subset based on area of interest (AOI) from the satellite images for two different time periods separately, and the NDVI maps and forest fragmentation maps were prepared as digital database. Population data for the period of 1991 and 2011 were collected from census of India for assessing anthropogenic influence of population growth on forest health. Schematic form of methodology for this study is shown in Fig. 2.

2.3 Image analysis

Two types of image analysis techniques were applied in this study for mapping and monitoring of forest cover of the study area. First, normalized difference vegetation index (NDVI) was applied for identify the forested pixel and unsupervised image classification techniques for separation of forest land from non-forest areas. Infrared wavelength reflects well off healthy vegetation so the infrared bands were used for mapping and monitoring vegetation cover [42]. NDVI is very reliable and have been a widely used vegetation index for monitoring forest health by many authors over the last few decades [43, 44]. The associated derivation of indices is given below:

$$NDVI = (NIR - Red)/(NIR + Red)$$

Red and NIR stands for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. The results under NDVI vary between -1.0 and $+1.0$. In less vegetated areas NDVI values derived from Landsat 8 are greater than the NDVI values derived from Landsat TM. NDVI values of both the images increase and the difference of NDVI values becomes smaller in Landsat 8 than Landsat TM. If the area is under dense forest cover then NDVI values remain consistent for both the images [45, 46]. NDVI pixel values were used to differentiate the forest pixel from non forest pixel by using unsupervised classification techniques. The generated unsupervised images were used to apply forest fragmentation model.

Fig. 2 Flow chart of the methodology for assessing anthropogenic disturbance on forest health in Durgapur Forest Range in West Bengal, India
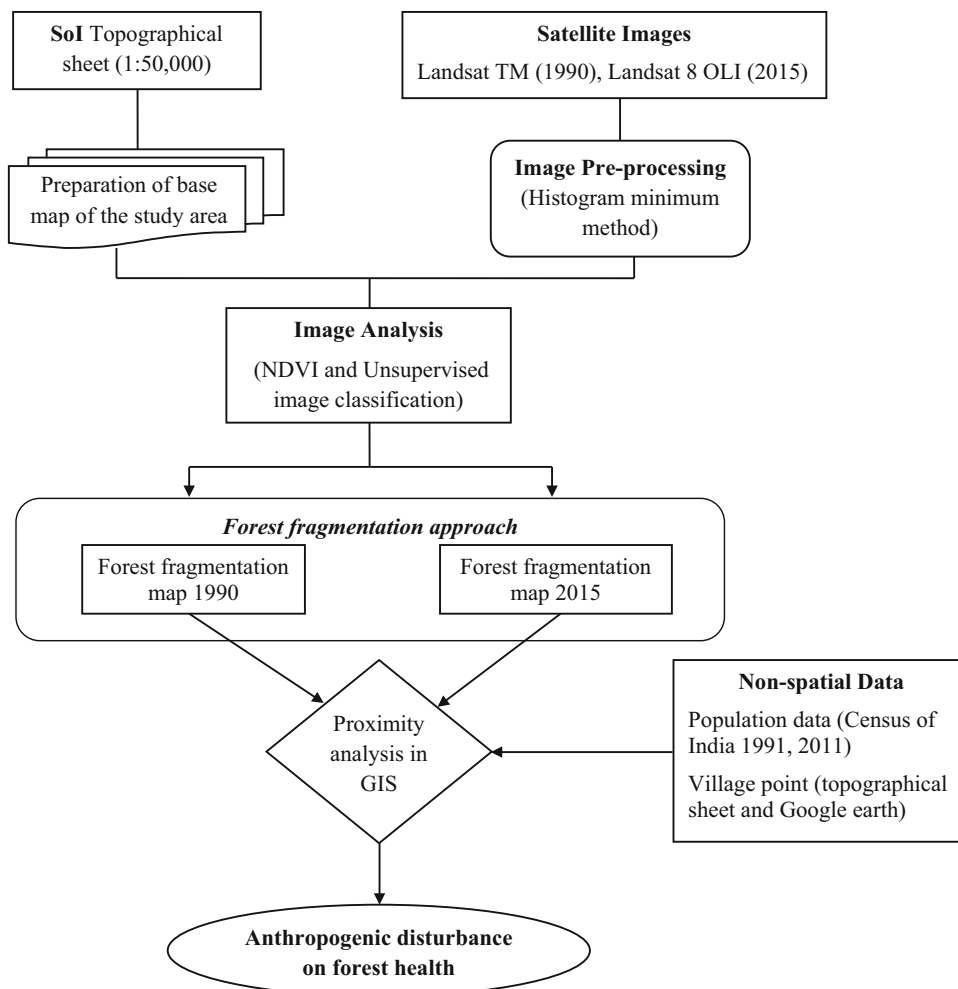
2.4 Forest fragmentation approach

Many researchers used FRAGSTATS model to analyze fragmentation [38] but CLEAR tool has some advantages over FRAGSTATS since it provides spatial, as well as, visual results [35, 47]. Fragmentation of forest is assessed taking into account two forest types uniquely and separately—Protected Forest and Opens Forest. The forest fragmentation maps two time periods 1990 and 2015. They were prepared and areal change in each fragmentation class was extracted from numeric datasets. In the present work, fragmentation was categorized into five; (1) non-forest, (2) patch, (3) edge, (4) perforated, and (5) core, using specified edge width (100 m) identified with reference to observations during field visits (Table 1). The core was further sub-divided into three sub categories viz. Core I (>2 km), Core II (1–2 km), Core III (>2 km) based on width of the edges. A fourfold categorization was done to identify the fragmentation level with decreasing disturbance. These are patch, edge, perforated and Core. Edge width indicates the distance within which other land covers (built-up land) can

degrade the forest. To produce a general overall spatial reflection of forest fragmentation, 100 m value was used as edge width parameter in both the cases with Landsat images of TM and OLI sensor with a 30 m resolution. If the effects of atmosphere create uncertainty in the edge class of fragmentation due to its small width, which contains fewer pixels, then it was a limitation of our study. However, this limitation may have had negligible effects on the fragmentation results since few atmospheric haziness pixels may affect only the edge class but not the fragmentation classes. Core is defined as the area far from the disturbance of the edge effect, as well as, something which is relatively far from the forest non-forest boundary. These are forested areas surrounded by more forest cover. The perforated region makes up the interior edge of small non-forested areas surrounded by the Core forest. That in actuality is the boundary between core forest and relatively small green space (perforations) within the forest-landscape. Edge categories are the boundary zone between Core forest area and the non-forested ones whereas, Patches symbolize the-mostly affected green spaces which

Table 1 Forest fragmentation classes and its respective changes

Fragmentation classes	Area in sq km		Area in Percentage		Change in area (sq km)	Rate of change (%)
	1990	2015	1990	2015		
Patch	14.0	19.3	5.0	6.9	−5.3	37.9
Edge	37.9	34.3	13.6	12.3	3.6	−9.6
Perforated	33.1	9.6	11.9	3.5	23.5	−71.0
Core III	11.2	5.2	4.0	1.9	6.0	−53.6
Core II	4.6	1.5	1.7	0.5	3.1	−67.4
Core I	45.2	38.6	16.3	13.9	6.6	−14.6
Total forest area	146.0	108.5	52.5	39.0	37.5	−25.7
Non forested area	132.0	169.5	47.5	61.0	−37.5	28.4

stand as small fragments of forest totally enclosed by non-forested areas.

2.5 Anthropogenic disturbance and impact analysis

Population growth and associated anthropogenic activities in terms of increases in built-up land, construction of transportation networks, as well as, conversion of natural land cover into man-made land uses are the prime factors behind any kind of disturbance on natural landscape. Present study area also experiences such kinds of dynamics into land uses for the last few decades. Forest disturbance due to anthropogenic activities has been assessed with the help of proximity analysis from three parameters. These are: rate of population growth in the 1991–2001 census year, proximity to settlements, and distance from the major road lines in the study area. Among them, population growth rate is spatial information but no physical appearance whereas the other three i.e., village boundary and road lines have physical entity. So, first one is only used to correlate to deforestation rate but in two fold methods which are deforestation within 1 km buffer and more than 1 km buffer. Here population growth rate is used as independent variables and the remaining area used as dependent variables in village level analysis.

At initial stages road lines and village boundaries are vectorized and the center point location of each settlement units has been identified. Village location and major road networks were digitized from the topographical sheet and it was verified and validated by Google Earth imageries by using arc kml file. After that village boundary and road lines, used as disturbance units. Degree of dynamics in each fragmentation class has been assessed from proximity to village and road line separately in two different time phase. The road and village proximity were assessed by using Euclidean distance between village point location and a road line using the Pythagoras equation:

$$a^2 = b^2 + c^2$$

Population growth of each settlement unit i.e., Villages have been calculated by using census data of two time point i.e., 1991 and 2011 with a near about 20 years time span form following formulae:

$$GR = \frac{P2 - P1}{P1} \times 100$$

where GR = Population growth in %, P2 = Population 2011, P1 = Population 2001.

The further rate of population growth in the aforementioned buffer zones has been correlated to draw the relation between them and their extent in the study area. Correlation is use to denote the degree of association between two variables. If two variables x and y are so related that changes in magnitude of one variable are associated with the changes in magnitude of the other variables. Here population growth has resulted into deforestation, so population growth used as independent variable i.e. x and deforestation rate is the outcome of increase in population and, therefore, termed as dependent variable i.e., x. A scatter diagram evolved by plotting these two variables which reflects their degree of association. Whereas actual quantification of their association, as well as, the strength of association has been measured through the correlation co-efficient i.e., denoted in 'r'.

3 Result and discussion

3.1 Forest fragmentation and degradation

Fourfold categorization was done to identify fragmentation level from patch to different order of core forest categories based on width of the edges as well as with decreasing forest disturbance (Table 1). There were marked changes in the distribution of perforated area, edge and patch within

the Core forest during 1990–2015 (Fig. 3). Perforated area also has also experienced maximum decrease from (11.9%) in 1990 to (3.5%) in 2015 registering a decrease of 71% while the total Core area has sharply gone down from 22% in 1990 to 16.3% in 2015 registering a decrease of 36.0% which is a threat to the forest (Table 1). Negligible amount of changes in Edge throughout the study period is detected. Forest under Patch categories has slightly increased from 5 to 6.9% in between 1990 to 2015 recording a change of 37.9%.

Core forest fragmentation and transformation into lower density classes i.e., into perforated forest has mainly occurred in the dense forests of Gopalpur, Arrah and Kanksa beat in the southern part of the DFR which is in close proximity to the National Highway, state highways and railways. High proportion of increased patches was observed near the outgrowth of Durgapur Industrial complex in the southern part. Increase in area under agriculture and settlement in the rural area have resulted in major deforestation over years in the Bistupur and Basudah beat of the study area (Fig. 4).

Fragmentation classes reveal many disturbances in forested areas. The detectable amount of area increase in patch and perforated forest has been found due to increase in anthropogenic interferences like increase in the population, establishment of more built-up lands, and conversion of cart track and pack track into metalled roads, land encroachment, and development of urban built-up land in terms of Census Towns especially after 1991. The Core I (>2 km) area has decreased from 45.2% in 1990 to 38.6% in 2015, Core II (1–2 km) was 1.7% in 1990—0.5% in 2015 and Core III (<1 km) from 4 to 1.9% over the last 25 years. All three sub-categories under core forest experienced a decrease of 14.6, 67.4 and 53.4% respectively over the study period.

Core forest areas have been continuously transformed to lower density classes such as perforated, edge and patch categories. A deep insight into the real scenario would reveal that Core (along with Core I, II, III) forest in the last 25 years was converted to patches (37.9%) due to human inferences (Table 1). Out of total deep forest, 52.5 km^2 was fragmented during 1990 and 2015 and 37.5 km^2 of forest land was transformed to non forest area (28.4% increases). Of the fragmented dense forest, perforated area (71% decreases) significantly transformed to patches (37.9% increase). Out of total forest area, forest under patch, edge and perforated area the significant decrease was from 30.5 to 22.7% (Table 1) in the period of 25 years signifying the conversion of forest land into non-forest land (28.4% increases).
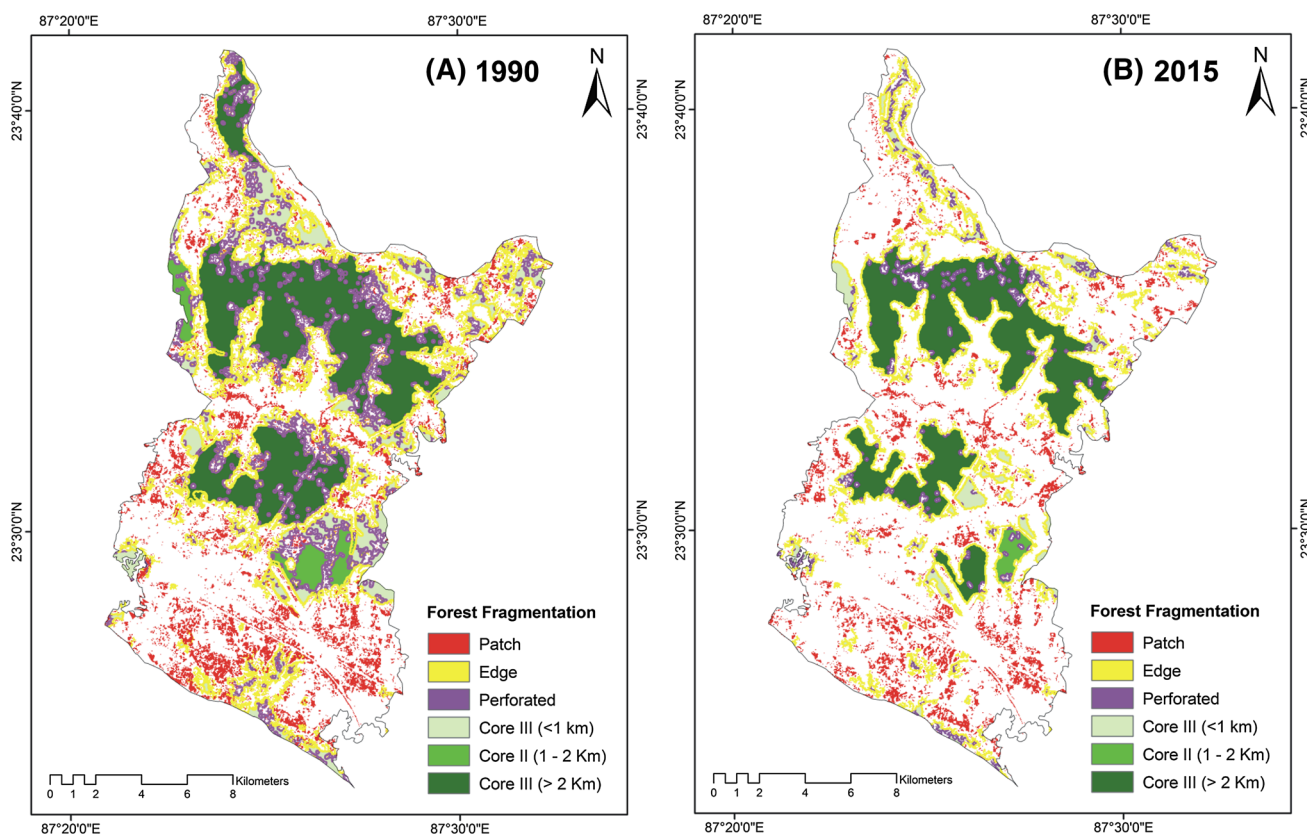

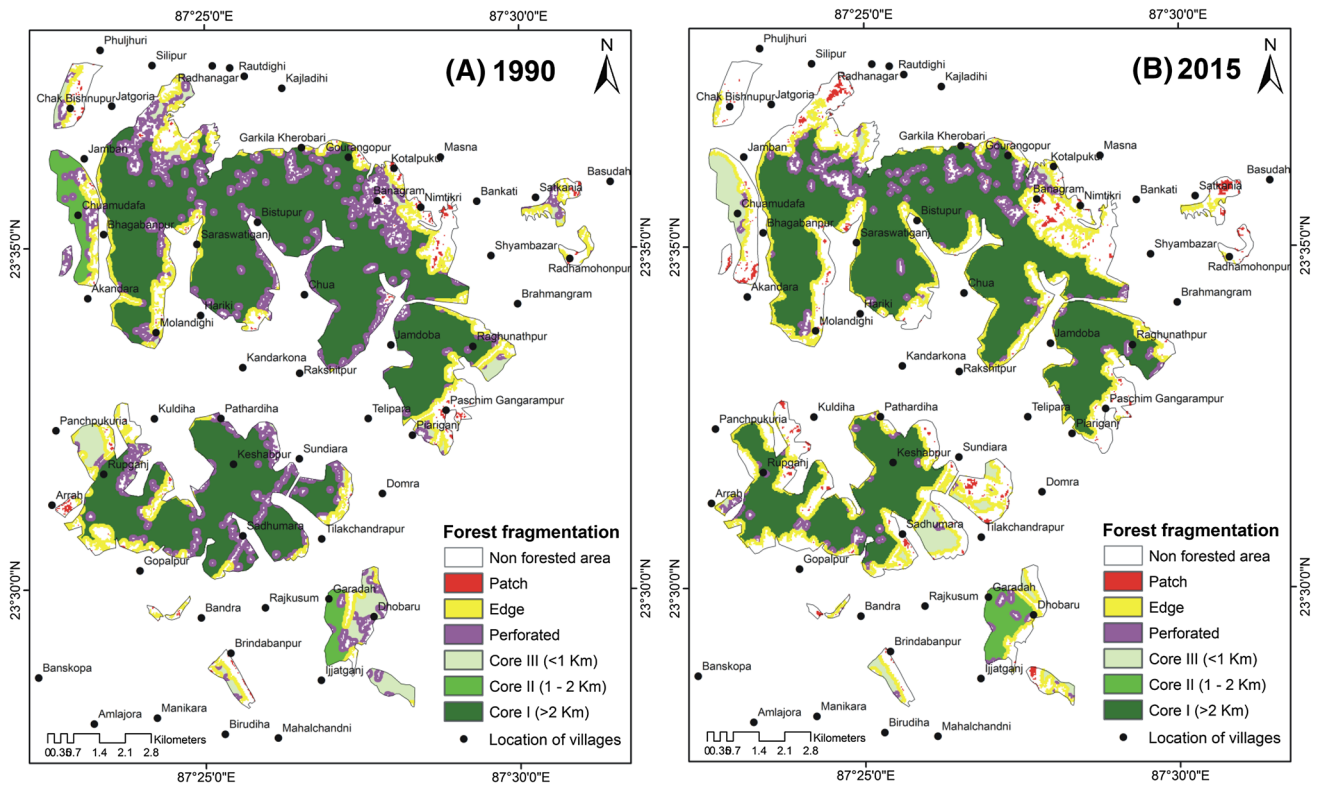**Fig. 3** Nature of forest fragmentation in DFR in 1990 (**A**) and 2015 (**B**)

Fig. 4 Forest fragmentation under protected forest area of Durgapur Forest Range in 1990 (**A**) and 2015 (**B**)
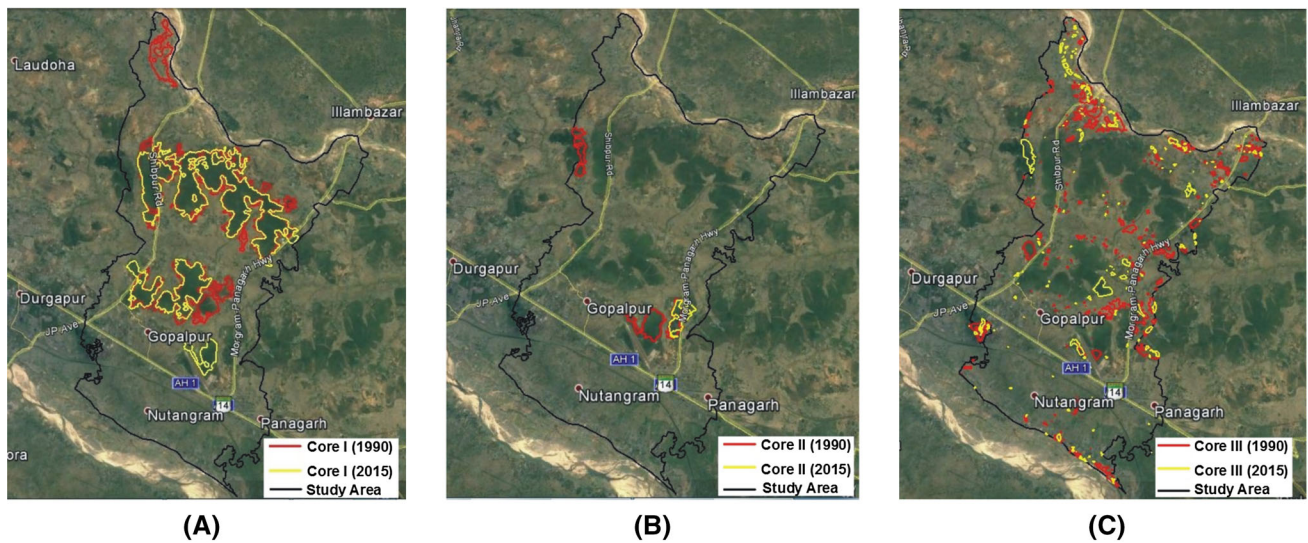

Fig. 5 Fragmentation of Core I (**A**), II (**B**) and III (**C**) forest in study area

In the protected forest region under different beats of DFR perforated and Core forest was found converted into edge and patch forest significantly (Fig. 5). A total 11.2 km^2 of patch forest and 4.1 km^2 of edge forest increases in cost of perforated and Core forest (Table 2). Among them Core II forest decreases 37.5% following the other two as 10.03 and 9.75% respectively in case of Core I

and III. Open forest lying in the middle part of the whole area along the channel of river Kunur and in the southern part i.e., the bank of river Damodar covering the villages of Silampur, Mana etc. were fragmented mainly due to anthropogenic activities, increases in rural habitat and construction of urban built up area in census towns (CTs). Most of the area of this category has been transformed into

Table 2 Nature of forest fragmentation under in protected forest and unprotected forest area

Fragmentation classes	Protected forest area				Unprotected forest area			
	Area in sq km		Area in percentage		Area in sq km		Area in percentage	
	1990	2015	1990	2015	1990	2015	1990	2015
Patch	0.6	11.9	0.9	19.1	13.4	7.4	17.1	19.2
Edge	8.8	12.9	14.1	20.6	29.1	21.5	37.1	55.6
Perforated	13.6	5.5	21.8	8.8	19.5	4.1	24.8	10.7
Core III	2.8	2.6	4.5	4.1	8.4	2.6	10.7	6.8
Core II	2.0	1.3	3.2	2.0	2.6	0.2	3.3	0.6
Core I	39.8	35.8	63.8	57.4	5.4	2.8	6.9	7.2
Non forested area under protected forest area (protected) and open forest area (unprotected)	22.6	26.6	36.2	42.6	78.4	38.6		

patch (12.28% increases) and edge (48.86% increases) (Table 2). Perforation in dense forest under protected forest region has decreased while under open forest it has increased. Perforation decreased in the forest beat of Gopalpur, and Arrah in the southern part of the Range. The transportation line or road corridor as State Highways connecting Illambazar and Moregram via Panagarh in the eastern and western part in north south direction of the study area, has contributed to the transformation of protected forest into perforated, as well as, isolated forest fragments (Fig. 1). The present study under fragmentation reveals that the whole range has lost about 37.5 km^2 (13.5%) forest due to development activity during the last period of 25 years. Perforated forest loss during this time scale was more than the overall loss of forest in the DFR. A massive proportion of 28.4% forest was transformed into non-forest area. Large percentages of the Core forest was converted to perforated area and patch forest due to encroachment by nearby land-use land cover changes induced by rapid anthropogenic interferences. Core forest has become thinner in density leading to perforated and patch forest area.

3.2 Forest disturbance due to anthropogenic interference

In global context as well as regional context too, developmental activities are the major contributors to the fragmentation of dense forest [48, 49]. The generated polygons and population data are used to analyse the impacts of various types of anthropogenic activities (villages and roads) on forest fragmentation. Maximum population growth is found to occur in the villages close proximity to road for better connectivity factors. Area belongs to Census towns (e.g. Bamunara Debipur, Kanksa etc.) and large villages (Birudiha, Basudah, Ijjatganj, Kuldiha etc.) of

Panchayat headquarters. A considerable increase in population and associated anthropogenic activities in terms of increase in land use conversion, construction of road networks as well as conversion of cart and pack tracks into metalled road for better connectivity from main road to village interior, are the significant factors behind any kind of disturbances on forest landscape under DFR. The focused area has also experienced such dynamics into over the last few decades. In between 1991 and 2011, population growths, urbanization around the Durgapur Municipal Corporation and industrial areas in the southern part and land use-land cover change have become more pronounced.

Population growth rate is more responsible for forest degradation in the area of outside 1 km buffer zone of population-settlement unit in comparison to area within 1 km buffer zone which is clearly depicted from the degree of correlation (Figs. 6, 7). Correlation coefficient between the village-wise population growth (x) and degree of deforestation (y) has resulted negative in both the cases which sharply indicate that the deforestation occurs as a result of population growth. For the better insight as well as to evaluate the strength of association between these two, it is better to notice the correlation coefficient (r) value. It is clear that correlation coefficient between the village-wise population growth (x) and degree of deforestation (y) in outside 1 km buffer (i.e., r = −0.67) from settlement is high than the correlation with deforestation rate within 1 km buffer zone (i.e., r = −0.22). Actually deforestation rate and fragmentation in terms of alteration of core forest to perforate one, as well as, perforated to edge forest are high in the region far from settlement unit. The region in the buffer zone of more than 1 km is mostly affected by the population growth, more specifically, settlement growth over the last 25 years. Actually in the initial stage a continuous forest tract is dissected by the people when they

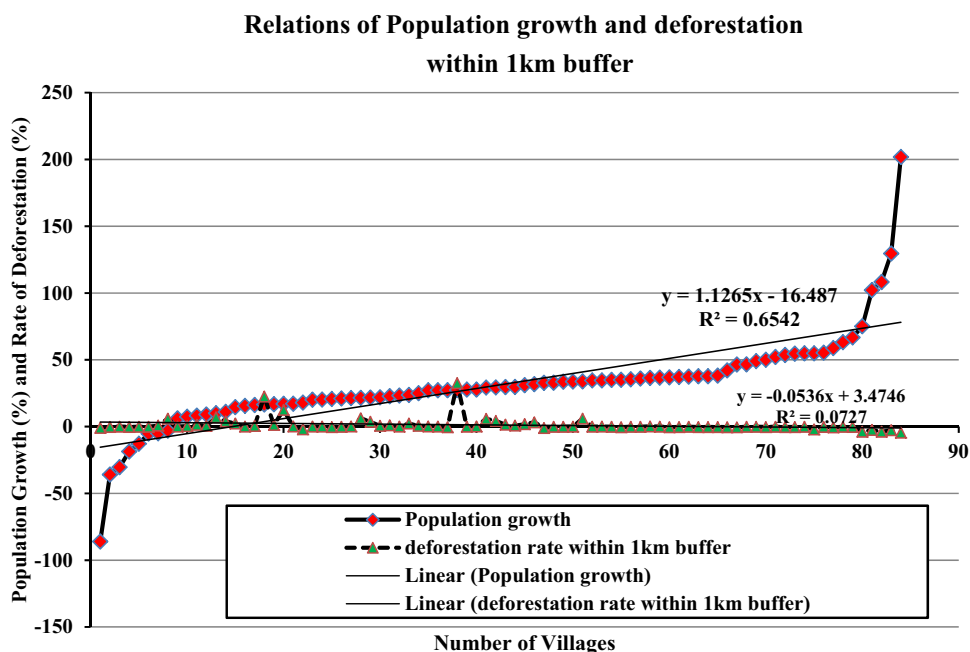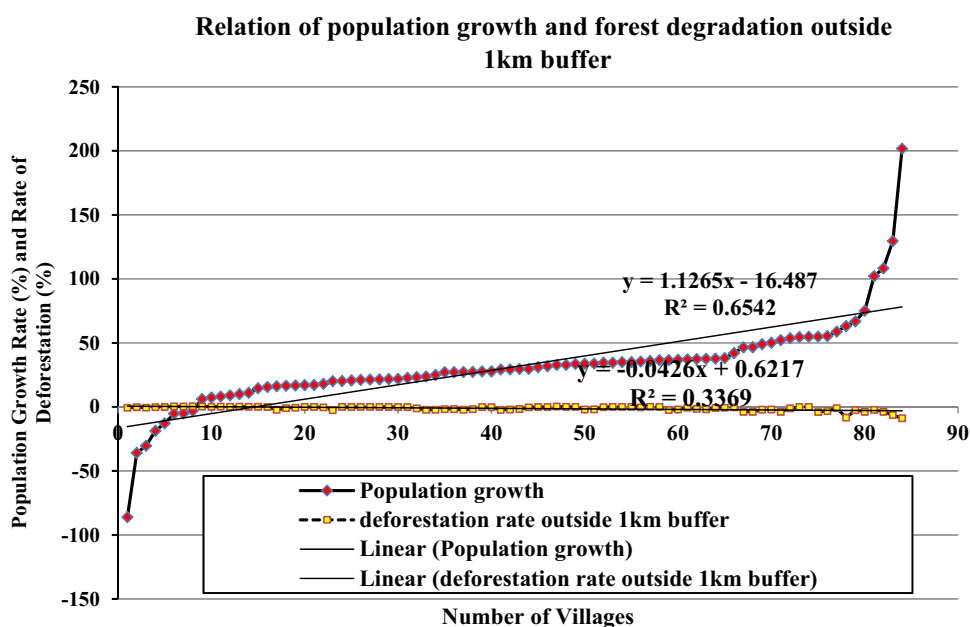**Fig. 6** Relation of population growth and deforestation within 1 km buffer

Relations of Population growth and deforestation within 1km buffer

$y = 1.1265x - 16.487$
$R^2 = 0.6542$

$y = -0.0536x + 3.4746$
$R^2 = 0.0727$

- ◆ Population growth
- ▲ deforestation rate within 1km buffer
- —— Linear (Population growth)
- —— Linear (deforestation rate within 1km buffer)

Fig. 7 Relation of population growth and deforestation outside 1 km buffer

Relation of population growth and forest degradation outside 1km buffer

$y = 1.1265x - 16.487$
$R^2 = 0.6542$

$y = -0.0426x + 0.6217$
$R^2 = 0.3369$

- ◆ Population growth
- ☐ deforestation rate outside 1km buffer
- —— Linear (Population growth)
- —— Linear (deforestation rate outside 1km buffer)

built the pack tract by their daily activities throughout the forest which increased through passage of time and the importance of pack tract enhanced for better connectivity in limited time. But when the pack track was widened to convert it into metalled road that stole the area of forest cover by its extent. The forest area is equal to the area of road deforested by human activities. Population increase and associated construction works added to this connectivity dynamics and resulted to overall fragmentation of forest area adjoining to the roads and road side settlements. Through the total forest boundary under DFR is fixed but

the density changes to lower level due to illegal felling of trees from interiors part. More over the species modification (from Deciduous to Eucalyptus sp.) by influence of Joint Forest Management Programme influences much behind such types of density reduction of forest cover. Forest area is also compromised when homestead people want to cultivate their adjoining land through the other agricultural input for fulfilling their basic needs. This human demand has resulted in the continuous increase of agricultural land in an outward direction from periphery to forest boundary.

Table 3 Anthropogenic disturbance to forest fragmentation based on Village and Road proximity

Fragmentation classes	Village proximity to fragmentation classes				Road proximity to fragmentation classes			
	1 km buffer		Outside 1 km buffer		1 km buffer		Outside 1 km buffer	
	1990	2015	1990	2015	1990	2015	1990	2015
Patch	10.4	14.7	3.6	4.6	12.2	9.3	1.8	10.0
Edge	28.1	25.1	9.8	9.2	21.8	23.0	16.1	11.3
Perforated	23.0	6.2	10.1	3.4	6.6	2.0	26.5	7.6
Core III	8.5	4.3	2.7	0.9	2.6	6.5	8.6	−1.3
Core II	3.7	1.3	0.9	0.2	1.5	1.5	3.1	0.0
Core I	24.5	19.9	20.7	18.7	26.9	31.6	18.3	7.0

On the other hand analysis shows that the presence of villages and roads are important factors for forest fragmentation which indicates the forest disturbance in term of human interferences. Maximum settlement units are situated along the protected forest boundary and adjoining the small patches of green space. Therefore, the core forest area is less affected by the village proximity but reverse situation may be prevailed in case of road proximity because the entire road intersected the core forest from different direction.

Initially about 132 km² (47.4%) of the land around the villages and roads were non-forest areas in 1990 which is increased to 169.5 km² (60.97%). Within 1 km buffer from villages almost 4.7% of the forest area around villages and within more than 1 km buffer zone 1% of the forest area around villages has been converted into patch forest (Table 3). Approximately 17% forest area around villages within 1 km buffer and 7% forest area within more than 1 km buffer zone are transformed from perforated category to lower category forest. Substantial perforated areas were observed around the road. About 4 and 20% reduction in perforated region is found within 1 km and within more than one km road proximity region in this forest tract. However, it was apparent that the villagers' activities contribute more than the roads within 1 km buffer and reverse situation found outside 1 km buffer zone. Core I forest fragmentation is maximum within 1 km buffer from village than the area outside 1 km buffer zone of villages (Table 3). Because core II and III forest is absent in more than 1 km buffer zone from the villages. In more than 1 km buffer zone from road the fragmentation is significant in comparison to other zone i.e., 11% Core I forest fragmented to lower order. The absence or presence of a small area of the large and medium core forest around a 1 km buffer area of the villages and roads sites demonstrate the impact of human activities on forest health. So it is apparent that though the large core in terms of dense forest area is far from villages they are less affected or disturbed

by village proximity. But as the road connectivity is increased in term of increased number of mettalled road networks, then the degree, as well as, chance of core forest destruction also increases enormously.

4 Conclusion

Present research focuses on some of the spatio-temporal evaluation of forest health by incorporating forest fragmentation approaches, along with forest disturbance resulted by anthropogenic interferences in terms of proximity analysis. The DFR has passed through significant changes in land use and land cover, along with resultant forest fragmentation during the 25 years from 1990 to 2015. Protected forest, as well as, Open forest has decreased and fragmented remarkably during the study period. Small open forest patches have been transformed into built up settlement and housing due to increase in rural population. At the same time, peripheral region of protected forest has also been encroached by the human interferences. Dense forest area has been eventually gone from core to perforated and then from perforated to edge categories. Many small patches of open green spaces have been completely abolished and transformed into settlements. Fragmentation analysis indicates that the whole region has lost about 13.5% of green space during the 25 year period. Perforated and core forest are mostly affected categories due to the impact of developmental activities and disturbances. Core II sub-category forest cover has decreased almost 3% in the mentioned time span. The rate of change of perforated forest is maximum with a 71% decrease in 25 years. From the perspective of disturbance due to village and road proximity it is clear that perforated forest tract is mostly affected in both cases. Proximity from settlement clearly depicts that negative changes are greater within 1 km buffer zone (i.e., 16.8%) in comparison to the area within more than 1 km buffer

zone (e.g., 6.7%) in perforated forest region throughout the study area. Reverse situation from both the buffer zones has been found in case of road proximity form fragmentation classes. Here negative changes are greater within more than 1 km buffer zone (i.e., 4.6%) in comparison to the other area within 1 km buffer zone (e.g., 18.9%) for perforated forest region reflecting a clear-cut forest fragment gradation. There are twofold aspects of forest health assessment of the using fragmentation approach. The latter one is the most emerging dimension as the relationship between population growth and forest degradation, as well as, incorporation of anthropogenic factors concerning built environment is high, putting a new dimension to present study about change in ecological identity of the region in general and identification of ecological transformation of forest lands in particular.

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