Geospatial approach to identification of potential hotspots of land-use and land-cover change for biodiversity conservation

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Human-driven land-use and land-cover change (LULCC) is one of the most important causes for depletion of biodiversity. Few studies have been undertaken to spatially identify the natural areas prone to LULCC and hence biodiversity loss. This article describes a geospatial modelling technique using a combination of drivers of LULCC, spatial distribution of LULCC and topographic impedances for change in hotspot. A study has been carried out to establish the model. The model has shown that the natural areas having high population density in the vicinity are highly prone to LULCC.

Keywords: Change dynamics, hotspots, land cover, land use, modelling.

Introduction

LAND-use and land-cover change (LULCC) has been reported to be the prime cause of biodiversity loss[1], accounting for over 50% of the global biodiversity loss, and has thus gained global attention in the last decade[2–5]. Due to their influence on many of the environmental issues both direct and indirect, such as loss of biodiversity, changes in hydrological, carbon and nitrogen cycles, and climate change[6–8], it is important that the areas under intense LULCC be categorized for adapting suitable management strategies. Goa, a part of the Western Ghats biodiversity hotspot[9], has a large population[10] with relatively low human development index[11]. Therefore, the biologically rich forest area is under tremendous pressure from the population as it meets the sustenance and economic requirements of the people. Change in LULC is not only direct removal of forest cover, but also as a result of numerous other factors like infrastructure development, resource exploitation, NTFP extraction, etc. This leads to reduction in forest area and dwindling of biological diversity in the region. LULCC also influences the change in composition of the natural flora of the region by introducing multiple edges, where edge species predominate that are better adapted to utilize the scarce nutrients, replacing the endemic species especially in the climax or sub-climax forest[12]. An analysis of the intensity of the probable change in LULC would give us an indication of the spatial extent of areas most prone to biodiversity depletion.

The Western Ghats of Goa has some of the most biologically diverse vegetation patches in the region[13]. It is also one of the most stressed regions due to the burgeoning population, and need for more agricultural areas, mining and extraction of forest resources is leading to the habitat change and degradation of the natural forest areas[14]. In this region most of the natural regions are under pressure although there is no significant deforestation, these changes though not apparent pose a greater risk due to biological invasion leading to elimination of the endemic species[15]. Spatial information on the LULCC hotspots within the biodiversity hotspots[9] and their overlap with the biologically rich areas can help in prioritizing the conservation approach in the region. Although biodiversity plays an important role in ecosystem functioning, very little is known about the mechanism by which it influences ecosystem function at the landscape level[16]. To understand this, the study should include the influence of the external stressors like LULC, climate and biotic stresses on the biologically rich ecosystems. A number of conceptual frameworks have been proposed to address the vulnerability of an ecosystem to change as a result of perturbation, shocks and stresses[17,18]. These perturbations and stresses can both be human as well as environmental, and are affected by processes operating at scales larger than the event in question. Although ecosystems in general are resilient to occasional perturbations and stresses, if these persist over time, the type and quality of the system resistance changes and are potentially irreversible[19]. Land-cover change hotspots are the areas that are most vulnerable to change either due to their proximity to the drivers of change or their location attributes or the type of vegetation cover.

This article describes a geospatial model to identify the hotspots of LULCC. A case study to establish the model has been carried out in Goa situated in the Western Ghats of India, wherein population growth, landscape properties,

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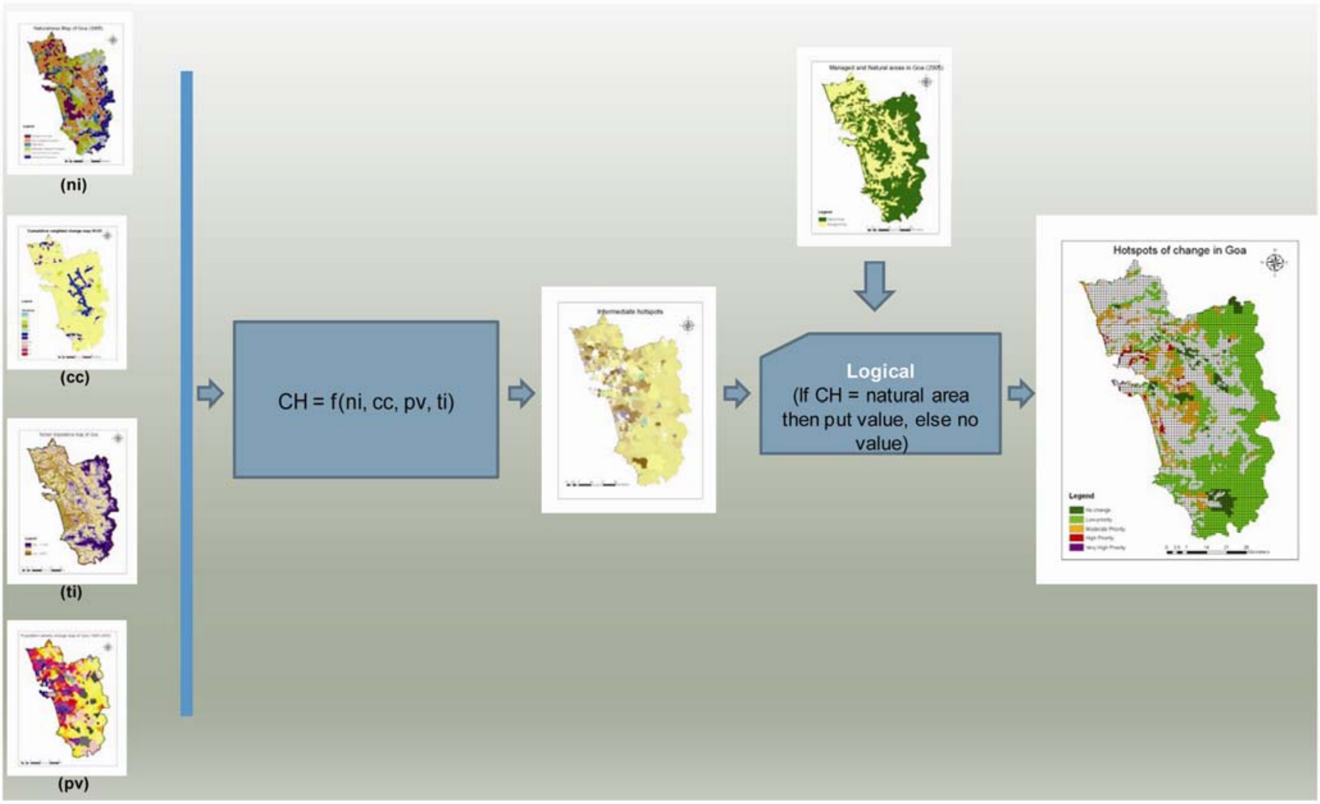

Figure 1. Dataflow diagram for modelling hotspots of change.

in terms of fractal dimension, terrain properties and LULCC trends have been considered as drivers of LULCC. This model enables identification of the potential areas of change in the natural vegetation in the biodiversity-rich areas and accordingly prioritizes the areas for conservation.

Study area

Goa is India's smallest state in terms of area and the fourth smallest in terms of population. Located on the west coast of India in the Konkan region, it is bounded by Maharashtra to the north and Karnataka to the east and south, while the Arabian Sea forms its western coast. Goa encompasses an area of 3702 sq. km (1430 mile^2). It lies between lat. 14°53′54″N and 15°40′00″N, and long. 73°40′33″E and 74°20′13″E. Most of Goa is a part of the coastal region known as the Konkan, which an escarpment raising up to the Western Ghats, which separate it from the Deccan Plateau. The highest point is Sonsogor, with an altitude of 1167 m (3827 ft). Goa has a coastline of 101 km and a population of 1.344 (2001 census) million residents with a growth rate of 14.9% per decade. There are 363 people for each square kilometre of the land[20]. About 49.77% of the population lives in urban areas and the remaining in 371 villages organized in 10 taluks. Since the state harbours diverse ecosystems in a small area, it is ideal for studying the impact of LULCC-induced biodiversity studies.

Methodology

LULC map comprising eight classes was prepared using IRS-P6 LISS-III data of 2005. The interpreted and field-validated map was modified using IRS-1B LISS-I data for depicting LULC in 1995. Further, the 1995 map was overlaid on the 1985 Landsat MSS data and the polygons showing changes were suitably modified to generate the 1985 map. The map was generated at 1 : 250,000 scale. The three-time period LULC maps were used as the base data for future analysis.

The hotspot of change involves the use of different landscape-based indices, terrain features and anthropogenic influences. The major inputs of the model are: (i) weighed cumulative LULCC, (ii) population variability, (iii) terrain impedance, and (iv) naturalness index (ni). Weighted cumulative LULCC map (cc), using three time period LULC maps for the years 1985, 1995 and 2005 was generated. The LULCC was assigned weightages based on the degree of change (Table 1). The 1985–1995 and 1995–2005 weighted change maps were geospatially modelled to produce the cumulative change maps.

Table 1. Land-use and land-cover change (LULCC) weightages. The weights have been assigned between 1 and 9 based on the type and extent of LULCC on the structure and functioning of the natural ecosystem. The land cover class which shows migration from one class to the other is only considered, the rest is given as 1. For example, if the change is from cropland to built-up, there is a change in level of cropland biodiversity. But if the cropland is changed to fallow, then there is relatively less change to biodiversity as the seed bank still exists which can germinate under favourable conditions. Similarly, in the case of mixed forest, to built-up is most, followed by cropland and then natural systems. If the class is retained over time, the weight is 1

Class change	Weightage	Class change	Weightage	Class change	Weightage	Class change	Weightage
1 to 1	1	3 to 1	1	5 to 1	9	7 to 1	9
1 to 2	1	3 to 2	1	5 to 2	7	7 to 2	8
1 to 3	1	3 to 3	1	5 to 3	3	7 to 3	8
1 to 4	1	3 to 4	1	5 to 4	4	7 to 4	8
1 to 5	1	3 to 5	1	5 to 5	1	7 to 5	3
1 to 6	1	3 to 6	9	5 to 6	8	7 to 6	9
1 to 7	1	3 to 7	1	5 to 7	1	7 to 7	1
1 to 8	1	3 to 8	1	5 to 8	1	7 to 8	5
2 to 1	9	4 to 1	9	6 to 1	1	8 to 1	9
2 to 2	1	4 to 2	1	6 to 2	1	8 to 2	7
2 to 3	3	4 to 3	1	6 to 3	1	8 to 3	8
2 to 4	1	4 to 4	1	6 to 4	1	8 to 4	8
2 to 5	1	4 to 5	1	6 to 5	1	8 to 5	1
2 to 6	3	4 to 6	1	6 to 6	1	8 to 6	9
2 to 7	1	4 to 7	1	6 to 7	1	8 to 7	1
2 to 8	1	4 to 8	1	6 to 8	1	8 to 8	1

1, Built-up; 2, Cropland; 3, Evergreen/semi-evergreen forest; 4, Deciduous forest; 5, Mixed forest; 6, Fallow land; 7, Water body; 8, Barren/waste land.

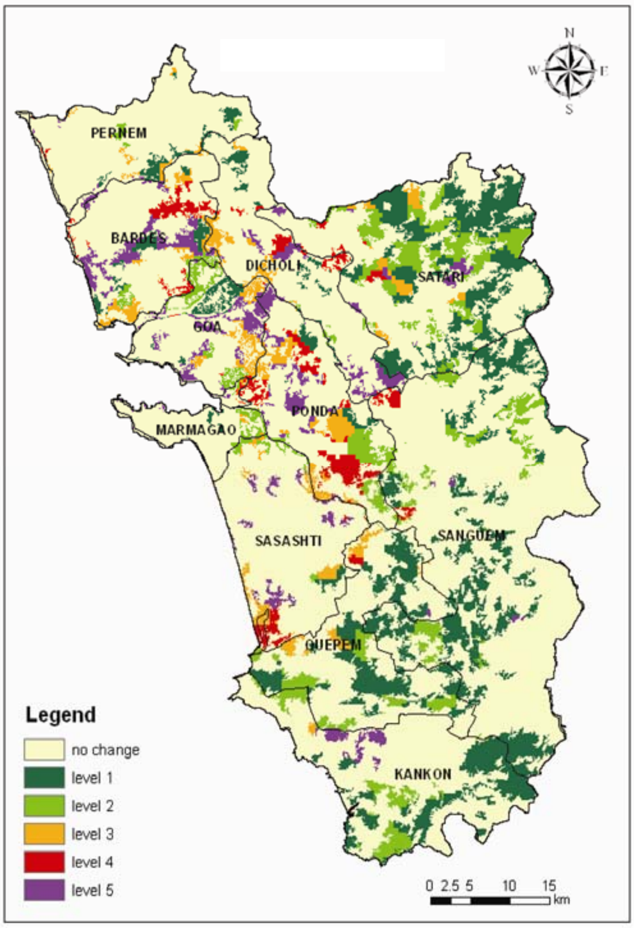

Figure 2. Hotspots of land-use and land-cover (LULC) change in Goa.

For population variability (pv) layer, the village-level population density of Goa has been prepared for the years 1995 and 2005 using the census data, and the increase or decrease of the population density has been geospatially computed to generate the population variability map. Terrain impedance (ti) has been computed from the elevation and slope maps derived from SRTM DEM. Using the following equation, ti has been geospatially computed.

$$\text{ti} = \ln(\text{sl}) + \ln(\text{ele}), \quad (1)$$

where sl represents slope and ele represents elevation.

Naturalness index (ni) is a representation of the level of disturbance to the landscape in terms of fractal dimension, landscape variability and proportion of the natural ecosystems as compared to managed ecosystems.

$$\text{ni} = f\,(\text{FD, LV, VT}), \quad (2)$$

where f is a multiplicative function.

$$\text{FD (fractal dimension)} = 2*[(\ln(P) - \ln(k))/\ln(A)]. \quad (3)$$

LV is the landscape variability in a unit area. VT is the proportion of natural ecosystems in the 1 km grid estimated by giving weightage to the LULC map from 1 to 10.

The change hotspot (ch) is generated by integrating the above four intermediate layers using the equation

$$\text{ch} = f\,(\text{cc, pv, ti, ni}), \quad (4)$$

where f is an additive function.

The intermediate change layer was again subjected to a geospatial logical modelling to identify the hotspots only in the natural areas.

The hotspot map generated was classified into six categories ranging from 1 to 6, where 1 represents the areas which are under managed ecosystem such as cropland, built-up, etc., 2 represents the areas that are expected to undergo least LULCC and 6 represents the areas subjected to most probable LULCC or the LULCC hotspots. Biodiversity is mostly concentrated in the few natural areas which are relatively less disturbed by the anthropogenic activities (contrary to the statement mentioned in the introduction). The natural areas were reclassified and weightages assigned to the land cover classes according to the degree of the naturalness observed from the previous studies[21]. Using the above-mentioned layers, the hotspot of change map computed is shown in Figure 1. For identification of biodiversity-rich areas, the spatial database of the biodiversity characterization at landscape level data of vegetation type, fragmentation, disturbance index and biological richness was used[22].

Results and discussion

There has been a gradual change in LULC in Goa. A constant increase in the area under the built-up category from 1985 to 2005 by around 0.23–0.48% of the total geographic area (TGA) has been observed, while the cropland has increased by 6.86% of TGA during 1985–1995, but then decreased nominally by 0.44% of TGA. Whereas evergreen and semi-evergreen forests have more or less remained constant, the deciduous forest and the mixed forest showed a considerable decrease of 2.36% and 3.85% of TGA respectively, during 1985–1995 and deciduous forest increased in the next decade by 1.4%, the mixed forest decreased by 2.08%, indicating the dynamic nature of LULC of Goa (Table 2).

Since population is one of the main drivers of LULCC, it was included as one of the inputs in the hotspot area model. The population-driven change in LULC generally induces variability in the landscape due to selective modification to the land cover[23]. Apart from variability, this also leads to complexity in the shape in the land cover classes as reflected by the fractal dimension[24]. The spatial variation on the scale of resource exploitation and land for agriculture or settlement is determined by the impedances caused by the topography to the resource[25]. Since high elevation and steep slopes are generally effective impedance to the access of the natural resources, these two terrain properties have been used to model the resource exploitation impedance map of Goa. The hotspot of change has been categorized into six classes (Figure 2). The no-change area occupies about 72% of TGA and levels 1 to 5 occupy 13.16%, 6.47%, 2.99%, 2.09% and 3.28% of TGA respectively. It is noteworthy that some natural areas are under high or very high level of LULCC. Although evergreen and semi-evergreen forests are mostly unchanged, the moist deciduous forests are under tremendous change. Out of the total area of 593.64 sq. km of moist deciduous forest, 78% is under some level of LULCC (i.e. levels 1 to 5). Most of the levels 3, 4 and 5 hotspots of change falls in the cropland, indicating the cumulative LULCC from natural areas to cropland.

Comparison of the fragmentation maps of Goa[22] indicates that most of the levels 3, 4 and 5 hotspots of change are in the scrubland. In the forested areas, the low fragmentation (value 1 in a scale of 1–10) areas occupy 13.4% of the area under hotspot of change, whereas moderately fragmented (value 2) areas have 1.43% and highly fragmented (values 3–10) areas occupy 0.1% of TGA under hotspots of change. This is also because forests of Goa are relatively less fragmented compared to other regions of India (Table 3). It is generally observed that anthropogenic pressure leads to fragmentation of patches; hence less fragmentation of Goa forests implies either that the terrain is too rugged for economical exploitation of the forest resources or that the forests are under good protection. It is observed that the category of hotspot of change is highly correlated with the population density of the area (correlation coefficient 0.77 at 0.01 level of significance; d*f* 9) (Figure 3). This implies that the human influence is most dominant in the vulnerability for

Table 2. Area (in hectare) under different LULC during three time periods (1985, 1995 and 2005) in Goa

LULC class	1985	1995	2005
Cropland	61,793	86,724	85,360
Fallow land	40,774	31,360	33,487
Barren/waste land	22,748	22,688	22,990
Water body	14,355	17,610	17,864
Deciduous forest	72,377	63,572	68,862
Built-up	20,796	21,589	22,561
Evergreen/semi-evergreen forest	35,000	38,657	38,475
Mixed forest	97,786	83,430	76,031

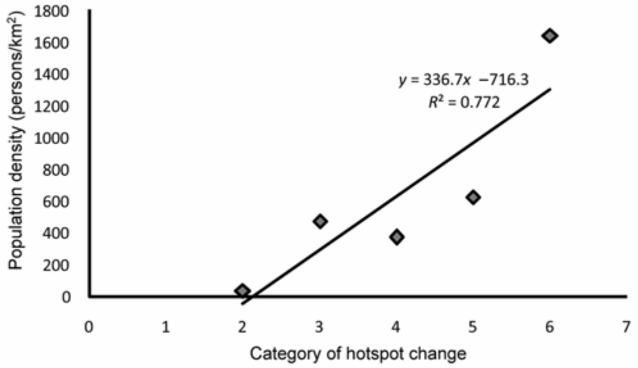

Figure 3. Plot of population density to the level of LULCC hotspot.

Table 3. Distribution of fragmentation, disturbance index and biological richness (*X*1) across different LULCC hotspots

	LULCC hotspot					
Category	No change (%)	Level 1 (%)	Level 2 (%)	Level 3 (%)	Level 4 (%)	Level 5 (%)
Fragmentation						
Low	13.782	7.156	4.276	0.685	0.677	0.632
Medium	1.223	0.836	0.240	0.139	0.061	0.153
High	0.173	0.054	0.032	0.009	0.003	0.004
Disturbance index						
Low	11.783	5.151	3.109	0.595	0.480	0.428
Medium	13.605	3.492	1.268	0.205	0.224	0.299
High	18.618	1.621	0.629	0.193	0.197	0.288
Very high	1.363	0.080	0.036	0.019	0.013	0.031
Biological richness						
Low	30.310	2.306	0.501	0.181	0.173	0.263
Medium	0.002	0.001	0.000	0.000	0.000	0.000
High	14.065	7.613	4.196	0.814	0.741	0.775
Very high	0.993	0.424	0.347	0.018	0.000	0.009

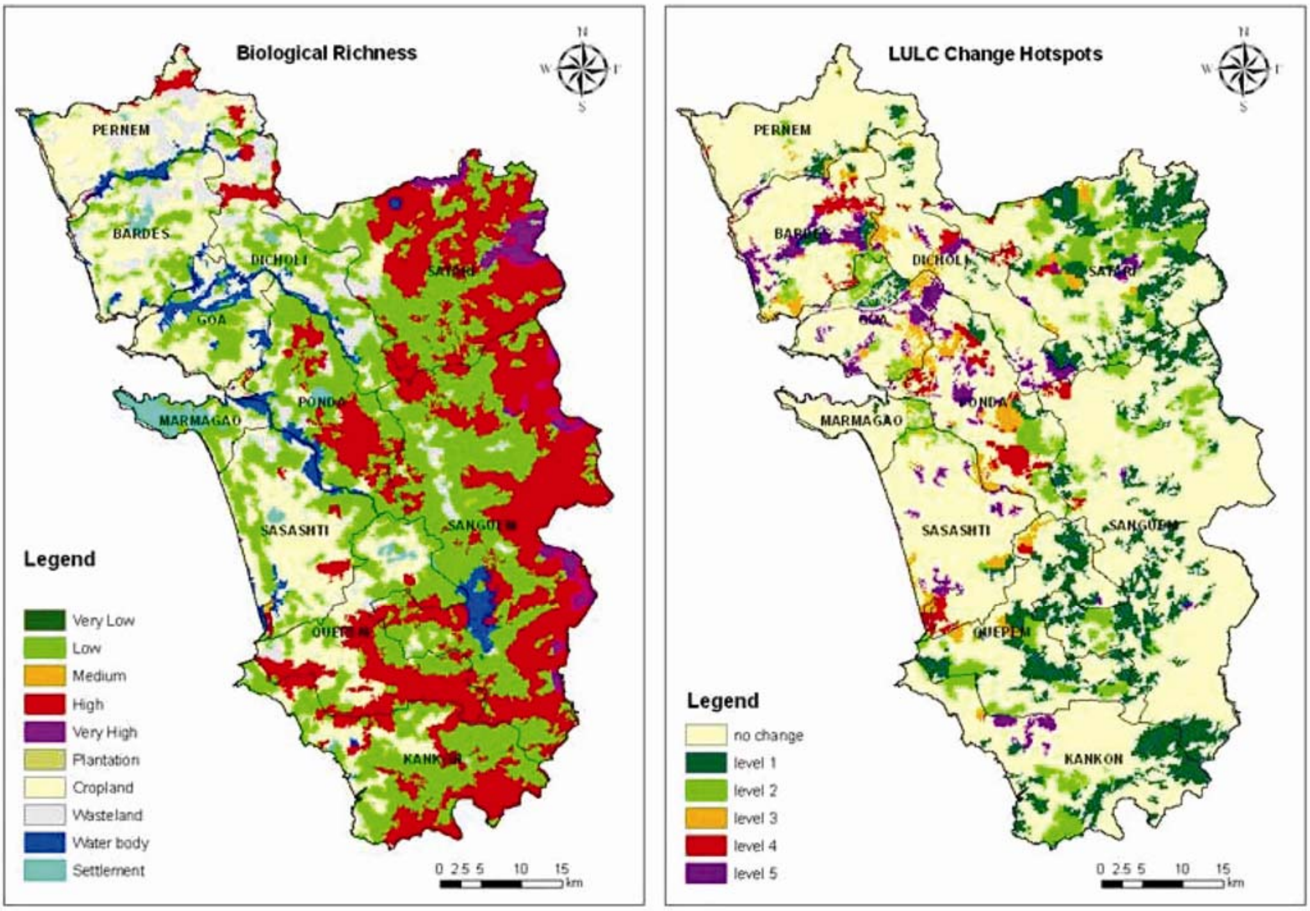

Figure 4. Comparison of biological richness map (left) with the LULCC hotspots (right) of Goa.

change of the natural ecosystems in Goa. Furthermore, it has been geospatially observed that the areas showing no change in the Valpoi-satari, Sanguem, Ponda and Canacona taluks are due to the presence of wildlife sanctuaries and sacred groves (sacred groves in Satari-Maharashtra border; Bondia Wildlife Sanctuary and Bhagwan Mahavir Wildlife Sanctuary in Sanguem and Cotigao Wildlife Sanctuary in Canacona) are under protection.

On comparison of the hotspot map with the biological richness map generated as part of Biodiveristy Characterization at Landscape Level project[22], it was observed that most of the areas having high biological richness are in the region with either no-change or level 1 probability of land cover change (Table 3). It was also observed that there are some high and very high biologically rich areas of around 25 sq. km which fall under level five LULCC hotspot and are in need of urgent conservation efforts mostly in Ponda taluk (Figures 4 and 5). This taluk does not have any protected areas, although it has biologically rich areas. Levels 1 and 2 hotspots may be graded as not significant, but levels 3, 4 and 5 may be taken as significant threat to biological diversity. These three significant hotspots of change are spread over 77 sq. km of evergreen, semi-evergreen and moist deciduous forests, which constitute 3.7% of the vegetated areas in the state. Since the Western Ghats has around 3049 endemic species[26] spread in the biologically rich areas with 13 endemic higher plants and five endangered plant species being recorded in Goa[22]. Existence of the LULCC hotspot in these areas will lead to loss of these endemic and endangered species.

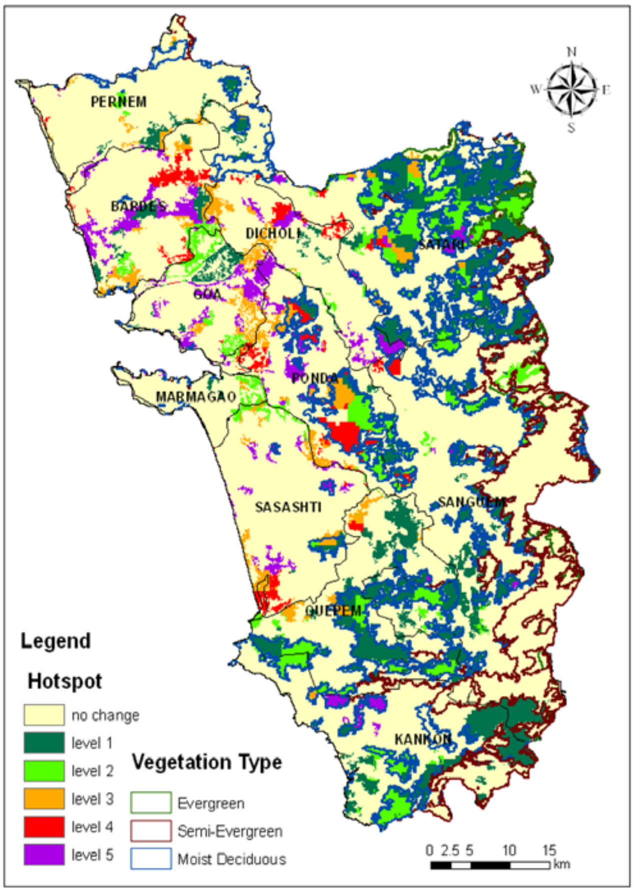

Figure 5. LULCC hotspots overlaid with vegetation type boundary.

Conclusions

The study has been carried out to establish the geospatial model of change hotspots. In the event of climate change impacts, these areas are furthermore vulnerable to degradation. The model for the hotspots of change has identified the potential areas of change in Goa and shows strong anthropogenic influences on the hotspots of change. The study indicates that the moist deciduous forests in the Ponda taluk are most prone to the degradation and land-cover change. This is logical due to the mining activities and development of infrastructure. Most of the high priority hotspots of change are in and around the highly populated district with intense agriculture or mining. The eastern parts of the state, which are relatively less accessible due to the rugged terrain, are less prone to change and hence fall under low-priority change areas. Presence of sacred groves in the north eastern and the southern part of the state may be the reason for unchanged areas, implying that institutional protection plays a major part in conservation of the biological diversity. Thus the areas in the state which fall under levels 4 and 5 hotspots have high to very high biological richness that needs to be conserved on a priority basis.

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