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Ecological Sustainability of Riverine Ecosystems in Central Western Ghats

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ABSTRACT The conservation and sustainable management of ecosystems are the vital requisites in the pursuit of environment friendly development goals. This requires an understanding of the complex functioning of ecosystems, diversity of resources, ecosystem goods and services and their quintessential role in supporting people's livelihood. Ecological units with the exceptional biotic and abiotic elements are designated as Ecologically Sensitive Regions (ESRs). Identification of ESRs has been done by considering spatially, both ecological and social dimensions of environmental variables. The current research maps ESR at village levels in the Kali River Basin of Central Western Ghats through aggregated weightage metric score as ESR (1-4) based on attributes (biological, Geo climatic, Social, etc.). There are 203 villages in ESR-1, 73 in ESR-2, 77 in ESR-3, and 181 villages in ESR-4. Ecologically fragile regions to be conserved on priority with no disturbances are ESR 1 and ESR 2, while ESR 4 is for development.

INTRODUCTION

Sustainable development of a region requires a synoptic ecosystem approach that relates to the dynamics of natural variability and the effects of human interventions on key indicators of biodiversity and productivity (Ramachandra et al. 2007). Ecosystems are the distinct biological entities that sustain the biosphere and are characterised by a range of functions: nutrient cycling, bio-geochemical cycle, hydrologic cycling, etc. They are interrelated in space and time in complex dynamic patterns depending on the health of landscape (Lin et al. 2018). Ecological sustainability refers to the ecosystems ability to cope with various kinds of environmental disturbances that have the potential of adversely changing the character of the natural landscapes while maintaining the sustenance of natural resources (water, soil, etc.). The landscape is a mosaic of interconnected forest and non-forest patches, constituting a complex ecological, economic and socio-cultural systems. Forest ecosystems have been playing a crucial role in sustaining life on the earth through the sustenance of ecological goods and services, biological diversity, regulation of climate, carbon sequestration, protection of soil and water bodies, etc. They provide abundant resources and sustain the livelihood of the global population (Gibson et al. 2011; Hansen et al. 2013), They act as prime biodiversity repositories (Kindstrand et al. 2008; Li et al. 2009) and mitigate global warming (Cabral et al. 2010) by absorbing 30 percent of fossil fuel CO_2 emissions (Pan et al. 2011). The goods and services provided by forested landscapes are vital to the socioeconomic development of human populations (DeFries et al. 2004) and their survival (Ramachandra et al. 2017). However, the forests are being altered due to the uncontrolled and unplanned anthropogenic activities such as agriculture, deforestation, etc. affecting the ecosystem structure and health. Forests cover about 30 percent today at globally as opposed to 50 percent of the earth's land area 8000 years ago depleted with the expanded extents of croplands, pastures, plantations, and urban areas (FAO 2011). The Earth's land surface has lost 40 percent of natural forest by 1990

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due to the expansion of cropland and permanent pasture (Ramachandra and Shruthi 2007). The rapid conversion of forests for agriculture, timber production, infrastructure activities and other anthropogenic uses has generated vast, human-dominated landscapes with potentially calamitous consequences for biodiversity to sustain (Gould et al. 2017). Despite significant services of these ecosystems, global deforestation rates have remained alarmingly high over the past decades (DeFries et al. 2010). This necessitates synthesis of causal factors which would aid in formulating location specific management plans to mitigate impacts. The structure of a landscape depends on land cover (LC), which decides the functioning of respective ecosystems. LC refers the physical cover of a landscape such as vegetation, non-vegetation (soil, water), etc., whereas land use (LU) describes management and modification of natural environment to a human with socioeconomic functions and services.

Land use land cover (LULC) analysis helps in understanding bio-geophysical processes and anthropogenic pressures on the ecosystem. LULC change resulting in deforestation has been recognized as an important driver of environmental changes due to alterations in temperature-humidity response pattern affecting plant physiology and diverse ecosystem functions (Findell et al. 2017). The uncontrolled LU changes in forested landscapes induce imbalances by subdividing the contiguous native forests in to smaller fragments with isolated patches, which is known as forest fragmentation (Laurance et al. 2002; Bharath et al. 2012). Fragmentation refers to breaking up of contiguous natural forest patches into smaller tracts of forest surrounded by other land uses, causing a disruption in continuity of the natural landscape (Ramachandra et al. 2016a). Forest fragmentation with subsequent edge effects due to infrastructure developments (linear projects, etc.) has impaired ecosystem goods and services including carbon sequestration ability, hydrologic regime, biodiversity (Harper et al. 2005; Vinay et al. 2013; Bharath et al. 2014), aggravate predation (Cagnolo et al. 2006), fire susceptibility, alters microclimate and enhance carbon emissions (Houghton and Nassikas 2017). The unrestrained deforestation will alter microclimate of the region, leading to increasing in land surface temperature and proliferation of exotic species (Ramachandra et al. 2018) and disease vectors. This necessitates quantification of LULC changes to evolve sustainable natural resource management strategies. Conservation of forest ecosystem has become a critical task due to increased high intensities of anthropogenic disturbances in the form of LULC changes as compared to natural disturbance processes (Kivinen and Kumpula 2013). This has led to the development of systematic conservation planning approaches as an increasingly vital tool for protecting the nature around the world.

The comprehensive knowledge about LULC has become increasingly important for planning and visualization of future growth to overcome the problems of haphazard, uncontrolled development in ecologically sensitive regions (Kennedy et al. 2009). Temporal remote sensing data, geographic information systems (GIS) techniques, free and open source software technologies are providing efficient methods for the analysis of LULC dynamics required for planning and protection (Ramachandra et al. 2014). The forests of Western Ghats are undergoing deforestation, while the forest under protected areas is also experiencing the risk of land use changes.

The conservation and sustainable management of ecosystems are the vital requisites for sustenance of natural resources. The impact of unplanned developmental activities during the post-independence period is evident from the barren hilltops, conversion of perennial streams to seasonal ones, loss of livelihood, etc. This necessitates an understanding of the complex functioning of ecosystems, diversity of resources, ecosystem goods and services and their quintessential role in supporting people's livelihood. Ecological units with the exceptional biotic and abiotic elements are designated as Ecologically Sensitive Regions (ESRs). Identification of ESRs has to be done considering ecological, bio-geo climatic, social dimensions of environmental variables. Ecologically Sensitive Regions (ESR) are defined under conservation planning approach as ''large units of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (Olson et al. 2001). ESR has the capacity to support and maintain the balanced and integrated ecosystem in a particular region under protective measures. Systematic conservation by prioritization of sensitive regions has become an effective and economical method (Myers et al. 2000) and is widely used to improve ecosystem by conservation practices. With respect to Indian scenario, Union Ministry of Environment Forests and Climate change (MoEFCC) has taken an initiative to protect forests and maintenance under section 3 of Environment (Protection) Act 1986 (EPA). Central Government can prohibit or restrict the location of industries and carry out certain operations on the basis of considerations like the ecological sensitivity under section 5 of EPA 1986. The MoEFCC had set up Pronab Sen Committee in the year 2000 to identify parameters for designating ESRs in the country to counter the rapid deterioration of the environment, both nationally and internationally (MoEF 2000). The committee has defined ecological sensitivity or fragility as permanent and irreparable loss of extant life forms from the world; or significant damage to the natural processes of evolution and speciation. Based on this, Western Ghats Ecology Expert Panel (WGEEP) demarcated ecological sensitive regions and suggested prohibited and regulated activities in the respective zones of the Western Ghats (Gadgil et al. 2011) considering multi-disciplinary inputs from the stakeholders. Subsequently, a high-level working group (HLWG), designated about 37 percent (that is, 60,000 sq. km.) of Western Ghats as ESA. However, both these reports were unsuccessful in generating confidence on the good intent of sustainable development and is not implemented till date. Unplanned developmental activities including tourism activities (under the guise of eco-tourism) have been causing irreplaceable losses even in protected areas (PAs). Now there is a move by the federal government to de-notify 75 percent of Kali tiger reserve (KTR) an eco-sensitive zone area (ESZ) (a major portion of Kali River Basin) to implement developmental activities (many projects are pushed under drinking water scheme) in the eco-sensitive regions (KFD 2017). As the drinking water projects gets both executive and judiciary nod (without environment clearance), most of the environmentally unsound projects are pushed under the guise of drinking water requirement leading to large scale destruction of prime forest ecosystems in the Western Ghats.

Objectives

The objectives of the current research are to delineate ecological sensitive regions (ESR) at village levels based on bio-geo climatic variables. This involves understanding LULC dynamics, ecology and socioeconomic status in the Kali River Basin (Kali Tiger Reserve - KTR).

Study Area

Kali River Basin is the lifeline of the district and water source for major agriculture, horticulture, and energy production. The Kali river has a catchment area of 5085.9 km^2 spread across districts of Uttara Kannada (Ankola, Karwar, Supa, Yellapur, Haliyal), Dharwad (Kalgatgi, Dharwad) and Belgaum (Khanapura, Bialhongal) (Fig. 1). Population in the Kali River catchment has increased from 4,97,892 (in 2001) to 5,42,036 (in 2011) as per the Census of India (http://censusindia.gov.in) and is projected to increase to 5,66,065 in the year 2016 at the decadal growth rate of 8.8 percent. Population density in the catchment is 111 persons per square kilometer as on 2016. Major Population is in towns such as Dandeli, Haliyar, Dharwad, Karwar, Yellapura, Ramnagar, Virje, Majali, Ammadalli, etc.

The major vegetation types in the Kali basin are broadly grouped as ‘natural vegetation’ which includes evergreen, moist deciduous and dry deciduous forests; ‘plantations or monocultures’ which includes plantations of *Tectona grandis* (Teak), *Eucalyptus sp.* (Bluegum) *Casuarina equisetifolia, Acacia auriculiformis, Acacia nilotica,* and other exotics. The most threatened and vulnerable species such as *Wisneria triandra, Holigarna beddomei, Holigarna grahamii, Garcinia gummi gutta, Hopea ponga, Diospyros candolleana, Diospyros paniculata, Diospyros saldanhae, Cinnamomum malabatrum, Myristica malabarica* and *Psydrax umbellate* are found in the basin. The forests are suffering from many detrimental developmental activities and policy interventions, subsequently leading to the heavy removal of lofty trees across the district (Ramachandra et al. 2016b).

The dams/reservoirs in Kali River Basin were constructed during post 1980’s, which include Supa dam, Bommanahalli reservoir, Tattihalla reservoir, Kodasalli dam, Kadra dam, Kaneri dam, etc., which receives water from Kali River catchment consisting of pristine forest cover of Kali Tiger Reserve (KTR) or Anshi-Dandeli Tiger Reserve (ADTR). The ADTR/KTR harbors diverse flora and fauna species (Fig. 2) with an

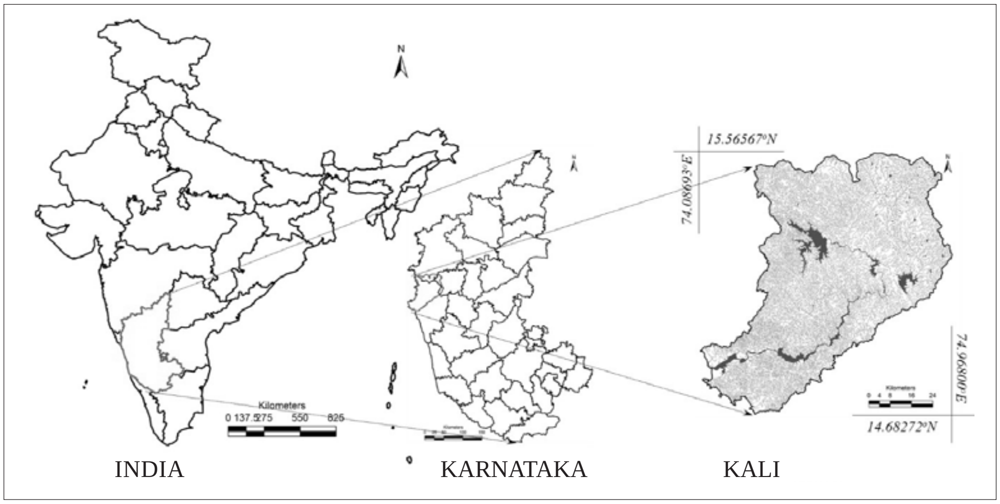

Fig. 1. Study area-Kali River Basin
Source: Author

area of 1427.35 km^2. The KTR was formed by merging Anshi national park, Dandeli Hornbill reserve and Dandeli tiger reserve in the year 2010. The Kali Tiger Reserve (KTR) is a part of 8,800 km^2 of tiger conservation landscape comprising Protected Areas and reserved forests of Dandeli Wildlife Sanctuary towards the north of KTR abutting Bhimghad Wildlife Sanctuary and further connects Radhanagari and Koyna Wildlife Sanctuaries in Maharashtra. The reserved forests in the south connect KTR with Bedthi and Aghanashini Conservation Reserves and further down to Mookambika and Sharavathi Valley Wildlife Sanctuaries.

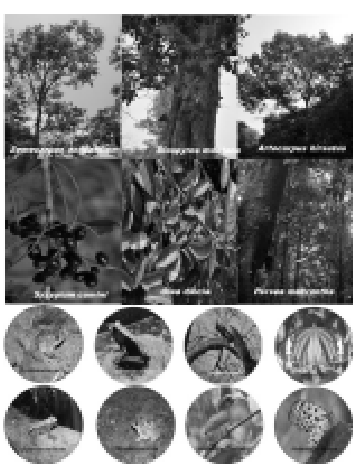

Fig. 2. Flora and Faunal diversity of Kali River Basin
Source: Author

METHODOLOGY

Quantification of Spatial Patterns of Landscape Dynamics

Figure 3 outlines the protocol adopted for the analysis. Multi-resolution RS data used for spatial analyses are Landsat multispectral sensor (MSS-1973; http://landsat.ugs.gov), Operational Land Imager (OLI-2016) and online Google Earth data (http://earth.google.com). The ancillary data is used to classify the remote sensing data and the interpretation of different land

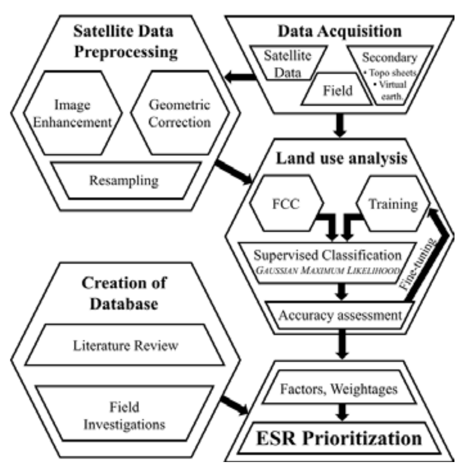

Fig. 3. Method followed for land use analysis
Source: Author

use types. Topographic maps (http://surveyof india. gov.in) provided ground control points to rectify remotely sensed data and digitized paper maps (topographic maps). The Survey of India (SOI) toposheets (1:50000 and 1:250000 scales) and vegetation map of South India (http//www. ifpindia.org/ifpsitedata/presentation) developed by French Institute (1986) of scale 1:250000 was digitized to identify various forest cover types and temporal analyses to find out the changes in vegetation. Field survey was carried out with the pre-calibrated GPS (Global Positioning System - Garmin GPS unit). Ground control points are used to geometrically correct remote sensing data and also to validate the classified land use information. The supervised classification scheme of Gaussian maximum likelihood classifier (GMLC) scheme is adopted for land use analysis under 10 different land use categories using GRASS GIS (Geographical Analysis Support System). GRASS is a free and open source geospatial software with the robust functionalities for processing vector and raster data available at (http://wgbis.ces.iisc.ernet.in/grass/). The training data (60%) collected has been used for classification, while the balance is used for accuracy assessment to validate the classification. The test samples are then used to create error matrix (also referred as confusion matrix) kappa (κ) statistics and overall (producer's and user's) accuracies to assess the classification accuracies (Lillesand et al. 2014).

Delineation of ESR

The study region is divided into 5'×5' equal area grids (97) covering approximately 9 km^2 to account for the changes at local levels. The data of various themes (vegetation cover, climate, flora, fauna, etc.) were collected from published scientific literatures, unpublished datasets, and field surveys. A detailed spatial database is created for various themes covering all aspects from land to estuarine ecosystem. The weightage metric score is computed to prioritize grids based on eco-sensitiveness considering various themes (Fig. 4.). Developing a weightage metric score requires knowledge from a wide array of disciplines (Termorshuizen and Opdam 2009). Planning should acknowledge and actively integrate present and future needs for landscape. The approach is based on the framework proposed by Beinat (1997) for identifying eco-sensitive regions based on weightage metrics score as it provides an objective and transparent system for combining multiple data sets together to infer the significance. The weightage metrics score for a region is deﬁned in Equation 1.

$$\text{Weightage} = \sum_{i=1}^{n} W_i V_i \quad \ldots(1)$$

Where, n is the number of data sets, V_i is the value associated with criterion (theme) i and W_i is the weights associated with that criterion. Each criterion is described by an indicator mapped to a value normalized from 10 to 1. The value 10 corresponds to very higher priority for conservation. The value 7, 5 and 3 corresponds to high, moderate, low levels of conservation. In particular, the weightages, are individual spatial variable proxy, based on GIS techniques, that stands out as the most effective method. The final ESR map (with grids prioritized based on the cumulative eco-sensitive metrics score) will aid in effective regional planning by the decision makers with the conservation of sensitive regions.

RESULTS

Spatiotemporal Land Use Analysis

The forests of Kali River Basin are acting as a rich resource base in the Western Ghats of Uttara Kannada district and supporting livelihood of dependent population. The land use analyses of Kali River Basin depict the spatiotemporal changes in the biodiversity-rich region during 1973 to 2016 (Figs. 5a, b and Table 1). The classified land use information is validated with field data and historical maps and overall accuracy ranges from 82.52 percent (1973), 90 percent (2016) with Kappa of 0.81 and 0.88 respectively. The evergreen forest cover has declined from 61.79 to 38.5 percent (1973-2016), due to hydroelectric, infrastructure projects and monoculture plantations (15%). The natural forest cover is replaced with exotic species such as Acacia, Eucalyptus, and Teak etc. as part of social forestry programme by the forest department. This has led to major forest cover changes in Dandeli, Haliyal, and parts of Supa regions. The construction of series of dams and reservoirs has submerged large-scale pristine forest land affecting ecology. Implementation of transmission lines of Kaiga nuclear powerhouse has bisected contiguous pristine native forests across the basin. The land conversions that is, conversion of forest to agriculture; agriculture

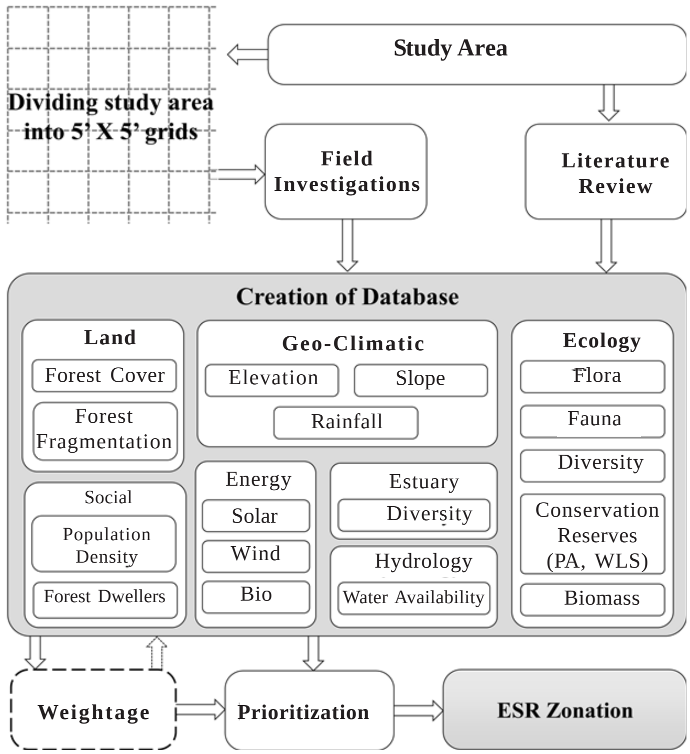

Fig. 4. Computation of ecologically sensitive regions
Source: Author

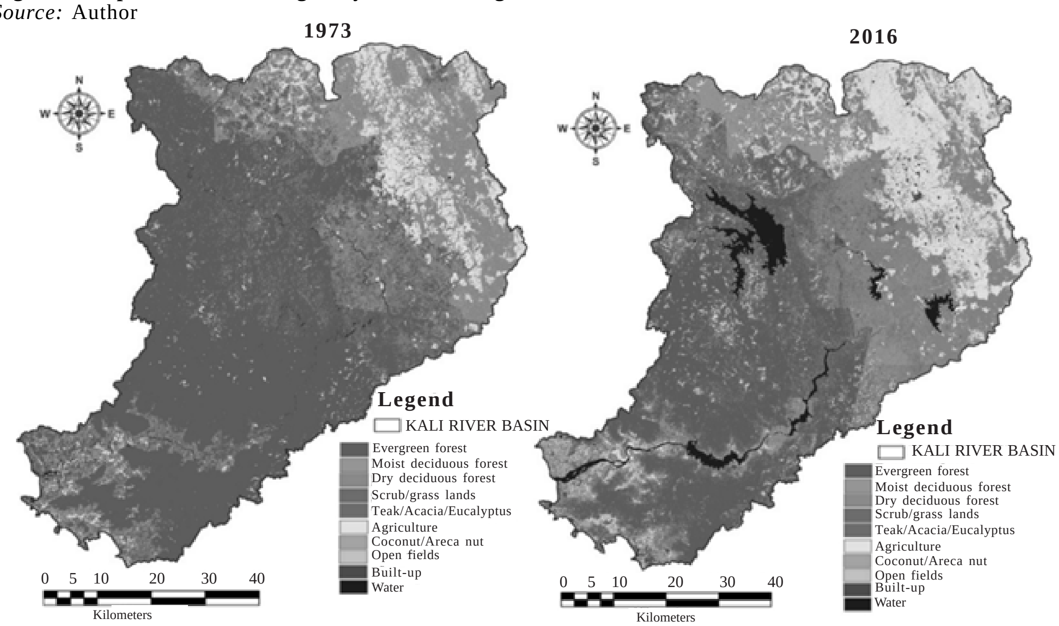

Fig. 5. Land use dynamics in the Kali River Basin
Source: Author

Table 1: Temporal changes in land use of Kali River Basin

S. No.	*Category*	*Year 1973*		*Year 2016*	
		Ha	*%*	*Ha*	*%*
1	Evergreen to semi evergreen forest	314265.07	**61.79**	195829.13	**38.50**
2	Moist deciduous forest	76713.55	15.08	72231.41	14.20
3	Dry deciduous forest	39765.85	**7.82**	11369.70	**2.24**
4	Scrub forest/grass land	12857.72	2.53	17138.54	3.37
5	Teak/Bamboo/Acacia/Eucalyptus/Other plantations	8383.26	1.65	76666.09	**15.07**
6	Crop land	46783.90	**9.20**	90086.56	**17.71**
7	Coconut/Areca nut /Cashew nut plantations	54.26	0.01	8805.30	1.73
8	Open fields	5703.57	1.12	9449.90	1.86
9	Built-up	1985.22	0.39	8433.95	**1.66**
10	Water	2068.93	0.41	18570.75	3.65
	Total	508581.33			

to coco/areca nut plantations are the major concerns in this region. The rehabilitation of families displaced due to river valley projects in the mid of forest regions has altered interior forests with the creation of more perforated forests with edges. The major portion of deciduous forest cover (7.82-2.24 %) in the eastern portion of the basin has been transformed to agriculture area from 9 to 17.7 percent by 2016.

Prioritisation of ESR

Ecosystem sustainability assessment is done through ESR demarcation to get a detailed picture of ecological status at village levels in the Kali River Basin considering various themes (ecological, social, hydrological, geo-climatic variables) for conservation planning. Values of various variables (of themes) were selected based on literature reviews and field-based measurements. The land use analysis highlights (Fig. 6a) the major forest cover (> 80%) is confined to KTR region, while eastern parts are degraded due to anthropogenic pressures and the natural forest cover in this region is about 54.94 percent. The wide-scale forest clearing and subsequent agricultural expansion, exotic plantations resulted in damage of large forest patches. Unplanned implementation of the major developmental projects have disturbed the landscape with the significant erosions in the forest cover. The forest cover weightages (Fig. 6b) illustrate higher to moderate ranking in KTR and its surroundings. The interior forest cover is considered as another important variable, which emphasizes conservation connectivity and ecological functionalities (Fig. 6c). The cultivation in the nearby plots and roads have influenced the natural cover. The presence of large number of edges and perforated patches reveal loss of connectivity and contiguous forest patches. The higher interior forest can be seen in grids of Supa taluk (Fig. 6d). The plains (Haliyal, Hubli, Belgaum portions) are with the least weightages (1, 3) due to more disturbed forest cover with least or no interior forest cover.

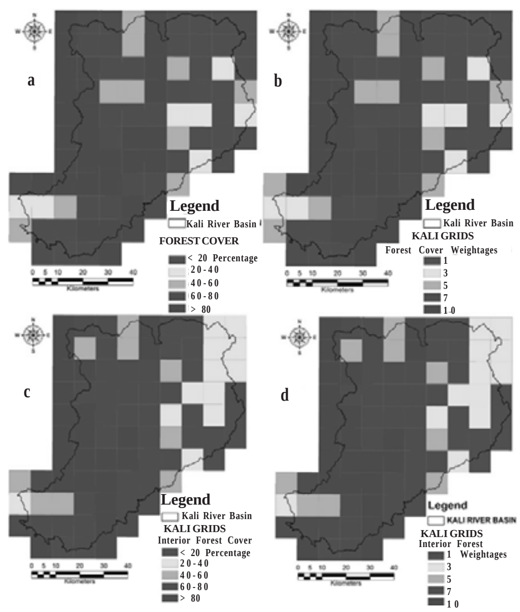

Fig. 6. Forest cover, Interior forest cover with their relative weightages
Source: Author

The ecology of Kali basin was assessed through assessment of biodiversity such as endemic flora, fauna, the biomass of forests, the status of conservation reserves etc. These information was compiled from literature review as well as field-based measurements. Field data was collected using pre-calibrated GPS (Global Positioning System), which provided coordinates of the location - latitude, longitude and altitude. This information was plotted to understand the spatial patterns of distribution and the respective habitats. Figure 7a, b gives the spatial distribution of endemic flora with its weightages. The region is home to very rare and endangered fauna (Fig. 7c). Main carnivores are tiger *(Panthera tigris)*, leopard, wild dog (dhole) and sloth bear. Leopards are in good number and wild dogs are in very less number, usually sighted in Kulgi and Phansoli ranges of Dandeli. Sloth bears are in very good number and these are frequently sighted in Ambikanagar, Virnoli, Bhagavati. Prey animals are barking deer, spotted deer (*Axis axis*), wild boar, *sambar* (*Cervus unicolor*), *gaur* (*Bos gaurus*). The region is part of an important elephant corridor between Karnataka and Maharashtra with at least 47 elephants which are frequently sighted near Sambrani, Bommanahalli dam backwaters. These regions are habitats for Malabar Giant Squirrel, Slender Loris, etc. Some of the important birds are Malabar Trogon, Malabar Pied Hornbill, Malabar Grey Hornbill, Indian Grey Hornbill, Great Indian Hornbill, Emerald Dove, Ceylon Frog mouth, Pompador Pigeon etc. Kali River accommodates at least 200+ marsh crocodiles and a good number of these can be sighted near Dandelappa temple in Dandeli town. Another rare reptile found is Draco (Flying Lizard) which can be easily sighted near Mandurli IB, Anshi Nature Camp, Sathkhand falls. There are diverse variety of snakes that is, King Cobra, Cobra, Malabar Pit Viper, Hump nosed pit Viper, Bamboo Pit Viper, Kraft, Ornate flying snake, wolf snake etc. the region has a wide variety of butterflies - Crimson Rose, Common Rose, Leaf, Clipper, Tigers, Southern Bird wing, Cruiser etc. Higher weights (10) are assigned to the grids (Fig. 7d) covering all endemic species and grids with non-endemic fauna were assigned 3.

Biomass is a significant variable in the analysis from carbon sequestration perspective and the role of forests in the mitigation of global warming. Earlier data (Ramachandra et al. 2013) was considered to assess the extent and quantum of biomass. The analysis was based on total standing biomass of forest's vegetation (Brown 1997; Ramachandra et al. 2000) and field data with the remote sensing data. The field transacts wise basal area were estimated, which was used to quantify standing biomass using allometric equations. The basal area computed using regression equations was valdated through comparison with data based on field estimations. The standing biomass in each grid is estimated based on the spatial extent of forests (Fig.7e). The forests in the Supa region have higher biomass (>1200 Gg) and eastern part are with deciduous to dry deciduous forests of Haliyal region and have lower biomass (< 200 Gg). The higher biomass regions are assigned greater weightages and vice versa (Fig. 7f). Net carbon storage in the forests is estimated as half of the biomass as per the standard protocol of published literatures (Brown 1997; Ramachandra et al. 2000). The study highlights that these regions are carbon repositories and degrading or disturbing these regions would result in higher carbon emissions and the loss of carbon sequestration potential. Hence the grids with higher carbon sequestration potential were assigned higher conservation values (Fig. 7g, h). Higher weights (Fig. 7i, j) were assigned to the protected area – KTR, as it is aiding in the conservation of keystone species and rice biodiversity.

Geo-climatic data were analyzed by considering altitude, slope, and rainfall. The high altitude regions are prone to landslides due to heavy rain and extreme weather conditions. The Figure 8a shows the altitude of the district, highest elevation is 1758 m in Supa taluk. The weightage map is generated by considering > 600 m as a higher priority for conservation and > 400 m is moderate and rest are of least concern (Fig. 8b). Slope map (Fig. 8c) is generated to identify the regions which are more sensitive; alteration of these regions will have a higher impact. In such areas, landscape disturbances will lead to soil erosion, landslides, secondary plant succession, and ultimately to land abandonment. The slope > 12 degrees is considered as a more sensitive region and assigned higher weightage (Fig. 8d). The rainfall pattern of the district is analyzed to mark the sensitive regions for conservation. Most of the KTR region (Fig. 8e) is in the high rainfall zone, except eastern parts of Haliyal. The endemic species are well distributed in high rainfall regions. The data analyses reveal that diversity, endemism, and rainfall are correlated. Figure 8f reflects weightages considering rainfall gradients.

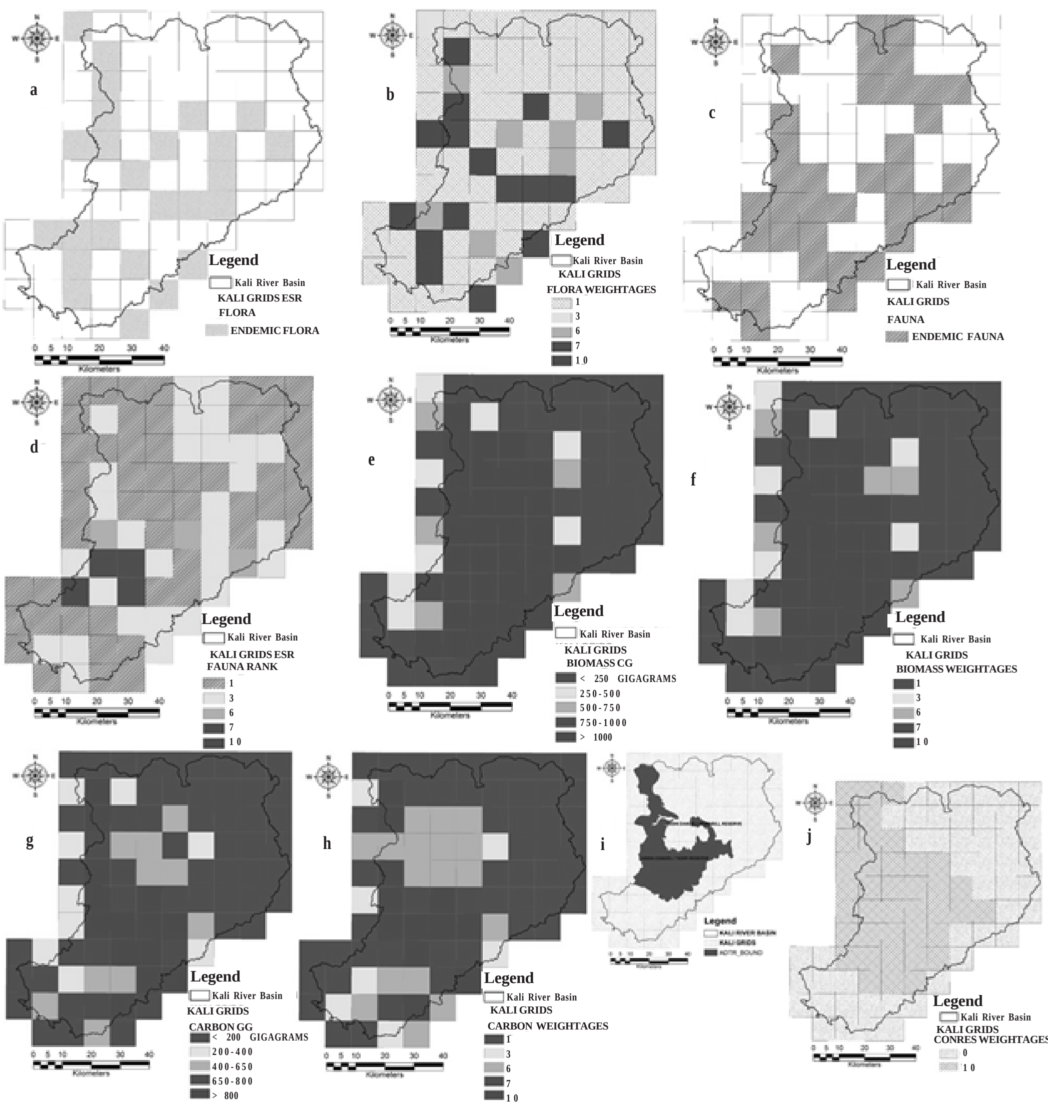

Fig. 7. Ecology variables with their ranking based on their weights
Source: Author

Hydrology is analyzed sub-basin wise by monitoring select streams to understand the factors responsible for perennial and seasonal flows of the region. The presence of perennial streams in the catchment dominated by native vegetation compared to seasonal streams with catchment dominated by degraded landscape or of monoculture plantations. Majority of streams in the region are perennial that reflects the health of the ecosystem. The Figure. 8g shows the stream flow at each grid of the district. The KTR, Supa region shows water availability of 12 months in the streams and Figure 8h reflects the relative weightages.

Environmentally sound alternative sources of energy are considered for prioritization. Solar, Wind, Bioenergy data sets are collected and analyzed and weightages assigned (Fig. 9a, b, c, d). The entire region receives an average solar insolation of 5.42 kWh/m^2/day annually and has

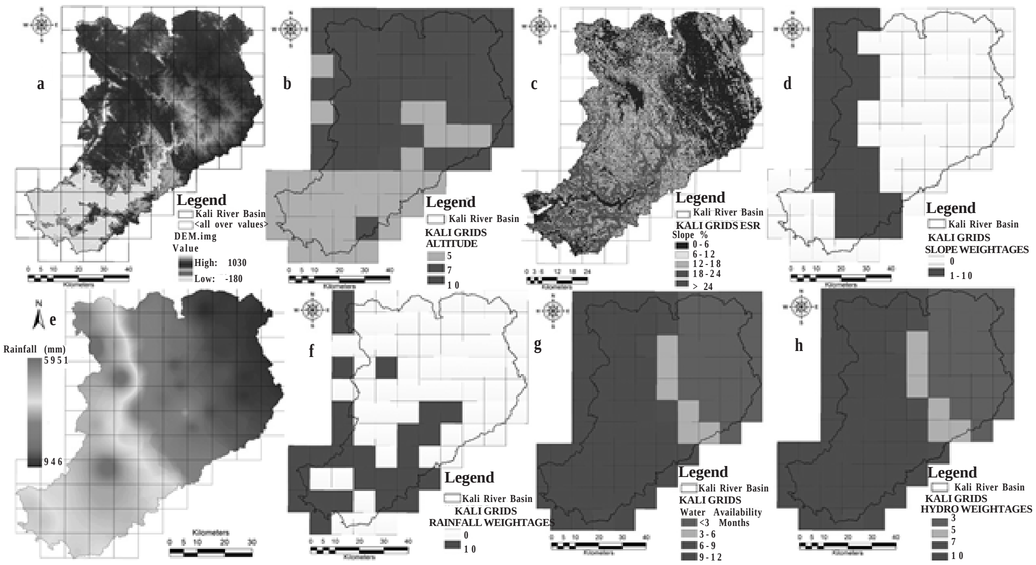

Fig. 8. Geo-climatic variables and their weightages
Source: Author

more than 300 clear sunny days. This solar potential is utilized to meet the domestic and irrigation electricity demand. Domestic demand of the household in a rural region is about 50 to 100 kWh per month. The solar potential assessment reveals that domestic demand can be supplied by installing rooftop SPV modules since less the 5 percent of the rooftop is required in the majority of the houses and irrigation demand can be met by installing PV modules in a wasteland where less than 3 percent of available wasteland area is sufficient. Bioresource availability is computed based on the compilation of data on the area and productivity of agriculture and horticulture crops, forests and plantations. Sector-wise energy demand is computed based on the National Sample Survey Organisation (NSSO study) data, primary survey data and from the literature. The supply/demand ratio in the district ranges from less than 0.5 to more the 2. If the ratio is less than 1 (demand >supply), then reflects of fuelwood deficit status and the ratio of more than 1 (supply>demand) reflects fuelwood surplus situation. Wind resource assessment shows Wind speed varies from 1.9 m/s (6.84 km/hr.) to 3.93 m/s (14.15 km/hr.) throughout the year with a minimum in October and maximum in June and July. Hybridizing wind energy systems with other locally available resources (solar, bioenergy) would assure the reliable energy supply to meet the energy demand at decentralized levels.

The forest-dwelling communities of the region are considered for prioritization (as per Forest Dwellers Act 2005 or Forests Rights Act 2005). These communities depend directly and indirectly on forest resources for their livelihood. The forest-dwelling communities are *Kunbis*, *Siddis*, *Goulis*, *Gondas*. They are socially and politically backward and most of them depend on casual labor, trading forest products for their livelihood. The grids with the presence of tribes were assigned higher weightages (Fig. 10a, b). Population density is considered as another proxy for ESR mapping. The population density of each grid is analyzed (Fig. 10c) and estimated for 2016 based on population census data of 2011. It is evident that with higher population, resource extraction is higher (Fig. 10d). The grids with the higher population density were assigned lower weights of 1 and lower density regions were assigned weights of 10.

Estuarine ecosystems are a tiny ribbon of land, but the emissions from their destruction are nearly one-fifth of those attributed to deforestation worldwide (Pendelton et al. 2012). The major mangrove species present are *Rhizophora mucronata*, *Sonneratia alba*, *Avicennia ma-*

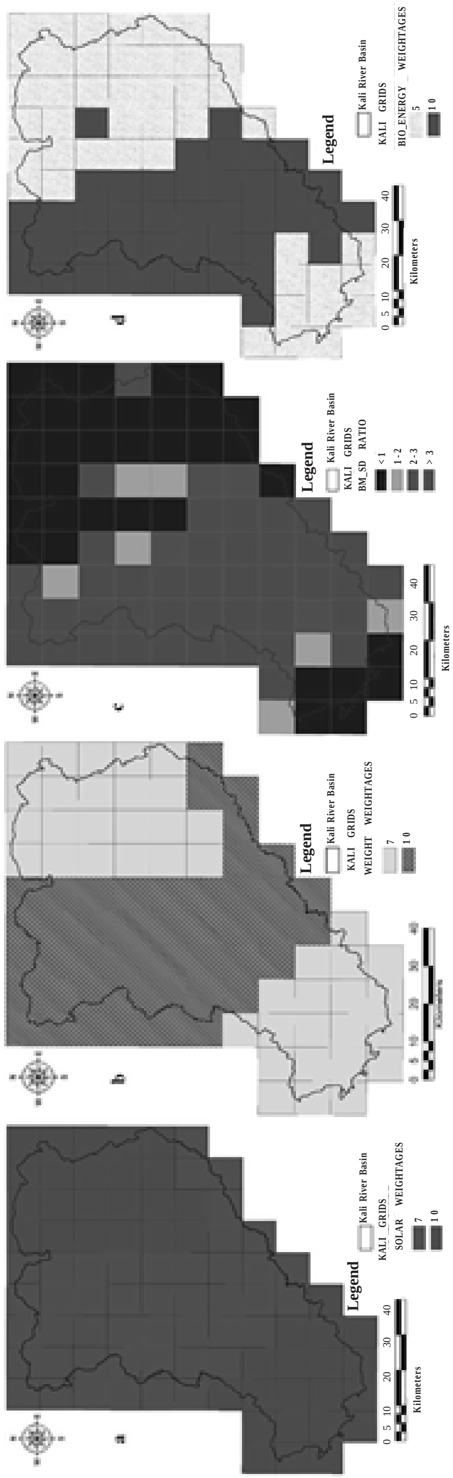

Fig. 9. Energy theme variables and their weightages
Source: Author

rina, Avicennia officinalis, Kandelia candel, Rhizophora apiculata, Sonneratia caseolaris. The farmers also plant rows of mangrove trees just outside these bunds to fortify them from collapse. This traditional system of estuarine cultivation with mangrove planting was a sustainable system. Kali River has major dams with hydropower stations have affected mangroves, fish yield, and other goods. The weightages are assigned as per the data analyzed emphasizing productivity (Fig. 10e).

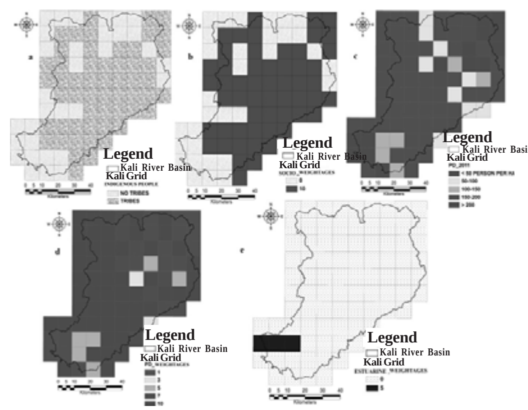

Fig. 10. Socio aspects and esturine diversity variables and their weightages
Source: Author

The aggregation of all metrics for each grid and intergrid analyses aided in prioritizing ecologically sensitive regions (ESR) based on the relative weights and grids are prioritized as ESR 1, 2, 3 and 4. Figure 11a shows 47 grids represent ESR 1, 9 grids represent ESR 2, 8 grids represent ESR 3 and the rest 23 grids represent ESR 4. The 54 percent of the grids represents ESR 1, 10.34 percent of the area shows ESR 2, 9.19 percent of the area shows ESR 3 and only 26.44 percent area covers ESR 4. Figure 11a and Table 5 shows village level ecological sensitive regions. ESR 1 represents zone of highest conservation, no further degradation allowed. ESR 1 can be treated as a high sensitive region of the district and more conservation is to be imposed by regulatory authorities as well as through VFCs (Village forest committees). ESR 2 represents a zone of higher conservation and forms a transition for highest conservation and moderate conservation regions. ESR 3 represents moderate conservation region and only regulated development is allowed in these areas. ESR 4 represents least diversity areas and the developments are allowed as per the requirement by strict vigilance from regulatory authorities. It is recommended that these regions also has a scope for further enrichment / improvement of environment through the involvement of local stakeholders by the forest department. In ESR 3, further developments are allowed only with the critical review from regulatory authorities in consultations with the local stakeholders. Small-scale tourism should be encouraged adopting benefit sharing with local communities such as homestay, spice farms, eco-friendly boating etc. The uncontrolled and unplanned development should be discouraged in and around of pristine lakes, primeval forest patches, perennial water bodies. The site-specific (clustered base) sustainable developments can be taken up at each panchayat, which has least effect on the ecosystem. The forest department should refrain from raising monoculture plantations and replace existing exotics in the stages (phased manner) with endemic species. Promote decentralized electricity, use of renewable energy sources such as (solar, wind, bioenergy, etc.). The region should promote agro processing industries to synthesize local resources while providing employment. Adapt only environmentally sound development projects and implementation by involving local community in decision making, social impact assessment and post-project environmental monitoring. No new major roads, widening of existing roads, railway lines are allowed, except when highly essential and subject to EIA, by imposing strict regulation and social audit. Tourism Master Plan should be based on MOEF regulations (after taking into account social and environmental costs). Controlled activities are allowed based on socio-economic importance, while activities leading to degradation of wetlands, natural forests or introduction of alien invasive species are prohibited in eco-sensitive regions.

Kali River Basin is spread across three districts with 524 villages (Table 2) and Figure 11b prioritises these villages as ESR 1 to ESR 4 based on the eco-sensitiveness. Forests of these villages need to be protected. Table 3 provides the details of the prohibited and regulated activities depending on eco-sensitiveness in each ESR region.

KTR region is a sensitive habitat for wild flora and fauna. As per Wildlife Conservation Strategy 2002, Union government had stipulated a 10 km buffer region as eco fragile zones (Eco-Sensitive Zones) around protected areas / national parks under Environmental (Protection) Act, 1986. Eco-Sensitive Zones are specified as transition zones around protected forest areas, that would minimize forest depletion and human-animal conflicts. These are intended to provide habitat improvement, enhance the environmental services, reduce edge effects, connectivity, reducing fragmentation of forests and also provides a physical barrier from human encroachments. Eco-Sensitive Zones are areas adjacent to protected areas/ national parks, on which land use is partially restricted to give an added layer of protection while providing valued benefits to neighboring rural communities. However, in recent times, the vested interests are pushing many projects under the guise of drinking water scheme and ecotourism projects, etc. to push consultant driven environmentally sound projects with the nexus of contractors and inefficient bureaucrats. The Ministry of Environment, Forests and Climate Change (MoEFCC) has approved a reduction of Eco-Sensitive Zones (from 10 km to 100m) by a series of notifications in the numerous national parks and wildlife sanctuaries. Honorable Supreme Court while taking serious objections to these unscientific reductions (driven by political), has directed that a 10-km limit as the Eco-Sensitive Zones. The guidelines for Eco-Sensitive Zones proposed that the boundary had to be site-specific, decided in consultation with a field-based team comprising representatives from the forest department, revenue department and Panchayat Raj institution. The purpose of delineating Eco-Sensitive Zones is to sustain the natural resources to support the livelihood of people. The approach adopts people inclusive path and ensures a legal framework to sup-

Table 2: ESR Villages under various districts of Kali River Basin

S.No.	*District name*	*ESR-1*	*ESR-2*	*ESR-3*	*ESR-4*	*Total*
1	Uttara Kannada	190	45	48	48	331
2	Belgaum	13	25	27	20	85
3	Dharwad	0	3	2	103	108
	Kali River Basin	203	73	77	171	524

Table 3: Prohibited and regulated activities in ESR -1, 2 3 and 4

S. No.	*Activities*	*Ecologically Sensitive Regions*			
		ESR-1	*ESR-2*	*ESR-3*	*ESR-4*
1	*Energy*	✓	✓	✓	✓
	(A) Solar (Rooftop)				
	(B) Wind power	×	✓	✓	✓
	(C) Bio energy	×	✓	✓	✓
	(D) Coal based (Thermal power)	×	×	×	×
	(E) Gas or liquid fuel based	×	×	×	✓
	(F) Hydro power (Major)	×	×	×	×
	(G) Hydro power (Micro)	×	×	×	✓
	(H) Nuclear power	×	×	×	×
2	*Forests*	×	×	×	×
	(A) Land use change (Forest to non-forest usages)				
	(B) Monoculture plantations	×	×	×	×
	(C) Extraction of medicinal plants	×	×	✓	✓
	(D) Forest improvement through VFCs	✓	✓	✓	✓
	(E) NTFP collection	✓ (Strict regulation by department)	✓	✓	✓
3	*Agriculture*	✓	✓	✓	✓
	(A) Agroforestry				
	(B) Organic farming	✓	✓	✓	✓
	(C) Land use change / Encroachments	×	×	×	×
	(D) Genetically modified crops	×	×	×	×
	(E) Animal husbandry	✓	✓	✓	✓
4	*Horticulture*	✓	✓	✓	✓
	(A) Organic farming				
	(B) Nitrogen and Phosphorus (N and P) fertilizers	×	×	×	✓ Dosage as prescribed by Agriculture department
	(C) Endosulfan	×	×	×	×
	(D) Pesticide	×	×	×	✓
	(E) Watermelon and muskmelon farming	×	✓	✓	✓
5	*Industries (Larger Scale)*	✓	✓	✓	✓
	(A) Agro-processing industries				
	(B) Information Technology industries (IT)	×	×	✓	✓
	(C) Red category (Polluting) industries	×	×	×	×
	(D) Garment industries	×	×	✓	✓
	(E) New establishment of industries	×	×	×	✓ (Allowed only after critical review by local stakeholders and experts)
	(F) Non-polluting (Green) industries	×	×	✓	✓
6	*Industries (Small Scale)*		✓	✓	✓
	(A) Garment industries				
	(B) Domestic (Home based) industries a.	*Papad*	✓	✓	✓ ✓
	b. Mango processing	✓	✓	✓	✓
	c. Areca nut processing and coir industries	×	✓	✓	✓
	d. Milk products and processing	✓	✓	✓	✓
	e. Dry fruits and spices	✓	✓	✓	✓
	f. Fruit processing (Ex: Kokum Juice *(Garcinia indica)*)	✓	✓	✓	✓
	g. Fish products processing	✓	✓	✓	✓
	h. Bee keeping and bee nurseries	✓	✓	✓	✓
	i. Pongamia plantations for biofuel (in private lands)	×	✓	✓	✓
	j. Bio pesticides manufacturing	×	✓	✓	✓
	k. Poultry farms and powdered eggs	×	✓	✓	✓
	l. Vegetable dyes; fruits and vegetables preservation	✓	✓	✓	✓

Table 3: Contd.....

S. No.	Activities	Ecologically Sensitive Regions			
		ESR-1	ESR-2	ESR-3	ESR-4
	m. Medicinal plants cultivation and processing	✔	✔	✔	✔
	n. Aromatic plants and essential oil distillation; orchids and cut flowers harvesting industries	×	✔	✔	✔
7	*Tourism Industry* (A) Ecotourism	×	✔	✔	✔
	(B) Organic village and homestay	✔	✔	✔	✔
	(C) VFC managed tourism	✔	✔	✔	✔
	(D) VFC managed homestay tourism in higher forest cover regions and protected areas	×	✔	✔	✔
	(E) Arts and handicrafts museum and trade center	✔	✔	✔	✔
8	*Mining and Mineral Extraction* (A) Iron ore	×	×	×	×
	(B) Manganese	×	×	×	×
	(C) Bauxite	×	×	×	×
	(D) Limestone	×	×	×	✔
	(E) Quartz	×	×	×	✔
	(F) Sand extraction (on a sustainable basis by Ban on exporting)	×	×	✔	✔
9	*Waste Disposal* (A) Hazardous waste processing units	×	×	×	×
	(B) Solid waste disposal	×	×	×	✔ (For composting and manure preparation)
	(C) Liquid waste discharge	×	×	×	✔ (Treatment plants (STP) for processing)
	(D) Recycling and waste processing and units	×	×	×	✔(compliant with PCB)
10	*Transportation*	×	×	×	✔(Allowed only after strict EIA)
	(A) Roads and expressways				
	(B) Rail and freight corridors	*Subject to EIA; Strict Regulation and Social Audit*			
	(C) Up gradation of existing infrastructure	×	×	✔(Subject to EIAs, strict regulation and social audit)	✔

port conservation of ecologically sensitive habitats to restrict further degradation of forests.

In the case of KTR, there is a serious move of reducing its Eco-Sensitive Zone (reduction of the area by 75%) to 100 m and reduction of spatial extent of the reserve by 30 percent. These eco-sensitive region (KTR with 10 km buffer) covers 155 villages, of which 97 falls in ESR-1, 26 falls under ESR-2 and 28, 4 falls under ESR-3, 4 respectively (Fig. 12a, b). KTR has 87 villages under ESR-1. These eco-sensitive regions need to be enriched with native species to reduce further degradation. The federal government should focus on sustainable management of eco-sensitive regions to sustain natural resources (water, food, fodder, etc.) and support people's livelihood than de- notifying region, which deprives the local biota their right to life.

DISCUSSION

Ecologically Sensitive Regions are ecologically fragile areas with rich repository of diverse

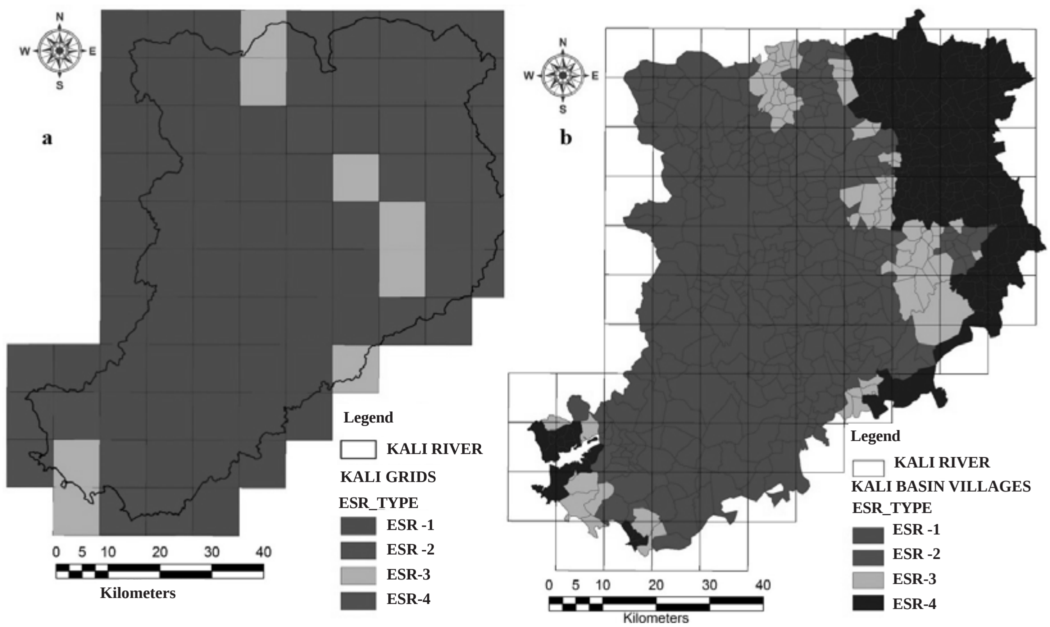

Fig. 11. Ecological Sensitive Regions of Kali River Basin and villages
Source: Author

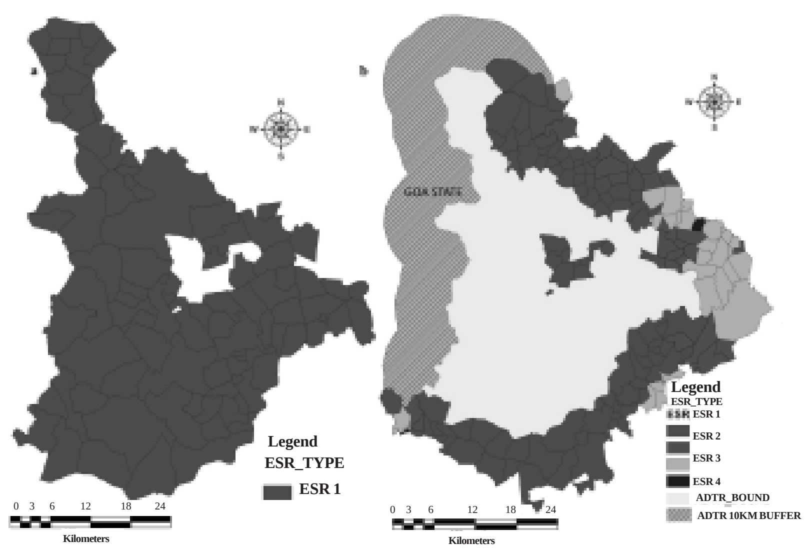

Fig. 12. Ecological Sensitive Regions of KTR
Source: Author

biological organisms and landscape elements. These regions contribute significantly in hydrological regime due to the catchment's ability to retain water which is evident from the existence of perennial streams. These biologically, hydrological and ecologically distinct regions are experiencing threats, especially in today's' rapid changing landscape scenario in the pursuit of development. Threats due to unplanned developmental activities affect the system at various levels with the serious consequences when once the activities cross the threshold. Some major threats are habitat fragmentation, negligence, conflict of interest and ineffective restoration/ improvement strategies. Lack of understanding of the complex ecological processes and evaluation of the ecosystem benefits have often led to the erosion of ecosystem quality affecting the sustenance of natural resources. To improve the scenario, thorough understandings of the complex ecosystem dynamics are important from conservation and management point of view. This entails identifying, mapping and monitoring of ESR for framing location specific conservation strategies. However, ESR demarcation and implementation process varies among regions, but the procedure to prioritise regions across geo climatic zones and development policies focuses on the conservation (Ndubisi et al. 1995). The legislative framework in India though made few sensible attempts towards assertiveness for the ecosystem protection, but many of these approaches have become redundant due to deliberate misinterpretation by the pressure groups and exclusion of all vital stakeholders. The Environment (Protection) Act (EPA), 1986, and Section 5(1) of the Environment (Protection) Rules (EPR), 1986 lends the power to restrict industries, operations, or processes or class of industries on the basis of considerations like the biological diversity of an area. The CRZ (coastal regulation zones) regulation, 1991 also reflects similar clauses. These legislative measures, if implemented will bring a radical change in the protection of natural resources as well as improving livelihood of the people. But, the deficiency in implementation due to the fragmented governance and misinterpretation of conservation goals are posing serious threats. The conservation strategies cannot be looked within regional and state boundaries. In this context, the ecosystem approach as outlined in this paper would help in maintaining the ecological integrity through the sustainable management of physical and chemical integrity of an ecosystem. The implementation of ecosystem approaches in managing ecosystem would overcome the lacunas and also aid in the development of region while ensuring sustenance of natural resources. Thus, delineation, mapping, monitoring and sustainable management of ESR involving all stakeholders and more importantly the appropriate legislative measures would certainly help in the ensuring water and food security in the peninsular India through conservation of ecologically fragile Western Ghats. The water course forests in this region have not only rare species but also high biomass and greater carbon sequestration potential, which also calls for revision of forest management policies, as the innumerable stream courses offer tremendous potential for carbon stocking per unit area while improving the water retention capability of the forests. Rendering such service would also help in mitigating global climatic change. Subsistence farmers and other forest dwellers in these ecologically fragile regions becoming partners in micro-level planning for prudent water management are also likely to gain from carbon credits for their role as conservators of watershed vegetation.

CONCLUSION

The conservation and sustainable management of ecosystems are the vital components in the pursuit of development goals that are ecologically, economically and socially sustainable. The goods and services provided by forested landscapes are vital to the socioeconomic development of human populations. Regions with the geographically distinct assemblage of species, natural communities, and environmental conditions are referred as Ecologically Sensitive Regions (ESR) and delineated for appropriate conservation planning. The evergreen forest cover in Kali Tiger reserve regions has declined from 61.79 to 38.5 percent (1973-2016), due to hydroelectric, infrastructure projects and monoculture plantations. KTR region is divided into 5’×5’ equal area grids (97) covering approximately 9 km^2 to delineate ESR’s. 54 percent of the grids (47 grids) in KTR represents ESR 1, 10.34 percent of the area (9 grids) shows ESR 2, 9.19 percent of the area (8 grids) shows ESR 3 and 26.44 percent area (28 grids) covers ESR 4. Village wise analyses reveal that there are 524 villages in KTR and 203 falls in ESR-1, 76 falls under ESR-2, 77, in ESR 3 and 174 falls under ESR-4 respectively. ESR demarcation outcomes shows our estimation is robust concerning all the themes of expressive variables which will establishes the principle of ecological conservation that assist in maintaining landscape condition. These eco-sensitive regions needs to be enriched with native species to reduce further degradation while adopting sustainable conservation strategies. The approach proposed here can assist decision makers to consider community-based conservation programmes in the era of burgeoning population and the pressure on the forest ecosystem.

RECOMMENDATIONS

Ecologically Sensitive Regions - ESRs 1 and 2 need to be conserved on priority without any detrimental activities. These regions are to be protected by regulatory authorities and managed involving all stakeholders as well as VFCs (Village forest committees). ESR 2 represents a zone of higher conservation and forms a transition for highest conservation and moderate conservation regions. ESR 3 represents moderate conservation region and only regulated development is to be allowed in these areas. ESR 4 represents least diversity areas and the developments are allowed as per the requirement by strict vigilance from regulatory authorities. It is recommended that these regions also have a scope for further enrichment / improvement of environment by the local stakeholders and forest department. In ESR 3, further developments are allowed only with the critical review from regulatory authorities in consultations with the local stakeholders. Small-scale tourism should be encouraged adopting benefit sharing with local communities such as homestay, spice farms, eco-friendly boating etc. The uncontrolled development should be discouraged in and around of pristine lakes, primeval forest patches, perennial water bodies. The site-specific (clustered base) sustainable developments can be taken up at each panchayat, which least affect the ecosystem. The forest department should refrain from raising monoculture plantations and replace existing exotics in the stages (phased manner) with endemic species. Promote decentralized electricity, use of renewable energy sources such as (solar, wind, bioenergy, etc.). The region should promote agro processing industries to synthesize local resources while providing employment. Adapt only environmentally sound development projects and implementation by involving local community in decision making, social impact assessment and post-project environmental monitoring. No new major roads, widening of existing roads, railway lines are allowed, except when highly essential and subject to EIA, by imposing strict regulation and social audit. Tourism Master Plan should be based on MoEFCC, GoI regulations (after taking into account social and environmental costs). Controlled activities are to be allowed based on socio-economic importance, while activities leading to degradation of wetlands, natural forests or the introduction of alien invasive species are prohibited in eco-sensitive regions.

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