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ORIGINAL CONTRIBUTION

Eco-Hydrological Footprint of a River Basin in Western Ghats

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Eco-Hydrological footprint of a river basin refers to the hydrologic regime for sustaining vital ecological functions considering the appropriation of water by biotic components (including humans). It provides crucial information about the ecological status of a river, while addressing the divergence from natural conditions of the actual hydrological regime. Thus, this highlights the implicit relationship of hydrologic regime in meeting the demand of the biota. Unplanned developmental activities have altered the catchment integrity which has threatened the regional water security due to the conversion of perennial streams to seasonal ones. This has necessitated prudent catchment management strategies to maintain the ecological water requirements so as to maintain the aquatic and terrestrial biodiversity and to sustain water resources. The skewed strategies oriented mainly towards societal benefits have led to large-scale degradation of the landscape. Large-scale alterations of the landscape structure have led to erosion in the ecosystem supportive capacity that plays a major role in sustaining the hydrological regime. Insights of eco-hydrological footprint in the catchment would aid in formulating policies to sustain the hydrologic regime and natural resources. The current study focuses on the assessment of the eco-hydrological footprint in the Kali River of central Western Ghats, Karnataka. Land use dynamics assessment using the temporal remote sensing data of four decades reveal decline of evergreen forest cover from 61.8 percent to 37.5 percent in the Kali river basin between 1973-2016. Computation of eco-hydrological indices shows that the sub-catchments in the Ghats with higher proportion of forest cover with native species has a better eco-hydrological index as against the plain. This highlights the vital ecological function of a catchment in sustaining the hydrologic regime when covered with the vegetation of native species. The presence of perennial streams in sub-catchment dominated by native vegetation compared to the seasonal streams in the catchment dominated by anthropogenic activities with monoculture plantations. Eco-Hydrological Status/Hydrological footprint reflected similar results as that of the eco hydrological index demonstrating the role of forests in maintaining the hydrological regime. Inter annual water budgeting across sub basins showed that the Ghats and Coastal areas are sustainable with perennial waters in the river as against the plains in the east which showed deficit of resource indicating water stress.

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†Abbreviations: WRCC, Water resource carrying capacity; FCC, False Color Composite; GPS, Global Positioning System; GML, Gaussian maximum likelihood.

Keywords: Supportive capacity, Kali River basin, Land use, Eco-hydrological index, Eco-hydrological status

INTRODUCTION

Water, the elixir of life, sustains the ecological processes and basic needs of all natural processes. Hydro-ecological footprint refers to the hydrological regime that sustains the biotic components of an ecosystem including anthropogenic demand. This emphasizes consumption behavior, transactions of resources among/between ecological and societal activities [1]. Freshwater ecosystems provide numerous ecological services including habitat for diverse species of flora and fauna. However, to sustain the biotic component, ecosystem has to maintain the minimum flows to ensure the quality and diversity. Ecological services provided by a river basin include drinking water, fish, fodder, food, building materials, apart from religious and cultural values. Earlier studies focused on domestic water footprint, production water footprint, and ecological water footprint [2-5]. Domestic water requirement or domestic water footprint considers water required for domestic purposes such as drinking, washing, flushing, cooking, etc. Similarly, production water footprint accounts for water demand by industries, agriculture, horticulture, power generation, and ecological water footprint accounts for water required by an ecosystem. Ecological footprint in general involves water for various aspects such as sustenance of ecosystem, minimal water requirements for aquatic fauna to survive and terrestrial flora in their natural condition. Eco-hydrological footprint assessment entails estimation of carrying capacity of a river basin considering water availability and demand of water for sustenance of biotic components. Carrying capacity deals with sustainable development of human beings and ecological wellbeing [2,6-8]. Figure 1 outlines various components for the sustainability of a region considering resources availability, uses and users' needs, and prudent allocation of resources within the ecosystem's sustainability threshold. Numerous studies of carrying capacities have been carried out considering aspects such as population, agriculture, industries, livestock, water and water bodies, forest, soil, urban, mining, marine, ecotourism, etc. [5,9-18].

Water resource carrying capacity (WRCC†) is defined as the rate at which the resource can be consumed (supportive capacity) and effluents that can be discharged (assimilative capacity) into the environment without affecting the ecological and biological functions, integrity, and productivity [13,19,20]. WRCC provides a theoretical basis and means of operation for sustainable development while accounting for the system's supportive and assimilative capacity. Sustenance of hydrologic regime in a river basin plays a pivotal role in maintaining ecosystem goods and services. It plays a prominent role in the productivity of forest and agriculture goods. This entails maintaining and restoring the ecological health for optimally meeting the demand for water by biotic components.

Uneven spatiotemporal distribution of water resource across the globe has led to restrictions in water availability across many countries. The United Nations World Water Assessment Programme 2015 [21] predicted that by 2050, the global demand of water would increase by 55 percent, while fresh water resources, either surface or ground water, are depleting due to environmental mismanagement with growing demands of burgeoning population, agriculture, and other socio-economic activities. This would lead to imbalance between water uses and users increasing risk of local conflicts, disruptions in ecosystems, etc. impacting the carrying capacity of the resource.

Natural forest ecosystems in the Western Ghats regulates the transfer of water from the precipitation through the process of evaporation, transpiration, infiltration, and interception [22]. This regulatory mechanism is controlled by various physiographic factors such as density, structure, maturity, understory, aerodynamic, surface resistances, root density, root depth, hydro-climatic condition, etc. The process of evaporation and transpiration from vegetation, which influences the productivity, water supply, and local climate [23] was the first physiological process employed in the water budget [24]. Forests through evapotranspiration transfers water to the atmosphere [25,26] leading to the formation of rain bearing clouds. Aerodynamically rough surfaces of the forests create turbulence in airflow allowing absorbance of large amounts of solar radiation. The process of evapotranspiration is controlled by the conductance or resistance along the pathway of water vapor from leaves to the atmosphere [23]. Canopy cover of forests play a major role in controlling the interception, studies carried out using Rutter Model and Gash models have demonstrated that continuous canopies have low interception whereas intermittent canopies have higher interception [27].

The process of infiltration varies with tree density, diversity, and maturity [28,29]. With increasing age of forests, organic matter in soil and micro fauna interaction with the roots improves the soil structure, stability, and porosity creating paths for rapid infiltration of water [30]. Increases in monoculture enhance the stream flow significantly [31] during monsoons, and litter forms thick layer reducing infiltration. Plantations containing vegetation such as Eucalyptus, Acacia, etc. have deeper tap roots due to which the quantum of water drafted from the subsurface region is very high [31], depleting ground water in the basin.

Countries in the tropics are facing imbalances in resource supply and demand with the rapid deforestation [32,33] due to implementation of unplanned developmental activities. Burgeoning population with an

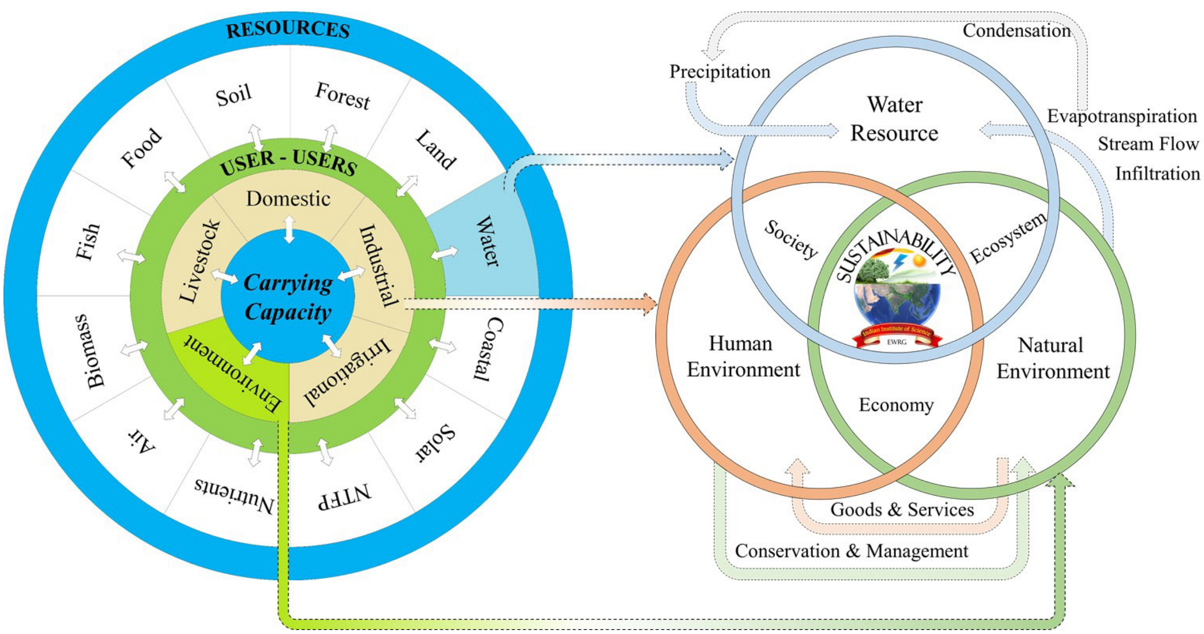

Figure 1. Resources interaction and footprint (hydro-ecological).

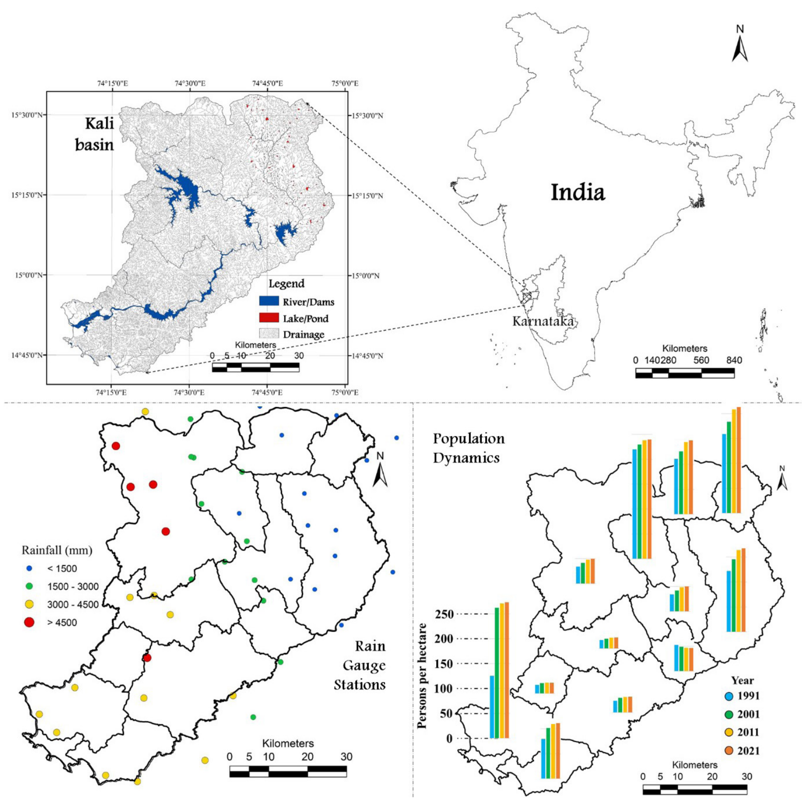

Figure 2. Physiography of the Kali riverscape – Central Western Ghats.

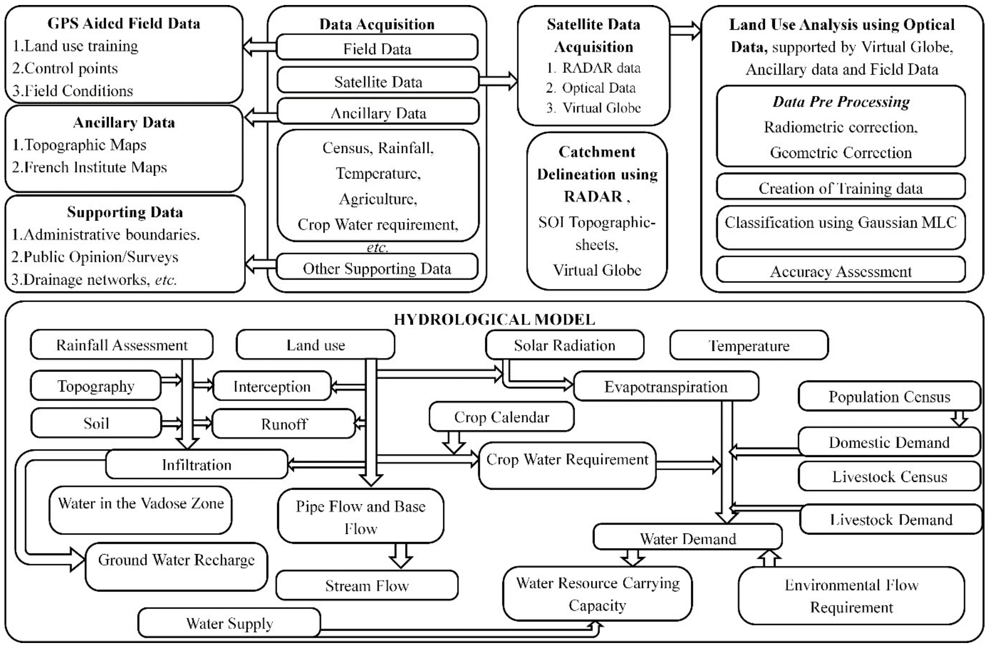

Figure 3. Method for land use and hydrological footprint assessment.

enhanced demand of natural resources, have led to the over-exploitation of natural resources such as water, forest, land, etc. Anthropogenic activities coupled with skewed policies have resulted in the disappearance of pristine forests and wetlands in the form of logging, afforestation by plantation trees, dam constructions, and conversion of land for other uses [34]. Structural changes in the forest ecosystem have affected the functional aspects, namely the hydrological cycle, bio-geo chemical cycles, and nutrient cycling there by impacting the assimilative and supportive capacity [35,36]. Increase in the magnitude and frequency of overland flows [37], reduction in aerodynamics roughness, leaf area, root zone depth consequently reducing evapotranspiration, and soil infiltration capabilities [38-41] occurs with clearing of forest lands for agricultural and other land use practices.

Revival of natural forest capabilities through reforestation or afforestation would take at least 25 to 30 years [42,43]. In the mature climax forests, the annual surface transpiration reduces with an increase in understory transpiration, due to increasing storage of water in the subsurface, stream becomes perennial with sustained yield [44]. This makes it very important to safeguard and maintain the exiting forests patches to preserve hydrological regime which caters biotic (ecological and societal) demands. Figure 1 depicts eco-hydrological footprint highlighting the interaction among water, human, and environment. In order to achieve sustainability in the water basins the water resource should be managed to cater both natural and human environment without hampering the natural resources. The environmental demand involves maintaining ecological flows and forest water requirements (such as transpiration) and human (including domestic, industrial, agriculture) demands. Conservation of the natural ecosystems would ensure sustenance of natural resources and contribute significantly to the region's economy. A well maintained natural ecosystem has better water retention capability through subsurface flows, soil water storage, evapotranspiration, etc. giving an edge over degraded catchments [45,46].

This communication focuses on eco-hydrological footprint of a river basin in the Western Ghats through assessment of hydrologic regime and ecological aspects along with the demand of the biotic components. Insights of eco-hydrological footprint assessment will aid in the land use management with the improved water use efficiency, appropriate cropping pattern, restrictions on unscientific land use changes towards the sustainable development of the river catchment.

MATERIALS AND METHODS

Study Area

Eco-hydrological footprint assessment is carried out in the Kali river basin of central Western Ghats, considering hydrologic regime with the ecological and anthropogenic (domestic, agriculture, livestock, etc.) footprints. The Western Ghats sustains perennial rivers, while ensuring the peninsular India's water and food security and hence aptly branded as the water tower of peninsular India. These series of hills are located in the western part of peninsular India with undulating terrains running in the

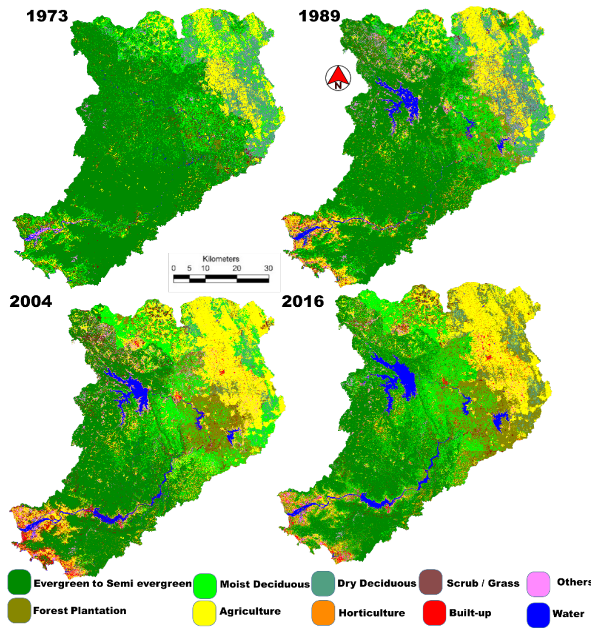

Figure 4. Land use dynamics 1973-2016.

Table 1. Land use in Kali River catchment.

Sl.no.	Land use	1973 (%)	1989 (%)	2004 (%)	2016 (%)
1	Evergreen to semi evergreen forest	61.79	48.92	39.87	38.50
2	Moist deciduous forest	15.08	12.96	14.91	14.20
3	Dry deciduous forest	7.82	8.88	2.46	2.24
4	Scrub forest/grass land	2.53	2.91	6.39	3.37
5	Forest Plantations	1.65	5.81	8.68	15.07
6	Crop land	9.20	14.07	19.71	17.71
7	Horticulture Crops	0.01	0.16	0.17	1.73
8	Open fields	1.12	3.01	3.26	1.86
9	Built-up	0.39	1.02	1.59	1.66
10	Water	0.41	2.26	2.95	3.65
Accuracy	Overall Accuracy	88.63	89.9	90.7	91.3
Assessment	Kappa	0.84	0.85	0.88	0.90

North-South direction for about 1,600 km parallel to the Arabian Sea along the west coast from south of Gujarat to the end of the peninsula (8°- 21° N and 73°- 78° E) with the spatial extent of about 1,64,280 km^2 (< 5 percent of India's geographical area). This region with exceptional biodiversity of endemic flora and fauna is one among 35 global biodiversity hotspots.

River Kali originates at Diggi village of Supa Taluk in Uttara Kannada District, Karnataka, India (Figure 2). This magnificent west flowing river flows for a distance of 184 kilometers and joins the Arabian Sea at Karwar [47-49]. River Kali has a catchment area of 5086 sq.km extending across three districts and nine taluks namely Uttara Kannada (Ankola, Karwar, Supa, Yellapur, Haliyal), Dharwad (Kalgatgi, Dharwad), and Belgaum (Khanapura, Bialhongal). Due to the topography and poor vegetation cover, stream network towards Belgaum and Dharwad, are sparse and the region is endowed with the interconnected lake systems. Denser stream networks are present in Sahyadrian Ghats, Transition zones and Coast. Some of the major tributaries of Kali include Pandrali, Kali, Tattihalla, Vaki, Kaneri, Thananala, Kariholé, etc. Geologically, Kali River is as old as the Western Ghats, major rock types in the region include granites

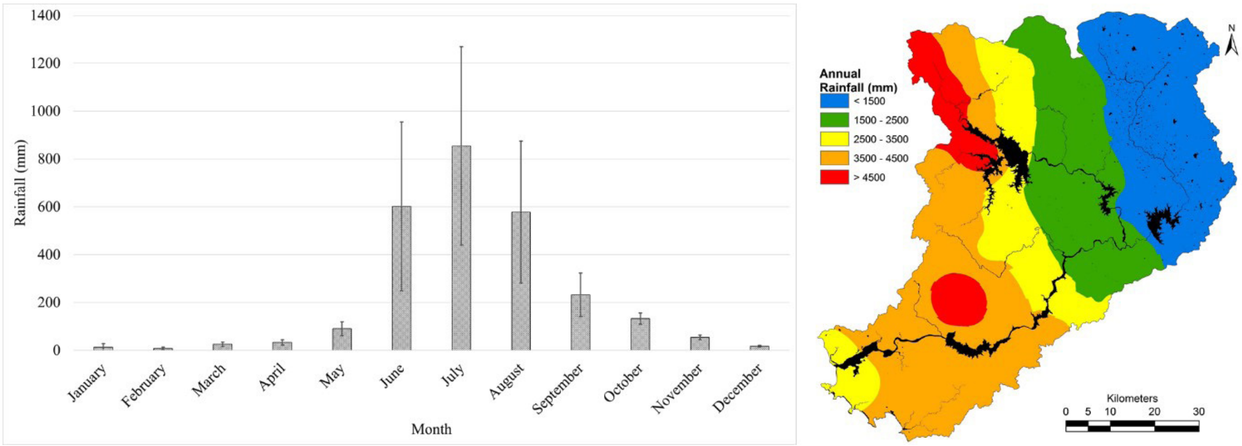

Figure 5. Rainfall Distribution in the Kali basin.

such as schist, shale, quartzite, phyllites, and soils such as red soil, lateritic soils, black soil, etc., are found in abundance. Ore found in the catchment are iron, bauxite, quartz, limestone, sand, clay, lime shell, manganese, asbestos, and mica [47]. River Kali has about six major dams namely Supa, Kodasalli, Tattihalla, Bommanalli balancing reservoir, Kaneri and Karda dams. Kali catchment has a rich terrestrial flora consisting of about 325 species in the evergreen, semi evergreen, moist deciduous, scrub, thorny, un-wooded forest type. The region is endowed with rich fauna with 190 species of avifauna, mammals, reptiles, amphibians, etc. Kali basin, due to its ecologically sensitive regions with large forest expanses have major wild life sanctuaries such as Kali Tiger Reserve, Hornbill reserve, and habitat for wild elephants [50-52]. Alteration in the physical integrity through the construction of a series of dams have altered the estuary productivity and diversity. Kali estuary has 37 fish species [53], bivalves, etc*.,* which is relatively lower compared to the neighboring unaltered Aghanashini river catchment [54]. Human population in the catchment increased from 3,67,604 (in 1991) to 4,97,892 (in 2001) and 5,42,036 (in 2011) [55] and is expected to reach 5,91,488 by 2021 at the same growth rate. Population density between 1991 and 2021 is as depicted in Figure 2. Population density has increased from 72.1 persons per hectare from 1991 to 106 persons per hectare in 2011 and is expected to reach 116.1 persons per hectare by 2021. Kali has a diverse population with over 30 communities [47,56]. Figure 2 depicts the rainfall variability ranging from 1000 mm in the Eastern plain to 4500 mm in the Ghats, with a tropical climate in the undulating topography of the catchment. Kali River catchment has been witnessing large scale land use changes leading to deforestation with the unplanned developmental activities altering hydrological regime leading to the decline of the supporting capacity and increases in water demand (domestic, agriculture, etc.).

Data

Optical remote sensing data acquired through Landsat MSS™ and OLI sensors between 1973 and 2016 were used to assess the landscape dynamics [57]. Long-term rainfall data for the period 1901 to 2010 were collected from the Directorate of Economics and Statistics [58] across rain gauging stations spread across the regions - Uttara Kannada, Belgaum, and Dharwad districts. Population data were obtained between 1991 and 2011 from Census of India [55], Livestock population and Crop data across all the three districts were obtained from respective districts at a glance [59]. Temperature data were downloaded from WorldClim [60], extra-terrestrial solar radiation from FAO [61]. Crop water requirements as per the crop calendar and growth stages were acquired from the Agriculture Department of Karnataka and National Food Security Mission [62,63]. Digital Elevation Model from SRTM [57,64]. In addition to these data, Virtual data such as Google Earth [65], NRSC-Bhuvan [66], Survey of India Topographic sheets [48,49], and French Institute maps [67] were used for the spatial analysis.

Method

The method depicted in Figure 3 involved in assessing the overall water footprint of the sustenance of water resource. Assessment of eco-hydrological footprint in the catchment involved the following:

Land Use Analysis: Land use in the catchment plays a decisive role in the hydrological processes such as infiltration, surface and subsurface flows, and storages, etc. Assessment of constituents in the landscape under different vegetation types such as agriculture, forest, and plantation helps in assessing the water demand in these sectors. Land use analysis using remote sensing data involved (i) generation of False Color Composite (FCC) of

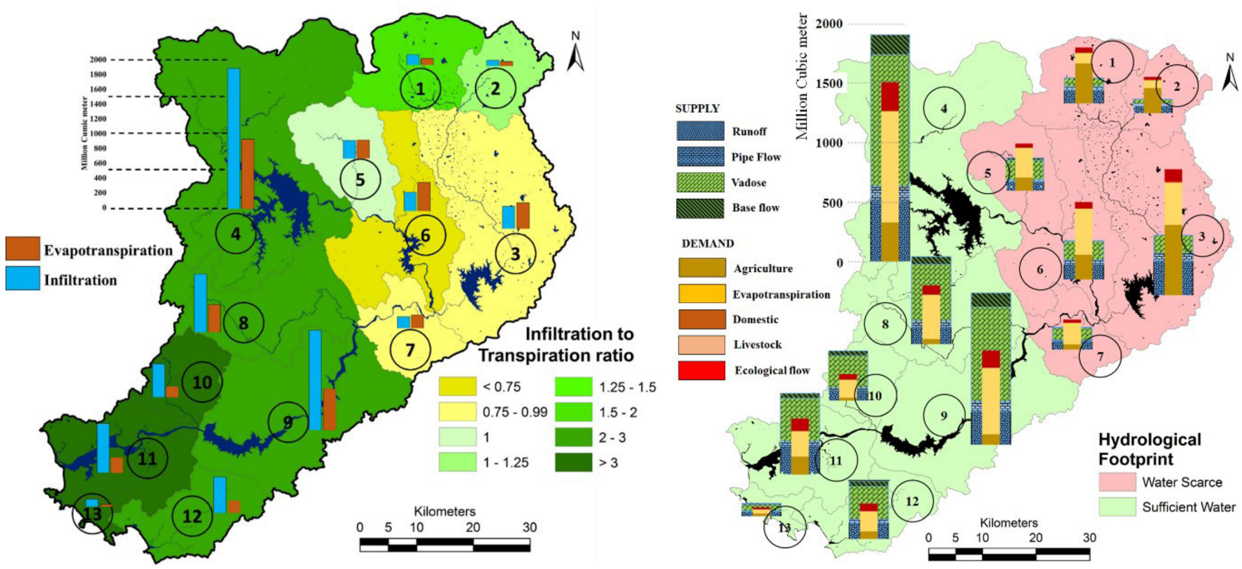

Figure 6. Eco-Hydrological Status in the Kali river basin.

remote sensing data (bands–green, red, and NIR). This composite image helped in locating heterogeneous patches in the landscape, (ii) selection of training polygons covering 15 percent of the study area (polygons are uniformly distributed over the entire study area) (iii) loading these training polygons co-ordinates into pre-calibrated GPS (Global Positioning System), (iv) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (v) supplementing this information with Google Earth and (vi) 60 percent of the training data has been used for classification, while the balance is used for accuracy assessment by error matrix and Kappa statistics. The land use analysis was done using a supervised classification technique based on the Gaussian maximum likelihood (GML) algorithm with training data (collected from field using GPS). GML is a widely used statistical classification method assigning a given pixel to a specific class based on the conditional probability [68-70]. SRTM DEM, SOI Topographic maps [48,49] were used to delineate sub basins in the Kali river catchment.

Assessment of Hydrological Footprint: Hydrologic footprint is a function of land use, climatic factors (such as rainfall, temperature, solar radiation, etc.), surface and subsurface flows, ground water, vadose water, etc. Spatial and temporal (monthly variability) patterns of rainfall were assessed using data of 110 years from rain gauge stations distributed in the catchment. Net rainfall in each sub-basin were quantified based on deducting interception storage in each land use. Runoff in the basin was quantified using Rational equation [71], runoff coefficients were based on the earlier field estimations carried out in Sharavati basin and Aghanashini basin [72]. Infiltration is quantified as difference between net rainfall and runoff (overland flow). Ground water recharge was estimated using Krishna Rao equation [73]. Water in the hypomorphic zone (vadose zone) was estimated as the difference between net rainfall, runoff, and ground water recharge. Subsurface flows were derived [72] based on soil and lithological characteristics of the catchment.

Assessment of Ecological Footprint: Ecological footprint depends on the ecological, agriculture, domestic, and livestock water demands. Based on the cropping pattern, growth phase and water requirement for each crop, agriculture water demand was quantified. Based on livestock census and water requirement for each animal per day was used to estimate water demand for livestock. Similarly, water demand for the domestic sector is assessed based on the population and per capita water demand. Evapotranspiration from forests was used as a part of terrestrial natural water demand and quantified using maximum, minimum temperatures and extra-terrestrial solar radiation [73-75] based on the modified Hargreaves [76] method. Environmental flow was estimated as 30 percent mean annual runoff based on Tennant method [77-79].

Quantification of Eco-hydrological Footprint: Eco-Hydrological footprint is evaluated using eco-hydrological indices developed in the model to understand the role of forests in maintaining the hydrological cycle and catering the biotic demands. Eco-hydrological index is quantified as the ratio of infiltration to evapotranspiration in the catchment. Lower the values of infiltration *i.e.*, less than 1 indicates poor water availability and values greater than 1 indicates better water availability sustaining the

Table 2. Spatial Extent of Forests and Eco Hydrological Status in each Sub-basin (SB).

SB id	Rainfall (mm)	Area -sq.km	Total Forest	Evergreen Forest	Moist Deciduous Forest	Dry Deciduous Forest	Infiltration (mm)	AET (mm)	Eco-Hydro index
1	1283.1	293.3	14%	0%	5%	9%	475.5	306.8	1.55
2	1097.3	186.0	11%	0%	0%	11%	422.9	354.9	1.19
3	1250.7	727.5	11%	1%	3%	7%	421.4	485.8	0.87
4	3595.3	1094.9	63%	39%	23%	1%	1734.1	860.8	2.01
5	1950.7	268.4	73%	38%	34%	1%	920.0	928.3	0.99
6	1759.5	406.7	49%	24%	24%	1%	632.6	963.9	0.66
7	1975.4	194.1	52%	24%	28%	0%	809.9	933.9	0.87
8	3374.1	427.2	87%	80%	7%	0%	1843.1	876.8	2.10
9	3749.2	645.5	78%	68%	10%	0%	2090.3	868.7	2.41
10	4434.7	180.2	88%	79%	9%	0%	2521.7	840.8	3.00
11	3678.6	361.5	57%	45%	13%	0%	1852.3	590.9	3.13
12	3465.2	59.6	60%	50%	10%	0%	1692.9	542.9	3.12
13	3814.4	240.8	76%	67%	9%	0%	2027.3	712.5	2.85

domestic and ecological demands.

Assessment of Eco-hydrological status: Hydrological supply and ecological demand were analyzed monthly to understand the eco-hydrological status. The region indicates deficit (supply < demand) and surplus (supply > demand) situation.

RESULTS AND DISCUSSIONS

Land use assessment is carried out by classifying temporal remote sensing data into 10 categories for the time period between 1973 and 2016 and are depicted in Figure 4 and land use details are listed in Table 1, which highlight the reduction of forest cover from 84.69 percent (1973) to 54.94 percent (2016). The construction of a series of dams on Kali river during 1980-2000 has resulted in large scale land use changes. The major change in evergreen forest cover was during 1973-1989 and 1989-2004. The evergreen forest has decreased from 61.79 percent to 38.50 percent and dry deciduous forest has reduced from 7.82 percent to 2.24 percent in the catchment from 1973 to 2016. Monoculture plantations of social forestry (*Acacia* sp.) and horticulture (*Areca*) has increased from 1.66 percent to 16.8 percent. Large scale conversion of forests to monoculture plantation near the eastern plains is due to the industrial demand by the Dandeli paper mill and other purposes. Agriculture has increased in plains of Haliyal, Kalgatgi, Yellapur, and Dharwad taluks, from 9.20 percent to 17.71 percent. Increase in water bodies from 0.41 percent to 3.65 percent is due to the construction of major reservoirs during this period, stretching their expanses in the forested landscape. Built up areas have increased from 0.39 percent to 1.69 percent, major increase in built areas can be observed at Yellapur, Dandeli, Kalgatgi, Kaiga, Karwar, Ankola, Haliyal, Ramanagar, Londa, Khanapura, Joida, etc. The overall accuracy (88 to 91 percent) and Kappa statistics (0.84 to 0.90) depict agreement of classified data with field and reference data.

Spatio-temporal pattern analyses of rainfall (Figure 5) show that nearly 84 percent of the rainfall occurs due to the South West monsoon between June to September and average rainfall in the catchment is about 2597 mm. Annually rainfall varies between 1000 mm at the plains of Dharwad to over 4500 mm at the Ghats of Supa, Yellapur taluks. The coastal belt of Karwar and Ankola receive annual rainfall of 2500 mm and 4500 mm.

Hydrological assessment was carried out to understand water availability and water demands (Figure 6). Interception loss in the basin ranges between 187 mm and 1248 mm with an average of 640 mm. Net rainfall in Kali basin is about 1944 mm *i.e.*, about 9923 million cubic meters. River Kali has over 58 percent forest cover indicating higher percolation into the subsurfaces, this is explained by runoff and infiltration. Runoff in the basin is about 2227 million cubic meters and infiltration of 7696 million cubic meters. Presence of rich evergreen forest cover in the Ghats, has contributed to higher infiltration *i.e.*, about 4035 million cubic meters. Ground water recharge in the catchment ranges between 125 mm to 880 mm in the plains and Ghats, on an average 460 mm contributed to ground water recharge accounting to 2360 million cubic meters. Water available in the hypomorhpic layer is about 5022 million cubic meters. Sub-surface flows as function of pipeflow and baseflow was estimat-

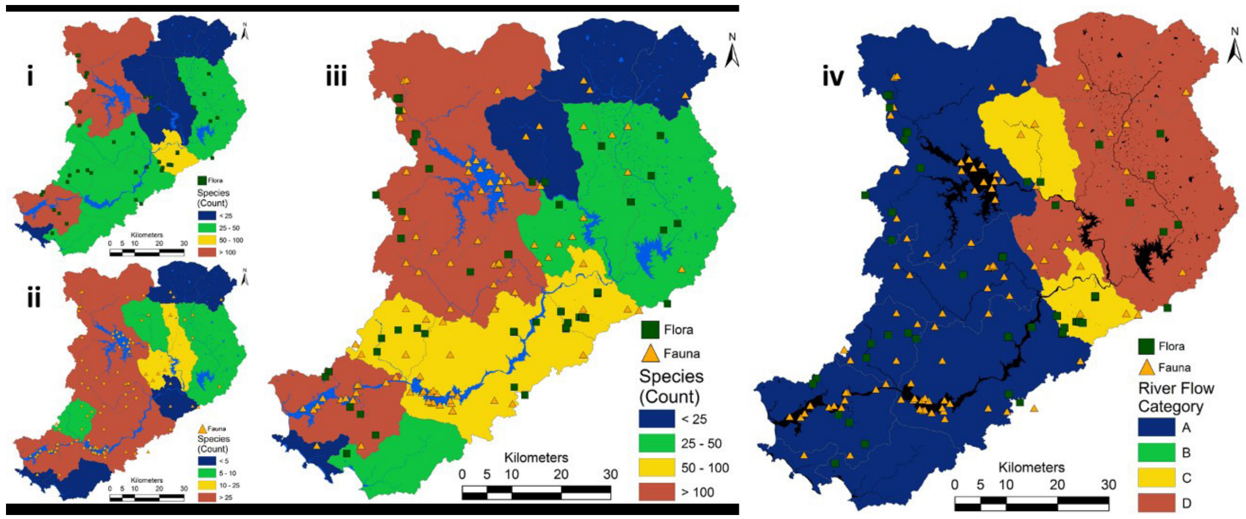

Figure 7. Endemic Flora and Fauna distribution in Kali Basin (**i**-Flora distribution in the catchment, **ii**-Fauna distribution, **iii**-Flora and Fauna distribution, **iv**-Flora and Fauna with water flow regime–perennial, intermittent, seasonal).

ed, considering the soil and geological characteristics of the region. Pipeflow in the basin is about 550 million cubic meters whereas base flow is about 514 million cubic meters both together contributing to a sub-surface flow of 1064 million cubic meters.

Agriculture water demand was estimated based on cropping pattern, growth stages, cropping cycle, etc. Agriculture water demand was found to be higher in sub-basins 1, 2, 3, 4, 5, 6, 11 (Figure 6) with over 100 million cubic meters as against Ghats, and annual agriculture demand in the basin is about 2272 million cubic meters. Taluk level livestock census showed of higher population in plains compared to the Ghats or Coasts, with water demand of over 1000 kilo cubic meters. Annual livestock demand in the basin is about 10.2 million cubic meters. Domestic water requirement in the basin is about 27.1 million cubic meters across the basin. Both livestock and human population combined together has a domestic footprint of 37.3 million cubic meters.

Water demand of the forested landscapes and minimum ecological flow requirements were computed as explained in the methods section. Terrestrial demand is a function of evapo-transpiration, which is about 3779 million cubic meters during non-monsoons which could be catered by the water in the hypomorphic layer. Ecological flow in the basin is assumed to be 30 percent of mean annual flow. Annual average flow in the basin considering runoff and sub-surface flows is about 3291 million cubic meters with the environmental flow of about 987 million cubic meters. Ecological footprint of the basin is about 7075 million cubic meters and of this 6088 million cubic meters is the water footprint in agriculture, domestic, livestock, and evapotranspiration from forests.

Considering terrestrial demand is met by water in the hypomorphic layer, then total ecological footprint would be the aggregation of agriculture, livestock, domestic demands, and ecological flow *i.e*., about 3297 million cubic meters, whereas the supply footprint naturally available as flow would account to 3291 million cubic meters, almost catering the annual demand.

Ecohydrological status (Figure 6, Table 2) assessment confirms the role of native vegetation (native forests) in retaining the water in the catchment. Hydrological footprint (Figure 6) shows water scarce situation in sub-basins 1, 2, 3, 5 and 6 located in the eastern plains whereas sub-basins in the Ghats and Coasts *i.e*., 4, 7, 8, 9, 10, 11, 12 and 13 show sufficient water availability to cater domestic, irrigation, horticulture, livestock, and ecological needs. Presence of dense forest cover in the Ghats make it more favorable to cater most of the environmental flow demands in each sub-basin and ecological flow demands in the river downstream.

Hydrological status of Kali river was calculated based on the interannual variability of water supply and demand (Figure 7). Kali river showed sufficient water in the Ghats and coasts, whereas the transition zones and plain lands with higher monoculture, agricultural activities has led to water scarcity between 4 to 9 months. Based on flow in the river the sub-basins were classified into 4 categories (A, B, C, D). Perennial rivers are categorized under A (with 12 months flow), intermittent river with 9 to 11 months flow (category B), 8 to 6 months (cat-

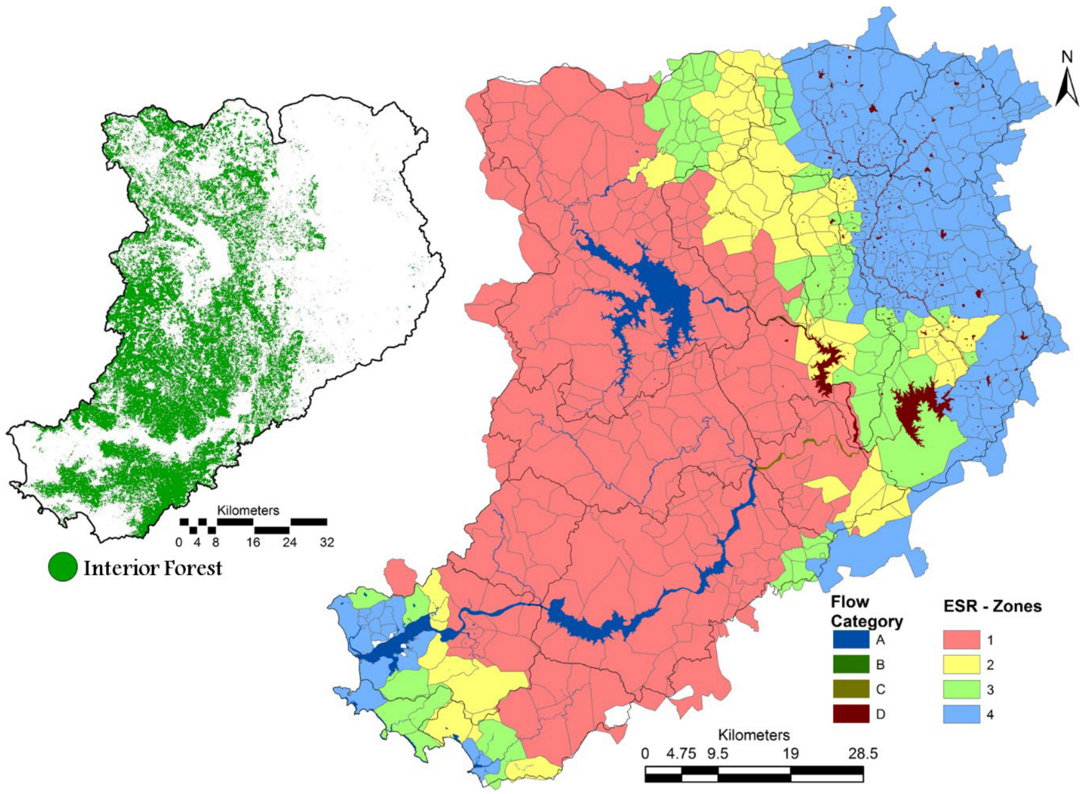

Figure 8. Ecologically Sensitive Zones (Villages).

egory C), whereas seasonal river stretches were classified under D category. Accordingly, the Ghats and coasts have perennial river system as against the upper plainlands.

Kali river catchment is a habitat to very rare and endangered wildlife and endemic flora. Ecology of Kali basin is assessed through biodiversity (such as endemic flora and fauna) based on field measurements, and review of published literature [50,52,80]. Figure 7 depicts the distribution of endemic flora and fauna in Kali river basin. The flora includes 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,* etc. Wildlife includes predators such as tiger (*Panthera tigris*), leopard, wild dog (*Cuon alpinus*) and the sloth bear. Prey animals are barking deer, spotted deer (*Axis axis*), wild boar, sambar (*Cervus unicolor*), gaur (*Bos gaurus*). The region has an important elephant corridor between Karnataka and Maharashtra for about 47 elephants. Birds include great hornbill (*Buceros bicornis*), malabar pied hornbill (*Anthracoceros coronatus*), blue winged parakeet, Nilgiri thrush, malabar lark, bulbul, thrush, etc. There are about 22 amphibians and 31 fish species, which are endemic to Western Ghats. This highlights the occurrence of endemic flora and fauna in catchments with the perennial water resource and sufficient hydrological footprint.

The information related to biodiversity and ecology of the region were compiled through literature review and field measurements. Ecological Sensitive Regions (ESR) were delineated based on the geo-climatic, land, ecological, hydrological parameters [80]. ESR spatial data is integrated with hydrological status of the river (perennial, seasonal) and is presented in Figure 8. The study confirms the ecological sensitiveness linkages with the hydrologic regime of a region with the occurrence of perennial streams in ESR 1 and 2. Figure 7 and Figure 8 confirms the role of native forests (contiguous interior forests) in sustaining the water evident from the occurrence of perennial streams compared to the seasonal streams in the catchment dominated by degraded forest patches. This highlights the linkages of hydrology, biodiversity, and ecology with the land use dynamics in a catchment.

CONCLUSIONS

Kali River catchment physical integrity is altered with the implementation of unplanned developmental projects such as the construction of series of dams, Kaiga nuclear power plant, Dandeli paper mill, etc. leading to large-scale land cover changes evident from the decline of forests from 84.6 percent (1973) to 54.9 percent (2016) and the reduction of evergreen forests from 61.7 percent to 38.5 percent. These structural alterations of the landscape in the basin have altered the natural hydrologic regime. Assessment of water footprint indicates the requirement of 2309 million cubic meters for the societal and livestock demand, 3779 million cubic meters for terrestrial ecosystems, and environmental flow of 987 million cubic meters (to sustain aquatic biota). The terrestrial demand is met by percolated water in the hypo-morphic zone, supply in the basin would be function of surface and subsurface flows which accounts 3292 million cubic meters. Eco-hydrological footprint emphasizes the role of forests on infiltration and evapotranspiration capabilities. Sub-basins with higher forest cover had higher eco-hydrological index supplementing that the availability of water can satisfactorily maintain the demands, where sub-basins dominated by monoculture had low index indicates water scarcity. Hydrological footprint shows sustained water supply catering societal and environmental demands in the catchment dominated by native forest cover of endemic flora. Inter-annual variability of supply and demand footprints indicate that the sub-basins between coasts and Ghats are with perennial river streams, whereas the transition zones between Ghats and plains towards the eastern portions showed a deficit of water for 6 to 10 months with intermittent and seasonal flow. Occurrence of streams with 12 months flow in the ecologically sensitive region (1 and 2) confirms of linkages of hydrologic regime with the ecological sensitiveness of a region. This highlights that streams are perennial in the catchment with forest cover > 70 percent and with higher endemic plant species confirming the linkage between ecology and hydrology with the land use dynamics in the catchment. This provides invaluable insight to the need for integrated approaches in the river basin management in an era dominated by mismanagement of river catchment with the enhanced deforestation process, inappropriate cropping, and poor water efficiency. The premium should be on conservation of the remaining evergreen and semi-evergreen forests, which are vital for the water security (perennial streams) and food security (sustenance of biodiversity). There still exists a chance to restore the lost natural evergreen to semi-evergreen forests through appropriate conservation and management practices. Current management practices adopted by 20th century civil engineers has been contributing to the erosion of water retention capability in the catchment with severe water scarcity, evident from 279 districts in the country reeling under droughts during the last three consecutive years. The current study provides insights of the role of forests with native species in maintaining the hydrological regime while sustaining the local demand, which is useful in the watershed (catchment / basin) management by the respective government agencies.

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