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- **Title of the paper:** Assessment of the future of potential dispersal corridors of Asiatic Lions (*Panthera leo persica*) across the agro-pastoral landscape between Gir & Girnar Wildlife Sanctuary.

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Assessment of the future of potential dispersal corridors of Asiatic Lions (*Panthera leo persica*) across the agro-pastoral landscape between Gir & Girnar Wildlife Sanctuary.

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Abstract

Wide ranging species are susceptible to fragmentation effects and small isolated populations become unviable due to environmental stochasticity & inbreeding effects. The recently colonized Girnar lion population is a typical example where the expansion of human settlements along the dry river channels and conversion of scrub patches into agricultural & urban areas results in substantial impacts on the functionality of dispersal corridors between the lion source population of Gir and Girnar. Monitoring these changes and planning urban development can be successfully achieved using multitemporal remotely sensed data, spatial metrics, and modeling. Three land cover maps (1998, 2002 and 2009) were used to study the patterns and quantities of land use dynamics. This agro-pastoral landscape is now being modified to towns, dams and roads. Results indicate increasing decline in vegetative patches from 1998-2002 (14%) and 2002-2009 (57%) with an increase in areas under barren land & settlements (90%) from 1998-2009. Land use change along the dispersal corridors was modeled using a Cellular Automata based approach for the year 2015. The predictive power of the model was successfully validated using Kappa variations. Projected land cover changes show a growing tendency in urban land use, threatening areas used by animals as passageways and day refugia. There is an urgent need for protecting the remaining natural, undisturbed vegetation patches thereby facilitating dispersal of lions between Gir and Girnar wildlife sanctuary in order to ensure long-term viability of the small Girnar lion population.

Keywords: Fragmentation, corridors, land-use dynamics, land-cover change modeling, dispersal.

Introduction

Gir remained connected with Girnar, Mitiyala, Barda, Alech hills, Dhank and Chorwad by corridors of rough semi-wooded forests, grasslands, and sparsely populated villages till the early part of the 19th century. This enabled lions to move freely in this region. Lions become locally extinct from Barda and the Alech hills towards the later half of the last century (Singh 2007). They disappeared from Girnar and Mitiyala by 1963 and 1955. By 1965, lions were found only in the compact forest of the Gir. The agro-pastoral landscape of Saurashtra that covers most of the distributional range of Asiatic lions (*Panthera leo persica*) have been vulnerable at the expanse of human driving forces like demand of land for agriculture, pasture, logging, limestone mining and urban sprawl. Soil and drainage conditions made this land more suitable for a variety of agriculture and urban land uses. As a result, expansion of urban, residential, agricultural land uses in this landscape have eliminated and fragmented the habitat available to Asiatic lions.

The correlated processes of habitat loss and fragmentation are probably the most important threats to global biodiversity. Historically, studies of fragmented ecosystems have relied heavily upon the conceptual model of island biogeography theory (MacArthur & Wilson 1967). In due course of time, the simple Island biogeography theory has been superseded by landscape ecology (Forman & Godron 1986), which further emphasizes factors such as fragment shape, spatial configuration of fragments, movement corridors, and structure and composition of the surrounding matrix. Metapopulation theory was also helpful in understanding the responses of subdivided populations to fragmentation (Hanski & Gilpin 1996).

Studies have yielded important insights into the responses of various taxa to fragmentation and into the effect of fragment size, shape, connectivity and other landscape features on species assemblages and ecological processes (Debinski & Holt 2000; Saunders et al. 1991; Laurance & Bierregaard 1997). Because lions have extensive home ranges, large contiguous forested areas are required to sustain viable populations. The most recent estimate of the total lion population of 411 individuals (Gujarat Forest Department, 2010) exist as one large (297) population in Gir PA and other small populations of 10-50 individuals including Girnar (24). These smaller populations can only persist in a metapopulation framework (Banerjee et al. 2010). Therefore, understanding the patterns of movement of individuals between subpopulations is essential managing the dynamics of the metapopulation structure to ensure long-term survival of the species (Gilpin and Hanski, 1991; Hanski and Gilpin, 1997).

In Gir, the population of lions remained almost constant during last censuses (267 in 1990, 262 in 1995 and 297 in 2010) (Singh 1995; Gujarat Forest Department, 2010). The population of important ungulates has increased at the rate of 14.2% per year during the last three decades and food is not a major limiting factor (Singh 1995). Lions being territorial, are socially regulated (Schaller 1972) resulting in dispersal out of the Gir protected area (PA). Natural dispersal of lion started after the last draught in 1987. The emigrant lions take advantage of the riverine habitat that exists between Gir and the other satellite populations. Some of the groups intermingle with the parent population in Gir whereas others remain confined to the isolated sites (Singh 1995).

Gir-Girnar corridors provide an important biological linkage between Gir Wildlife Sanctuary (WLS) and the Girnar WLS. Discontinuous cover and the scattered distribution of shrubs play an important role in lion's use of this landscape though it has been observed that there is a persisting problem of unrestrained encroachment and urban sprawl in this landscape disrupting the functionality of corridor habitats. However, the extent of land use changes has not yet been quantified. The present study identified different land use changes overtime in this landscape.

Study Site

The study area comprises Girnar WLS and the adjacent human dominated landscape connecting it with the Gir WLS. (Figure 1). The landscape on the south-eastern fringe of the Girnar WLS includes the revenue lands of approximately 90 villages extending in east from Malinda to Ravani Mundya and in western side from Khadiya to Nataliya. This human governed landscape matrix consists of broken topography, small drainage systems, Government and private owned wastelands, fallow lands and is predominantly agricultural with seasonal crops and fruit (mango) orchards. Climate is generally dry with two main seasons' viz. summer and winter. The monsoon which has few rainy days fuses with the summer period. The principal rivers flowing through the area are Ozat and Gundajali. Gundajali merge with the river Ozat, together forming the main water source of the area. Several small rivers, joining these two main rivers, are used by lions as passage ways.

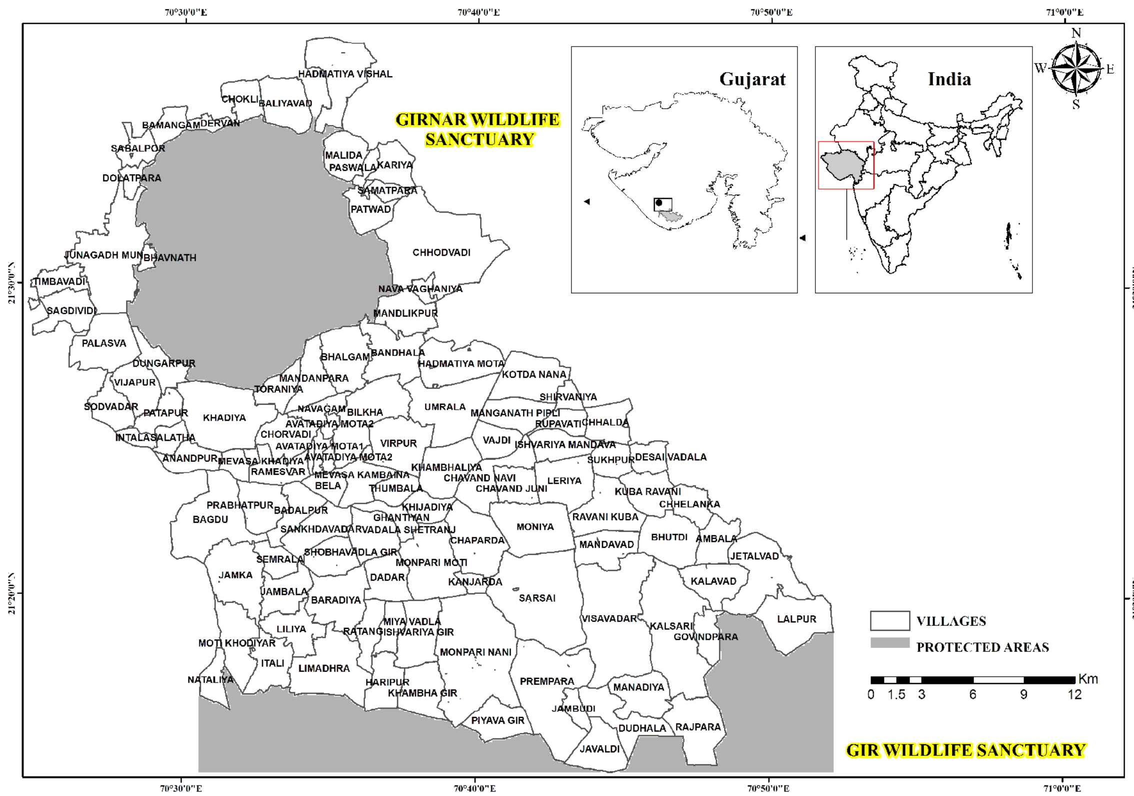

Figure 1: Location of Girnar WLS, Gir WLS and villages within the corridor landscape between Girnar and Gir WLS

The area is interwoven with road and rail networks. There are four major state highways and three metre gauge railways going through our study area. The main crops cultivated in this area are bajri (*Pennisetum glaucum*), jowar (*Sorghum bicolor*), wheat (*Triticum spp*), paddy (*Oryza sativa*), sugar-cane (*Saccharum officinarum*), ground nuts (*Arachis hypogaea*), cotton (*Gossypium spp*), sesame (*Sesamum indicum*), onions (*Allium cepa*), chillies (*Capsicum frutescens*) etc. Ground nut, cotton, jowar and wheat considered as the major crops of the district.

Methodology:

Image Classification & Calculation of Spatial Metrics:

Landsat5 TM imagery of the year 1998, 2002 and 2009 of resolution of 30 m X 30 m (Jensen, 1996) were used for the land use land cover classification. A field survey was carried out in November-January 2010 to assess the variation in land use/cover in this landscape. Fifty vegetation plots were sampled of 10 meter and 5 meter radius to collect phytosociological data of plants. Other descriptive parameters like: topography, precipitation, hydrology, vegetation structure, and human land use, cultivable lands, presence of roads etc. were also used to differentiate habitats within the habitat matrix. Unsupervised classification in ERDAS 9.2 was used to create land cover map describing four major land use classes present in this landscape such as cropland, sparse vegetation, waterbodies, and barren land including bare areas, road networks, and settlements (Figure 4).

The changes in areas under sparse vegetation & urban structures were measured and analyzed using the FRAGSTATS (McGarigal et al. 2002) and the classified map. Five spatial metrics (Class area, Number of patches, Edge density, Largest patch index, Euclidian mean nearest neighbor distance, Area) that showed significant difference were used for analyzing transformations. These indices are described in table 1.

Table 1: Spatial metrics used in change detection analysis of the corridor landscape

Metrics	Description	Units	Range
Class Area (CA)	CA measures total areas under different land use classes in the landscape.	Hectares	CA>0, no limit
Number of Patches (NP)	NP is the number of patches of all land use classes in the landscape	None	NP=0, no limit
Edge Density (ED)	ED equals the sum of the lengths (m) of all edge segments involving the patch type, divided by the total landscape area (m^2)	Meters per hectare	ED=0, no limit
Largest Patch Index (LPI)	LPI percentage of the landscape comprised by the largest patch	Percent	0<LIP=100
Euclidian Mean Nearest Neighbor Distance (EMN-MN)	Equals the distance (m) to the nearest neighboring patch of the same type, based on the shortest edge-to-edge distance	Meters	EMN_MN>0, no limit

Land use change modelling using Cellular Automata (CA)-Markov

Cellular Automata (CA)-Markov Model Description

For this study, we used Cellular Automata (CA)-Markov Chain analysis modeling technique, embedded in IDRISI Andes software (Eastman 2000). This incorporates two techniques: Markov Chain analysis and CA. The Markov Chain analysis explains the likelihood of land cover alteration from one period to another by developing a transition probability matrix between t1 and t2. The Markov module is based on the first law of Geography by using a contiguity rule (Cabral & Zamyatin 2006). According to the rule a pixel that is near one specific land cover category is more liable to become that category than a pixel that is farther. CA is integrated into the Markovian approach to add the spatial character to the model. CA-Markov models the change of several classes of cells by using a Markov transition matrix; a suitability map and a neighborhood filter.

In this study, the Markov Chain analysis model was executed using the Markov module. The first step in the model was to develop a transition probability matrix for each of the land cover classes between the years 2002 and 2009, and this in turn was used as an input for modeling land cover change. CA analysis was carried out with the CA-Markov module, which uses the output from the above stated Markov Chain analysis and transition suitability image collection, and applies a contiguity filter.

Implementing and validating the model

The predictive power of the model was evaluated by comparing the result of the simulation t2 (2009) to a real classified map of t2 (2009) by means of using three different Kappa statistics (Ponitus 2000, Dushku et al 2003): Kappa for no information (K_{no}), Kappa for location ($K_{location}$), and Kappa for quantity ($K_{quantity}$). K_{no} describes the overall accuracy of the simulated map. $K_{location}$ validate the model's ability to predict location. $K_{quantity}$ is a measure of validation of the simulations to predict quantity perfectly. If the predictive power of a model is considered strong then it is used to make future projections assuming that the transition mechanism verified between t1 and t2 is going to be repeated.

Results & Discussion

Land cover areas of 1998 were dominated by cropland (57.9%) followed by sparse vegetation 23.7%, barren land and settlements 17.4%, while Waterbodies and earth dam occupied 0.98% of the total area. On the other hand, in 2009 though cropland continued to occupy the largest area of 57.5% there was an increase in barren land and settlements to 33.1%,followed by sparse vegetation (8.79%) and the lowest cover was of the waterbodies and earth dam occupied.

During this period (1998-2009) sparse vegetation decreased in area by 63% while barren land and settlements increased in area by 90%. Furthermore, in year 2002 sparse vegetation decreased in terms of coverage from previous 24% to 20% of the total area but it continued to take the second lead in coverage of the area followed by barren land and settlements (14%) and waterbodies, earth dam occupied 0.7% of the total area. The calculation of amount of percentage change was based on initial values of individual land use classes for year 1998 and 2002. For instance, in 1998-2002 cropland increased 11% with the decrease in area of sparse vegetation (13%) and barren areas and settlements (18%). In 2009 there was no significant change in area under cropland but area under barren land and settlements increased by 134% with a decrease in areas under sparse vegetation (57%) (Figure 2).

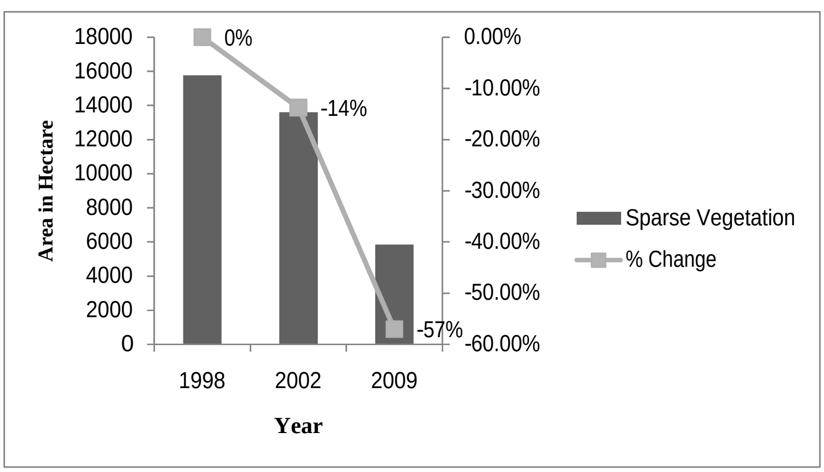

Figure 2: Change in sparse vegetation land cover class between 1998 to 2009 in the corridor landscape between Gir and Girnar WLS

Spatial metrics and their variation were calculated for the barren land and settlement areas (Table 2), which increased by 90% and for areas under sparse vegetation which decreased by 63% in the landscape between 1998 and 2009.

Table 2: Landscape indices & percentage of changes in areas under Barren land-settlement land-use in the corridor landscape between 1998 to 2009

Metrics	Year			Changes in areas under Barren Land-Settlement land use	
	1998	2002	2009	Δ% 1998-2002	Δ% 2002-2009
CA	11575.34	9415.11	22038.81	-0.19	1.34
NP	9610	6634	8432	-0.31	0.27
LPI	1.08	1.03	8.21	-0.05	6.95
ED	69.01	51.18	71.29	-0.26	0.39
ENN_MN	86.37	91.75	79.16	0.06	-0.14

* See Table 1 for abbreviation

The NP in a landscape analysis indicates the aggregation or disaggregation in the landscape, while LPI measures the proportion of total landscape area comprised by the largest urban patch. The NP (i.e., urban blocks and patches of barren area) decreased considerably (31%) between 1998 and 2002 (First Period), and increased (27%) between 2002 and 2009 (Second Period). This suggests an urbanization made by agglomeration of pre-existing urban patches in the first period while, in the second period, urbanization was characterized by dispersion. The development of a number of isolated fragmented or discontinuous built-up areas occurred in the second period. LPI increased by 7% between 1998 and 2009, thus indicating considerable growth within the historical urban core. ED decreased by 26% in the first period indicating urban sprawl around historical urban core while increased by 39% in the second period thus indicating an increase in the total length of the edge of the urban patches, as due to land use fragmentation. The decrease in ENN_MN by 14% after 2002 reveals a reduction in the distance between the built-up patches, thus suggesting coalescence.

Table 3: Landscape indices & percentage of changes in areas under sparse vegetation in the corridor landscape between 1998 to 2009

Metrics	Year			Changes in areas under Sparse Vegetation	
	1998	2002	2009	Δ% 1998-2002	Δ% 2002-2009
CA	15765.69	13596.42	5846.24	-0.14	-0.57
NP	10281	8777	14614	-0.15	0.67
LPI	1.62	0.95	0.02	-0.41	-0.98
ED	103.22	80.61	45.20	-0.22	-0.44
ENN_MN	77.44	84.33	83.67	0.09	-0.01

* See Table 1 for abbreviation

Observation of changes occurred in areas under sparse vegetation (Table 3) revealed that the NP (i.e, patches of sparse vegetation) decreased considerably (15%) indicating removal of forest patches in the first period and increased considerably (67%) in the second period showing fragmentation in existing patches. The decrease in class area in first and second period (14% and 57%) assured that there was no addition of new vegetation patches and the increase in number of patches in second phase was surely due to fragmentation of existing patches. The loss of vegetation patches and encroachment on the existing patches were more evident by the decrease in LPI (41%) in the first period and (98%) in the second period. Decrease in ED (22%) in 1998-2002 and (44%) in 2002-2009 indicates decrease in shape diversity of patches and rounding up of the existing patches, clearly showing the loss of forest habitat.

Increase of agriculture, changes in farming practices and urban sprawl impedes wildlife movement from one protected area to another. Saurashtra has been the agricultural bowl of for the past 800 years. Very fertile lands historically farmed but intensity of agriculture has changed. The current land uses are not compatible with wildlife and biodiversity conservation. Land use changes along wildlife corridors caused negative impacts on Gir-Girnar corridors. Study of land use changes and their impacts on wildlife corridor between Gir and Girnar wildlife sanctuary revealed that settlements and agriculture expanded into wildlife grazing and dispersal areas which reduced the area under sparse vegetation patches within the corridor (Figure 3).

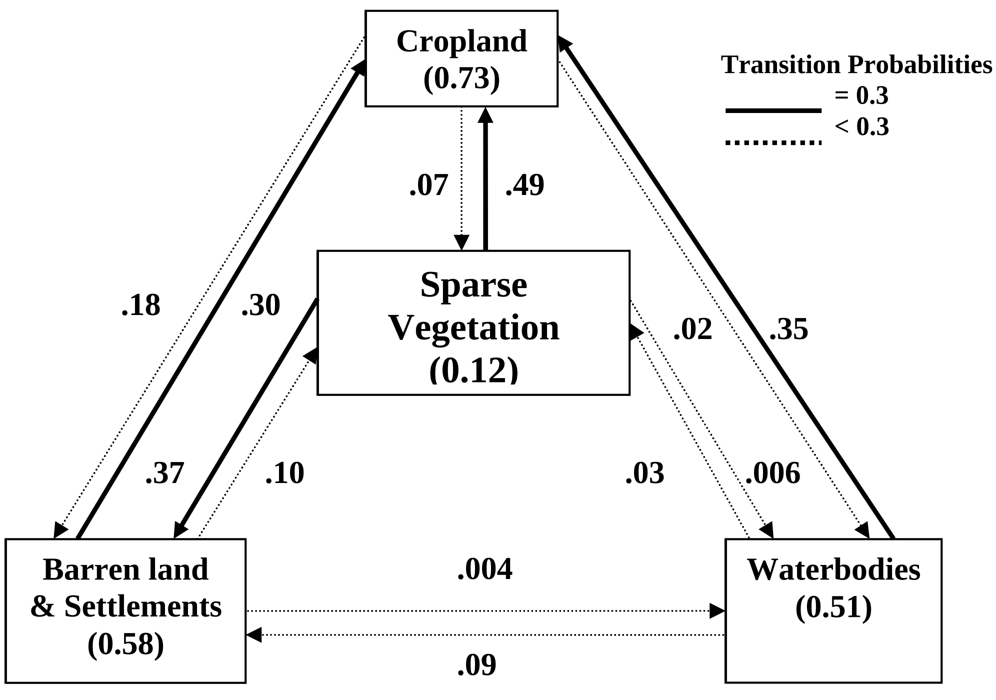

Figure 3: Box and arrow diagram illustrating land cover transition probabilities for the corridor landscape 2002-2009. Values within boxes are self replacement probabilities, whereas values positioned on arrows are transition probabilities

Land Cover Modeling and Validation

Visual interpretation of the modeling results shows that the simulated map for the year 2009 is reasonably similar to the real map for that year. A more detailed analysis was accomplished using the Kappa variations. The closer the values of these indices are to 100%, the stronger the agreement is between two maps. The K_{no}, which also gives the overall accuracy of simulation, is calculated to be 66%. The model performed well in the ability to specify location correctly ($K_{location}$ = 64%), and also in the ability to specify quantity ($K_{quantity}$ = 64%). Thus the classified map of 2009 was used for the future projection of 2015 (Figure 5).

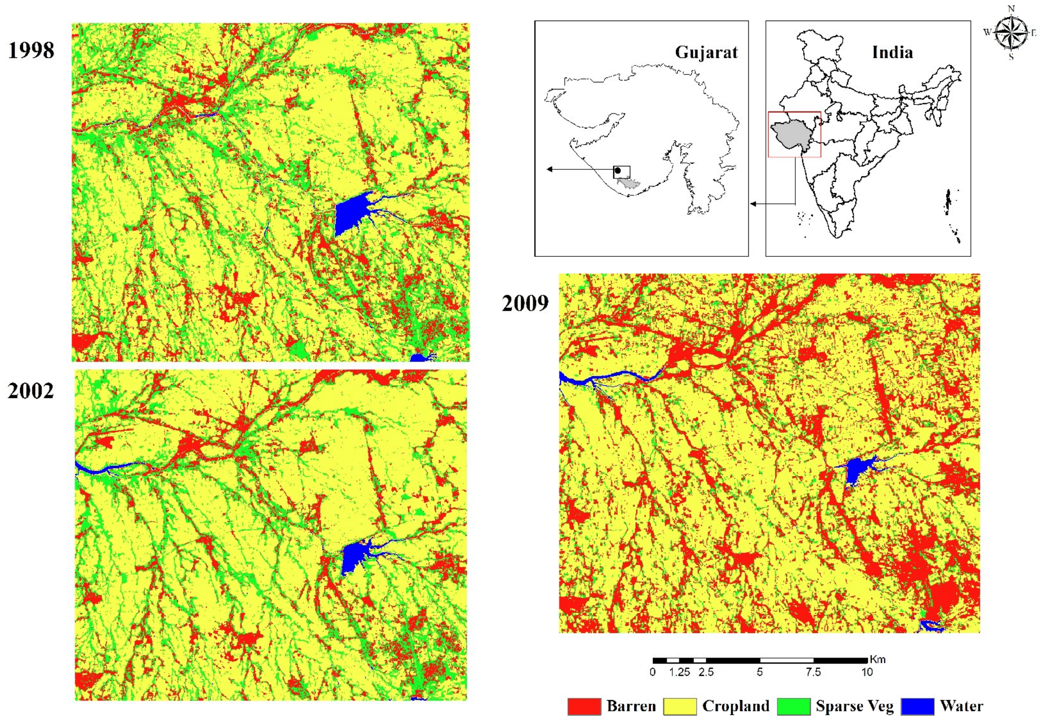

Figure 4: Three classified images (1998, 2002 and 2009) of the landscape

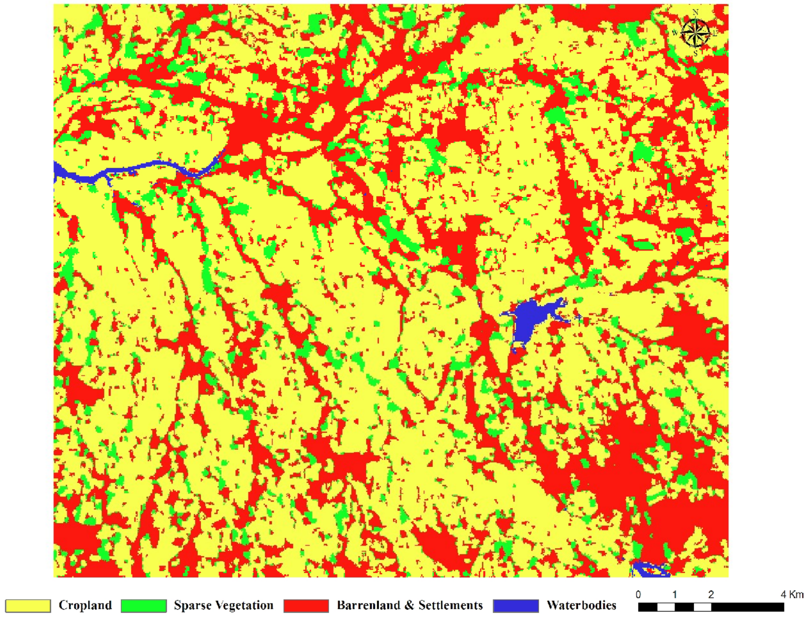

Figure 5: Simulated land cover map of 2015

A cross-tabulation that describes the changes in land cover classes included in the study is given in Table 4. The table shown below demonstrates the number of pixels that are expected to change from 2009 to 2015. The diagonal of the matrix indicates the number of pixels that have persisted during the simulation, while the off-diagonal shows the number pixels that changed class.

Table 4: Cross tabulation of simulated land cover map of 2015 with actual land cover map of 2009 (number of pixels)

		Actual Land Cover Map 2009				
	Land Use Classes	**Cropland**	**Sparse Vegetation**	**Barren land & Settlements**	**Waterbodies**	**Total**
Simulated Land Cover Map 2015	**Cropland**	174620	3783	3165	302	181870
	Sparse Vegetation	5084	17097	4011	0	26192
	Barren land & Settlements	11871	5444	78907	0	96222
	Waterbodies	15	48	169	2084	2316
	Total	191590	26372	86252	2386	307622

Conclusions

Gir protected area is at its carrying capacity for lions (Singh 1995), positive changes in the habitat may improve this figure marginally, but for better management of the increasing lion population, habitat improvement in new areas naturally colonized by the lions and maintaining the linkages in between these areas are necessary. The human dominated landscape surrounding Gir protected area is fragmented. Analyses of land use and cover change processes within the Gir-Girnar corridors suggest that riverine patches are vanishing at an alarming rate and the remaining patches are likely to be converted to agriculture. Sustainable management of these forest fragments huddled along the riparian corridors of tributaries of the main river Ozat and other small rivers is urgent with a focus on biodiversity.

Comparison of the 1998 Landsat TM classified image with the classification derived from the 2009 Landsat TM data shows that forests have been drastically impacted by conversion to agriculture and settlements during the period. Consequently, the area experienced extensive conversion to urban land cover in the last few decades. The continuous augment in land use changes is also reflected in an increased area under settlements. The occurrence of land use changes in areas adjacent to the Gir-Girnar wildlife corridor has not only reduced wildlife habitat but also may result into obstruction of wildlife movement from either part in future if the situation is left unattended. Results of the simulated land cover map of 2015 indicate that urban growth might continue to expand further in the future, and might have an irrefutable impact on land resources, unless some conservation policy is enacted.

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