Assessment of forest fragmentation in greater Gir landscape area, Gujarat using geospatial techniques

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Abstract: Due to the negative consequences of climate change, the fragmentation of forest areas worldwide as a result of increased anthropogenic pressure has become a source of concern. The objective of this research study was to evaluate forest fragmentation analysis around the Greater Gir Landscape, Gujarat. The Fragmentation assessment was performed based on Land-use & Land-cover (LULC) analysis using the Landsat 8 OLI images of 2015 and 2019 as primary datasets for the study. Geographic Information System (GIS) techniques were employed for LULC mapping with seven classes showing increment in the agriculture and vegetation patches with the year 2019 in compare to year 2015 due to accumulative rainfall pattern. The Spatial Metric was performed with the use of FRAGSTATS software, where Landscape Metrics were quantified using Class level, Landscape level and Moving Window Analysis. The trend observed in all the metrics calculated indicates increasing of continuity in Greater Gir Landscape. The forest has not undergone severe degradation but a rise in the natural classes like agriculture, vegetation patches, and waterbodies has led to increase in the level of continuity which is leading to conversion of these land patches in homogeneity of the areas using geospatial techniques. These spatial metrics using FRAGSTATS helps in simplifying quantification of the complex spatial processes and can be used for generating a positive framework for forest conservation.

Keywords: LULC, Homogeneity, Landscape Metrics, GIS, FRAGSTATS

1. Introduction

Forest plays a vital role in our ecosystem being a habitat to the flora and fauna (Siti Yasmin et al., 2019) and sustaining human lives. Human-induced pressure on the forest ecosystem has risen rapidly in recent years, isolating certain forest sections in the process (Referowska-Chodak, 2019).

Fragmentation being an important factor leads to deprivation of habitat, biodiversity, ecosystem functions including detrimental impact on continuous patches and quality of forest (Sharma et al., 2022). Fragmentation is a non-random process where the conversion of forest area to agricultural, Built-up, road networks and other land use is done knowingly by mankind for developmental purposes (Laurance, 2008). The intensity of fragmentation in the landscape is based on reduction in size, deformation of shape, Isolation, increase in edge effects and reduction of core area (Tolessa et al., 2016). A study revealed that about 20% of the forest around the world is within 100m of an edge to agricultural, urban, or other modified environments where the ecosystem is affected most severely and about 70% is within 1 km radius from the forest edge (Ripperger et al., 2013). Remote sensing is being widely used for the assessment of fragmentation occurring around the world by the means of Landscape metrics (Dutta et al., 2020).

Landscape metrics is an entity which facilitates quantification of land use and understand the pattern of land cover distribution(Singh et al., 2014) i.e., changes in the spatial structure of patches and understanding the relationships between different patches present in the landscape (McGarigal, K. and SA Cushman, 2012). Landscape heterogeneity, assessed using metrics, is an important feature which can be used for the protection of biodiversity (Syrbe et al., 2012). Comparison of landscape metrics belonging to different temporal periods help in quantifying the changes that has taken place in the landscape, the degree of fragmentation, the spatial isolation of ecosystems, the disappearance or increase of their surface (Badora et al., 2020). The degree of fragmentation can be explained as a function of the varied size, form, spatial distribution, and abundance of patches (David et.al, 1993). In the recent past, Government of Gujarat has taken many initiatives for consolidating the conservation of Asiatic Lions. The concept of Greater Gir Landscape (GGL) has been adopted through which additional suitable habitat for lion is being developed for the habitation of lion. (Pandey et.al, 2014)

According to a study, with timely and stringent protection given by the erstwhile rulers and the subsequent Government, the lions showed a steady increase in their population (Ram, 2022). Dispersal in the areas adjoining the Gir Protected Areas PAs required the rise of the Greater Gir region concept to conserve and manage the lions and their habitat (Bharat Pathak, 2002). Due to the efforts of the Forest Department and local communities, the Kathiawar region contains a number of sanctuaries and National Parks, including Mitiyala, Paniya, and Velavadar (Black Buck National Park), which are the best examples of conservation methods. Due to the pioneering conservation action plan and the cooperation of the local community, threats like grazing, logging, hunting, poaching, etc. are less of a concern here. Study area map with the major State/National highway that passes through the Landscape can posed a great barrier to faunal species of the sanctuary and its movement (Figure 1). A framework for better management and conservation of the Greater Gir Landscape must be put in place as a result of this anthropogenic strain. The objective of this research study is to identify the factors causing fragmentation in and around the GGL using landscape metrics based on satellite derived landuse datasets. This study can help the planners comprehend how fragmentation has changed the environment and help them develop better GGL conservation policies.

2. Materials and methods

2.1 Study area

Greater Gir Landscape is situated in Kathiawar region of Amreli, Gir Somnath, Bhavnagar and Botad Districts in the state of Gujarat. The Study area comprises of regular animal movement between two districts of Amreli and Bhavnagar, India with the geographic range between 20°45' and 22°7' N latitude and 71°5' and 72°22'E Longitude (Mehta et al., 2021). GGL has hilly terrain with forest patches, natural vegetation and agricultural land with covering of coastal areas of Rajula, Mahuva etc. The plains are starting from 0mtrs above mean sea level as it is touching the Gulf of Khambhat in Eastern side and Arabian Sea in southern side towards 580mtrs near Palitana hills basically observed and derived Digital Elevation Profile tool using Google Earth Software. The river streams present in the area includes streams of Shetrunji, Kalubhar rivers. GGL falls under the administration of Wildlife Circle-Junagadh covering Forest Division of Amreli, Shetrunjai & Bhavnagar Division. Kamnath, Kalubhar & Shetrunji are the major man-made reservoirs existing in the landscape. The area supports an ecological setting for a range of faunal and floral species because of its unique geographic location. The climate of this region is classified as Hot Semi-arid climate (Bsh) with hot dry summers and mild winters as per Köppen-Geiger climate classification map (Peel et al., 2007). Teak (Tectona Grandis) and other species like Acacia, Ziziphus, etc. make up the majority of the forest cover in the area.The major fauna of the area is displayed by the presence of Asiatic Lions, Jungle cat, Leopard, Wild pigs, Nilgai, Sambar, Chital, Common mongoose, Hyena, and Indian porcupine (MoEFCC, 2019). The Average Yearly Precipitation is 561.8 mm for Amreli and 655.9 mm for Bhavnagar. Average Daily Max. air temp. for Amreli is 34.3°C and for Bhavnagar is 33.9°C whereas Average Daily Min. air temp. is 20.1 °C and 21.7 °C respectively (Indian Meteorological Department, 2010).The annual precipitation for Bhavnagar and Amreli is 556 mm and 782 mm, respectively, according to the 2015 IMD statistics. Also, for 2015 post-monsoon Bhavnagar and Amreli received a meagre 0.4 mm and 6.3 mm rainfall respectively. Whereas, in 2019 Bhavnagar and Amreli received annual precipitation of 813 mm and 886 mm respectively where in post monsoon season Bhavnagar and Amreli 53 mm and 83.2 mm rainfall respectively (IMD 2015 & 2019).

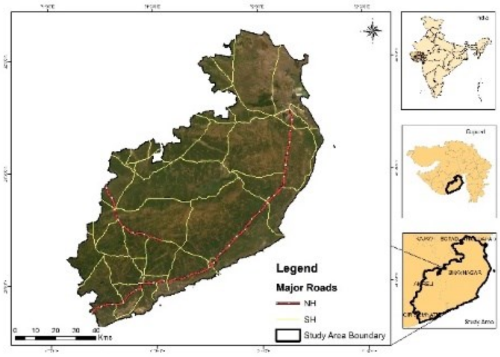

Figure 1. Study area map of The Greater Gir Landscape (GGL)

2.2 Methodology

The study was performed using two USGS LANDSAT-8 images geometrically and atmospherically corrected to level 2, where sensor OLI (Operational Land Imager) provides 9 Optical bands and 2 Thermal bands from TIRS (Thermal Infrared Sensor). Satellite imageries were acquired from Earth explorer platform which is Free & Open access (FOSS) worldwide. Images with acquisition dates of 16 November 2015 and 3 December 2019 were chosen because they have the lowest cloud cover and are temporally compatible with post-monsoon mapping to achieve most land-use and habitat mapping classes. Additionally, 2015 was used as a reference point for the 2015 Asiatic Lion Census study, which calculates points of occurrence of direct and indirect evidence for lions over the habitats, and 2019 was used as the groundtruthing survey conducted during this time of period. LULC map was prepared using these datasets for 2015 and 2019 classified into 13 classes of supervised classification scheme using Maximum Likelihood Classifier (MLC) algorithm of Semi-automatic Classification (SCP) Plugin under QGIS 3.16 version. SCP Plugin allows to perform the supervised classification of remote sensing satellite images, providing tools for the download, the preprocessing and postprocessing of images (https://plugins.qgis.org/plugins/SemiAutomaticClassificationPlugin). Study area boundary was prepared using Block level (Taluka) boundaries contained in the Greater Gir Region as per the movement pattern of Lions using occurrence data. To analyze the fragmentation occurring in the sanctuary, raster files of LULC were assessed using the FRAGSTATS v.4.2 software which is an open-source program for analyzing spatial pattern in the classified maps. FRAGSTATS is a free programme that analyses rasterized maps to characterize spatial patterns of land cover. Quantifying variances and alterations in land cover over time is possible by using FRAGSTATS on two landuse images obtained at different times. After importing the LULC raster files for 2015 and 2019 FRAGSTATS allows to set various parameters like that of Class descriptor file with '.fcd' extension which contains information about the LULC classes used. Apart from that, the edge depth which accounts for the distance from the edge of the patch to the core area was kept fixed at 30m which is approximately 1 pixel as the resolution of satellite image is 30 m.

Landscape level analysis representing spatial pattern for the whole landscape mosaic, which considers different patch types simultaneously was performed (McGarigal, 2014). Class level analysis represents the structure and spatial distribution of patches belonging to same patch type was performed. For cell-level analysis, the moving window method was integrated using 100 m windows. It is calculated at the class level of the forest class and returns the results in raster format.

Table 1. Detailed description of FRAGSTATS metrics used for the study (after McGarigal et al., 1995)

Metrics & Analysis Level	**Description**
Number of patches (NP) **Class Level**	Total number of patches as per forest class (No Units)
Patch Density (PD) **Class Level**	Total patches for forest class divided by the total forest area, multiplied by 100 ha. (Number/100ha.)
Edge Density (ED) **Class Level**	Total lengths (m) of all edge segments (perimeter) of the forest class divided by total area (ha). (Metres/Ha.)
Euclidean nearest neighbor distance (ENN_MN) **Class Level**	Total distance (m) to the nearest neighboring patch of the same class. (Meters)
Shannon's Diversity Index (SHDI) **Landscape Level**	More the number of different patch classes (i.e., patch richness, PR) more the SHDI. (No Units)
Largest Patch Index (LPI) **Landscape Level**	Area of the largest patch of the forest class, depicted as percentage of total forest cover. (Percent)
Contiguity Index (CONTIG) **Cell Level**	Analyses patch shape depending on spatial connectedness of pixels inside a single patch. (No Units)
Radius of Gyration **Cell Level**	The mean distance (m) between each pixel of the patch and the centroid of the patch. (Meters)
Aggregation Index (AI) **Class & Cell Level**	Expresses the frequency of ambiguous pairs of patches class (including like adjacencies between the same patch type) appearing next to each other. (Percent)
Interspersion and Juxtaposition Index (IJI) **Class Level**	Provides the interspersion observed over the possibility of highest interspersion for the number of forest class present. (Percent)

3. Results and discussion

3.1 LULC Change analysis

The major trends in LULC change includes conversion of Agriculture majorly from Fallowland and barrenland respectively. Additionally, major positive shift can be seen in vegetation patches/plantation from Barrenland. Moreover, Forest patches can be seen as somewhat decreased but due to classification techniques & pixel reflectance there are chances that it is mixed up with vegetation patches class in 2019. Overall landuse shows positive trends towards the good agricultural practices and contiguity between landscape patches. (Figure 2(a)(b)(c)).

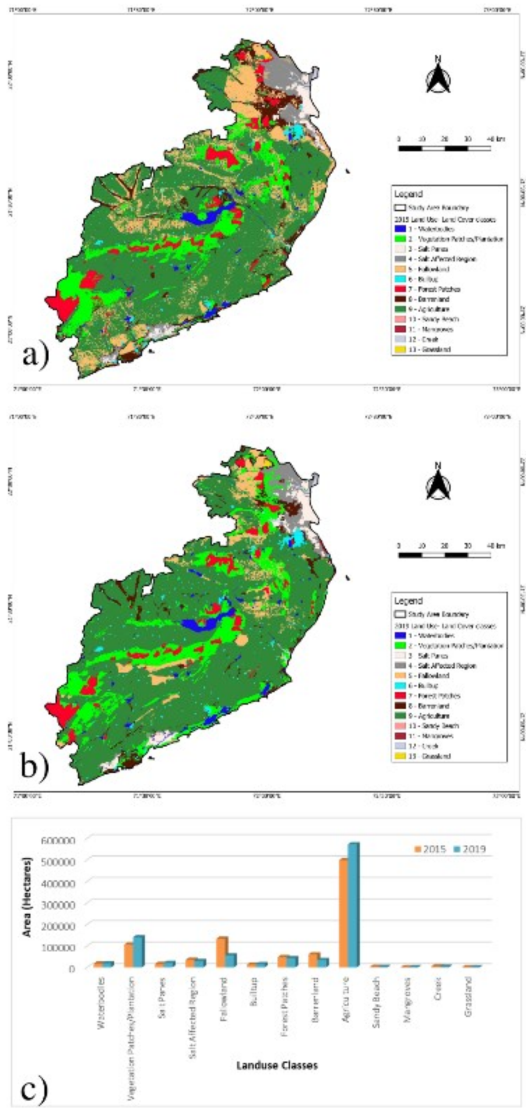

Figure 2. LULC map of the study area a) 2015 LULC Map& b) 2019 LULC Map c) Graph showing LULC Changes

3.2 Fragmentation analysis

3.2.1 Landscape Level Metrics

The values for the average contiguity index showed increase in the value from 2015 to 2019 (Table 3) indicating increase in larger contiguous patches and thus more spatial connectedness and less subsequent fragmentation (Lagro, 1991).Additionally, the CAI (Core Area Index) shows growth, indicating that core areas of classes are expanding generally on a landscape level.

However, the Shannon Diversity Index (SHDI) shows a decline in value, indicating that over the study years, the heterogeneity of distinct classes has been declining.

Table 2. Landuse Statistics (IMD, 2015 & 2019)

Srno	Landuse Classes	2015	2019
		Area(Ha)	Area(Ha)
1	Waterbodies	17626.95	19819.17
2	Vegetation patches/Plantation	105916.77	140324.94
3	Salt Panes	16388.28	21271.95
4	Salt Affected Regio	35526.78	29797.83
5	Fallowland	133747.65	55777.95
6	Builtup	14236.2	15597.29
7	Forest Patches	48148.65	42779.54
8	Barrenland	60727.95	34652.43
9	Agriculture	499155.2	572001.43
10	Sandy Beach	2632.86	2477.25
11	Mangroves	722.88	1249.74
12	Creek	4642.83	3718.53
13	Grassland	855	859.95
	Total	**940328**	**940328**

Table 3. Landscape Metrics summary

Landscape Metrics	SHDI	CAI	CONTIG
2015	1.58	30.68	0.61
2019	1.41	42.83	0.68

3.2.2 Class level metrics (for forest & vegetation patches classes)

In addition, to the landscape metrics the class metrics analysis was also included. The Class level metrics used in this study to infer the results include Euclidean Nearest-Neighbor Distance (ENN), Aggregation Index (AI), Edge Density (ED), Patch Density (PD), Number of Patches (NP), Largest Patch Index (LPI) and Interspersion and Juxtaposition Index (IJI).

It was noted that the NP decreased pretty noticeably between 2015 and 2019, which caused the PD value to fall. In contrast, while ED denotes perimeter, the patches are becoming significantly larger in terms of perimeter in 2019 as compared to 2015.

In addition, ENN and AI also increased simultaneously in the time period (Table 4). Increasing value of ENN in 2019 exhibits overall increases in large patches of forest & vegetation patches (Tolessa et al., 2016) whereas lower value of AI in 2015 compared to 2019 indicates more disaggregation, thus higher the fragmentation in previous year.

LPI comparisons between research years reveal that, as seen in 2019, the area of the largest patches is expanding. Moreover, IJI is slightly higher in 2019 than 2015 which depicts higher interspersion with other classes thus it shows more intervals. As per the IJI value which is slightly higher than 55% that means it is adjacent with at least 6 classes.

Table 4. Class metrics for forest class for 2015 and 2019

Class Metrics	NP	PD	ED	ENN	IJI	AI	LPI
2015	544	0.057	4.373	672.6	55.30	96.39	2.02
2019	232. 5.5	0.024	4.424	874.4	55.44	97.11	2.35

3.2.3. Moving window analysis

This technique was used to build a raster file with the findings by computing values for each cell. Analysis was done for obtaining Contiguity Index map at Landscape level and Aggregation Index map at Class level. The classes for Aggregation Index map include Vegetation Patches and Forest patches.

The result for Contiguity Index (Figure 3(a & b)) for year 2019 shows increased values in the area having higher values which implies more interconnections between various classes in 2019 as compared to 2015 indicating less fragmentation. According to the Aggregation Index results (Figure 4(a & b)), there was an increase in the area with a higher fragmentation value in 2015 than in 2019, indicating that over the course of the study period, forest and vegetation patches became more aggregated, resulting in a larger aggregated habitat that is conducive to animal movement.

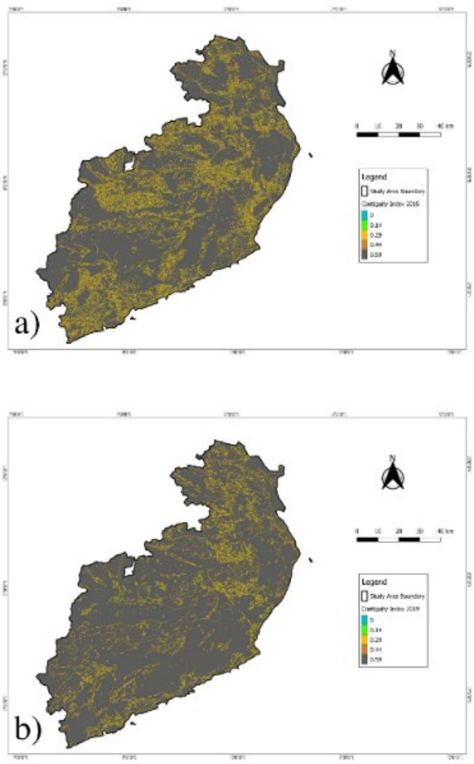

Figure 3. Contiguity Index of the study area. a) 2015 Contiguity Index Map b) 2019 Contiguity Index Map Note: Lesser value of Contiguity Index means high degree of fragmentation and vice versa.

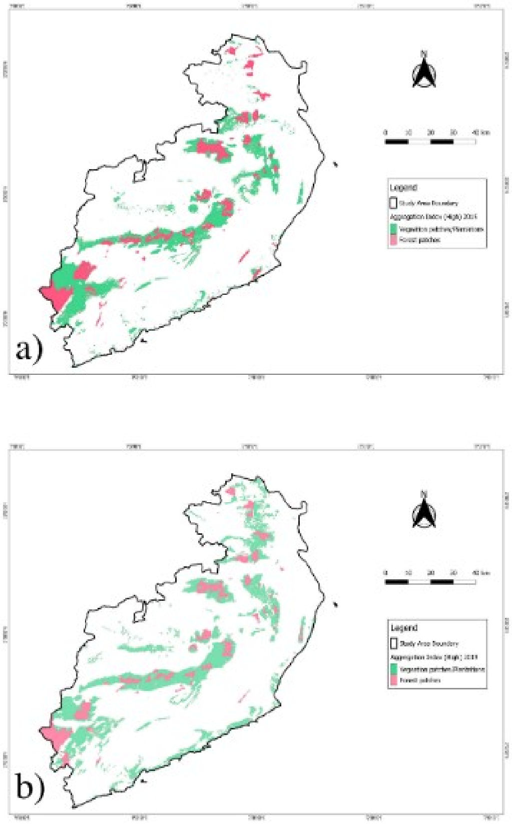

Figure 4. Aggregation Index of the study area. a) 2015 Aggregation Index Map b) 2019 Aggregation Index Map

The aggregation index decreased significantly near the canals originating from Shetrunji reservoir in both the study years. Major positive changes can be seen over 2019 in compare to 2015 is due the positive rainfall trend in 2019. Additionally, State Highway 31 and National Highway 351 passes close to the same canal at the Shetrunji reservoir, which is located in the north-western portion of the research area. It also has a low aggregation index, which may indicate that the traffic movements and the effects of the road on the accompanying infrastructure had an effect on the vegetation patches. (Figure 1, 4(a & b)). As roads take up substantial area of forest and plays a detrimental role causing fragmentation (Reed et al., 1996). Increase in number of fragments, leading to isolation of patches and there was further decrease in mean patch size. The increase in the number of patches could be attributed to conversion of the forest to other categories like road construction (Narmada, 2021).

4. Conclusions

Based on study and comparison between 2015 and 2019, the landscape analysis (class level) based on FRAGSTATS metrics reveals that there is little evidence of forest fragmentation in many patches. Additionally, it demonstrates how buffering vegetation patches outside protected forest areas can expand the space available for wildlife to migrate and may even contribute to the genetic diversity of Asiatic Lions.

In addition, larger vegetation patches and forest patches can be brought to focus for conservation which can increase connectivity between the landuse classes. Increasing interspersion and juxtaposition may be beneficial in wildlife movement since diversity of classes including Agriculture, Fallowland, Grassland etc. are also important to include in study as these classes serve as the potential home for the Asiatic Lions.

Under the SDG (Sustainable Development Goals) 15, For the continued existence of life on Earth and in the fight against climate change, forests are crucial and making investments in land restoration is essential for enhancing livelihoods, lowering vulnerabilities, and lowering economic risks. Moreover, Fragmentation Analysis is an important parameter for any landscape dynamics as it is becoming an important issue towards the gene flow & corridor mapping for the wild species and sustainable land development.

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