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Analysis of fragmentation and disturbance regimes in south Gujarat forests, India

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Abstract: Forests, world over, have degraded, fragmented, and depleted as human population has swelled. In the present study, the forest fragmentation and the disturbance regimes were assessed in south Gujarat using satellite image-based forest and land use mapping followed by landscape analysis using Spatial Landscape Modelling (*SPLAM)* software. The on-screen visual interpretation of Resourcesat-1 LISS-III imagery facilitated in mapping of 9 forest and 12 non-forest classes. The observations revealed that 51.68 % of the forest area had low fragmentation while the rest had medium to high fragmentation. Among the vegetation types, 62.84 % of Tropical Moist Mixed Deciduous (TMMD) and 54.88 % of Tropical Mixed Dry Deciduous (TMDD) forests had low level of fragmentation whereas 15.5 % mangrove forest had high fragmentation. The study also showed that 72.53 % of the total forest area had low disturbance. High disturbance was noticed in Riverine forest (22.78 %) while TMMD forest was found to be less disturbed than TMDD forest. District-wise analysis revealed that forests of Valsad, Navsari and Bharuch were highly disturbed as well as fragmented whereas forests of The Dangs, Surat and Narmada had low disturbance and fragmentation. The study demonstrated important role of remote sensing, GIS, and SPLAM in forest/land use mapping and disturbance regimes and fragmentation status assessment.

Resumen: Los bosques del mundo entero se han degradado, fragmentado y empobrecido conforme la población humana ha aumentado. En el presente estudio se evaluó la fragmentación de los bosques y los regímenes de disturbio en el sur de Guyarat mediante la cartografíade los bosques y el uso de la tierra basado en imágenes de satélite, seguido de análisis del paisaje usando el programa Spatial Landscape Modelling (*SPLAM*). La interpretación visual en pantalla de las imágenes Resourcesat-1 LISS-III facilitó en la cartografía de 9 clases de bosque y 12 clases no forestales. Las observaciones mostraron que 51.68 % de la superficie forestal estaba poco fragmentada, mientras que la fragmentación en el resto varió entremedia y alta. Entre los tipos de vegetación, 62.84 % del bosquetropical húmedo caducifolio mixto (TMMD) y 54.88 % del bosque tropical mixto seco deciduo (TMDD) tenían un nivel bajo de fragmentación, mientras que en 15.5 % del manglar la fragmentación fuealta. El estudio también mostró que 72.53 % de la superficie forestal estaba poco perturbada. Se registró perturbación alta en el bosque ribereño (22.78 %), mientras que se encontró que el bosque TMMD estaba menosperturbado que el bosque TMDD. Un análisis por distritos reveló que los bosques de Valsad, Navsari y Bharuchestaban fuertemente perturbados y fragmentados, mientras que los bosques de The Dangs, Surat y Narmadateníanniveles bajosde perturbación y fragmentación. El estudio demostró el importante papel de la percepción remota, los SIG y el programa SPLAM para la cartografía del uso forestal y de la tierra, así comoen la evaluación de los regímenes de

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disturbio y el estado de fragmentación.

Resumo: Por todo o mundoas florestas têm-se degradado, fragmentado e empobrecido com o aumento da da população humana. No presente estudo, a fragmentação florestal e os regimes de perturbação foram avaliados no sul de Gujarat usando como base imagens de satélite da floresta e o mapeamento do uso do solo, seguido de análise da paisagem com recurso ao software de Modelação Espacial da Paisagem (*SPLAM*). A interpretação visual no monitor da imagemda floresta usando o Resourcesat-1 LISS-III facilitou o mapeamento de 9 classes de floresta e 12 classes não-florestais. As observações mostraram que 51,68 % da área de floresta apresentava baixa fragmentação, enquanto o restantorevelou uma fragmentação média a alta. Entre os tipos de vegetação, 62,84 % da floresta Tropical Mista Húmida Decídua (TMMD) e 54,88 % da floresta Tropical Mista Seca Decídua (TMDD) apresentavam baixo nível de fragmentação, enquanto que 15,5 % do mangal apresentava alta fragmentação. O estudo também mostrou que 72,53 % da área total de floresta foi sugeita a baixa perturbação. Alta perturbação foi notado naFloresta Ribeirinha (22,78 %), enquanto a floresta TMMD revelou ter sido menos perturbada que a TMDD. A análise por Distrito mostrou que as florestas de Valsad, Navsari e Bharuch foram altamente perturbadas, assim como fragmentadas, enquanto que as florestas de The Dangs, Surat e Narmada apresentavam baixa perturbação e fragmentação. O estudo demonstrou o papel importante dos sistemas de detecção remota GIS e SPLAM, no mapeamento da floresta / uso da terra e dos regimes de perturbação e avaliação do estado de fragmentação.

Key words: GIS, landscape, land use, remote sensing, SPLAM, vegetation type.

Introduction

Forests in India have been used by the people over millennia for a variety of purposes and practices (Lele & Hegde 1997; Uma Shankar *et al.* 1998). Of these, the livestock grazing, non-timber forest product, fodder, medicine, food, timber, resin, dye, fuel, oil, tannin, and other forest products collection are historic and continuing uses of the forest (Banerjee 1995; Bhat *et al.* 2001; FAO 2006). Among various causes of forest fragmentation and degradation, the live-stock grazing, fuelwood, fodder extraction, and burning for cultivation are recognized as the chronic disturbances (Singh 1998) with substantial impact on flora, fauna, soil, water and the micro-climate (Tilman & Lehman 2001). The extraction, exceeding regeneration, depletes forest ecosystems. The pressure on forests has steadily increased with an ever-increasing human population in the country. The quantitative studies on the landscape level impacts of disturbance on the forests in India are relatively few (Shahabuddin & Prasad 2004). Majority of the studies have focused on the impacts either on vegetation (Kumar & Shahabuddin 2005; Madhusudan 1999; Sagar *et al.* 2003; Uma Shankar *et al.* 1998), soil (Sahani & Behera 2001), or wildlife (Madhusudan 2000). No study involving landscape level assessment of the disturbance regimes and the forest fragmentation is known from this part of India.

The geospatial technology, including remote sensing, geographic information system (GIS) and global positioning system (GPS), involving acquisition and analysis of the remote sensing data to extract meaningful information, has developed substantially in the past four decades (Mas 1999). Remotely-sensed data has been used in the past for a variety of purposes such as forest cover monitoring (NRSA 1983), land use / land cover mapping and monitoring (Kushwaha 1990; Kumar & Mathur 2014) stand volume assessment (Köhl & Kushwaha 1994), biomass estimation (Pandey *et al.* 2010; Roy & Ravan 1996), wildlife habitat evaluation (Kushwaha & Roy 2002; Nandy *et al.* 2012; Singh & Kushwaha 2011), etc. An effort was made in late nineties to use remote sensing data for nationwide rapid biodiversity characterization and a three-pronged method involving satellite imagery, landscape analysis and field inventory of biodiversity was developed for the first time in India and implemented (Roy & Tomar 2000). Several studies have subsequently used the methodology to characterize biological richness in the country (Kushwaha *et al.* 2005; Nandy & Kushwaha 2010).

Forests in India are subjected to various disturbance regimes and majority of them are anthropogenic. Disturbance, a common and widespread phenomenon in our anthropocentric world, is defined as a discrete event with the passage of time that modifies landscapes, ecosystems, communities and the populations (Forman & Godron 1986). The disturbance also leads to processes like fragmentation, degradation, depletion, species migration, and extinction. The impact of the disturbance regimes on the landscapes can be well understood by analyzing the spatial and temporal nature of the disturbance (White & Pickett 1985). At landscape level, disturbance is related to patch structure and spatial arrangement of patches, and determines the fate of patches, their size, and the duration. Severe disturbance generally has depressing effect on the biodiversity, but intermediate disturbance seems to enhance diversity in any system (Moloney & Levin 1996).

Disturbance, which is a major driver of the landscape dynamics, acts at all spatio-temporal levels. Human-induced disturbance differs from natural disturbance, especially in the extent, severity and the frequency. When capacity of the landscape to assimilate the human disturbance is overwhelmed, the disturbance process is transformed into a stress process, which reduces biodiversity. Human activity has widespread impact on biodiversity, affecting ecological entities from species to whole communities and the ecosystems, though heterogeneity in the landscape can sometimes be due to moderate disturbance (Li & Reynolds 1994). The disturbance regimes, however, can be quantified by using different indices, *i.e.,* degree of fragmentation, fractal dimension, contagion, juxtaposition, evenness and patchiness (Patel 1997). In this study, we studied the status of the disturbance regimes and the forest fragmentation in south Gujarat, India.

Materials and methods

Study area

Biogeographically, Gujarat province can be divided into four major zones *viz.,* the Indian desert, the semi-arid, the Western Ghats, and the coastal areas. It is bounded in the north by Rajasthan, in the east by Madhya Pradesh, in south by Maharashtra provinces, and in the west by international boundary of Pakistan. The Arabian Sea lies on its western and south-western sides with two gulfs- the Gulf of Kachchh and the Gulf of Khambhat. The south Gujarat (21°14'-22°49' N and 72° 22' - 74°15' E) consists of seven districts *viz.*, Valsad, Navsari, The Dangs, Surat, Bharuch, Narmada, and Vadodara, covering a geographical area of 31,495 km^2 (Fig. 1). The plains of south Gujarat are watered by Purna, Par, Damanganga, Auranga, Kolak, Ambica, Darota, Narmada, and Tapi rivers. The region shows a typical sub-humid to humid climate (Anonymous 2006). The mean annual temperature is about 26 °C and the mean summer and winter temperatures are 41 and 22 °C respectively with 70 - 75 % mean relative humidity. The average annual rainfall varies from 1300 - 2200 mm (Patel 1997).

The major forest types in the south Gujarat are: *Moist Teak Forest* (3B/C_1(b,c)), *Southern Moist Mixed Deciduous Forest* (3B/C_2), *Southern Secondary Moist Mixed Deciduous Forest* (3B/$_2S_1$), *Mangrove Forest* (4B/TS_1) and *Mangrove Scrub* (4B/TS_2), *Dry Teak Forest* (5A/C_1(b)), *Southern Dry Tropical Riverine Forest* (5/$_1S_1$) and *Desert Thorn Forest* (6B/C_1) (Champion & Seth 1968). The main tree species are: teak (*Tectona grandis* L.f.), sadad (*Terminalia crenulata* Roth.), shisham (*Dalbergia sissoo* Roxb.), khair (*Acacia catechu* L.f. (Willd.), timru (*Diospyros melanoxylon* Roxb.), mahuda (*Madhuca longifolia* var. *latifolia* (Roxb.) A. Chev.), dhavdo (*Anogeissus latifolia* Roxb. ex DC. Wall ex Bedd.), khakhar (*Butea monosperma* (Lam.) Taub.), kalam (*Mitragyna parvifolia* (Roxb.) Korth.), bondarao (*Lagerstroemia parviflora* Roxb.), billi (*Aegle marmelos* (L.) Correa. ex Roxb.), moina (*Lannea coromandelica* (Houtt.) Merr., etc. The critically endangered species are *Sterculia guttata* Roxb., *Toona ciliata* M. Roem. and *Wrightia dolichocarpa* Bahadur & Bennet. The endangered species are *Casearia championii* Thwaites, *Tamrix aphylla* (L.) H. Karst., *Melia dubia* Cav., and *Ficus nervosa* B. Heyne ex Roth. The vulnerable species are *Firmiana colorata* (Roxb.) R. Br., *Boswellia serrata* Roxb. ex Colebr., *Garuga pinnata* Roxb., *Ceriops tagal* (Perr.) C.B. Rob., and *Ehretia laevis* Roxb (Ambasta 1986).

The main faunal species found in south Gujarat forests are panther (*Panthera pardus* L.), sloth bear (*Melursus ursinus* Shaw), chinkara (*Gazella bennetti* Sykes), and grey hornbill (*Ocyceros birostris* Scopoli) (Anonymous 2006). The study area is rich from biodiversity point of view (IIRS 2011). It has three wildlife sanctuaries (WLS) - Jambughoda WLS in Vadodara district, Shoolpaneshwar WLS in Narmada district, and Purna WLS in The Dangs district, and Vansda National Park in Navsari district. Physiogra-

Fig. 1. Location of the study area in India.

Table 1. Satellite imagery used in the study.

Satellite	Sensor	Bands	Spatial resolution (m)	Path-row	Date of pass
Resourcesat-1	LISS-III	Band-1 (0.52 - 0.59 μm) Green Band-2 (0.62-0.68 μm) Red Band-3 (0.77-0.86 μm) NIR	23.5	93-56	19 Oct. & 04 May 2006
-do-	-do-	-do-	-do-	93-57	19 Oct. & 10 Apr. 2006
-do-	-do-	-do-	-do-	94-56	24 Oct. & 09 May 2006
-do-	-do-	-do-	-do-	94-57	24 Oct. & 09 May 2006
-do-	-do-	-do-	-do-	94-58	24 Oct. & 15 Apr. 2006
-do-	-do-	-do-	-do-	95-57	10 Oct. & 20 Apr. 2006

phically, the area is divided into two parts: the western part comprising coastal plain (locally known as *kantha vistar*) and the eastern part comprising hills (*dungar vistar*). The elevation ranges from 100 to 1000 m, the highest peak being 1000 m at Saputara in The Dangs district.

Vegetation type and land use mapping

Twelve Resourcesat-1 LISS-III satellite imagery- six belonging to October-November (wet season) and another six belonging to April-May (dry season) 2006 were used for the present study (Fig. 2). Image details are given in Table 1. Dark pixel subtraction technique was used to minimize the haze in the images (Lillesand *et al.* 2007). The satellite imagery was geo-referenced using Landsat ETM+ orthorectified images (UTM projection and WGS 84 datum) and nearest neighborhood resampling method. The images were mosaiced using feather overlap function of *ERDAS Imagine* and the study area (31,495 km²) was extracted. The overall methodology is shown in Fig. 3. All vegetation type and land use categories were field-visited (Table 2) and their location was recorded using a Trimble Juno-SB GPS receiver. The two-season satellite data facilitated in vegetation type and land use (Fig. 4) mapping using on-screen interpretation technique. Two-season satellite data was used to derive phenological inferences, which helped in forest and land use types mapping. All forest types described by the Champion & Seth (1968) for south Gujarat could be mapped. The accuracy of the classification was field-verified using 131 randomly distributed points. A confusion matrix was generated in the process.

A semi-expert Spatial Landscape Modelling (SPLAM) software was developed in-house in Windows environment for landscape analysis. The SPLAM was customized in the *ArcInfo* using Arc Macro Language (AML) and the libraries of the GRID module. A new toolbar, *ArcObjects* was developed in *ArcMap* for landscape analysis (Jeganathan & Narula 2006). The vegetation type/ land use map was used as input to SPLAM. A disturbance index (DI), indicative of the disturbance regimes, was calculated as a function of fragmentation, porosity, patchiness, interspersion, juxtaposition and biotic disturbance. For fragmentation computation, the forest types and land uses were reclassified into forest and non-forest categories. A user grid cell of 500 m x 500 m was moved through the spatial data layer for deriving the number of patches within the grid cell. A look-up table (LUT) was generated to keep the normalized patch data per cell in the range of 0 to 10. Porosity (Po) (Forman & Godron 1986) is the measure of number of patches or density of patches within a particular type, regardless of patch size:

$$Po = \sum_{i=1}^{n} Cp_i \qquad (1)$$

where, n is number of patches and Cpi is the number of closed patches of i^{th} cover class.

Table 2. Area under different vegetation/land use categories.

Vegetation type/land use	Area (km²)	Area (%)
Teak mixed moist deciduous forest	243.01	0.77
Teak mixed dry deciduous forest	4718.54	14.98
Mangrove forest	32.90	0.10
Mangrove scrub	75.40	0.24
Riverine forest	0.16	0.0004
Ravine thorn forest	144.29	0.46
Forest plantation	19.53	0.06
Degraded forest	0.36	0.0011
Scrub	912.38	2.90
Prosopis juliflora scrub	257.85	0.82
Grassland	19.10	0.06
Orchard	4.56	0.01
Agriculture	20452.35	64.94
Barren land	77.03	0.24
Mine	72.49	0.23
Mudflat	109.30	0.35
Salt-affected land	605.43	1.92
Salt pan	169.50	0.54
Waterbody	3021.55	9.59
Wetland	33.09	0.11
Settlement	526.19	1.67
Total	31,495.00	100.00

Patchiness is a measure of the density of patches of all types or number of clusters in a given mask. In other words, it is measure of the number polygons over a particular area (Romme 1982):

$$P = \frac{\sum_{i=1}^{n} D_i}{N} \times 100 \qquad (2)$$

where, N is the number of boundaries between adjacent cells, and D is the dissimilarity value for

i^{th} boundary between adjacent cells.

Interspersion (Int) is measured as a count of dissimilar neighbors with respect to central pixel. In other words, it is measurement of the spatial intermixing (Lyon 1983) of the vegetation types:

$$Int = \sum_{i=1}^{n} SF_i / N \tag{3}$$

where, $SF_i = \sum_{j=1}^{n} \frac{Edge}{\sqrt[2]{Area_j \times n}}$

Edge - the length of edge, in both x and y directions and Area- the area of the j^{th} polygon formed by groups in the i^{th} vegetation types/land uses.

Juxtaposition is defined as measure of proximity of the vegetation (Lyon 1983). Its measurement includes relative weight assigned by the importance of the adjacency of two cover types. The added weight in juxtaposition gives the correct perspective in ultimately deriving the disturbance index:

$$Jux = \sum_{i=1}^{n} D_i \frac{Jux_i}{Jux_{\max}} \tag{4}$$

where, Jux_{max} is the average total weight edge per habitat unit, D_i is edge desirability weight for each cover type combination based on the field data and Jux_i is length of edge between combinations of vegetation types/land uses on either side of an edge.

The disturbance in any forest area is directly related to the access by the people to forest for

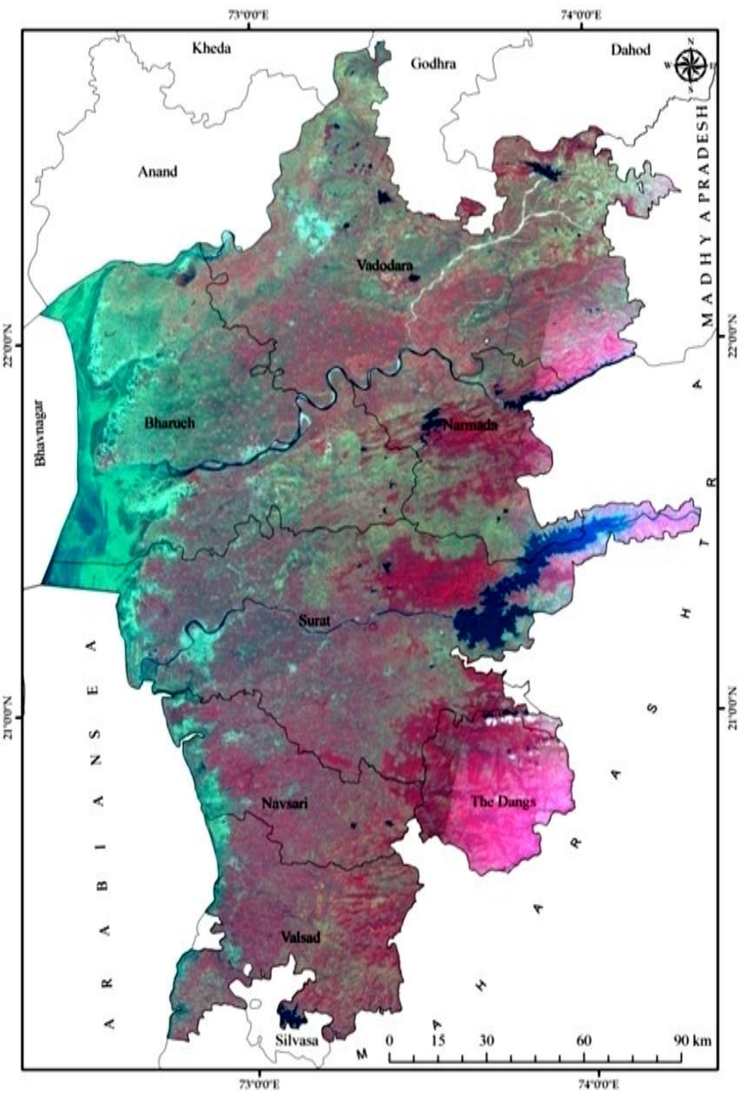

Fig. 2. False colour composite of the study area.

various purposes. Infrastructure such as roads, railway lines and settlements are key access elements, which act as drivers of disturbance. Topographic maps were used to extract the road, rail, and settlement features. Variable distance buffers were created to address the proximity issue with the hypothesis that greater the distance lesser the disturbance. The buffers of varying distances were generated for calculation of the disturbance index through a probabilistic weight-based linear additive model:

$$DI = \int_{i=1}^{n} Po \times wt_i 1 + P \times wt_i 2 + Frag_i \times wt_i 3 + Int_i \times wt_i 4 + Jux_i \times wt_i 5 + BD_i \times wt_i 6 \quad (5)$$

where, DI = Disturbance index, Po = Porosity, P = Patchiness, Frag = Fragmentation, Int = Interspersion, Jux = Juxtaposition, BD = Biotic Disturbance.

Three classes of fragmentation and disturbance regimes *viz.*, low, medium and high were computed by interpreting the histogram and the area under each category was calculated. The values were classified using cluster principle. Histogram is a graphical tool to explore the statistical distribution of classes and clusters in attribute space (Apan 1997). The fragmentation and disturbance index maps were intersected with the vegetation type/land use map to derive at forest type - wise status of fragmentation and

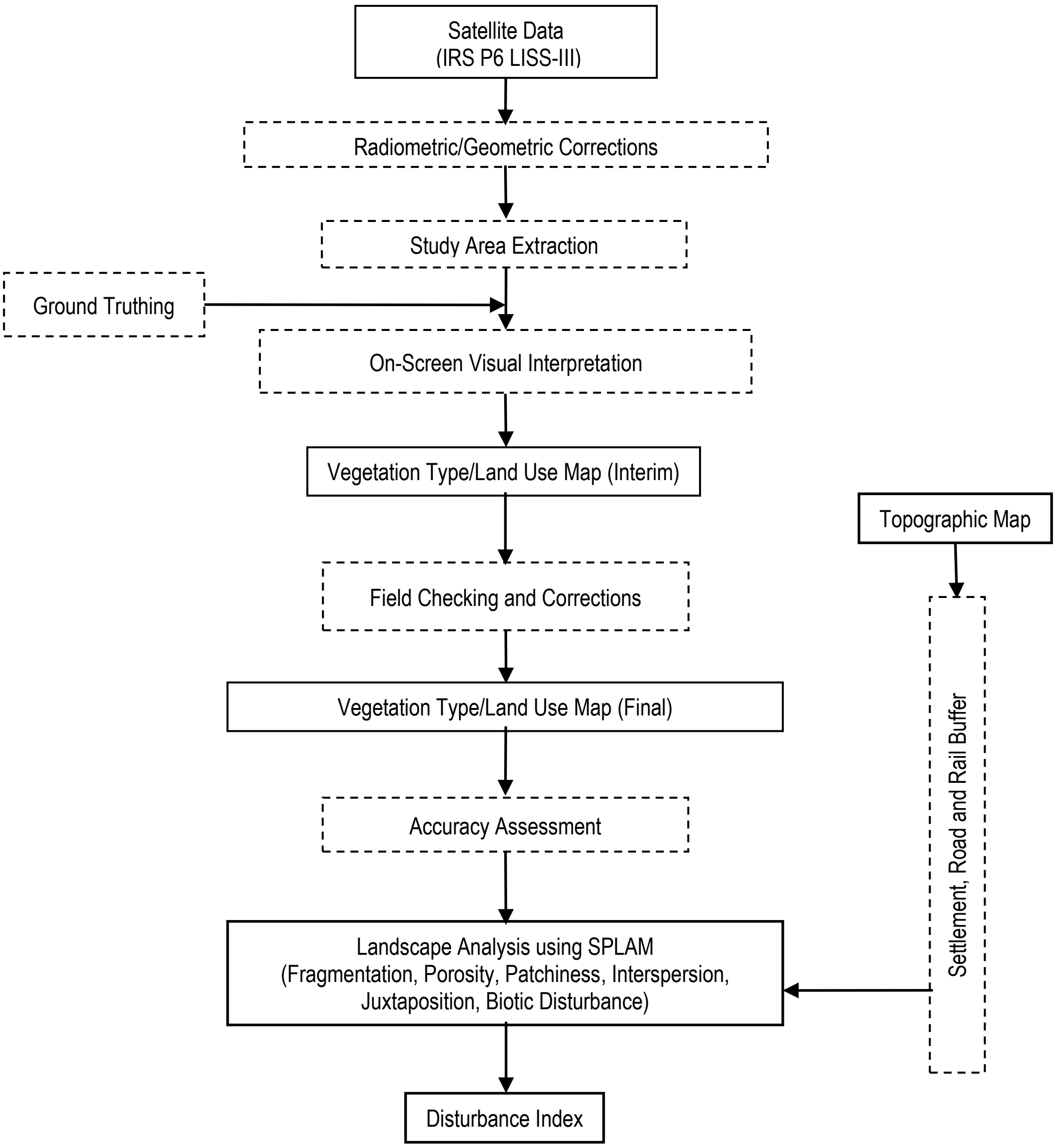

Fig. 3. The methodology.

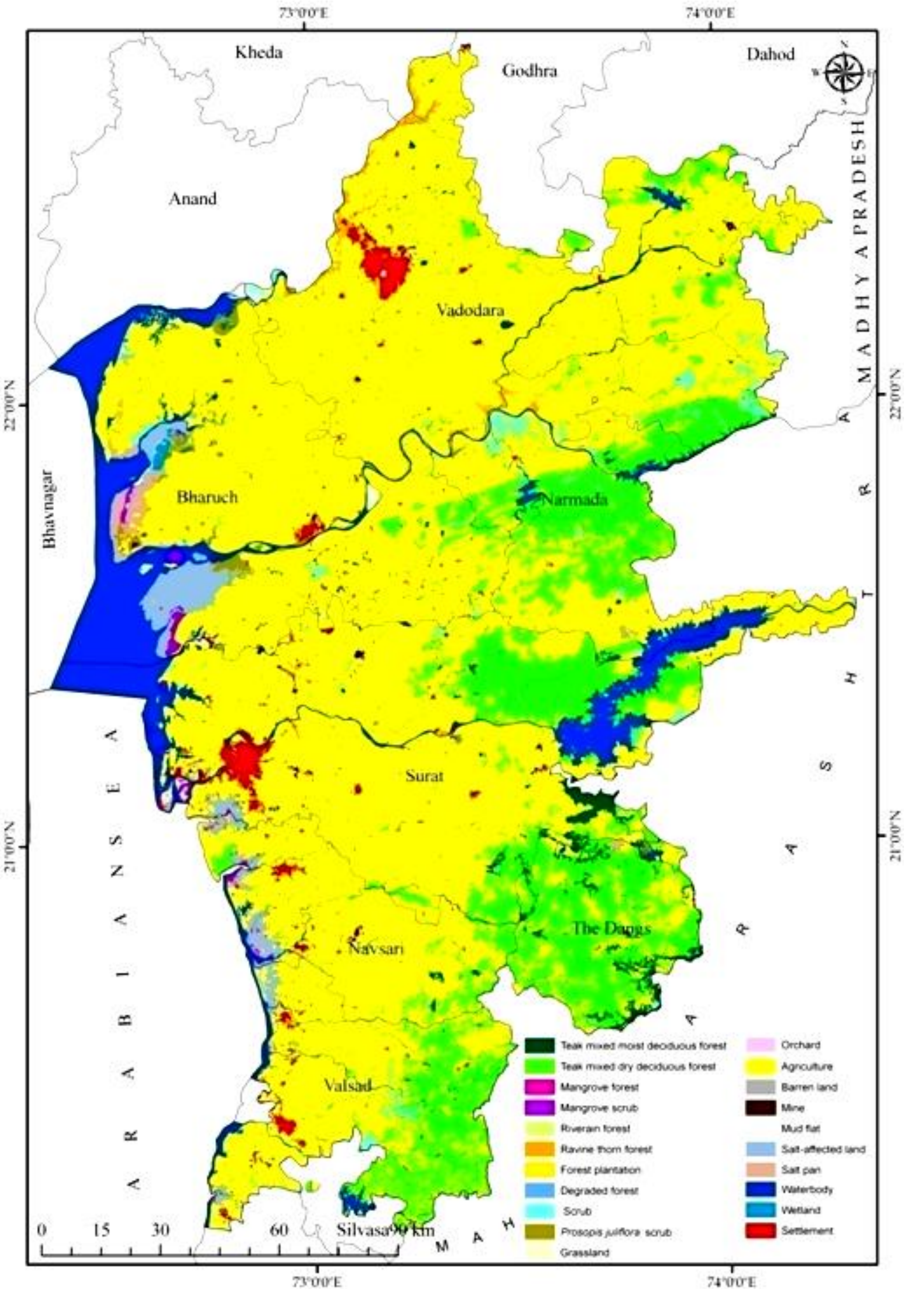

Fig. 4. Vegetation type/land use map.

disturbance index. The district-wise status of fragmentation and disturbance index was also worked out.

Results and discussion

The on-screen visual interpretation method facilitated in overall mapping of 21 categories of vegetation types and land uses (Fig. 4). The maximum forest area (4718.54 km^2 or 14.98 %) was covered by Teak Mixed Dry Deciduous Forest whereas Riverine Forest covered minimum area (0.16 km^2 or 0.0004 %). The maximum area in land use category was covered by agriculture (20452.35 km^2 or 64.94 %) and minimum by wetland (33.09 km^2 or 0.11 %). Table 2 shows the area under different vegetation types and the land uses in the study area. The forest classes *viz.,* Teak Mixed Moist Deciduous (TMMD) Forest, Teak Mixed Dry Deciduous (TMDD) Forest, Mangrove Forest, Mangrove scrub, Riverine Forest, Ravine Thorn Forest, Degraded Forest, *Prosopis juliflora* scrub, and the

Table 3. The error matrix.

Vegetation type/land use	TMMD	TMDD	M	MS	RV	RTH	FP	DF	SC	P	GR	OR	AG	BL	M	MF	SL	SP	WB	WL	S	Total	Producer's accuracy	User's accuracy
TMMD	8	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	10	88.89	80.00
TMDD	1	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	95.00	95.00
M	-	-	6	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	85.71	85.71
MS	-	-	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	83.33	83.33
RV	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	100.00	100.00
RTH	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	100.00	100.00
FP	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	100.00	100.00
DF	-	-	-	-	-	-	-	4	1	-	-	-	-	-	-	-	-	-	-	-	-	5	100.00	80.00
SC	-	-	-	-	-	-	-	-	10	-	-	-	1	-	-	-	-	-	-	-	-	11	80.00	90.91
P	-	-	-	-	-	-	-	-	-	8	-	-	-	1	-	-	-	-	-	-	-	9	90.91	88.89
GR	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	4	88.89	100.00
OR	-	-	-	-	-	-	-	1	-	-	1	5	-	-	-	-	-	-	-	-	-	7	66.67	71.43
AG	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-	-	-	-	4	100.00	75.00
BL	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	1	-	-	-	-	-	5	75.00	80.00
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	2	80.00	100.00
MF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	4	100.00	100.00
SL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1	-	-	-	5	80.00	80.00
SP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-	-	4	80.00	75.00
WB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	4	75.00	75.00
WL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	-	5	80.00	80.00
S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	100.00	100.00
Total	9	20	7	6	3	6	7	5	11	9	6	5	4	5	2	5	5	4	4	5	3	131		

Overall accuracy = 87.78 % $K_{hat} = 0.85$

TMMD - Teak mixed moist deciduous forest, TMDD - Teak mixed dry deciduous forest, M - Mangrove forest, MS - Mangrove scrub, RV - Riverine forest, RTH - Ravine thorn forest, FP - Forest plantation, DF - Degraded forest, SC - Scrub, P - *Prosopis juliflora* scrub, GR - Grassland, OR - Orchard, AG - Agriculture, BL - Barren land, M - Mine, MF - Mud flat, SL - Salt - affected land, SP - Salt pan, WB - Waterbody, WL - Wetland, S - Settlement.

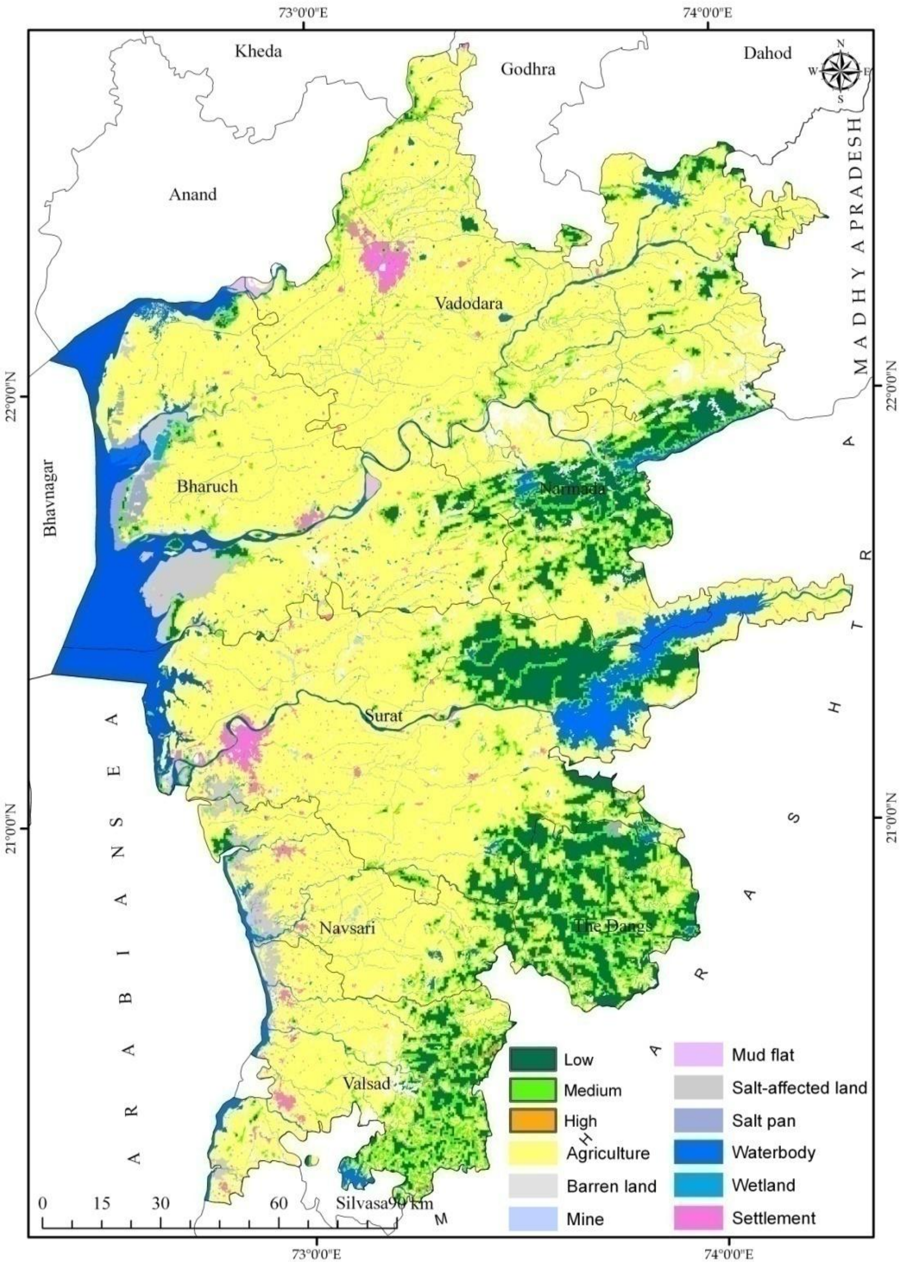

Fig. 5. Fragmentation map.

forest plantation, together covered 17.44 % of the geographical area. The overall classification accuracy was 87.78 % (K_{hat} = 0.85) (Table 3).

Fig. 5 illustrates the levels of forest fragmentation in the study area. It was observed that 51.68 % of forest area was under low fragmentation while the rest of the area fell under medium to high fragmentation (Table 4) though the area under medium fragmentation was quite high. If proper conservation measures are not taken, the area under this category might increase. High fragmentation was observed around the settlements and along the roads. The study also revealed that 62.84 % of TMMD and 54.88 % TMDD forests had low level of fragmentation. High level of fragmentation was observed in Mangrove forest (15.5 %) followed by Ravine Thorn forest (10.47 %). It was also observed that 83.59 % of forest plantation, 75.74 % of Ravine Thorn Forest, and 75.34 % of *P. juliflora* scrub had medium fragmentation. More than 85 % of the Mangrove Forest, forest plantation and Ravine Thorn Forest had medium to high fragmentation.

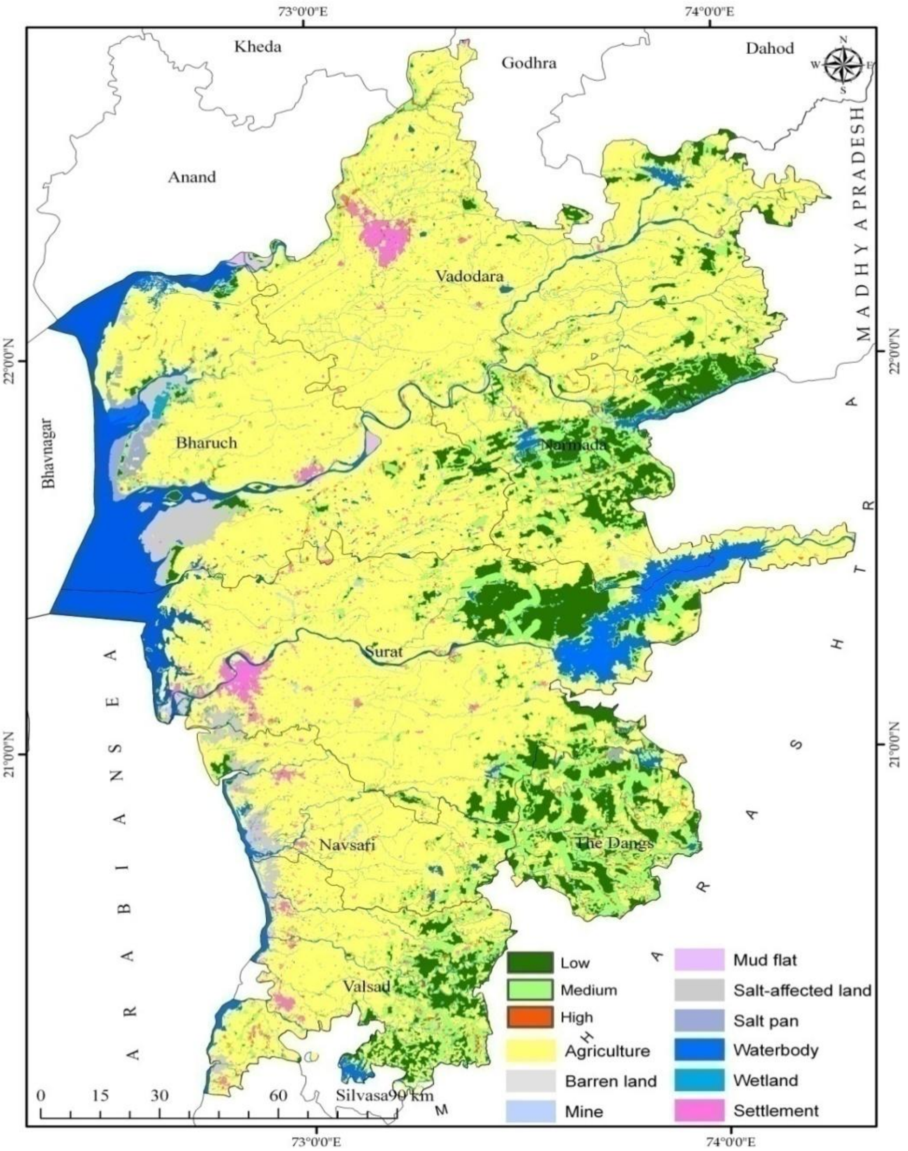

Fig. 6. Disturbance index map.

Fig. 6 shows the different levels of forest disturbance in south Gujarat forests. The level of disturbance in different vegetation types is indicated in Table 5. An area equivalent to 72.53 % of the total forest area had low disturbance, indicating that most of the forest areas were intact. The disturbance levels also showed that 22.99 % and 4.48 % of forest areas respectively were medium and highly disturbed. It was observed that 76.18 % of TMDD forest, 72.91 % of Mangrove scrub and 68.28 % of TMMD forest had low level of disturbance. High level of disturbance was observed in Riverine forest (22.78 %) followed by Mangrove forest (18.53 %) and *P. juliflora* scrub (16.36 %). The study also revealed that 97.51 % of degraded forest had medium level of disturbance followed by Riverine forest (77.22 %) and *P. juliflora* scrub (49.07 %). All degraded forest and Riverine forests were found to be under medium to high disturbance category, indicating these forest categories as the most disturbed ones in the study area.

Among districts, low fragmentation was observed in the forests of Surat followed by Narmada and The Dangs (Fig. 7). It was noticed that 61.14 % of forests of Surat district had low fragmentation whereas in Narmada and The Dangs districts, low fragmentation covered 58.77 % and 58.51 % of the forests respectively. High fragmentation was observed in 8.03 % forest area

Table 4. Vegetation type-wise area (km²) under different fragmentation levels.

Vegetation types	Low	Medium	High	Total
Teak mixed moist deciduous forest	152.71	83.11	7.20	243.01
Teak mixed dry deciduous forest	2589.51	1958.83	170.20	4718.54
Mangrove forest	3.06	24.75	5.10	32.90
Mangrove scrub	30.84	43.59	0.98	75.40
Riverain forest	0.16	0.00	0.00	0.16
Ravine thorn forest	19.89	109.29	15.11	144.29
Forest plantation	2.51	16.32	0.70	19.53
Degraded forest	0.25	0.11	0.00	0.36
Prosopis juliflora scrub	39.44	194.26	24.15	257.85
Total	2838.37	2430.24	223.43	5492.05

Table 5. Vegetation type-wise area (km²) under different disturbance regimes.

Vegetation types	Low	Medium	High	Total
Teak mixed moist deciduous forest	165.93	64.37	12.71	243.01
Teak mixed dry deciduous forest	3594.37	961.82	162.35	4718.54
Mangrove forest	14.04	12.77	6.10	32.90
Mangrove scrub	54.97	17.54	2.89	75.40
Riverain forest	0.00	0.12	0.04	0.16
Ravine thorn forest	56.41	69.51	18.38	144.29
Forest plantation	8.77	9.43	1.32	19.53
Degraded forest	0.00	0.35	0.01	0.36
Prosopis juliflora scrub	89.16	126.52	42.17	257.85
Total	3986.00	1260.43	245.62	5492.05

of Valsad district followed by 6.91 % and 5.63 % of forest areas of Navsari and Bharuch districts respectively. District-wise disturbance status showed that 59.58 % of forest areas of The Dangs district had low disturbance followed by Narmada (51.50 %) and Surat (47.79 %) districts (Fig. 8). High disturbance was observed in Navsari, where 25.72 % of forest area falls under high disturbed category, followed by Bharuch (22.26 %) and Valsad (19.96 %) districts. The analysis showed that the forest areas of Valsad, Navsari and Bharuch districts were highly fragmented and disturbed too. This may be due to the developmental activities, high population pressure, agricultural expansion, and industrial growth prevailing in these districts. The forests of The Dangs, Surat and Narmada districts had low disturbance and consequent low fragmentation. Location of the Purna wildlife sanctuary (area 16.84 km²) in The Dangs district and Shoolpaneshwar wildlife sanctuary (607.70 km²) in Narmada district appear to have significantly contributed to the protection and conservation of the forests, thereby indicating low fragmentation in these districts.

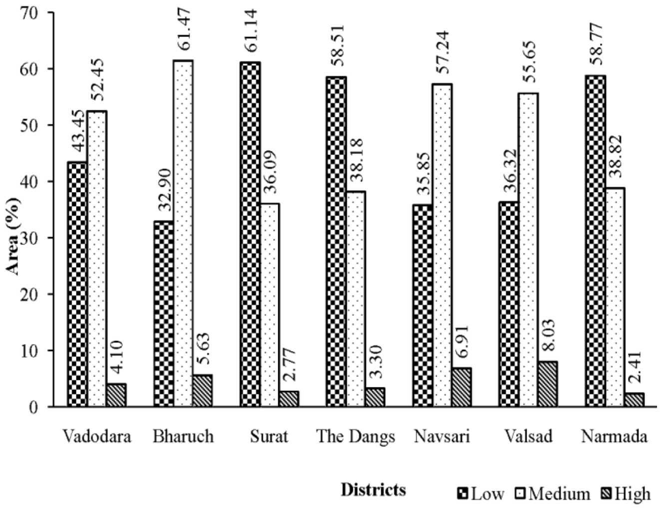

Fig. 7. District-wise fragmentation in south Gujarat.

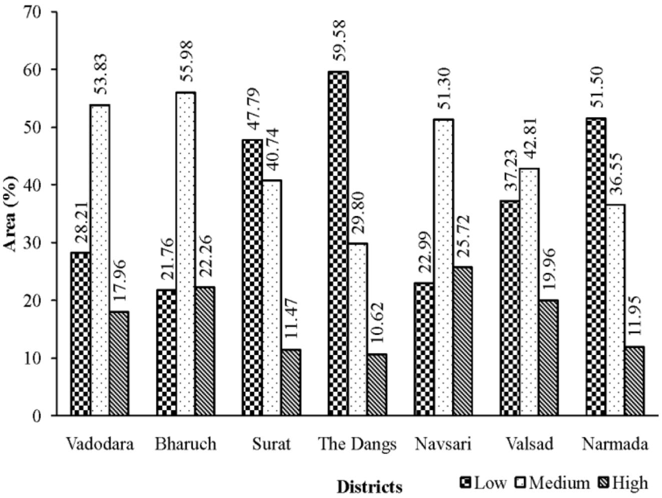

Fig. 8. District-wise disturbance index in south Gujarat.

The forest fragmentation and disturbance problems in the south Gujarat are very similar to those in other parts of Gujarat as far as they are related to geology, topography, demography, climate, forest, and the soil. The local people are dependent upon the limited forest resources for fodder, fuelwood, medicinal plants, timber, etc. and are responsible for the forest degradation. Lopping and man-made fires are some other deleterious activities contributing to forest degradation (Jhariya *et al.* 2012). Local inhabitants clear the ground cover by burning for collecting the mahuda (*Madhuca latifolia*) flowers and fruits, which severely impairs regeneration. During the rainy season, parts of the forests are cultivated. This, coupled with the traditional agricultural practices, causes considerable disturbance to the forests in tribal district of The Dangs. Additionally, the area is grazed by the cattle, sheep, and goats. Since forests belong to the State Forest Department, local people evince little or no interest in the protection or conservation activities. Banning of lopping, reduction in the grazing pressure by stall-feeding, protection from fire, and extensive plantations of suitable native species for fodder and timber - besides installing vegetative and engineering soil conservation structures are suggested to overcome the problem.

The study attempted to assess the fragmentation and disturbance in south Gujarat and put forward a rapid and user-friendly methodology. It is expected that the maps and information so generated will be useful in the forest conservation planning by the government and non-government organizations. Although this study focused on southern Gujarat but the approach can be applied to any landscape for the assessment of fragmentation and disturbance regimes.

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