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Hydrological Responses at Regional Scale to Landscape Dynamics

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ABSTRACT Western Ghats is the primary catchment for most of the rivers in peninsular India. Pristine forests in this region are rich in biodiversity and are being cleared due to unsound developmental activities. Rapid land-use changes have undermined the hydrological conditions, there by affecting all the components in the hydrological regime. The development programs based on ad-hoc decisions, is posing serious challenges in conserving fragile ecosystems. These changes have adversely affected the hydrological regime of river basins resulting in diminished river / stream flows. This necessitates conservation of ecosystems in order to sustain the biodiversity, hydrology and ecology. In this situation, in order to resolve present problems and to avoid a future crisis, a comprehensive assessment of land use changes, its spatial distribution and its impact on hydrological regime was carried out to explore appropriate remedial methods for the sustainable utilization management of natural resources.

INTRODUCTION

Developing countries in the tropics are facing threats of rapid deforestation due to unplanned developmental activities based on adhoc approaches and also due to policies and laws that considers forest as national resource to be fully exploited. The land use changes, involving conversion of natural forests to other land uses; agriculture (enhanced grazing pressure and intensive cultivation practices) and plantation (widespread acacia and eucalyptus planting) have led to soil compaction, reduced infiltration, groundwater recharge and discharge, and rapid and excessive runoff (Ray et al. 2015; Scott and Lesch 1997; Sikka et al. 1998; Van Lill et al. 1980). The structural changes in the ecosystem due to land cover changes, will influence the functional aspects namely hydrology, bio-geo chemical cycles and nutrient cycling. These are evident in many regions in the form of conversion of perennial streams to seasonal and disappearance of water bodies leading to a serious water crisis. Thus, it is imperative to understand the causal factors responsible for changes in order to improve the hydrologic regime in a region. It has been observed that the hydrological variables are complexly related with the vegetation present in the catchment. The presence or absence of vegetation has a strong impact on the hydrological cycle. This requires understanding of hydrological components and its relation to the land use/land cover dynamics. The reactions or the results are termed hydrological response and depends on the interplay between climatic, geological and land use variables (Ramachandra et al. 2014a).

Hydrological responses can be understood by analysing land use changes using temporal remote sensing data and traditional approaches. Traditional approaches considers spatial variability by dividing a basin into smaller geographical units such as sub-basins, terrain-based units, land cover classes, or elevation zones on which hydrological model computations are made, and by aggregating the results to provide a simulation for the basin as a whole. Modelling is thus simplified because areas of the catchment within these units are assumed to behave similarly in terms of their hydrological response. Remote sensing and GIS techniques have been used to determine some of the model parameters. The main applications of remote sensing in hydrology are to, i) determine watershed geometry, drainage network and other map type information for hydrological models, ii) provide input data such as land use/land cover, soil moisture, surface temperature etc. GIS on the other hand allows for the combination of spatial data such as topography, soil maps and hydrologic variables such as rainfall distribution or soil moisture (Ramachandra et al. 2013c).

Land cover is the observed physical cover at a given location and time as might be seen on the ground or from remote sensing. This includes the vegetation (natural or planted) and human constructions (buildings etc.), which cover the Earth surface. Land use is, in part a description of function, the purpose for which the land is being used. Land use and cover changes are the result of many interacting processes. Each of these processes operates over a range of spatial, temporal, quantitative, or analytical dimension used to measure and study objects and processes. Land-use and land-cover are linked to climate and weather in complex ways (Ramachandra et al. 2012). Key links between changes in land cover and climate include the exchange of greenhouse gases (such as water vapour, carbon dioxide, methane, and nitrous oxide) between land surface and atmosphere, the radiation (both short and long wave) balance of land surface, the exchange of sensible heat between land surface and atmosphere. Artificial changes to the natural cycle of water have produced changes in aquatic, riparian, wetland habitats and agricultural landscape. These interferences have had both positive and negative impacts on the problems that they were intended to solve. Some of these activities have greatly constrained the degree of interactions between the river channel and the associated floodplain with catastrophic effects on biodiversity.

Land Use Changes and Its Effect on Hydrology

Human activities have been recognized as a major force shaping the biosphere (Karthick and Ramachandra 2007; Turner and Meyer 1994). In the 1980's, terrestrial ecosystems as carbon sources and sinks were highlighted and later the important contribution of local evapotranspiration to the water cycle-that is precipitation recycling-as a function of land use/land cover highlighted yet another considerable impact of land use/land cover change on the climate. A much broader range of impacts of land use/land cover change on ecosystem goods and services were further identified (Lambin et al. 2003). A most efficient way of capturing the spatial and temporal details is by remote sensing. Hydrological models coupled with remote sensing data can efficiently characterize temporal and spatial effects of land use changes on the ecology and hydrology. Earlier studies confirm the relationship among the watershed physical characteristics and the storm-based hydrologic indices indicated that the greatest impact of land management is found with statistically significant predictive models for indices of time base, response lag, and time of rise of hydrograph (Ramachandra et al. 2015; Bhat et al. 2007).

Remote Sensing and GIS Techniques in Hydrology

Remote sensing uses measurements of the electromagnetic spectrum to characterize the landscape or infer properties of it (Ramachandra et al. 2015; Schultz and Engman 2000; Schmugge et al. 2002). Satellite observations are available since the early 1970's and it is possible to relate trends such as vegetation cover densities to stream flow. The land cover maps derived by remote sensing are the basis of hydrologic response units for modelling. Geographic information System (GIS) helps in the spatial data analysis, integration of a combination of spatial data (such as soil, topography, hydrologic variables, etc.) and modelling (Schultz and Engman 2000). GIS deals with information about features that is referenced by a geographical location. These systems are capable of handling both locational data and attribute data about such features through database management system (DBMS).

Western Ghats

The Western Ghats comprise the mountain range that runs along the western coast of India, from the Vindhya-Satpura ranges in the north to the southern tip. This range intercepts the moisture laden winds of the southwest monsoon thereby determining the climate and vegetation of the southern peninsula. The steep gradients of altitude, aspect and rainfall make the region ecologically rich in flora and fauna. There is a great variety of vegetation all along the Ghats: scrub jungles, grassland along the lower altitudes, dry and moist deciduous forests, and semi-evergreen and evergreen forests. Out of the 13,500 species of flowering plants in India, 4500 are found in the Western Ghats and of these 742 are found in Sharavathi river basin (Ramachandra et al. 2004). Climax vegetation of the wet tract consists of *Cullenia, Persea, Diptercarpus, Diospyros* and *Memecylon*. The deciduous forest tract is dominated by *Terminalia, Lagerstroemia, Xylia, Tectona* and *Anogeissus*. The region also contains potentially valuable spices and fruits such as wild pepper varieties, cardamom, mango, jackfruit and other widely cultivated plants. There is an equal diversity of animal and bird life. Noticeable reptile fauna in the evergreen forests include burrowing snakes (uropeltids) (Gadgil and Meher-Homji 1990) and the king cobra and among amphibians, the limbless frog (caecilians). The Nilgiri *langur*, lion-tailed macaque, Nilgiri *tahr* and Malabar large spotted civet are some examples of endangered endemic mammals belonging to this area. Sharavathi river valley lies in the Central Western Ghats and represents an area of 2985 km^2. Sharavathi is a west flowing river originating at Ambuthirtha in Shimoga district and during its course, falls from a height of around 253 m at the famed Jog Falls. It flows through Honnavar and eventually into the Arabian Sea.

Karnataka Power Cooperation Limited (KPCL) has set up a dam at Linganamakki across Sharavathi in 1964 to harness electricity, which has divided the river basin into upstream and downstream. The construction of this dam has made considerable hydrological and ecological alterations in the river basin. The dam resulted in the submergence of wetlands and forest areas of unmeasured biodiversity. The effects are particularly seen in the upstream of the river basin where the dam submerged many villages and forests to give rise to small isolated islands. These island and surrounding areas have created niches for 150 species of birds, 145 species of butterflies and 180 species of beetles along with mammals such as spotted deer, barking deer, civet, leopard and the Indian *gaur.* The reservoir has provided further impetus to farmers and plantation agriculturists. Large tracts of forestlands have been cleared for paddy cultivation and plantation trees such as areca and acacia. Apart from these, vast tracts of natural vegetation has been cleared and replaced with monoculture plantations of *Acacia auriculiformis*, Eucalyptus sp. and *Tectona grandis*. As a result of these activities, there is evidence of changes in runoff and stream flow regimes. There are instances where wells have 'run dry' in the wet spots of the basin, mainly because percolation of rainwater into the ground has decreased due to deforestation. Studies are thus required to quantify the hydrological responses in order to gain an understanding of the effect of anthropogenic activities on the hydrological components and thus the vegetation of study area.

Objectives

The objectives of the study are:

i. Quantification of hydrologic components of Sharavathi River Basin, Western Ghats using Remote Sensing and GIS.
ii. Study the impact of land use/land cover changes on hydrologic components.

Study Area

Sharavathi river (Fig. 1) originates at Ambuteertha, near Kavaledurga in Tirthahalli *taluk.* It flows in a north-westerly direction and receives the Haridravathi on the right and Yenneholé on the left. Near the border of the district, it bends to the west and hurls down the *ghats* near Jog where it is harnessed for generating electricity. It discharges into the sea at Honnavar in Uttara Kannada (Fig. 2). Its total length is 128 km and in Shimoga district its length is 32.2 km. Figure 1 depicts the location of the study area in India and Karnataka. Sharavathi river basin falls in two districts namely Uttara Kannada and Shimoga. Upstream river basin extends to two *taluks* in Shimoga viz. Hosanagara and Sagara. The entire basin has an area of 2985.66 km^2 with upstream and downstream respectively 1988.99 km^2 and 996.67 km^2 each. The basin slopes from west to east. The general elevation along the basin is about 640 m above sea level in the west. The western side of the upstream river basin rests upon the Western Ghats also known as the Sahyadri, which is a very mountainous area. The raise towards the crest of the Ghats is very rapid, a height of 1343 meters at Kodachadri according to the Survey of India. Figure 3 gives the digital elevation model of upstream. Slope percentage map derived from digital elevation model was classified into various slope groups.

Figure 4 classifies slope into 5 major slope groups. This classification is given in Table 1. Steep to strongly sloping are characteristics of *malnadu* (mountainous region) on the western side and is covered by dense vegetation such as evergreen/semi-evergreen and moist deciduous forests. Slopes attain nearly level ground at

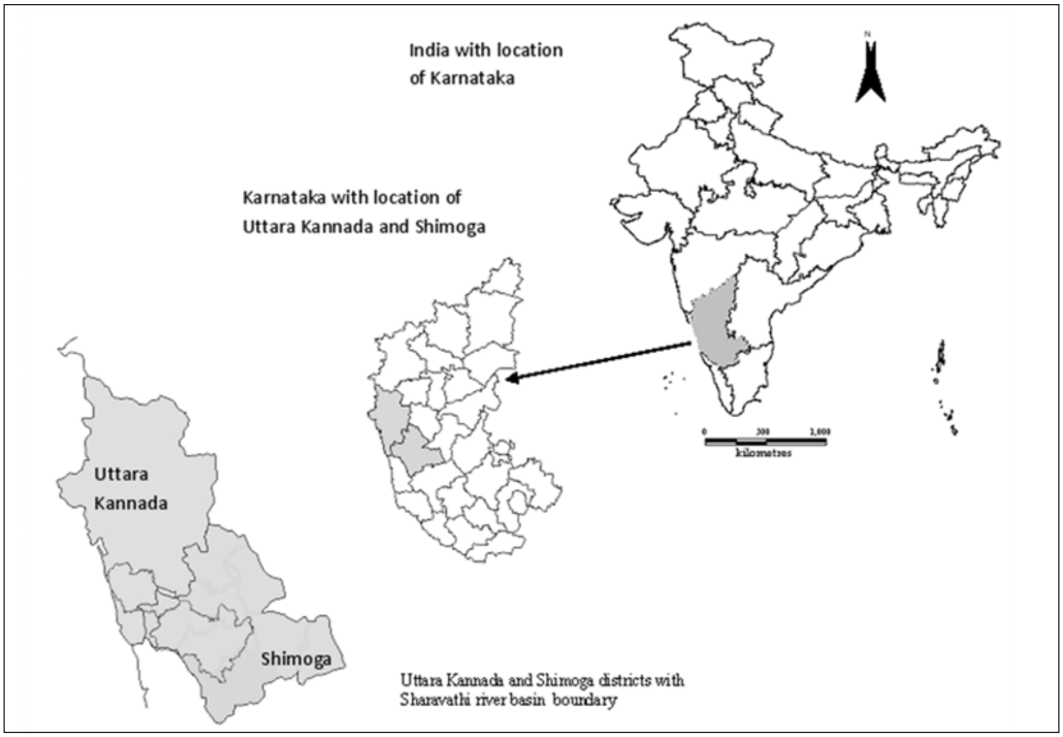

Fig. 1. Study Area – Sharavathi river basin, Karnataka state, India

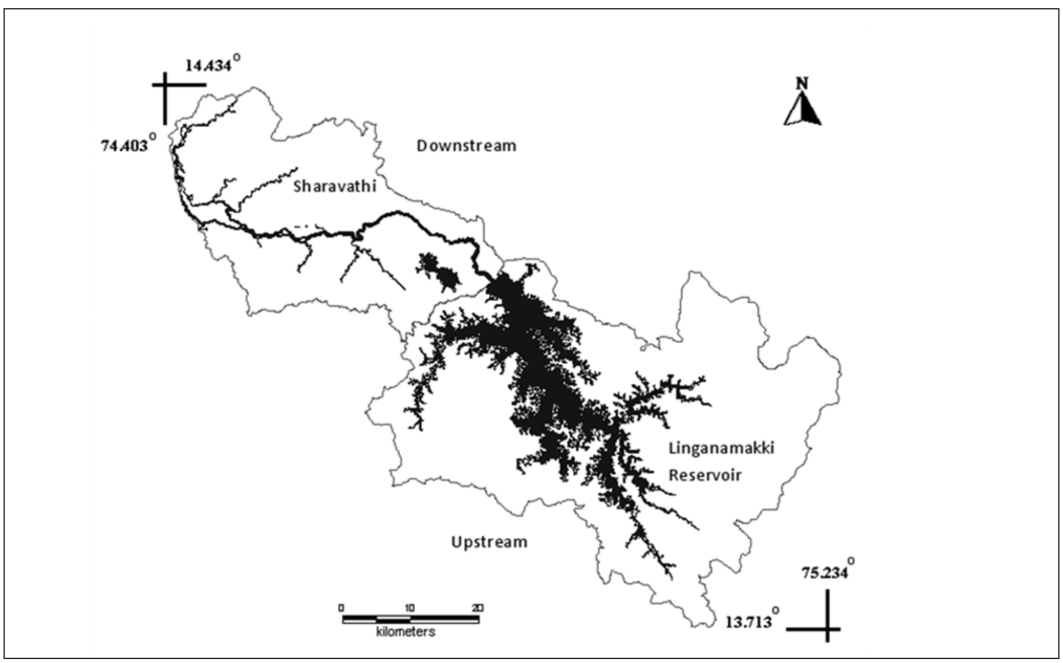

Fig. 2. Sharavathi River Basin –Upstream and Downstream

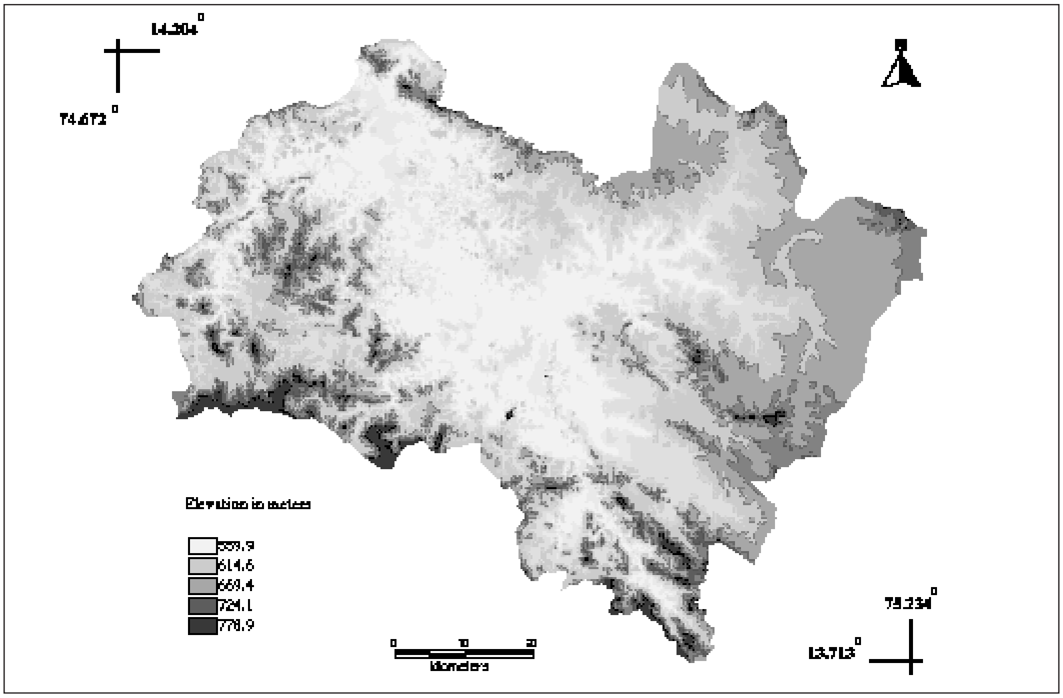

Fig. 3. Digital Elevation Model – Sharavathi upstream

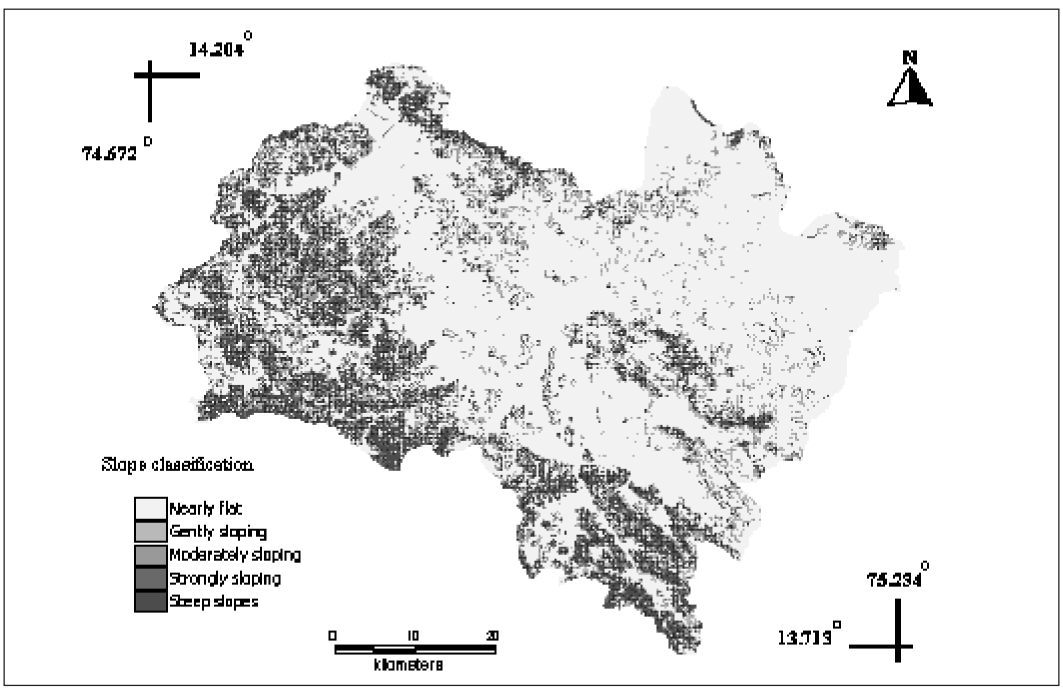

Fig. 4. Slope Classification – Sharavathi upstream

Table 1: Slope classifications

Slope in percentage	*Slope group*
0-10	Nearly flat
10-15	Gently sloping
15-20	Moderately sloping
20-30	Strongly sloping
30-80	Steep sloping

the centre of the basin (reservoir) and gently slope upward towards the east. Eastern portion especially Haridravathi and Nandiholé sub basins consists of nearly level or flat land, where paddy cultivation is practiced. As can be seen from Figure 5, dense drainage network is observed in the western portion of the basin. These are areas of very steep to steep slopes. Eastern portion especially, Nandiholé and Haridravathi basins with gentle slope are characterized by less dense network. In areas of high permeability soil (such as sand) *viz*. in Haridravathi and Nandiholé, the drainage density is low as compared with low permeability soil (clay) and high drainage density on the western side for example Yenneholé, Hurliholé etc. Sub-basins have been delineated according to the main tributaries flowing into the reservoir as depicted in Figure 6.

The climate in the study area is characterized by the monsoon regime, which superimposes itself over a regime of thermic convectional rainfall lined to the zenithal passage of the sun. The cold season is from December to February and is followed by the hot season which is from March to May. The rainfall is very heavy in the region of Western Ghats especially along the western side of the river basin. Mean annual rainfall ranges from 4500 mm in the western side to 1700 mm in the eastern side of the basin. About 95% of the rainfall is received during the south west monsoon months, June to September, July being rainiest. There is some rainfall in the post monsoon season, particularly in October, and it is mostly in the form of thundershowers. Some rainfall in the form of thundershowers also occurs during the summer months of April and May. After January, there is a rapid increase of tem-

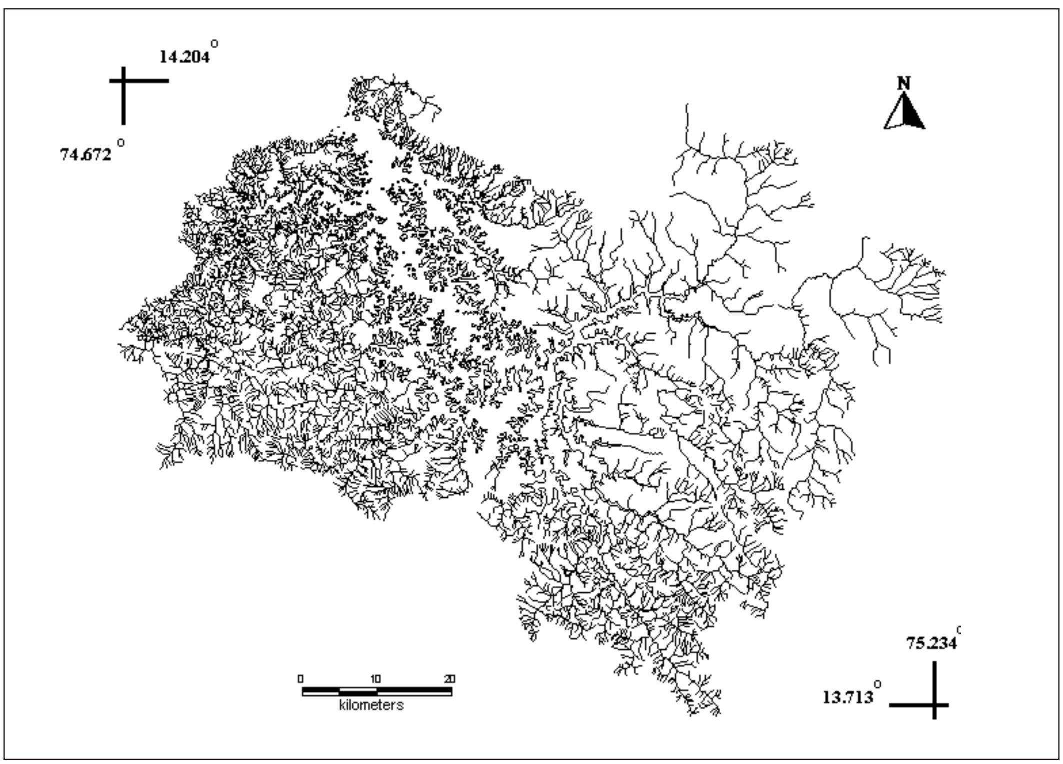

Fig. 5. Drainage – Sharavathi upstream

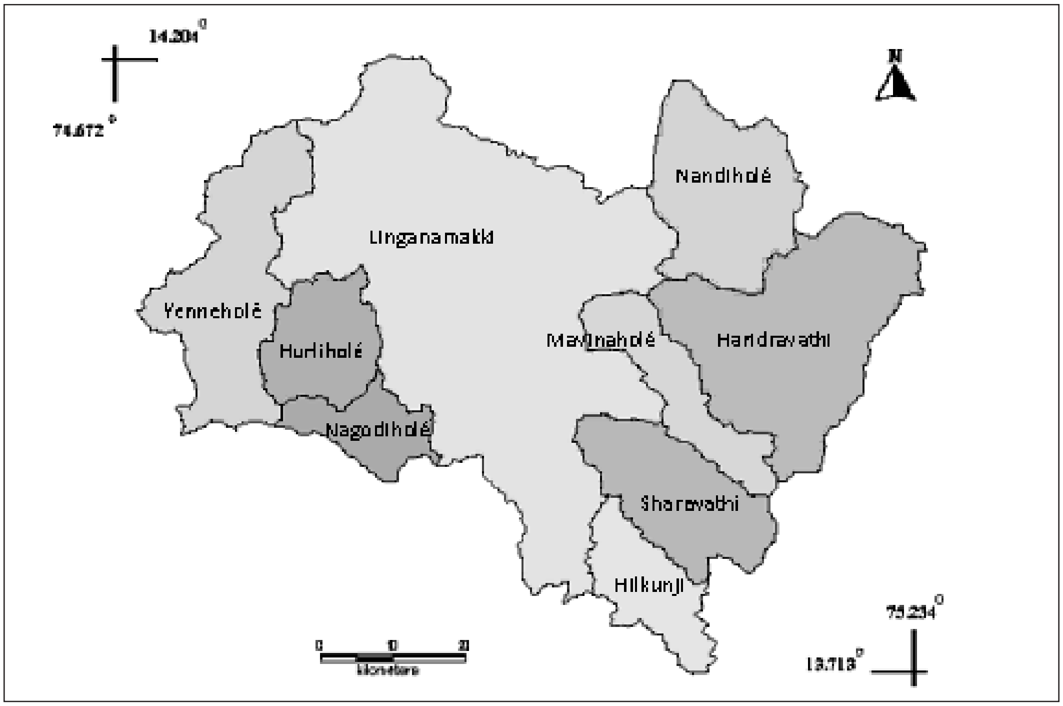

Fig. 6. Sub basins of Sharavathi upstream

peratures. April is usually the hottest month with the mean daily maximum temperature at 35.8°C and the mean daily minimum at 22.2°C. The relative humidity during the mornings throughout the year generally exceeds 75%. During the monsoon months, the relative humidity in the afternoon is quite high and is ~90 %. The driest part of the year is the period from January to March when the relative humidity is less than 35%.

Evergreen to semi-evergreen forests are confined to the western part of the basin. Many of the hills are covered with heavy forests while ravines and valleys produce luxuriant trees known for their great height and size (KSG 1975). Scattered shrubs and thickets are found in the regions surrounding the reservoir. Moist deciduous forests are found in the northern and eastern part of the study area. Plantations include acacia, teak, areca, rubber, eucalyptus etc. Areca nut also called betel nut is a widely used article of consumption and is grown in valleys. Acacia plantation is found in patches, amidst evergreen forests and is mainly used for paper production. Plantation constitutes 7-9% of the total vegetation in the upstream. Evergreen /semi-evergreen and moist deciduous forests constitutes 11% and 25% respectively.

DATA AND METHODS

Remote sensing and collateral data used for the analysis are:

Satellite Data

Table 2 gives information on the satellite data used in the study.

Table 2: Satellite/sensor details

Satellite/sensor	*Date of Pass*	*Path/Row*	*Bands*	*Source*
Landsat TM	Nov, 1989	146/50	2,3, 4,5,6 and 7	http:// glcf.umiacs.umd.edu
IRS LISS III	Mar, 1999	97/63	1,2,3 and 4	NRSA, Hyderabad

Note: Data for March 1989, was not available for IRS LISS III, while for 1989, only Landsat data was available.

Ground Truth and Ancillary Data

GPS points along with attribute information were collected in upstream to determine the type of land cover and land use such as vegetation, which includes evergreen-semi-evergreen and moist deciduous forests and plantations, degraded vegetation, agricultural activities, settlements, etc.

Maps and other ancillary data used for the study include:

i. Forest Map of South India (1982) by J.P. Pascal, French Institute of Pondicherry.
ii. Soil map published by the National Bureau of Soil Survey.
iii. Topographic maps of scale 1:50000 and 1:250000 from the Survey of India (SOI)
iv. Reconnaissance Soil Map of Forest Area, Western Karnataka and Goa
v. Geology map, Department of Mines and Geology
v Bio-climate of the Western Ghats (1982), J.P.Pascal, French Institute of Pondicherry.

Climate Data

i. IMD *Taluk*wise rainfall data (1901-2001) for Sagara, Hosanagara, Soraba and Tirthahalli (Shimoga) and Honnavara, Kumta and Siddapur (Uttara Kannada).
ii. Daily rainfall data from Karnataka Power Corporation Limited for 18 rain gauge stations in Sharavathi river basin (1989-1999).
iii. IMD maximum and minimum temperature data (1969-2000) for Shimoga.
iv. IMD extraterrestrial solar radiation and number of sunshine hours for Shimoga (1989-1999).
v. Water table level data (1989-1999) for selected wells in and around the study area from Dept. of Mines and Geology.

Remote Sensing Data Analysis

This involved the initial processing of remote sensing data to correct for geometric distortions, to calibrate the data radiometrically and to eliminate the noise present in the data. Creation of false colour composite (FCC) consisted of assigning primary colours to gray values from near infrared, red and green bands (Figs. 7 and 8). This helped in identifying heterogeneous patches, which were chosen for ground data collection (training polygons). Common classification procedures like supervised classification and unsupervised classification were adopted. Unsupervised classification involves clustering algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values (Lillesand and Kiefer 2002). Supervised classification was done using Gaussian maximum likelihood classifier (GMLC) to classify the remote sensing data. GMLC uses the mean, variance and covariance data of the signatures to estimate a probability that a pixel belongs to each class. It tends to be more accurate if a large number of training sites are available. Here, the distribution of reflectance values in a training site is described by a probability density function, developed on the basis of Bayesian statistics.

Estimation of Hydrological Components

The aim here has primarily been to predict the amount of discharge from a basin apart from modelling water movement with in the basin through spatially distributed models. Attempts have been made in the development and application of hydrological models at a range of spatial levels, from plot to catchment, and temporal scales from event based models to annual water budgeting (Skidmore 2000). Figure 9 gives the flow chart of the method used in estimating each hydrological component. In order to capture the movement of water with in the basin, a spatially explicit approach using temporal remote sensing data is appropriate. It aids in quantifying land surface parameters that serves as input to the model in a spatially continuous fashion. Water budgeting of a basin describes the water movement with in the basin and the relation between the input, storage and output of water, which is given as:

Input –Output = Change in Storage in the system ……1

The following factors combine to express the water balance equation

Input: Direct precipitation (R) and Groundwater discharge (GD)

Output: Interception (I); Surface runoff (SR); Pipeflow (Pf: sub surface flow); Transpiration (ET: Evapo-transpiration from vegetation); Evaporation (E: evaporation from soil and open water); Groundwater recharge (GR). Equation 1, can be written as

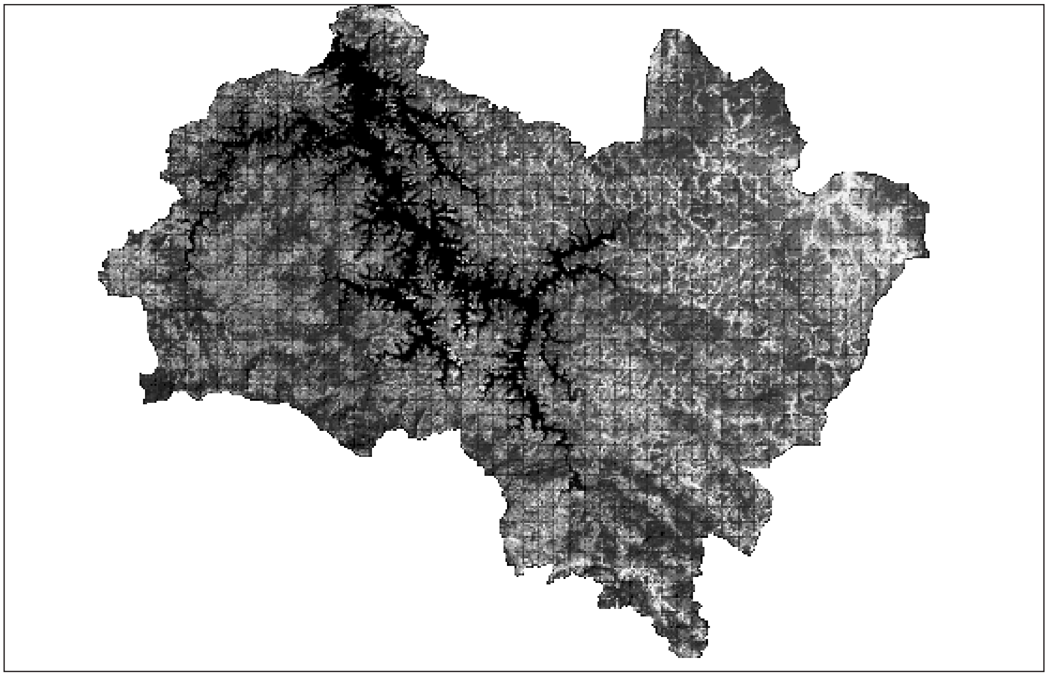

Fig. 7. Landsat TM, 1989 FCC

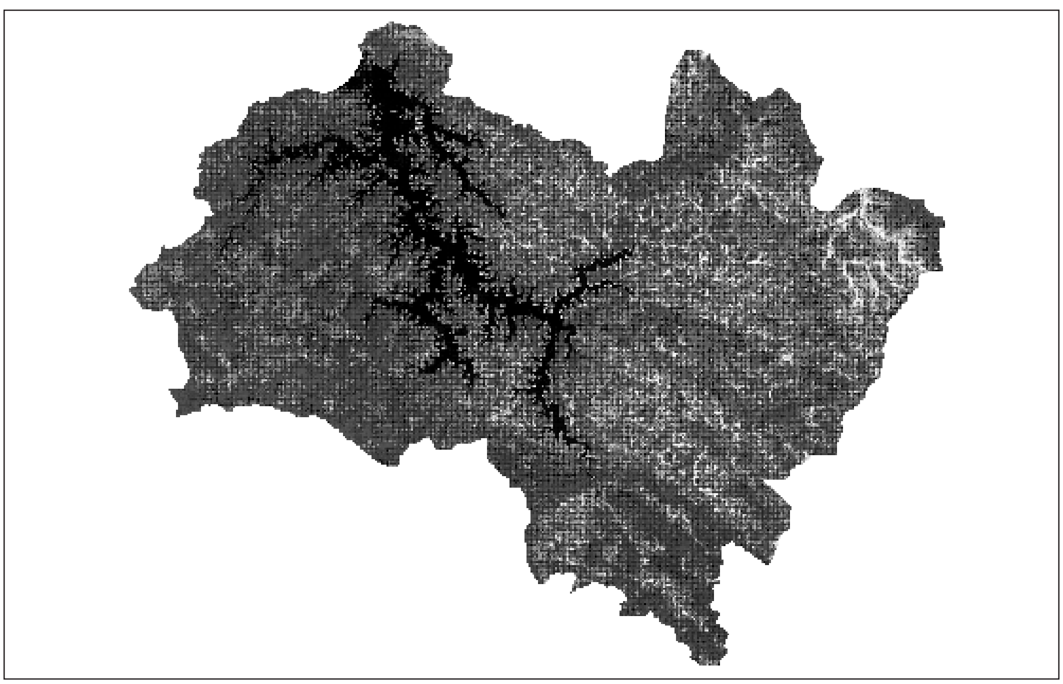

Fig. 8. IRS LISS III, 1999 FCC

Note: TM – Thematic Mapper
IRS - Indian Remote Sensing Satellite
LISS - Linear Imaging Self Scanning

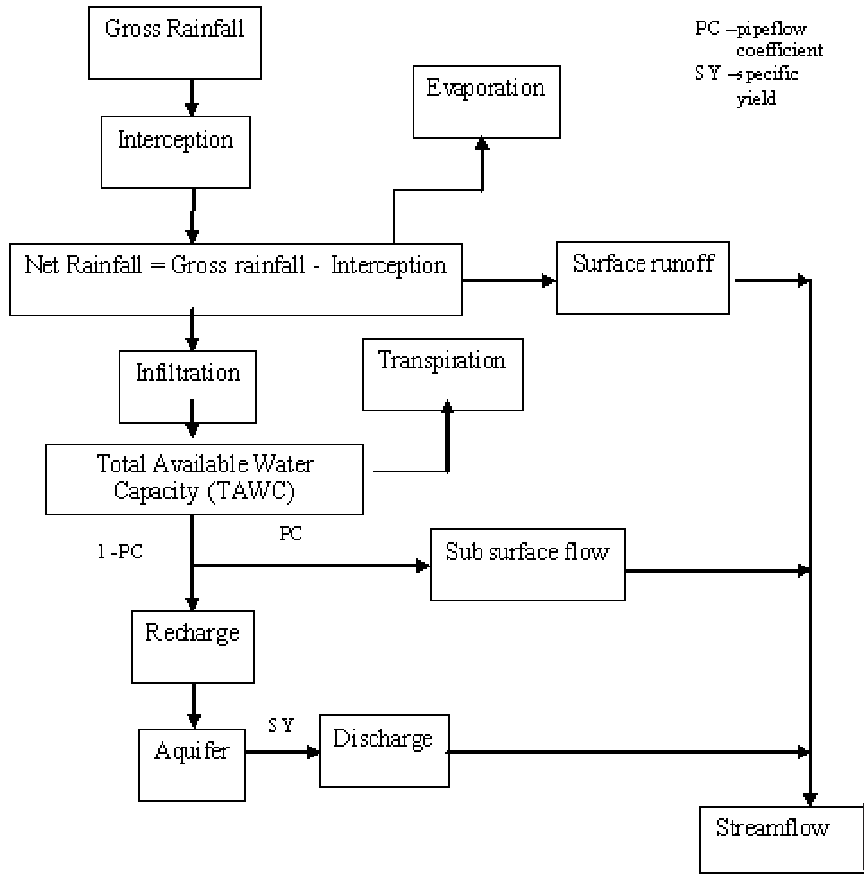

Fig. 9. Estimation of hydrological components

P ±GWD ±I ± SR ± Pf ±ET ±E±GR = ±DS ……… 2

Methods adopted for quantifying various hydrological constituents (Darcy 1856; Saint-Venant 1871; Singh 1992) are: P (Singh 1992; Raghunath 1985), I (Rutter et al. 1971; Calder and Newson 1979; Gash 1979; Singh 1992), SR (Horton 1933; Brakensiek 1967; Raghunath 1985), Pf (Putty and Prasad 2000), ET (Penman 1948; Turc 1961; Homes 1961; Monteith 1965; Shuttleworth and Calder 1979; Shuttleworth 1993), GR (Raghunath 1985; GWEM 1997), GD (Barnes 1939; Bruijnzeel 2004).

RESULTS AND DISCUSSION

Hydrological integrity of a river basin ensures the maximum amount of water available naturally as stream flow, soil moisture etc., to meet ecological and social (domestic, irrigation and livestock) demands in a river basin. Monthly monitoring of hydrological parameters reveal that stream in the catchments with good forest (evergreen to semi-evergreen and moist deciduous forests) cover have reduced runoff as compared to catchments with poor forest covers. Runoff and thus erosion from plantation forests was higher from that of natural forests. Forested catchment have higher rates of infiltration as soil are more permeable due to enhanced microbial activities with higher amounts of organic matter in the forest floor (Ramachandra et al. 2013a). Streams with good native forest cover in the catchment showed good amount of dry season flow for all 12 months. While strems in the catchment dominated by agricultural and monoculture plantations (of Eucalyptus sp. and *Acacia* *auriculiformis*) are sesonal with water availability ranging between 4-6 months. This highlights the impacts of land use changes in tropical forests on dry season flows as the infiltration properties of the forest are critical on the available water partitioned between runoff and recharge (leading to increased dry season flows). This emphises the need for integrated watershed conservation approaches to ensure the sustained water yield in the streams.

Land Use Change

Sharavathi river basin in the Western Ghats has been a subject of research and debates due to its ecologically rich environment (Ramachandra et al. 2013b; Ramachandra et al. 2014b). The 1940 SOI toposheet show that the entire river basin was covered with forests. Table 3 gives the percentage change analysis of forest cover (reserved forests) based on 1940 toposheets (48K/13, 48J/16 and 48O/1), and 1989 (Landsat TM) and 1999 (LISS III) imageries. This shows that more than 50% of the forests have decreased/removed by human activities and submergence due to damming the Sharavathi River.

Classified remote sensing data corresponding to the upstream of Sharavathi river basin (upstream) for 1989 and 1999 are given in Figures 10 and 11 respectively. Table 4 gives the error matrix generated for Landsat TM 1989 classified data, which indicates an overall accuracy of classification as 96.4%. Similarly, Table 5 lists the confusion matrix (error matrix) for IRS LISS III data with an accuracy of 97.6%. Low accuracy for settlements from both the imageries is

Table 3: Changes in Reserve Forests Area (1940-1999)

1940 (sq.km)	*1989 (sq.km)*	*1999 (sq.km)*	*Change in % (1940-1999)*
185.09	99.46	89.73	-51.52%

Table 4: Error matrix (Landsat TM 1989)

	Evg/SE	*MD*	*Plant*	*Grass*	*Agri*	*Open*	*Sett*	*Water*	*Total*
Evg/SE	4125	0	0	0	0	0	0	0	4125
MD	208	319	2	0	0	0	0	0	529
Plant	2	1	85	0	0	0	0	0	88
Grass	0	0	0	17	0	0	0	0	17
Agri	0	0	0	0	326	0	0	0	326
Open	0	0	0	1	1	62	0	0	64
Sett	0	0	0	0	0	9	8	0	17
Water	0	0	0	0	0	0	0	1211	1211
Total	4333	320	87	18	327	71	8	1211	6377

Note: Evg/SE - evergreen/semievergreen forests; MD – moist deciduous forests; Plant – plantations; Grass – grasslands and scrubs; Agri – agricultural lands; Open – open fields; Sett- settlements

Table 5: Error matrix (IRS LISS III 1999)

	Evg/SE	*MD*	*Plant*	*Grass*	*Agri*	*Open*	*Sett*	*Water*	*Total*
Evg/SE	553	0	19	0	0	0	0	0	572
MD	0	586	0	0	0	1	0	0	587
Plant	17	0	101	0	0	0	0	0	118
Grass	0	0	0	191	0	0	0	0	191
Agri	0	0	0	1	168	0	0	0	169
Open	0	0	0	0	0	278	0	48	326
Sett	0	14	0	0	0	0	7	0	21
Water	0	0	0	0	0	0	0	981	981
Total	570	600	120	192	168	279	7	981	2965

Note: Evg/SE - evergreen/semievergreen forests; MD – moist deciduous forests; Plant – plantations; Grass – grasslands and scrubs; Agri – agricultural lands; Open – open fields; Sett- settlements

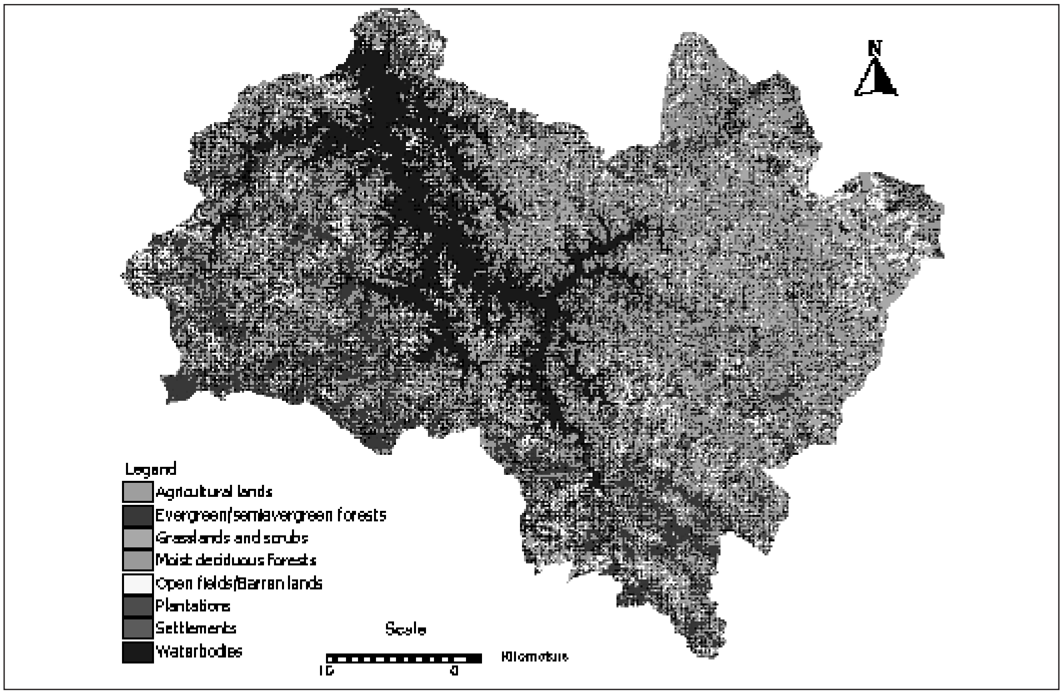

Fig. 10. Land use classification (Landsat TM 1989)

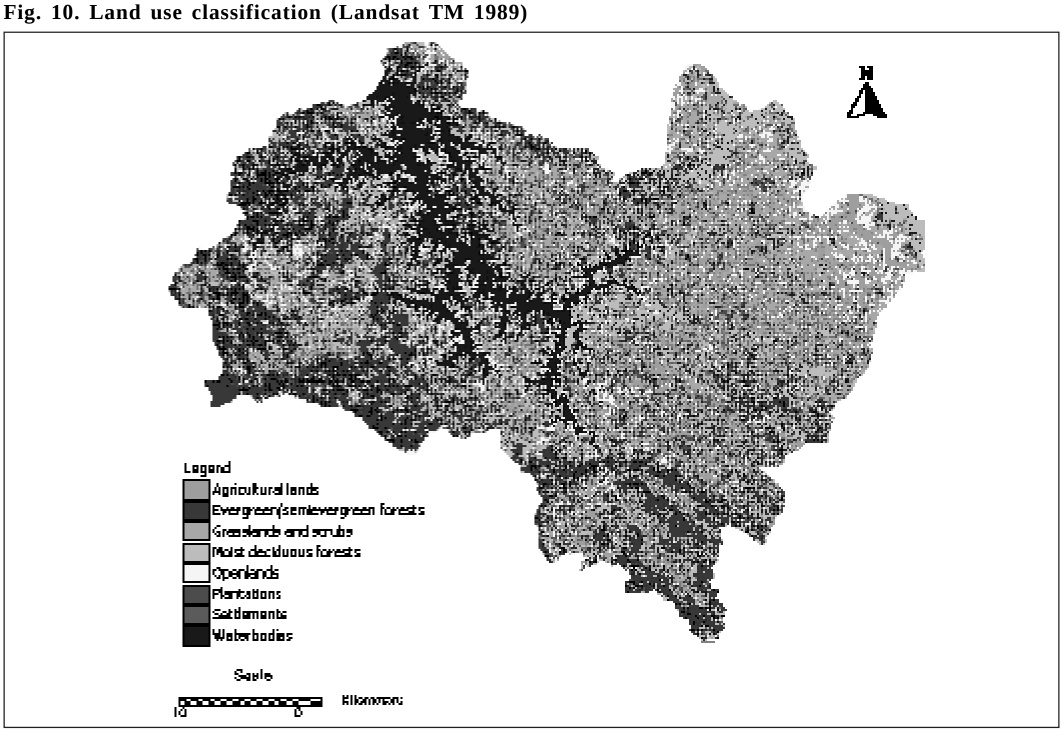

Fig. 11. Land use classification (IRS LISS III 1999)

partly due to spectral signature overlap with vegetation as most of the houses are surrounded by vegetation inside and outside the compound. Townships are few and houses are sparsely distributed separated by hundreds of meters. Since the building material is also different as almost all houses have tiled roof than concrete, overlap also occurred between open fields. Overlap of spectral signatures was also observed between evergreen/semi-evergreen forest and moist deciduous forests in full leaf.

Table 6 compares the percentage change in the land use in Sharavathi upstream river basin based on 1989 and 1999 data. It is seen that natural forests such as evergreen/semi-evergreen and moist deciduous forests have decreased by 28.2% whereas monoculture plantations (due to afforestation work of the forest department) have increased by 17.3%. Grasslands and scrubs have decreased by 28.4% in 1999 but this can be attributed to the season as in summer, grasses dry out leaving only the scrubs. The main anthropogenic activity apart from plantation is paddy cultivation, which has increased by 5% in 1999. Paddy cultivation is the most common agricultural activity in the basin and is usually grown in valleys.

Human population is increased in the basin and there has been immigration of people from adjoining districts of Karnataka and also from neighbouring States. Although the dam has provided electricity, water and other benefits to the surrounding areas, it has proved to be at the cost of the valuable ecosystem. Evergreen forests are being cleared to yield timber, which are used for electric transmission poles and railway sleepers. The felled areas are sometimes tended for getting the natural regeneration of valuable species. Deciduous forests supply timber, firewood, charcoal, bamboo, matchwood and plywood. Monoculture plantations of teak, silver oak *(Gravillea robusta)*, matchwood, Acacia sp., etc. are planted by the forest department in clear felled forest areas. Table 7 give the sub-basin wise area under different land uses.

Rainfall Analysis

Yearly data for hundred years were available for 7 *taluks* in and around the river basin *viz*. Hosanagara, Sagara, Soraba and Tirthahalli (Shimoga district) and Honnavar, Kumta and Siddapur (Uttara Kannada district). Since these are the *taluks* surrounding the river basin, rainfall analysis is done to study any variation in rainfall for 100 years. The rainfall periods were divided into 1901-1964 and 1964-2001, which represents respectively the periods before construc-

Table 6: Changes in land use in upstream (1989-1999)

Land use/Land cover	*1989 (km^2)*	*1999 (km^2)*	*Change in* **%**
Evergreen/semievergreen forests	272.67	209.39	- 23.2
Moist deciduous forests	539.26	512.25	- 5
Plantations	122.09	143.29	+17.3
Grasslands and scrubs	433.98	310.6	- 28.4
Agricultural lands	102.77	157.36	+ 53.1
Open fields/Barren lands	247.96	430.29	+ 73.5
Settlements	52.63	78.48	+ 49.1
Water bodies	218.01	147.31	-32.4

Table 7: Land use in the upstream of Sharavati (Sub basinwise in sq.km)

Sub basins	*Evg/SE*	*MD*	*Plant*	*Grass*	*Agri*	*Open*	*Sett*
Yenneholé	54.22	45.52	29.27	22.82	2.07	38.5	6.05
Nagodiholé	26.17	15.21	8.87	3.09	.03	8.42	2.81
Hurliholé	22.14	30.45	7.99	13.37	1.24	18.26	3.08
Linganamakki	50.47	202.38	55.41	13.37	50.47	194.91	25.72
Hilkunji	25.79	30.02	5.57	6.53	4.94	9.9	3.67
Sharavathi	16.29	40.66	14.16	16.35	19.37	27.31	7.06
Mavinaholé	2.36	33.9	4.87	20.47	10.3	18.08	6.62
Haridravathi	3.87	64.87	11.65	79.9	49.93	73.39	14.34
Nandiholé	2.22	48.48	5.19	52.71	18.71	41.03	8.96

Note: Evg/SE - evergreen/semievergreen forests; MD – moist deciduous forests; Plant – plantations; Grass – grasslands and scrubs; Agri – agricultural lands; Open – open fields; Sett- settlements tion and after construction of Linganamakki dam. Table 8 gives the mean and standard deviation of rainfall in Shimoga district. Hosanagara, Sagara, Tirthahalli and Siddapur *taluks* showed reduction in the mean annual rainfall with a significant reduction in Tirthahalli *taluk*. Sagara and Hosanagara were selected for further studies as these districts cover the study area.

The sub-basins were further classified into clusters viz. west, east, south and central depending on their geographical locations. Rainfall data were available for 18 rain gauge stations (within the upstream) from 1989-1999. The mean rainfall (1989-1999) was determined for each sub basin in order to observe the rainfall variation and distribution within the river basin. They were classified as follows:

- West-Yenneholé, Nagodiholé and Hurliholé
- Central-Linganamakki
- East- Nandiholé, Haridravathi and Mavinaholé
- South- Sharavathi and Hilkunji

Figure 12 illustrates the mean annual precipitation variability in western and eastern sub-basins.

Regression analysis was carried out for each rain gauge station considering rainfall as dependent variable and latitude, longitude, altitude and land cover as independent variables. The area of influence of each rain gauge station in the upstream was delineated with respect to contours and drainage and the land cover expressed as NDVI was determined using the imagery for each area around the gauge. Regression analysis showed rainfall having significant relationship with variables such as land cover, latitude, longitude, and altitude. At 5% level of significance rainfall showed good relationship between land cover, latitude, altitude and longitude. The probable relationships are given in Table 9. From the regression relationship, it is evident that the rainfall increases with land cover (NDVI) and decrease with latitude, longitude and altitude. Sensitivity analysis show the relationship holds good for all sub basins in the upstream region of the river basin.

Table 8: Variation of rainfall in Shimoga

Taluk	*1901-2001 (mm)*	*COV (%)*	*1901-1964 (mm)*	*COV (%)*	*1965-2001 (mm)*	*COV (%)*	*Change in rainfall (%)*
Hosanagara	2813.9 ± 754.4	26.8	2854.2 ± 683.4	23.9	2752.8 ± 859.9	31.2	-3.55
Sagara	2098.1 ± 523.6	24.9	2144.5 ± 560.3	26.1	2018.4 ± 444.2	22	-5
Soraba	1583.8 ± 430.0	27.1	1627.3 ± 388.6	23.8	1511.4 ± 488.6	32.3	2.4
Tirthahalli	3051.8 ± 783.6	25.6	*3132.9 ± 841.4	26.8	2742.6 ± 607.0	22.1	-12.45
Honnavar	3485.1 ± 687.8	19.7	3360.6 ± 775.4	23	3636.3 ± 565.5	15.55	8.2
Kumta	3755.9 ± 750.7	19.9	3633.8 ± 831.9	22.8	3391.1 ± 575.3	16.9	-6
Siddapur	2999.8 ± 769.9	25.6	3037 ± 793.2	26.1	2935.6 ± 734.4	25	-3.3

Table 9: Probable relationships of rainfall

X (independent)	*Y (dependent)*	*Probable relationships*	*r*	*p*
Latitude	Rainfall	Rainfall = -6541.28 (latitude) +95120.76	0.45	0.043
Land cover	Rainfall	Rainfall = 1243.97 (land cover)-3679.31	0.71	0.0
Longitude, latitude	Rainfall	Rainfall =(1864.41(long) -8504.99(lat)+262543.8	0.56	0.036
Longitude, land cover	Rainfall Rainfall	Rainfall = -234.71 (long) +1232.78 (land cover)+	0.71	0.002
Altitude, land cover	Rainfall	Rainfall = -4.33 (alt)+1273.63 (land)-1201.39	0.72	0.002
Land cover, latitude	Rainfall	Rainfall = -4.33 (alt)+1273.63 (land)-1201.39	0.74	0.001
Longitude, altitude, latitude	Rainfall	Rainfall = - 1868.78 (long)-8989.5 (lat) -4.97 (alt)+ 272688.8	0.58	0.076
Longitude, latitude, land cover	Rainfall	Rainfall = -926.48 (long) -4486.52 (lat) +997.16 (land)+130029.1	0.75	0.003
Altitude, land cover, longitude	Rainfall	Rainfall = - 4.2 (alt) +1264.58 (land) -171.13 (long)+11623.16	0.72	0.007
Land cover, altitude, latitude, longitude	Rainfall	Rainfall = 1016.06 (land) -6.07 (alt) -5002.23 (lat) -914.05 (long)+139910.8	0.77	0.005

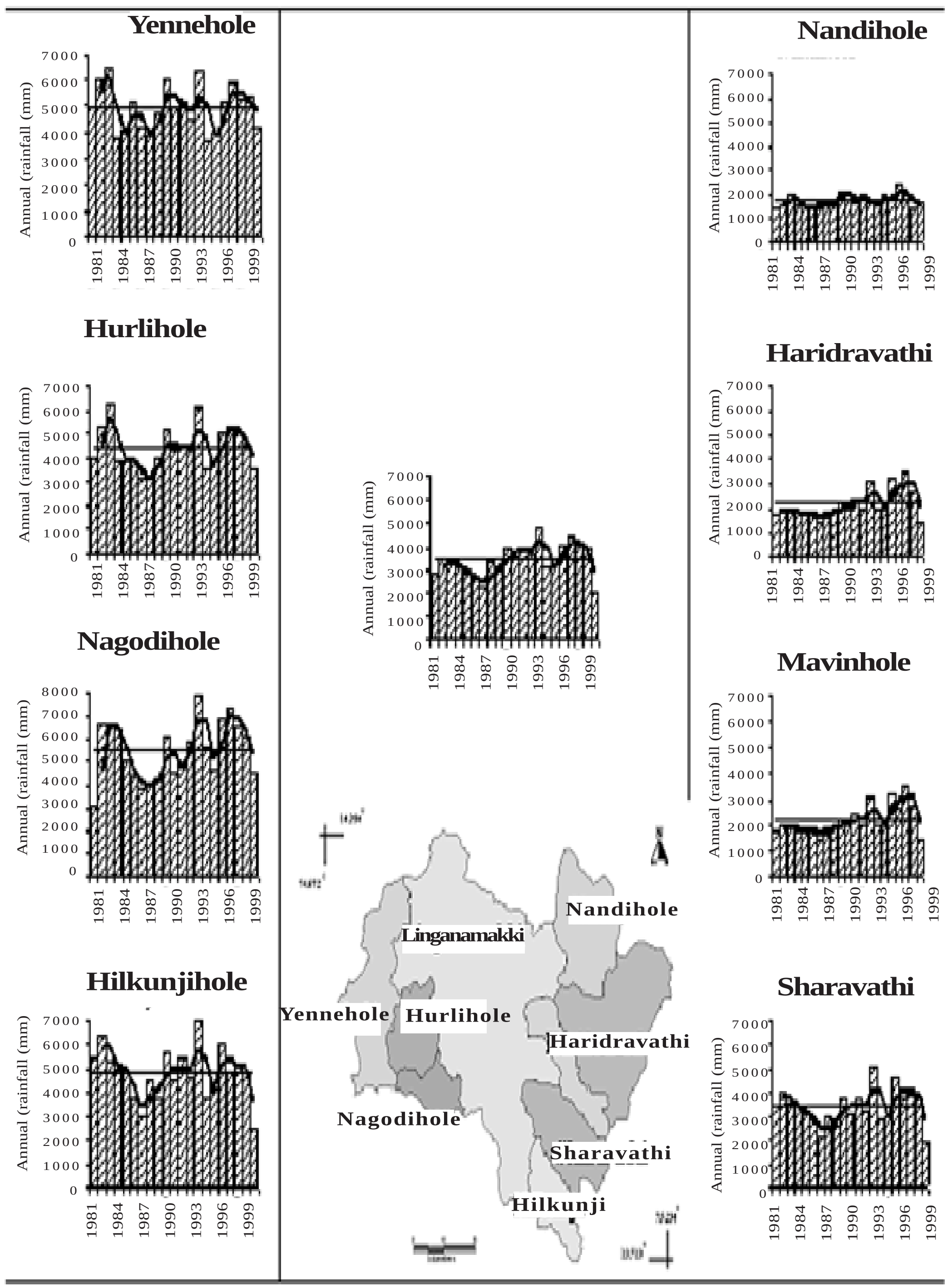

Fig. 12. Annual rainfall pattern in last two decades in the sub-basins of Sharavathi river upper catchment

Interception

Evergreen forests are multilayered and are replete with climbers: lianas and epiphytes. They also have a thick canopy, which can attribute to higher interception in evergreen forests. It is followed by moist deciduous forest which even though have large leaves are more open compared to evergreen/semi-evergreen forests. The structure and composition is also different. There is no layering but the amount of underbrush is high as compared to evergreen forests due to better light penetration. Evergreen/semi-evergreen forests are almost bare of ground vegetation and plants grow only if sufficient light penetrates through gaps in the canopies (Putty and Prasad 2000; Ramachandra et al. 2015). Plantations (acacia) show low values due to the smaller leaf size, which reduces the overall canopy interception. Acacia and areca constitutes a major portion of the plantation trees and have long narrow, vertically aligned leaves. Vertically aligned leaves intercepts lesser rainfall as compared to broad leaves. Areca plantations do have some understorey – small shrubs that yields fruit and sometimes mulching with green leaves is practiced to prevent soil erosion during high intensity precipitation. Paddy intercepts the least rainfall, which shows that interception is highest in trees than in crops or grasses (Calder and Newson 1979; Gash et al. 1980; Lloyd et al. 1988; Shuttleworth 1989; Singh 1992). Interception is highest during July as it receives the highest rainfall and lowest during September and October as these months receive the lowest rainfall in the basin (Fig. 13). Table 10 clearly shows the increase in interception with vegetation and rainfall. High interception in western sub basins is due to good vegetation cover such as evergreen/semi-evergreen forest and moist deciduous forests whereas the vegetation cover such as natural forests is lesser in eastern sub basins. Plantations and agricultural activities are higher in the eastern and southern basins.

Table 10: Percentage of interception w.r.t rainfall

Sub basins	*Interception (%)*
Yenneholé	26.13
Nagodiholé	28.21
Hurliholé	26.73
Linganamakki	24.92
Hilkunji	27.69
Sharavathi	25.48
Mavinaholé	23.61
Haridravathi	21.82
Nandiholé	23.29

Runoff

The most common drainage pattern found in upstream river basin is dendritic. However, the drainage density differs from west to east of the

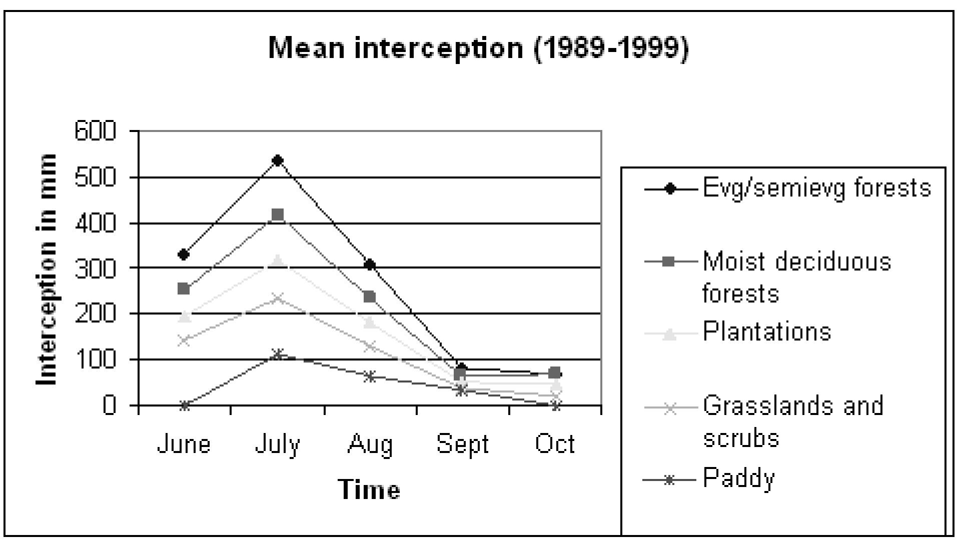

Fig. 13. Mean Interception for Different Vegetation Types

basin that is it decreases from west to east. High drainage densities usually reduce the discharge in any single stream, more evenly distributing runoff and speeding runoff into secondary and tertiary streams. Where drainage density is very low, intense rainfall events are more likely to result in high discharge to a few streams and therefore a greater likelihood of "flashy" discharge and flooding in humid areas and suggests resistant bedrock. Table 11 lists the drainage densities and sediment yields in the sub basins.

Western sub-basins, which are highly vegetated show the highest values due to steep slopes and clayey soil texture. Sediment yield is inversely proportional to vegetation cover. Though western sub basins have steeper slopes compared to eastern sub basins for example Nandiholé, good vegetation cover in the former impedes much of the sediment load and thus erosion during high rainfall events. Table 12 gives the mean monthly surface runoff from each sub basin. Surface runoff progressively increases from evergreen/semi-evergreen forests to settlements, indicating that where there is good vegetation cover, surface runoff is less. Forests usually have thick leaf litter and a spongy humic horizon, both of which retard surface runoff or overland flow. Among the forest types, plantation forests showed higher runoff. Certain species such as *Tectona Grandis*, which are mostly found in the eastern sub basins, cause severe erosion. This is due to the large leaves, which produce big raindrops, which roll of the leaves, and causes splash and subsequently rill erosion if not protected by underbrush.

Groundwater Recharge and Discharge

Groundwater recharge analysis results are given in Table 13. The rate of replenishment or recharge is dependent on the soil moisture status, which in turn is dependent on soil texture. Soil texture in the study area varies from loamy sand to clay loam. From soil studies (Kumar and Ramachandra, 2005), sand is an important constituent in the basin and is responsible for high infiltration rates. Average recharge in the basin is 30.3% of the rainfall. Total mean monthly recharge is observed to vary from west to east with the eastern sub basins receiving the least recharge. Mean monthly recharge under different land use indicate that recharge under vegetation is higher as compared to other land cover types.

Table 11: Drainage density and sediment yield

Sub basins	*Drainage density (km/km^2)*	*Sediment yield ($x\ 10^6\ m^3$/year)*
Yenneholé	2.43	0.016
Nagodiholé	2.8	0.040
Hurliholé	2.6	0.019
Linganamakki	0.9	0.354
Hilkunji	2.16	0.057
Sharavathi	1.64	0.087
Mavinaholé	1.42	0.057
Haridravathi	1.01	0.176
Nandiholé	0.74	0.11

Table 12: Mean monthly surface runoff (1989-1999)

Months Sub-basins	*June (mm)*	*July (mm)*	*August (mm)*	*September (mm)*	*October (mm)*	*Total (mm)*
Yenneholé	311.05	499.64	309.65	79.89	48.06	1241.96
Nagodiholé	398.42	603.27	343.27	86.37	96.16	1496.39
Hurliholé	305.97	499.79	256.57	69.39	54.67	1180.72
Linganamakki	324.11	530.22	290.1	71.36	81.74	1287.72
Hilkunji	257.06	408.14	232.17	59.98	47.94	1000.1
Sharavathi	262	364.06	176.1	48.39	76.35	914.29
Mavinaholé	218.79	356.71	176.64	52.68	80.48	871.5
Haridravathi	262	364.06	176.1	48.39	76.35	702.28
Nandiholé	141.28	217.82	139.67	42.08	95.44	623.9
Upstream	266.42	421.37	236.88	62.71	82.12	1058.05

Table 13: Mean monthly recharge (1989-1999)

Months *Sub basins*	*June (mm)*	*July (mm)*	*August (mm)*	*September (mm)*	*October (mm)*	*Total (mm)*
Yennehole	373.61	620.46	380.94	98.59	46.94	1513.76
Nagodihole	506.22	770.94	438.34	109.72	65.5	1883.3
Hurlihole	329.02	546.28	280.09	75.23	58.44	1282.99
Linganamakki	280.83	495.75	270.88	66.03	58.7	1164.7
Hilkunji	294.71	503.31	286.14	73.55	45.44	1198.12
Sharavathi	212.25	338.87	163.59	44.53	52.81	803.28
Mavinahole	178.7	291.96	144.72	42.68	65.12	712.04
Haridravati	125.9	217.48	135.84	42.98	63.57	576.13
Nandihole	119.75	205.33	131.17	39.17	56.17	544.55
Upstream	220.16	360.62	200.06	55.44	59.33	886.71

The determination of groundwater volumes and flow rates requires a thorough knowledge of the geology of the groundwater basin (Viessman 1989). The geologic structure of a groundwater basin governs the occurrence and movement of the groundwater beneath it. Base flow contribution to stream flow varies widely according to the geologic nature of the aquifer. The two major rock types occurring in the basin are gneisses /granites and greywackes. Gneisses and granites have the lowest specific yield (3%) and occur in the eastern portion of the study area such as Mavinahole, Haridravati and Nandihole. Hence, streams here are ephemeral indicating baseflow only during monsoon season. Western sub basins have perennial streams, which is an indication of the rock types present in the area. The region consists of greywackes, which has higher specific yield of 27%. Another important reason for better discharge in western sub basins is the good vegetation cover. Natural forests retard much of the overland flow facilitating in enhanced infiltration and thus recharge. In other words, regardless of the geology the amount of water entering an aquifer is dependent first on the vegetation and soil present in the area. Forestlands cleared for agriculture or other purposes increases overland flow thus decreasing recharge and subsequent discharge into the streams.

Mean monthly water table levels in the select observation wells showed similar seasonal fluctuations that is water table rises during monsoon season and thereafter decreases. Water table is almost steady during August to September and decreases with the maximum decline in the month of May. Decrease in water levels is partly due to natural discharge or base flow and partly due to artificial extraction of groundwater. Streams located south of the basin receive substantial base flow during non-monsoon season. The amount of base flow decreases from south to east such as Nandihole and Haridravati. It is observed that wells in the region have reported decrease in water levels and as such fail to provide base flow during the lean season. Streams in these sub basins are ephemeral. The total change in storage for each sub basin is given in Table 14. Storage consists of the water contained in soil and the underlying rock. Higher storage in western sub basins is responsible for the lush vegetation present in these areas. Mean annual volumes of hydrological components in each sub basin are given in Table 15.

Table 14: Total storage in Sub-basins

Sub basins	*Mean Total Storage ($x\ 10^6$ M cu.m) (June-Oct)*
Yenneholé	233.09
Nagodiholé	171.56
Hurliholé	86.80
Linganamakki	834.69
Hilkunji	68.55
Sharavathi	70.54
Mavinaholé	48.03
Haridravathi	51.21
Nandiholé	17.6

The evergreen forests have high humidity thereby are the major driving forces in determining the amount of rainfall in these regions. Thus in the upstream, heavy rainfall occurs along Nagodi, Kogar and Aralagodu rain-gauge stations. Forest cover in these regions is also high (land cover analysis, land use analysis) indicating the close relationships between rainfall in Western Ghats regions with the type (evergreen, semi-evergreen, etc.) and spatial extent of vegetation cover (Table 16). Within the catchment

Table 15: Mean annual volumes of hydrological component (x 10^6 m^3)

Sub-basins	*R*	*I*	*ET*	*E*	*SR*	*Pf*	*GR*	*GD*
Yenneholé	983.6	191.96	80.7	25.37	281.78	0.67	286.79	26.47
Nagodiholé	374.68	86.63	32.22	6.7	88.91	0.79	115.75	16.98
Hurliholé	413.69	85.32	42.13	12.74	111.88	0.62	200.72	11.55
Linganamakki	2915.53	379.06	265.12	228.73	815.2	-	749.01	78.05
Hilkunji	337.85	77.31	39.45	7.72	83.03	0.8	99.38	9.23
Sharavathi	358.68	61.53	50.4	17.89	119.0	0.26	105.46	9.46
Mavinaholé	254.41	42.71	33.16	13.58	78.81	0.3	64.97	1.17
Haridravathi	555.82	77.56	90.3	51.25	188.13	-	184.79	3.25
Nandiholé	31.08	49.84	61.24	29.67	125.3	-	97.37	1.86

Table 16: Land-use pattern (%) and associated annual rainfall in the sub-basins of Sharavathi River upstream.

Locality	*Annual forests rainfall (mm)*	*EVG/SE*	*MD*	*Plantation*	*Grassland*	*Agri*	*Open*	*Sett*
Nandiholé	1715.2	1.25	27.34	2.93	29.73	10.55	23.14	5.05
Haridravathi	1776.49	1.30	21.77	3.91	26.82	16.76	24.63	4.81
Mavinaholé	2157.88	2.44	35.09	5.04	21.19	10.66	18.72	6.85
Sharavathi	3382.4	11.54	28.80	10.03	11.58	13.72	19.34	5.00
Hilkunji	4801.25	29.84	34.74	6.45	7.56	5.72	11.46	4.25
Huruliholé	4410.05	22.94	31.54	8.28	13.85	1.28	18.92	3.19
Nagodi	5597.5	40.51	23.54	13.73	4.78	0.05	13.03	4.35
Yenneholé	4933.01	27.32	22.94	14.75	11.50	1.04	19.40	3.05
Linganamakki	3423.25	8.51	34.14	9.35	2.26	8.51	32.88	4.34

* Water body constitutes 15.8% of the region

Note: EVG/SE: Evergreen/semi evergreen; MD: Moist deciduous; Agri: Agriculture; open: open area; sett: settlements

area of Linganamakki, the areas surrounded by rich vegetation like Nagara, Karimane, Byakodu etc. receive high rainfall compared to fragmented, poorly vegetated eastern regions like Ulluru, Anandapura and Ripponpet.

It is found that western side sub-basins (Nagodiholé, Huruliholé, Yenneholé) have rain fall ranges from 4500-6500 mm and their stream flow is quite high having grade of A (perennial streams). Sub-basinwise stream flow is given in Table 17. South east region (Sharavathi, Hilkunji) has rain fall of around 5000mm with stream flow moderate to high having grading of B-C (stream flow for 6 – 9 months). Finally sub-basins of eastern side (Nandiholé, Haridravathi and Mavinaholé) have rain fall of 1400-3000 mm which is very less and their stream flow is also quite low, graded C-D (4 – 6 months: mostly during monsoon).

Table 17: Stream flow data for major tributaries of streams in the Linganamakki catchment

Stream	*Location*	*Stream flow measurement (Discharge m³/sec)*				*Stream Grading**
		Oct.	*Nov.*	*Dec.*	*Jan*	
Nandiholé	Northeast	01.23	03.68	0.09	0	D
Haridravathi	East	16.23	03.02	0.46	0	D
Mavinaholé	East	05.93	03.00	0.44	0	D
Sharavathi	Southeast	26.73	5.83	1.08	0.964	C
Hilkunji	Southeast	46.27	10.64	2.64	1.67	B
Nagodiholé	West	22.56	4.84	1.90	1.42	A
Hurliholé	West	06.30	1.37	0.78	0.661	A
Yenneholé	West	NM	13.40	1.81	1.68	A

* Based on numbers of months with flow a: 12 months, B: 9 months; C: 6 months and D: 4 months

Natural and artificial forces operating over a watershed or a basin ultimately impacts its stream flow regime. Western clusters enjoy the benefit of good rainfall, vegetation and geology to give rise to stream flow even during the lean season. A contrast is seen on the eastern side as volume of stream progressively decreases from Hilkunji to Nandiholé sub-basins. Modification of land by agriculture and other uses, unfavourable geology, clearcutting of natural forests and poor rainfall have resulted in decline in base flow during the non-monsoon months and significant decrease during summer (Mar-May). The study shows that spatial and temporal variation in rainfall corresponding to land use changes has significant role in the water yield in the catchment and hence the reservoir yield. Higher rainfall and the presence of perennial streams (and higher drainage density) in the Western side compared to the eastern side (relatively lower rainfall, poor drainage density and seasonal streams) is due to the large scale land use changes in the east.

CONCLUSION

This study explored and quantified the altered hydrological parameters due to large scale land use and land cover changes in a river basin. In this regard, remote sensing data has offered excellent inputs to monitor dynamic changes through repetitive, synoptic and accurate information of the changes. It also provided a means of observing hydrological state variables over large areas, which was useful in parameter estimation of hydrologic components. GIS offered means for merging various spatial themes (data layers) that was useful in interpretation, analysis and change detection of spatial structures and objects. Studies reveal the linkages among variables such as land use, hydrology and ecology:

i) Rainfall analysis based on one hundred years data for Sagara and Hosanagara show reduction of 3.55% and 5% respectively in the Sharavathi upstream river basin Regression analysis was carried out for each rain gauge station considering rainfall as dependent variable and latitude, longitude, altitude and land cover as independent variables. Regression analysis showed rainfall having significant relationship (5% level of significance) between land cover, latitude, longitude, and altitude. Sensitivity analysis show the relationship holds good for all sub basins in the upstream region of the river basin.

ii) Catchments with good forest (evergreen to semi-evergreen and moist deciduous forests) cover showed reduced runoff as compared to catchments with poor forest covers. Runoff and thus erosion from plantation forests was higher from that of natural forests. Erosion rates in undisturbed natural forest could be considered to represent a natural baseline or background erosion rates against which the erosion rates from all other land uses.

iii) Sub basins with good forest cover showed good amount of dry season flow for all 12 months with the flow decreasing as we move towards east. Decrease of low flows in eastern sub basins can be partly attributed to eucalyptus plantations. Eucalyptus trees have deep roots that tap water deep in the soil mantle creating severe soil moisture deficits. It may take many years of rainfall before field capacity conditions can be established and recharge of the groundwater aquifer and perennial flows can take place. Another reason is the low specific yield of the underlying rock.

iv) This highlights the impacts of land use changes in tropical forests on dry season flows as the infiltration properties of the forest are critical on the available water partitioned between runoff and recharge (leading to increased dry season flows).

v) The anthropogenic influences on the land cover are related to the land use for agriculture, plantation forestry and urbanisation. It was obvious from the present study that land use has an implication on the hydrological components operating in the river basin.

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Ecohydrology of Lotic Systems in Uttara Kannada, Central Western Ghats, India

T.V. Ramachandra, M.D. Subash Chandran, N.V. Joshi, B. Karthick and Vishnu D. Mukri

Abstract The Western Ghats is the primary catchment for most of the rivers in peninsular India. Pristine forests in this region are rich in biodiversity but are under environmental stress due to unplanned developmental activities. This has given rise to concerns about land use/land cover changes with the realization that the land processes influence the climate. Rapid and unscientific land-use changes undermine the hydrological conditions, and deteriorate all the components in the hydrological regime. The developmental programs, based on ad-hocdecisions, are posing serious challenges to the conservation of fragile ecosystems. Considerable changes in the structure and composition of land use and land cover in the region have been very obvious during the last four decades. Pressure on land for agriculture, vulnerability of degraded ecosystems, the vagaries of high intensity rainfall and consequent occurrences of accelerated erosion and landslides, lack of integrated and coordinated land use planning become some of the reasons for rapid depletion of natural resource base. These changes have adversely affected the hydrological regime of river basins, resulting in diminished river/stream flows. This necessitates conservation of ecosystems in order to sustain their biodiversity, hydrology and ecology. In this situation, for resolving present problems and to avoid any future crisis, a comprehensive assessment of land use changes, its spatial distribution and its impact on hydrological regime were carried out. Accordingly, appropriate remedial methods have been explored for the sustainable utilization of the land and water resources in the catchment. The current research, focusing on five rivers located in the central Western Ghats, monitors water quality along with that of diatoms, land use in the catchment and threats faced by these ecosystems.

Keywords Western Ghats · Lotic ecosystems · Water quality · Diatoms

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1 Introduction

Freshwater ecosystems are grouped into lotic and lentic systems, that is, systems comprising of flowing or standing water. There are many varieties of plant and animal communities in these ecosystems which have adapted to the physical conditions associated with them. Environmental pollution, mainly pertaining to water, has gained public interest (Niemi et al. 1990) in recent times. Not only the developed countries have been affected by environmental problems, but also the developing nations suffer the impact of pollution (Listori and World-wide Bank 1990) due to unplanned developmental activities. Surface waters are vulnerable to pollution due to their proximity to pollutants on land which get dispersed off as polluted runoff and wastewaters and also due to the sustained inflow of untreated sewage. Quality of the surface waters are altered by the natural processes such as precipitation, erosion, and weathering as well as from the anthropogenic influences such as agricultural activities, urbanization, industrialization and intensive-exploitation of water resources (Jarvie et al. 1998). These impacts reduce both water quality (Sweeting 1996) and biological diversity of aquatic ecosystems (Maddock 1999).

Rivers play a major role in the assimilation or in carrying off the municipal and industrial wastewater and run-off from agricultural land. The surface run-off is a seasonal phenomenon, which is largely influenced by the climate prevailing in the basin. Seasonal variations in precipitation, surface run-off, interflow, groundwater flow and water inflows/outflows have a strong effect on the river discharge and subsequently on the concentration of nutrients/pollutants in the river water (Vega et al. 1998). Rivers are the main inland water resources for domestic, industrial and irrigation purposes and it is imperative to prevent and control river pollution. This necessitates regular monitoring to have reliable information on quality of water for effective management. In view of the spatial and temporal variations in hydrochemistry of rivers, regular monitoring programs are required for reliable estimates of water quality and conservation of riverine biodiversity. An integrated aquatic ecosystem management requires sound understanding of physical, chemical and biological aspects. An attempt is made in the present study to determine the water quality status through diatoms as bio-indicators in the rivers of central Western Ghats.

The Western Ghats of India, one of the global biodiversity hotspots, is a chain of mountains on the Western Coast with about 1,600 km long and about 100 km wide stretch (between 8°N and 21°N). The region has varied forest types from tropical evergreen to deciduous to high altitude sholas. It is also an important watershed for the peninsular India with as many as 37 west flowing rivers, three major east flowing rivers and innumerable tributaries. In this paper, the water quality along with diatoms, land use in the catchment and threats faced by these ecosystems are evaluated based on the study of five rivers in central Western Ghats. Aim of this work is to understand the ecohydrology of west flowing rivers in the central Western Ghats. The work involved exploring the current water quality status of five rivers of the Uttara Kannada District, Karnataka, assessment of the seasonality of diatoms and application of diatoms in bio-monitoring in Western Ghats, understanding the impact of catchment land-use and land-cover on water quality and diatom community in streams, identification of the stretches with major water pollution and provide recommendation for mitigation and conservation of rivers of Uttara Kannada.

2 Lotic Ecosystems of Central Western Ghats: An Overview on the Study Area

Rivers of the central Western Ghats are unique in their geomorphology, due to the presence of 'river capture' in most of the rivers. When the Indian plate moved away from the Gondwanaland, peninsular portion experienced an eastward tilt, which changed the pattern of drainage in many rivers. In many cases, like Sharavathi and Kali rivers in Uttara Kannada (Fig. 1), the western faulting led to 'river capture' and diversion of the easterly drainage to the west (Radhakrishna 1991; Kamath 1985). Five rivers are chosen for the present study. Brief descriptions on them are presented herein.

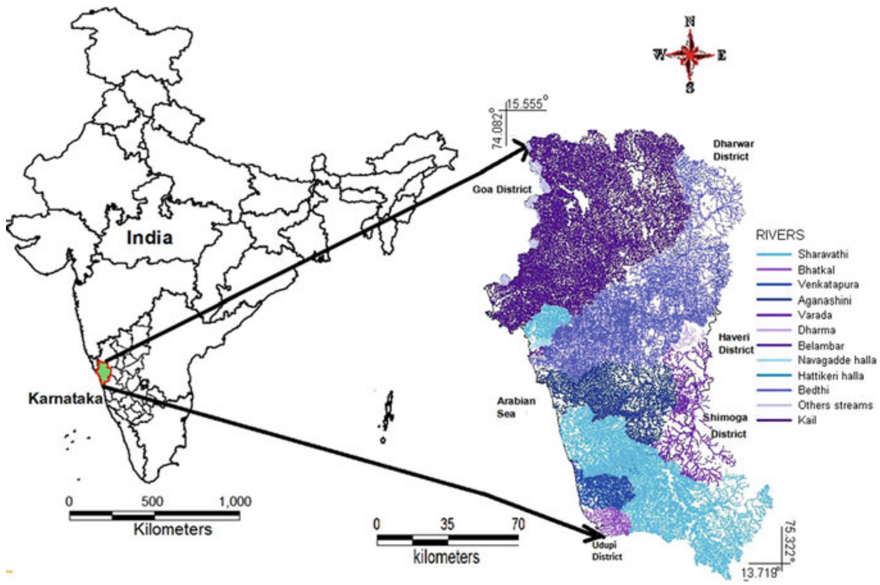


Fig. 1 Study region—Uttara Kannada district with rivers (*Source* Energy and Wetlands Research Group, CES, Indian Institute of Science)

2.1 Kali River

The Kali River (Fig. 2) flows for a length of 184 km. Previously, it originated near the village Diggi in Supataluk, as Karihole. After the construction of the dam near Supa, the entire region is now submerged in the reservoir. Pandri and Ujli are the two main tributaries of this river in the North and the stream Tattihalla also joins near Haliyal. The Kaneri and the Vaki are its two main tributaries that join at Dandeli and Anshi Tiger Reserve respectively. Later near Kadra, Thananala joins the main river. In all, the catchment area of the river is about 5,179 km^2 and the annual river discharge is estimated to be 6,537 million cu. m (Bhat 2002). There are four major dam projects on this river—the Supa reservoir near the headwaters, the Bommanhalli reservoir near the Dandeli Wildlife Sanctuary, the Kodasalli dam near Ganeshgudi and finally, one at Kadra (which is the part of the Kaiga project).

2.2 Bedthi River

The River Bedthi River (Fig. 3) originates near Hubli taluk. The river, has a total length of 152 km with a catchment area of 3,902 km^2. It discharges 4,925 million cu. m of water annually.

2.3 Aghanashini River

The Aghanashini River (Fig. 4) originates at Manjguni near Sirsi. After winding westerly course of about 70 km, it debauches into the sea about 10 km south of Bedthi. The river has two sources—a tributary called Bakurhole, rising at Manjguni, about 25 km west of Sirsi and Donihalla, which is close to Sirsi. These two streams meet at Mutthalli about 16 km south of Sirsi. Under the name Donihalla, it flows for about 25 km south of Sirsi westwards to Sahyadri's west face and at Heggarne in Siddapur, it falls off a height of about 116 m as the Lushington (or the Unchalli) falls. Further down 6 km from Bilgi near Hemanbail, it flows down again as the Burdejog. It finally meets the sea at Uppinpatna. The Aghanashini covers a catchment area of 2,146 km^2. It has an annual discharge of 966 million cu. m.

2.4 Sharavathi River

The 128 km long Sharavathi River (Fig. 5) originates at Ambutirtha in Tirthahallitaluk of Shimoga District. After a northerly course of about 64 km from Sagar, it forms the southeastern border of the Uttara Kannada District for about 13 km and flows a further

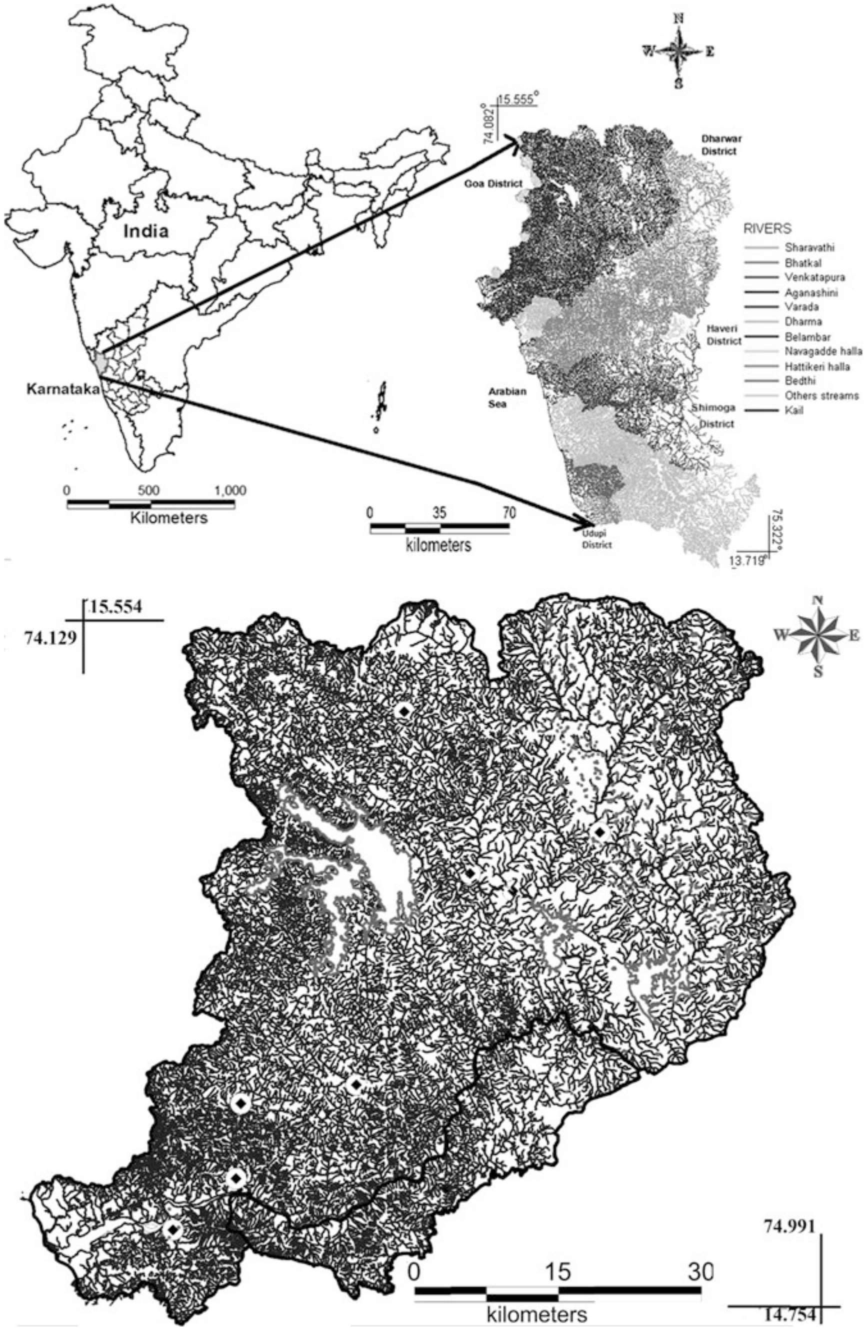


Fig. 2 River Kali with sampling sites

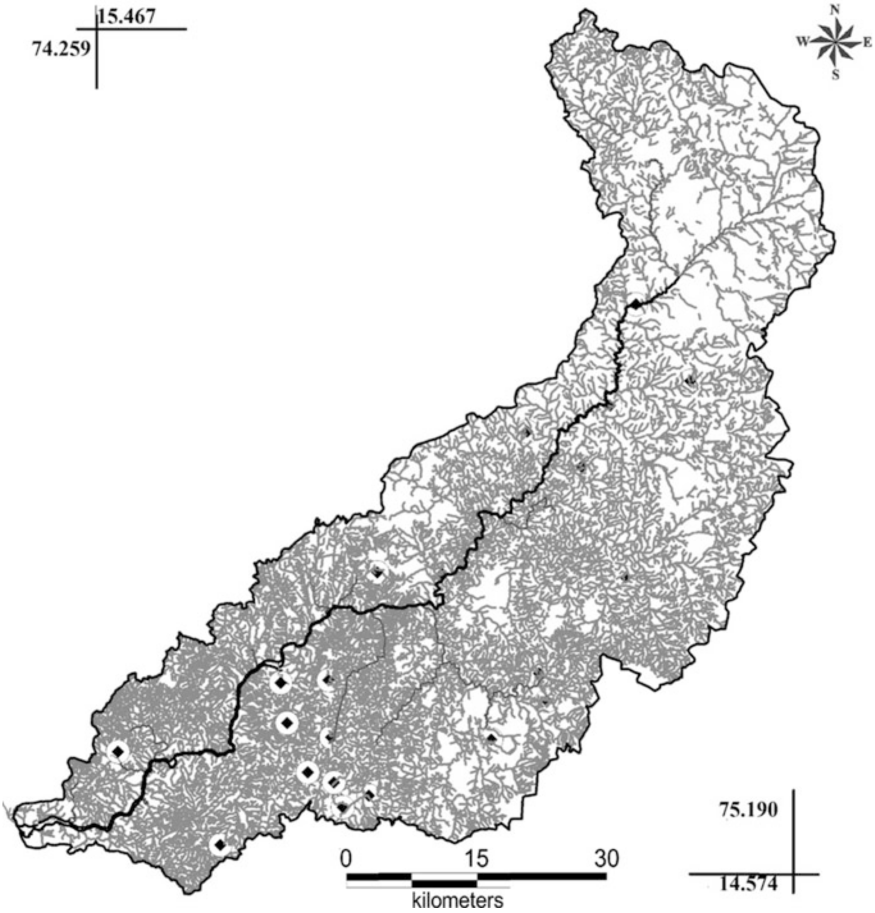


Fig. 3 River Bedthi with sampling sites

32 km to join the sea at Honnavar. Soon after touching the Uttara Kannada border the river falls off the western face of the Ghats in Jog falls at a height of 252 m into a pool 117 m deep. About 30 km west, it reaches Gersoppa. The Sharavathi has a catchment area of 2,209 km^2 and an annual discharge of 4,545 million cu.m.

2.5 Venkatapura River

The Venkatapura River (Fig. 6) originates in Western Ghats and confluence into Arabian Sea after a course of 45 km near Venkatapura with a catchment of 335 km^2. The river basin is divided into sub basins namely Chitihalla, KatagarNala, BastiHalla, Kitrehole and Venkatapura based on major tributaries.

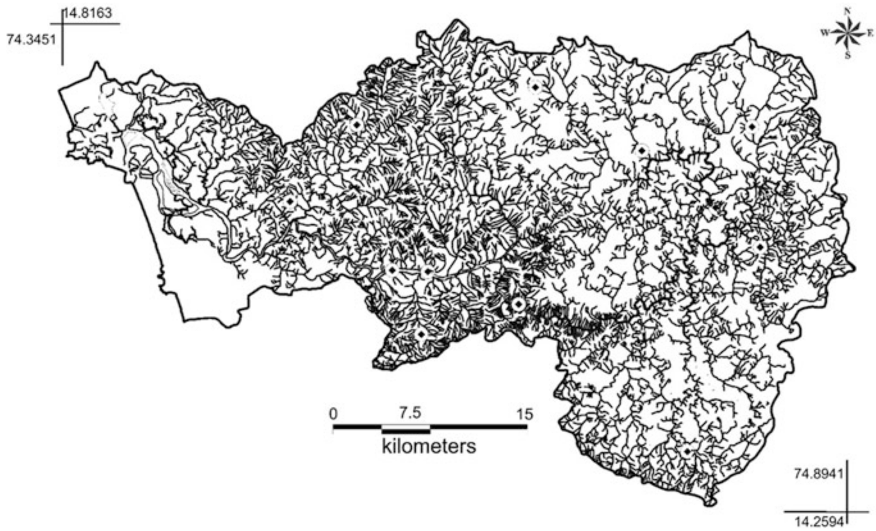


Fig. 4 River Aghanashini with sampling sites

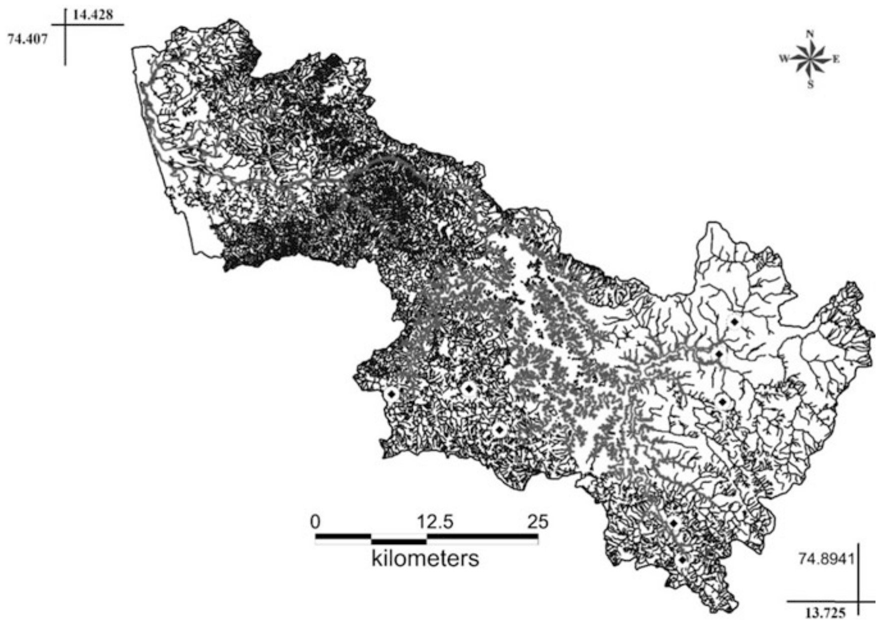


Fig. 5 River Sharavathi with sampling sites

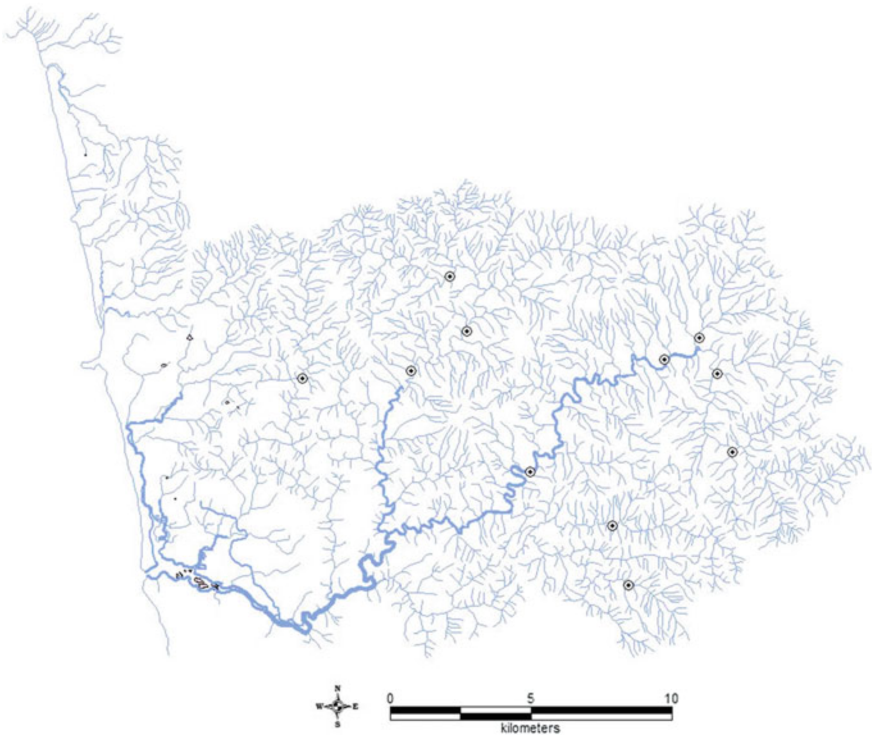


Fig. 6 Venkatapura River with sampling sites

3 Materials and Methods

3.1 Water Quality Monitoring

Water samples were collected at each sampling locations (Table 1) from each source in clean polythene containers of 2.5 L capacity. The sample containers were labeled with a unique code and date of collection. pH, water temperature, Total Dissolved Solids, Salinity and Nitrates were recorded immediately after collection using EXTECH COMBO electrode and Orion Ion Selective Electrode. Other parameters namely, chloride, hardness, magnesium, calcium, sodium, potassium, fluoride, sulphate, phosphates, and coliform bacteria were analyzed in lab. All the analyses were carried out as per the procedures provided in Standard Methods for the examination of water and wastewater (APHA 1998). Details of the methods of water quality determination are presented in the Table 2.

Table 1 Details of the sampling sites (river basin-wise—marked in Figs. 2, 3, 4, 5, and 6)

SITES	CODE	LAT	LON	SITES	CODE	LAT	LON
Aghanashini river basin (ARB)				*Kali river basin (KRB)*			
Sonda	A1	74.4834	14.4868	Beegar	K1	74.5818	14.9163
Nellimadke	A10	74.8431	14.5289	Astolli	K10	74.5383	15.4289
Neralamane	A11	74.8439	14.4554	Kervada	K2	74.6368	15.2454
Balur	A12	74.8098	14.4853	Mavlangi	K3	74.5923	15.2561
Baillalli	A13	74.7920	14.3013	Tatwala	K4	74.7466	15.0879
Hulidevarakodlu	A2	74.6643	14.4040	Sakathi	K5	74.3378	14.9185
Donehole	A3	74.5878	14.4330	Naithihole	K6	74.2593	14.8543
Deevalli	A4	74.5584	14.4332	Kesrolli	K7	74.7412	15.3037
Ullurmatha	A5	74.5823	14.3844	Kaneri	K8	74.4676	15.0247
Yanahole	A6	74.5355	14.5344	Badapoli	K9	74.3560	15.0144
Jalagadde	A7	74.6127	14.5480				
Kurse	A8	74.6900	14.5595				
Sappurthi	A9	74.7562	14.5234				
Bedthi river basin (BRB)				*Sharavathi river basin (SRB)*			
Mathigadda	B1	74.5926	14.6730	Nandiholé	S1	75.1245	14.0418
Vajgadde	B10	74.6154	14.6213	Haridravathi	S2	75.1084	14.0209
Nycti. Site	B11	74.6120	14.6390	Mavinaholé	S3	75.1055	13.9735
Angadibail	B12	74.5332	14.6067	Sharavathi	S4	75.0804	13.8532
Daanandhi	B13	74.8667	14.7358	Hilkunji	S5	75.0896	13.7730
Hemmadi	B14	74.8586	14.7510	Nagodiholé	S6	74.8839	13.9269
Attiveri	B15	75.0357	15.0759	Hurliholé	S7	74.8428	13.9786
Yerebail	B16	74.9395	15.0470	Yenneholé	S8	74.7268	13.9650
Gunjavathi	B17	74.9140	14.9921				
Chitgeri	B18	74.9834	14.8557	*Venkatapura river basin (VRB)*			
Karadrolli	B19	74.8356	14.9918	Badabhag	V1	75.6293	14.0588
Kammani	B2	74.5958	14.7132	Bachochodi	V10	74.6907	14.0901
Dabguli	B20	74.6572	14.8508	Kelanur	V11	74.6959	14.0653
Ramanguli	B21	74.6054	14.1238	Undalakatle	V2	74.5900	14.0910
Kalghatghi	B22	74.9785	15.1586	Midal	V3	74.5543	14.0888
Manchiker	B23	74.7861	14.8910	Arkala	V4	74.6563	14.0415
Apageri	B3	74.5840	14.6389	Galibyle	V5	74.6085	14.1038
Hasehalla	B4	74.5840	14.7551	Nagoli	V6	74.6735	14.0946
Kaleswara	B5	74.6095	14.7587	Ondalasu	V7	74.6028	14.1213
Andhalli	B6	74.8016	14.6701	Hegganamakki	V8	74.6848	14.1018
Makkigadde	B7	74.4299	14.7095	Kurandura	V9	74.6616	14.0227
Kelaginkeri	B8	74.5926	14.6730				
Devanahalli	B9	74.6635	14.6281				
Kurandura	V9	74.6616	14.0227				

Table 2 Methods used for analysing water samples

Parameters	Units	Methods	Section no. APHA 1998
pH	–	Electrode method	4500-H^+ B
Water temperature	°C		2550 B
Salinity	ppm		2520 B
Total dissolved solids	ppm		2540 B
Electrical conductivity	µS		2510 B
Dissolved oxygen	mg/L	Iodometric method	4500-O B
Alkalinity	mg/L	HCl titrimetric method	2320 B
Chlorides	mg/L	Argentometric method	4500-Cl^- B
Total hardness	mg/L	EDTA titrimetric method	2340 C
Calcium hardness	mg/L	EDTA titrimetric method	3500-Ca B
Magnesium hardness	mg/L	Calculation method	3500-Mg B
Sodium	mg/L	Flame emission photometric method	3500-Na B
Potassium	mg/L	Flame emission photometric method	3500-K B
Fluorides	mg/L	SPADNS method	4500-F- D
Nitrates	mg/L	Nitrate electrode method and phenol disulphonic acid method	4500-NO3- D
Sulphates	mg/L	Turbidimetric method	4500-SO_4^{2-} E
Phosphates	mg/L	Stannous chloride method	4500-P D

3.2 Diatom Collection, Preparation and Enumeration

Figure 7 illustrates the habitat of diatoms—diatom colonies on stones, sand, etc. At each site, three to five stones were randomly selected across the stream and diatoms were scraped off the exposed surface of the stones using a tooth brush. Fresh samples were carefully checked to assure that majority of the diatom frustules were alive prior to acid combustion. A hot HCl and $KMnO_4$ method was used to clean frustules of organic materials. The cleaned diatom samples were dried on 18 × 18 mm cover slips and mounted with Pleurax. A total of 400 frustules per sample were enumerated and identified using compound light microscope (Lawrence and Mayo LM-52-series, with 1,000 X magnification) following the methods described by Taylor et al. (2005) and Karthick et al. (2010). Diatoms were identified at species level according to Gandhi (1957a, b, c, 1958a b, 1959a, b, c, 1960a, b, c), Krammer and Lange-Bertalot (1986–1991) and Taylor 2004; Taylor et al. (2007a, b).

Fig. 7 Diatoms on stone in streams

3.3 Land Use Land Cover (LULC) Analysis

The remote sensing data were processed to quantify the land use of respective basins broadly into 6 classes—forest and vegetation; agriculture and cultivated area; open scrub and barren; water bodies; built-up; and others (includes categories like rocky outcrop, etc.). The multi-spectral data of Indian Remote Sensing (IRS) LISS-III with a spatial resolution of 23.5 m were analyzed using IDRISI Andes (Eastman 2006; http://www.clarklabs.org) and GRASS (http://ces.iisc.ernet.in/grass). Land use analysis involved (a) generation of False Colour Composite (FCC) of remote sensing data (bands—green, red and NIR). This helped in locating heterogeneous patches in the landscape (b) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15 % of the study area and uniformly distributed over the entire study area, (c) loading these training polygons co-ordinates into pre-calibrated GPS, (d) 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, (e) supplementing this information with Google Earth (http://www.googleearth.com) (f) 60 % of the training data has been used for classification, while the balance was used for validation or accuracy assessment. Based on these signatures, corresponding to various land features, supervised image classification was carried out using Gaussian Maximum Likelihood Classifier (GMLC) to the final six categories.

3.4 Data Analysis

Compiled data were tested for normality before performing statistical analyses. Statistical analyses comprised Kruskal-Wallis test (H), Principal Component Analysis (PCA) and Non-Metric Multi Dimensional Scaling (NMDS). All the tests were performed using the R-software (R Development Core Team 2006). Box plots were used to visually summarize the data. The line in the box indicates the median value of the data. If the median line within the box is not equidistant from the edges of the box, then the data are skewed. "Gridding" is the operation of spatial interpolation of scattered 2D data points onto a regular grid. Gridding allows the production of a map showing a continuous spatial estimate. The spatial coverage of the map is generated automatically as a square covering the data points. Non-metric multidimensional scaling is based on Bray-Curtis distance matrix was performed for classifying the sites across river basins. In NMDS, data points are placed in 2 or 3 dimensional coordinates system preserving ranked differences.

The non-parametric Kruskal-Wallis test was used to assess whether species richness, species diversity and turnover across water quality regimes were significantly different. Temporal variation in diatom assemblages in each site was analyzed by NMDS using absolute abundance data. NMDS is an ordination method well suited to data that are non-normal or are arbitrary or discontinuous and for ecological data containing numerous zero values (Minchin 1987; McCune and Grace 2002). Results were visualized showing the most similar samples closer together in ordination space (Gotelli and Ellison 2004). A final stress value, typically between 0 and 15, was evaluated as a measure of fitted distances against the ordination distance, providing an estimation of the goodness-of-fit in multivariate space. Changes in species composition or percentage turnover (T) were used to indicate community persistence. T was calculated as $T = (G + L)/(S1 + S2)$ times 100 where G and L are the number of taxa gained and lost between months respectively, and S1 and S2 are the number of taxa present in successive sampling months (Diamond and May 1977; Brewin et al. 2000; Soininen and Eloranta 2004). The relationship between the local population persistence, the local abundance in terms of relative abundances, and the regional occupancy were examined using correlation analysis (Soininen and Heino 2005). For the species distribution model, the species were classified as core species as species that occurred in over 90 % of sites, and satellite species as species that occurred in fewer than 10 % of sites (McGeoch and Gaston 2002; Soininen and Heino 2005). Local occupancy of each diatom species was calculated by their percentage of occurrence at each site across the seasons. Seasonal diatom community was related to the water quality parameters using multiple linear regressions. Finally, water quality variables were used in PCA to elucidate the spatial water quality variation.

4 Results and Discussion

4.1 PH

The pH of river water is the measure of negative logarithm of hydrogen ion concentration that indicates how acidic or basic the water is on a scale of 0–14. Most of the peninsular rivers fall between 6.5 and 8.5 on this scale with 7.0 being neutral. The optimum pH for river water is around 7.4. Water's pH can be altered by industrial and agricultural runoff. Vajgadde at BRB (Bedthi River basin) has recorded low pH of 6.9 and Kalghatgi from the same river has recorded highest pH of 8.27. Low ranges of pH are observed in the forested streams and high alkaline pH are observed in sites contaminated with agricultural and urban runoff (Figs. 8 and 9). A pH of 8.0 should be sufficient to support most river life with the possible

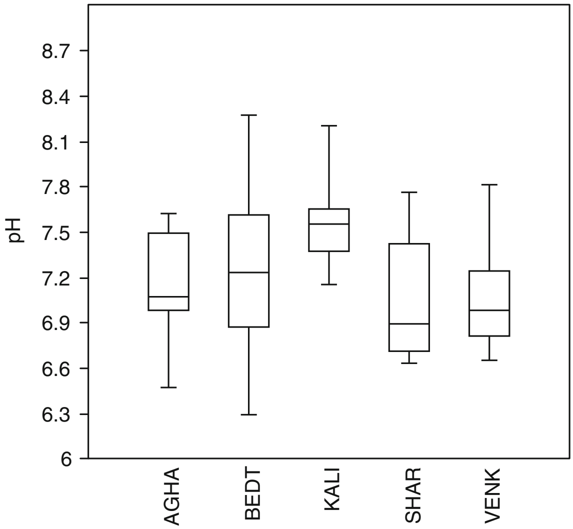


Fig. 8 pH across river basins

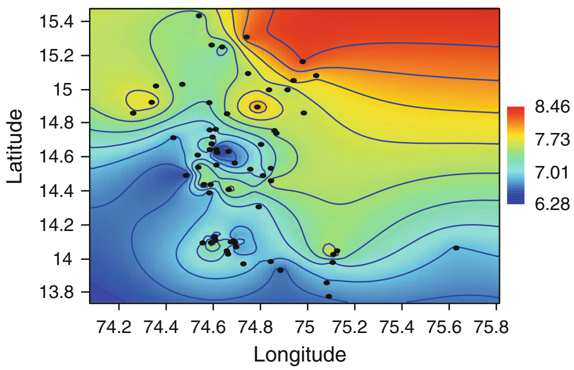


Fig. 9 Spatial representation of pH across sites

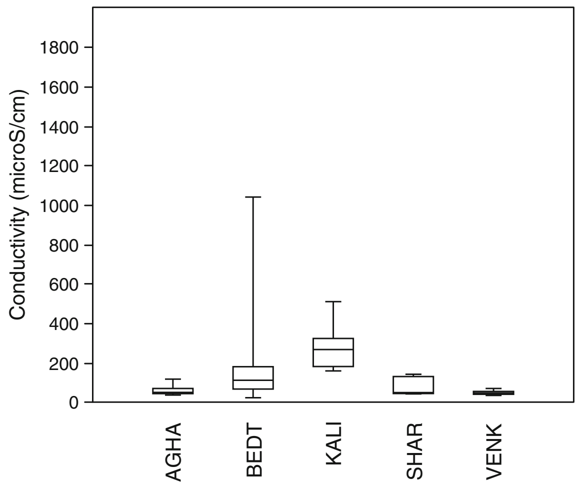
exception of snails, clams, and mussels, which usually prefer a slightly higher pH. The average pH in the study was 6.9, a value that is only sufficiently basic for bacteria, carp, suckers, catfish, and insects. BRB (Bedthi River basin) and KRB (Kali River basin) record most of the alkaline nature, whereas ARB (Aghnashini River basin), SRB (Sharavathi River basin) and VRB (Venkatapura River basin) sites record neutral to near acidic nature.

4.2 Electrical Conductivity and Total Dissolved Solids

Pure water does not conduct electricity. Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cat ions (ions that carry a positive charge). Organic compounds such as oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate in it; an oil spill would lower the conductivity.

Low level of electrical conductivity was observed at Vajgadde at BRB (22.5 μS/cm) and highest value was recorded from Kalghatghi of the BRB (1038.95 μS/cm), as illustrated in the Fig. 10. Sites of BRB showed high levels of variation when compared to the SRB and VRB. KRB sites recorded comparatively higher conductivity and

Fig. 10 Electrical conductivity across river basins



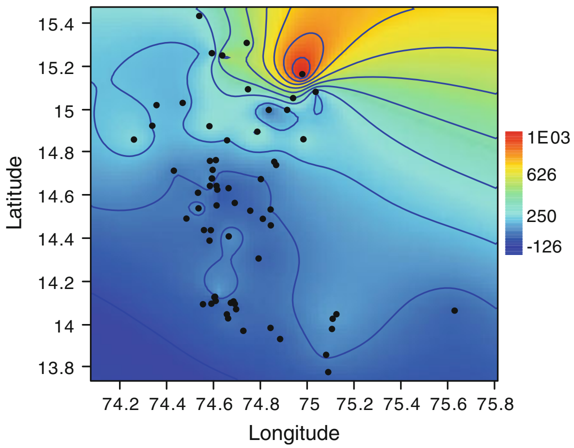


Fig. 11 Spatial representation of electrical conductivity across sites

total dissolved solids, perhaps due to the accelerated erosion associated with the conversion of natural vegetation into monoculture plantations in its catchment area in the north part of the river basin (Fig. 11).

4.3 Dissolved Oxygen

The atmosphere is a major source of dissolved oxygen in river water. Waves and tumbling water mix atmospheric oxygen with river water. Oxygen is also produced by rooted aquatic plants and algae as a product of photosynthesis. An adequate supply of dissolved oxygen (DO) is essential for the survival of aquatic organisms. A deficiency of DO in is a sign of an unhealthy river. There are a variety of factors affecting the levels of dissolved oxygen.

In the present study, lowest dissolved oxygen levels were observed in Kervada (3.67 mg/L) located in the KRB. This site is located adjacent to the effluent discharge point of a Paper mill (Fig. 12). The paper mill effluent is characterized with high levels of organic content, which might consume most of the oxygen for its degradation with the help of bacteria. Bacteria which decompose plant material and animal waste consume dissolved oxygen, and decrease the quantity available to support life. Ironically, it is life in the form of plants and algae that grow uncontrolled due to fertilizer that leads to the masses of decaying plant matter. This site is also infested with marsh crocodiles (*Crocodylus palustris*), which prevails as a major threat to the humans and livestock in the surroundings. Crocodiles are attracted to this particular place due to availability of the solid organic contents present the paper mill effluent. Sites at SRB recorded saturated levels of dissolved oxygen in the streams and all other sites recorded with high variation. Apart from the organic pollution other reason for low levels of dissolved oxygen is lack of mixing in water. Small to medium sized check dams are constructed in the middle

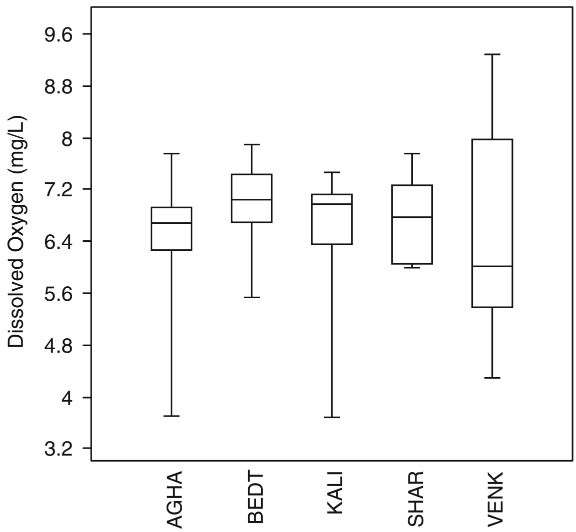


Fig. 12 Dissolved Oxygen levels across river basins

reaches of all the rivers, might have converted the lotic system into lentic system wherein diffusion of atmospheric oxygen into stored water is highly restricted due to the stagnant conditions. Thus, many factors namely organic pollution, active consumption by bacteria, algae and exotic plants and reduced influx due to damming have all contributed towards low levels of dissolved oxygen.

4.4 Nutrients

Unlike temperature and dissolved oxygen, the presence of nitrates usually does not have a direct effect on aquatic insects or fish. However, excess levels of nitrates in water can create conditions that make it difficult for aquatic insects or fish to survive. Nitrate-nitrogen is important because it is biologically available and is the most abundant form of nitrogen in Central Western Ghats streams. Like phosphorus, nitrate can stimulate excessive and undesirable levels of algal growth in water bodies leading to eutrophication. Nitrates come to the streams mainly from the runoff from the agriculture farms and eroded sediments. Runoff from the agriculture farms carries huge amount of fertilizer residues. Among the studied river basins, the KRB and BRB recorded high levels of nitrates from its upstream region (Fig. 13). Both KRB and BRB possess intense agriculture and limited surface water bodies in their upstream regions which leads to high levels of nitrates.

Along with the nitrates, phosphate also plays an important role in the river hydrobiology. Phosphorus is an important nutrient for plant growth. Excess phosphorus in the river is a concern because it can stimulate the growth of algae. Excessive algae growth, death, and decay can severely deplete the oxygen supply in

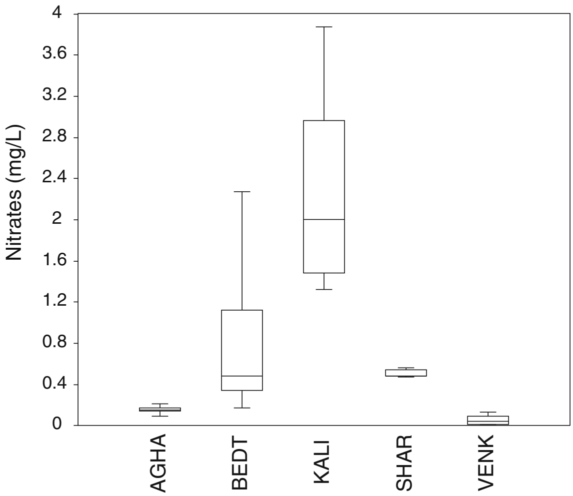


Fig. 13 Nitrate across River Basins

the river, endangering fish and other forms of aquatic life. Urban runoff is the major source for phosphates in the streams. Among the studied basins, BRB receives considerable amount of urban sewage from Hubli city. The impact of high levels of phosphates leads to algal blooms in many reaches of the Bedthi River. Manchikeri site located in between Sirsi and Yellapur has a check dam for pumping water for drinking water supply. Recently another check dam was constructed near the Manchikeri Bridge to store water for Yellapur drinking water supply. Though check dam stores water to support drinking water supply, owing to the intensive agricultural and other activities in the upstream regions, check dam also plays as a reservoir for pollutants and reduces the chances of the accumulated pollutants diffusing away. Stagnated water with heavy nutrient content leads to algal bloom. Preliminary investigations suggest that the algal bloom was created by algal genus *Microcystis,* a blue-green algae (also referred to as Cyanobacteria). It is a common bloom-forming algae found primarily in nutrient enriched river and lake waters. This genus is colonial, which means that single cells can join together in groups which tend to float on the water surface. Colony sizes will vary from a few to hundreds of cells. Any large algal bloom has the potential to result in fish kills by depleting the water of oxygen. The dead algal cells sink down and consume huge amount of oxygen for their decomposition. In such situations, there may not be enough oxygen remaining in the water to support fish in the vicinity. Furthermore, as these large blooms die and sink to the bottom, they commonly release chemicals that can produce a foul odor and musty taste. Some strains of *Microcystis* may produce toxins that have been reported to result in health problems to animals that drink the water, and minor skin irritation and gastrointestinal discomfort in humans that come in contact with toxic blooms. Uncontrolled growth of single species of algae will also lead to death of aquatic invertebrates and fishes due to unavailability of food, which in turn affects the aquatic food chain.

4.5 Lotic Ecosystems: Intra Basin Variations in Quality

Principal component analysis reveals that the BRB contains sites with pristine to heavily polluted waters. Most of the sites in northern part of BRB stand out separately in ordination space due to their very high amount of ions and nutrients. Sites in the SRB, KRB and ARB seem to fall in the same quality of water, whereas the VRB stands out separately with very pristine water quality status (Figs. 14 and 15). NMDS plot of the water quality variables shows that ionic and physical parameters have the same origin, where as nutrients arise from different source (Fig. 15).

4.6 Seasonality of Benthic Diatoms and Water Quality

The water chemistry data along the Bedthi River showed high annual variation across sites. The parameters which showed significant difference among the groups are pH, conductivity, chlorides, hardness, calcium, magnesium, sodium and potassium. All these parameters were found to be high in HPAS, moderate in MPPS and very low in LPFS (Table 3). Irrespective of the pollution status, dissolved

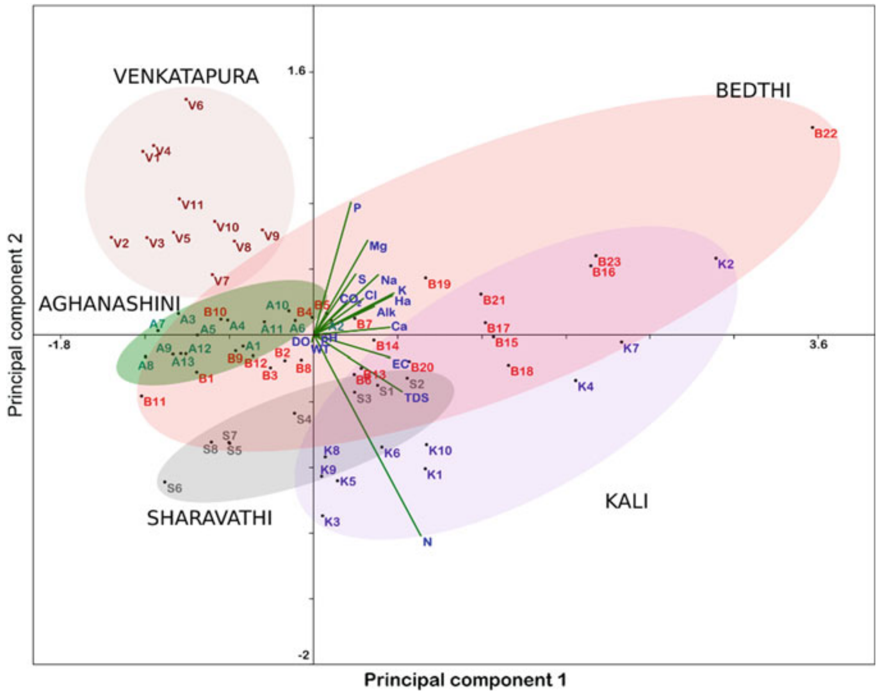


Fig. 14 PCA plot for water quality variables across the River Basins

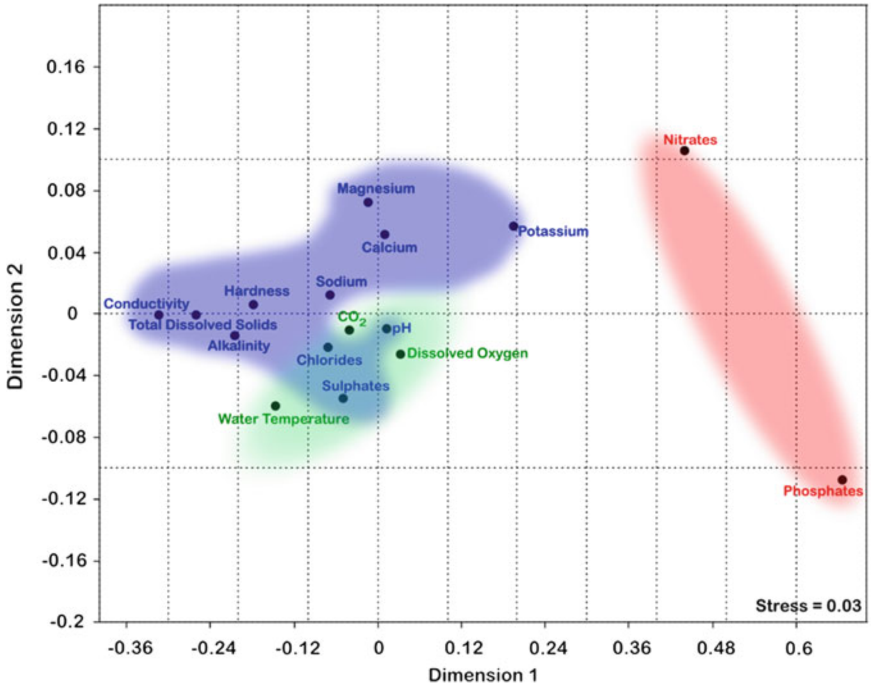


Fig. 15 NMDS plot of water quality variables across River Basins

Table 3 Species richness and diversity across space and time at BRB sites

Months	LPFS		HPAS		MPPS	
	KAM	HAS	KAL	MAN	AND	DAN
Jan	14 (1.10)	10 (1.04)	7 (1.58)	-L-	4 (0.81)	14 (2.27)
Feb	10 (1.58)	6 (1.10)	7 (1.65)	9 (1.63)	4 (1.04)	19 (2.34)
Mar	4 (1.25)	6 (0.85)	8 (1.73)	14 (1.90)	6 (0.95)	-D-
Apr	7 (1.47)	7 (0.67)	9 (1.65)	1 (0)	8 (0.93)	-D-
May	11 (1.40)	4 (0.47)	3 (0.92)	8 (1.34)	11 (1.76)	-D-
Jun	9 (1.16)	3 (0.15)	4 (1.02)	-M-	3 (0.98)	5 (1.14)
Jul	4 (0.77)	-M-	1 (0)	-M-	6 (1.19)	7 (1.46)
Aug	-M-	-M-	-M-	-M-	5 (0.79)	5 (1.35)
Sep	1 (0)	-M-	1 (0)	-M-	2 (0.69)	9 (1.67)
Oct	4 (0.78)	5 (0.77)	5 (1.34)	5 (1.15)	9 (1.29)	9 (1.35)
Nov	4 (0.82)	4 (0.94)	6 (1.54)	-L-	-L-	4 (0.84)
Dec	4 (0.87)	-L-	8 (1.76)	16 (2.02)	2 (0.69)	10 (1.39)

oxygen (DO) levels across water quality regimes were roughly similar with mean DO levels (Mean ± S.D) of 7.51 ± 1.67, 7.08 ± 2.21, 6.43 ± 2.91. However, anoxic DO level of 0.86 mgL^{-1} was observed in one sample from the HPAS (KAL). PCA results indicated that water quality differed markedly among sampling sites and across seasons (Fig. 14) with the first component explaining 84.6 % of the total variation. Three distinct clusters were observed along a pollution gradient. Sample scores from HPAS (KAL and MAN) were positioned to the right along PCA axis 1, and were characterized by higher conductivity, phosphates, nitrates, alkalinity, hardness, calcium, sodium and potassium levels. MPPS (AND, DAN) were positioned along the PCA axis 2. In contrast, samples from the LPFS (HAS, KAM) were located to the left along the PCA axis 1, and were characterized by higher DO and low levels of ions and nutrients. Water chemistry parameters namely, the pH, carbon dioxide, alkalinity, nitrates, sulphates were positively loaded while dissolved oxygen was negatively loaded with principal axes. These results indicate that the water chemistry between these sites was strongly different throughout the year. Stream water chemistry differed between the three groups of sites (Fig. 16). Clusters illustrated in Fig. 17 reveal distinct grouping based on the ion and nutrient concentrations in the respective sampling sites across the river basins.

One hundred and three species of diatoms were recorded from all the six sites during the study period, with a flora typical of oligotrophic to eutrophic conditions. Among the taxa recorded, the *Achnanthidium minutissimum* (Kütz) Czarn., *Gomphonema gandhii* Karthick and Kociolek, *G. difformum* Karthick and Kociolek, *Nitzschia palea* (Kütz) W. Sm., *Nitzschia frustulum* (Kütz) Grun., *Cymbella* sp. and *Navicula* sp. *Achnanthidium minutissimum*, *Gomphonema gandhii* and *G. difformum*, were present throughout the study period in LPFS and MPPS, while *Nitzschia palea* and *Nitzschia frustulum* were dominant in HPAS. In contrast, *Cymbella* sp. was the only diatom present at the MAN site during the month of April. The samples from headwater oligotrophic streams (often with low pH and conductivity) were characterized by the occurrence of *Gomphonema gandhii*, *Achnanthidium minutissimum and Gomphonema difformum*. Assemblages from eutrophic streams (HPAS) were characterized by dominance of *Nitzschia palea*, *N. frustulum and* occasionally with *Cyclotella meneghiniana*.

The species richness was highest at three sites; KAM, DAN and MAN, even though each one inherited different water chemistry regimes. All the six sites were characterized with very low species richness during the monsoon season (Table 3). In all the sites during the entire study period, the diversity (H′) ranged between the highest 2.34 in DAN during the month of February to lowest of 0 in KAM and KAL during the monsoon months. Kruskal–Wallis results showed that the species diversity across three water chemistry regimes were significantly different (Kruskal–Wallis, $H = 6.97$; $p = 0.03$).

Species abundances across season suggested trends within community composition in ordination space (Fig. 18). In sites KAM and KAL, the communities of post monsoon season aggregated in ordination space. However, this trend was not recognized in HAS, DAN, MAN and AND sites. In LPFS (KAM and HAS) and MPPS (AND and DAN), the diatom assemblages were identical for pre-monsoon,

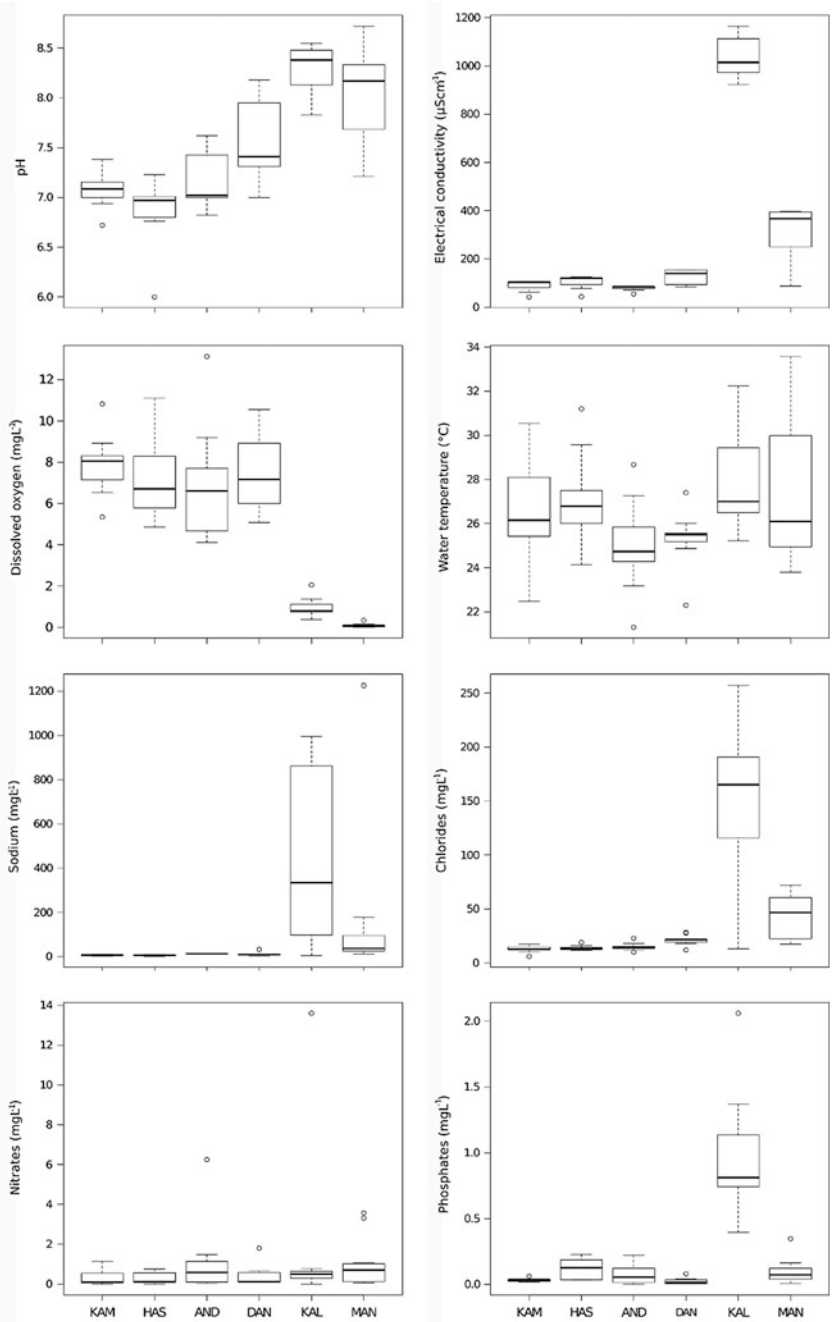


Fig. 16 Water chemistry at sampled sites during the study period at BRB

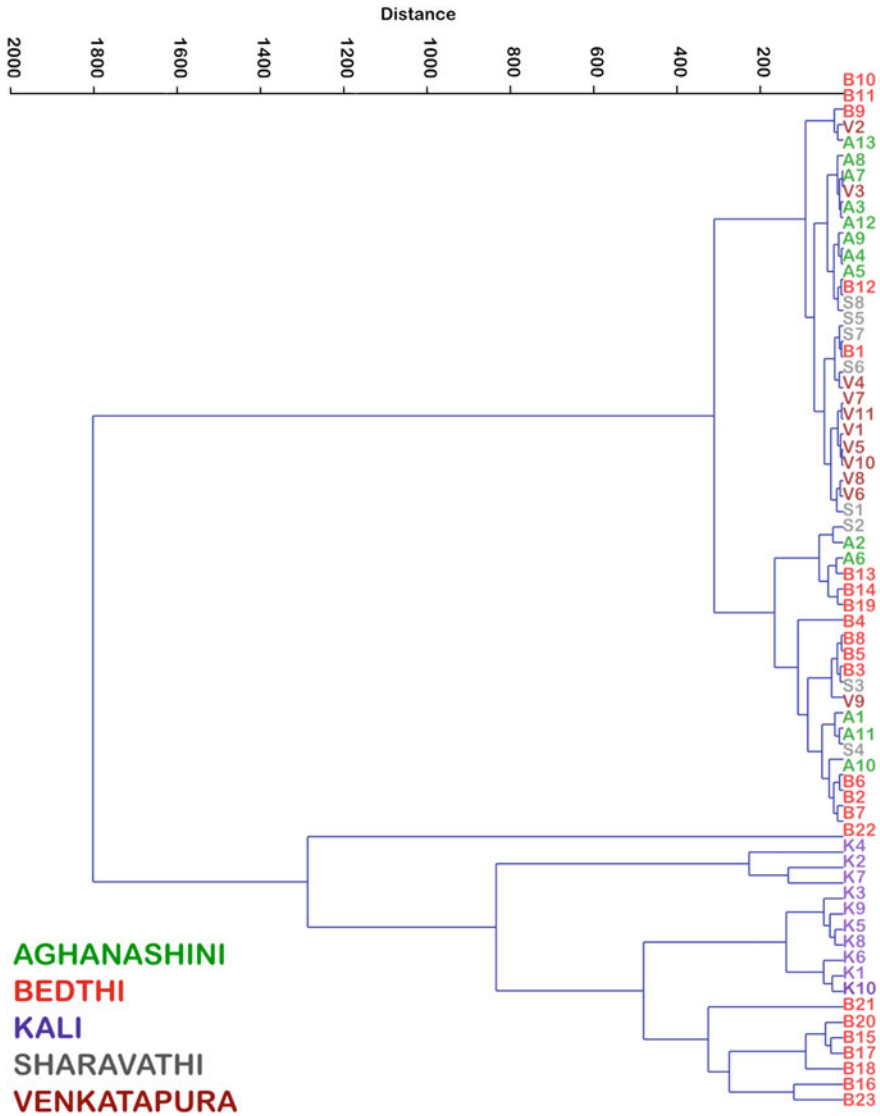


Fig. 17 Cluster analysis of sampling sites across river basins based on water quality

monsoon and post-monsoon seasons respectively, whereas the assemblages in HPAS (KAL and MAN) were not identical across seasons. Though there are trends on community composition, a strong relation with the seasonally dynamic environmental variables could also be envisaged. The difference in the species richness among sites were not significant (Kruskal–Wallis H = 6.07; p = 0.29). Species richness from highest to lowest within water quality regimes, followed the order: LPFS > MPPS > HPAS. Overall, species richness was lowest during the monsoon

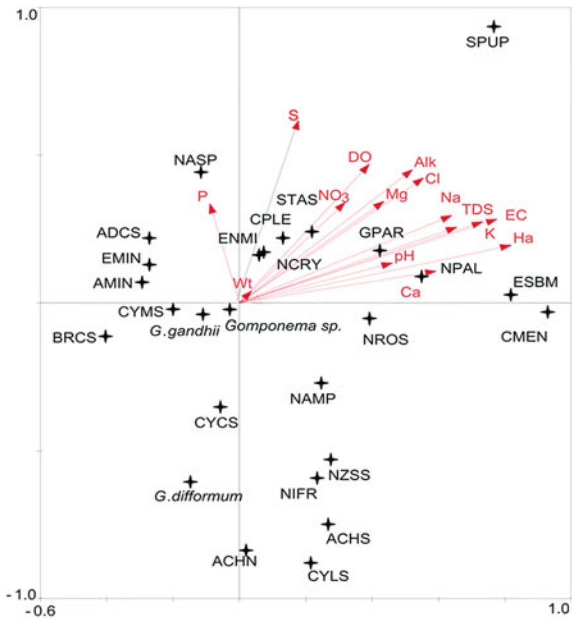


Fig. 18 CCA bi-plot of water chemistry variables and dominant species assemblages

months in all the sites. Changes in species composition or percentage turnover (T) did not follow any trend irrespective of site water chemistry. The highest mean turnover (94.44 % ± 11.11) was observed in MAN, indicating the lowest persistence (Table 3), followed by DAN (79.08 ± 14.47), HAS (70.46 ± 27.64) and AND (64.77 ± 23.71). The mean species turnover was less than 50 % in KAL (47.96 ± 38.1) and KAM (44.03 ± 20.85). Interestingly, KAL showed a wide range of turnover with a minimum of 9 % during the post monsoon and a maximum turnover of 100 % during the monsoon months. In LPFS sites 25 % of the species were persistent across seasons and in MPPS sites 30 % of the species were persistent. However in the HPAS sites, a minimum persistence of 7.14 % was observed for KAL and 80 % persistence in MAN. The differences in turnover were significant across sites (Kruskal–Wallis H = 17.52; p = 0.0036).

Percentage occupancy showed a significant relationship with local maximum species abundance (r = 0.49; P = <0.0001) and local mean species abundance (r = 0.37; P = <0.0001). This positive correlation was slightly stronger for the local maximum abundance. However, it was highly significant for both the local abundance measures. Species that occurred locally with more frequency also tended to be abundant across the sites. The species–occupancy frequency distribution (Fig. 18) followed a "satellite-mode" (Hanski 1982) of species distribution, where a high proportion of species occurred at a small number of sites. Sixty three species occurred at only one site, twenty two species occurred in two sites, eleven species occurred in three sites; five species occurred in four sites, three species occurred in five sites and none of the species occurred in all the six sites.

4.7 Diatom Based Biomonitoring

A total of 140 diatom taxa were identified across sites, 61 of them reaching a relative abundance of over 5 % in at least one site. Appendix 1 provides the checklist of diatoms. The species compositions were dominated by *Gomphonema gandhii* Karthick and Kociolek, *Achnanthidium minutissimum* Kützing, *Achnanthidium* sp., *Gomphonema* sp., *Gomphonema parvulum* Kützing, *Nitzschia palea* (Kützing) W.Smith, *Nitzschia frustulum* (Kützing) Grunow var. *frustulum*, *Navicula* sp., *Navicula cryptocephala* Kützing, *Cyclostephanos* sp., *Cymbella* sp., *Eolimna subminuscula* (Manguin) Moser Lange-Bertalot and Metzeltin, *Sellaphora pupula* (Kützing) Mereschkowksy, *Eunotia minor* (Kützing) Grunow in Van Heurck, *Nitzschia amphibian* Grunow f. *amphibia*, *Cyclotella meneghiniana* Kützing, *Gomphonema difformum* Karthick and Kociolek, *Navicula rostellata*Kützing, *Cocconeis placentula* Ehrenberg var. *euglypta* (Ehr.) Grunow, *Brachysira* sp., *Stauroneis* sp., *Encyonema minutum* (Hilse in Rabh.) D.G. Mann, *Cyclotella* sp. and *Nitzschia* sp. The species composition contains cosmopolitan to possible Western Ghats endemic species. In general, species from oligotrophy to highly eutrophic condition were observed. The current study also documents some of the species for the first time in Western Ghats and many new species descriptions are underway. Waters were circumneutral throughout the study area (Table 4), with certain tendency towards alkalinity in the streams drained from agriculture and urban catchment. The highest ionic and nutrient values correspond to the agriculture catchment dominated streams, particularly in the leeward side of the mountains. Oxygenation was generally close to saturation; the lowest values are due to wastewater water inflows in few localities. The most oligotrophic sites were located in mountain watercourses, while downstream sites were generally more polluted, becoming eutrophic in condition. The detailed water chemistry variables are presented in Table 5.

The results of correlation performed between diatom indices and water chemistry variables are presented in the Table 6. It is observed that significant correlations, albeit at varying degrees exist between most of the diatom indices and water chemistry variables. Diatom indices IPS, EPI and SID showed correlation with more number of water chemistry variables when compared to the other indices. TDI and IPS are negatively correlated with pH, EC, TDS, alkalinity, calcium, magnesium,

Table 4 Summary of the canonical correspondence analysis for the stream sites from central Western Ghats

Variables	Axis order			
	1	2	3	4
Eigen value	0.275	0.193	0.162	0.119
Species-environment correlations	0.815	0.755	0.890	0.754
Cumulative percentage variance of species data	10.0	17.0	22.9	27.2
Cumulative percentage variance of species-environment relation	25.8	43.8	59	70.1

Table 5 Waterchemistry variables in 45 sites of CWG streams

Variables	Mean	Std. dev	Median	Min	Max
pH	7.22	0.49	7.14	6.03	8.16
WT (°C)	25.31	2.70	25.07	19.00	33.00
EC (μScm^{-1})	160.55	207.10	107.67	41.55	1164.67
TDS (mg L^{-1})	122.24	204.98	60.30	20.88	1299.67
Alkalinity (mg L^{-1})	54.55	50.32	30.00	6.81	180.00
Chlorides (mg L^{-1})	32.39	40.40	22.72	5.90	220.24
Hardness (mg L^{-1})	51.26	71.05	28.00	10.00	348.00
Calcium (mg L^{-1})	13.88	16.14	8.02	1.60	78.56
Magnesium (mg L^{-1})	16.35	16.73	9.36	1.17	65.95
DO (mg L^{-1})	6.96	1.68	7.23	2.93	10.87
Phosphates (mg L^{-1})	0.36	0.56	0.04	0.00	2.30
Nitrates (mg L^{-1})	0.74	1.10	0.13	0.03	4.30
Sulphates (mg L^{-1})	25.73	20.84	16.87	0.00	74.10
Sodium (mg L^{-1})	25.77	72.18	9.09	4.11	370.00
Potassium (mg L^{-1})	6.33	15.72	1.30	0.19	75.00

sodium and potassium. Percent pollution tolerant diatoms were positively correlated with most of the ionic variables. None of the indices were correlated with water temperature. No correlation of temperature with any of the indices observed that may be due to differing temperature regime in tropical when compared to temperate streams. Similar observation was recorded by Taylor et al. (2007a) from South African rivers. The first four axes of CCA explain 70.1 % variance of species-environment relation and the ordination plot reveals two distinct clusters of species.

Among the species observed in this study, two species were possibly endemic to Western Ghats (*G. gandhii*, *G. difformum* and few other species that are yet to be identified). In few sites, these species were very dominant (>80 % of the total assemblages). The remaining dominant taxa were cosmopolitan and well documented in international literature (Krammer and Lange Bertalot 1986–1991). It is important to note that the indices that were developed and tested in European rivers, lack Western Ghats endemic taxa. Most sites were oligo-mesotrophic and only a few of the streams were eutrophic. The differences in the water quality of these rivers were reflected in the values for the diatom indices, by the relative abundances of indicators of trophic/saprobic stage and by different types of diatom community.

The correlations obtained in the present study are comparable to those demonstrated by Taylor et al. (2007b) in South Africa and by Kwandrans et al. (1998), Prygiel and Coste (1993) and Prygiel et al. (1999) in Europe. Significant correlations emphasize that diatom indices can be used to reflect changes in general water quality (Table 6). Canonical correspondence analysis (Fig. 18) demonstrates that certain widely distributed taxa have similar ecological characteristics in widely separated geographic areas. Species commonly associated with poor water quality in Europe e.g., *Eolimna subminuscula* Lange-Bertalot, *Nitzschia palea* (Kützing)

Table 6 Pearson correlation coefficients between measured water chemistry variables and diatom index scores in 45 sites of CWG streams

INDICES	pH	WT	EC	TDS	Alk	Cl	Ha	Ca	Mg	Na	K
SLA	−0.33*	–	−0.59**	−0.52**	−0.49**	–	−0.62**	−0.43**	–	−0.51**	−0.58**
DESCY	−0.32*	–	−0.54**	−0.46**	−0.41**	–	−0.65**	−0.47**	–	−0.49**	−0.52**
IDSE/5	−0.32*	–	−0.60**	−0.50**	−0.46**	–	−0.63**	−0.45**	–	−0.55**	−0.60**
SHE	–	–	−0.52**	−0.38**	−0.38*	–	−0.56**	−0.41**	–	−0.43**	−0.56**
WAT	–	–	–	–	–	–	−0.36*	–	–	−0.34*	−0.44**
TDI	−0.32*	–	−0.64**	−0.54**	−0.46**	–	−0.69**	−0.53**	−0.30*	−0.52**	−0.58**
%PT	0.36*	–	0.68**	0.62**	0.35*	0.43**	0.66**	0.50**	0.41**	0.65**	0.58**
GENERE	–	–	−0.49**	−0.39**	−0.30*	–	−0.54**	−0.41**	–	−0.41**	−0.41**
CEE	–	–	–	–	–	–	−0.36*	–	–	–	−0.40**
IPS	−0.36*	–	−0.68**	−0.59**	−0.42**	–	−0.66**	−0.46**	−0.31*	−0.56**	−0.58**
IBD	–		−0.56**	−0.43**	−0.34*	–	−0.61**	−0.46**	–	−0.46**	−0.51**
IDAP	–	–	−0.51**	−0.38*	−0.38*	–	−0.56**	−0.40**	–	−0.44**	−0.53**
EPI-D	−0.33*	–	−0.58**	−0.51**	−0.41**	−0.31*	−0.59**	−0.44**	–	−0.53**	−0.55**
DI_CH	–	–	−0.54**	−0.43**	−0.45**	–	−0.58**	−0.39**	–	−0.41**	−0.53**
IDP	–	–	−0.48**	−0.35*	−0.39**	–	−0.58**	−0.42**	–	−0.43**	−0.49**
SID	−0.36*	–	−0.50**	−0.45**	−0.40**	−0.38**	−0.47**	−0.37*	–	−0.43**	−0.46**
TID	–	–	−0.53**	−0.43**	−0.47**	–	−0.59**	−0.41**	–	−0.40**	−0.48**
Evenness	–	–	0.39**	0.40**		–	0.41**	–	–	–	–

WT Water temperature, *EC* Electric conductivity, *TDS* Total dissolved solids, *ALK* Alkalinity, *Cl* Chlorides, *Ha* Total hardness, *Ca* Calcium hardness, *Mg* Magnesium hardness, *Na* Sodium, *K* Potassium. *Diatom Indices SLA* Sládeček's index, *DESCY* Descy's pollution metric, *SHE* Steinberg and schiefele trophic metric, *WAT* Watanabe index, *TDI* Tropical diatom index, *GENRE* Generic diatom index, *CEE* Comission for economical community Index, *IPS* Specific pollution sensitivity metric, *IBD* Biological diatom index, *IDAP* Indice diatomique artois picardie, *EPI-D* Eutrophication/pollution index, *IDP* Pampean diatom index, *%PT* Percentage tolerant

*$p<0.1$ and **$p<0.05$

W. Smith, *Sellaphora pupula* (Kützing) Mereschkowksy, *Gomphonema parvulum* (Kützing) ordinate on the right side of the CCA together with elevated levels of ionic and nutrients. Taxa typical of cleaner, less polluted waters ordinate on the left side of the diagram e.g., *Gomphonema difformum* Karthick and Kociolek. However, *Gomphonema gandhii* Karthick and Kociolek seems to have a wider ecological tolerance when compared to its morphologically related species. *Achananthidium minutissimum* group from Western Ghats streams contains morphologically three distinct taxa with wide ecological preferences. Despite the reevaluation of this genus multiple times (Lange-Bertalot and Krammer 1989; Krammer and Lange-Bertalot 1986–1991; Potapova and Hamilton 2007) there are still major gaps in taxonomy and ecology apart from non-inclusion of specimens from tropical rivers. Similar problem holds good for some of the other genus like *Gomphonema*. This analysis had demonstrated that the widely distributed species encountered in the streams of Western Ghats are not only morphologically identical, but also have similar environmental tolerances. *G. gandhii* and *G. difformum* are few among the dominant taxa in this data set but are not included in any of the index calculations. Their omission in the index calculations could result in an under or overestimation of the index scores. Taylor et al. (2007b) cautioned about the associated problems with the usage of European indices in South African rivers. However, the data provided in the present study suggest that European diatom indices can be used in India provided indices address the issues concerned with ecology of endemic species. Hence, the list of taxa included in the indices needs to be adapted according to the study region by providing more importance to the local endemic flora which encourages taxonomic and ecological studies in tropics. The structure of benthic diatom communities and the use of diatom indices yield good results in water quality monitoring in India. However, the occurrence of possible endemic species necessitates a diatom index unique to India.

4.8 LULC Analysis

LULC showed considerable variability among catchments, with forest/vegetation land cover as a dominant class (mean = 64.36 %, range = 0.13–95.45 %), followed by agriculture/cultivation area (mean = 24.27 % range = 2.55–63.63 %), among the 24 catchments. LULC analysis shows that natural vegetation is poor towards the leeward side of the mountains (eastern region), due to the intense anthropogenic activities. This region has more of agriculture, open scrub/barren land, and built-up area. In the entire study region, the class forest/vegetation covers predominantly moist deciduous type, with small isolated patches of semi-evergreen vegetation in the eastern region and the western region (windward side) with rugged hilly terrain and heavier rainfall ($\sim$5,000 mm) having characteristic evergreen to semi-evergreen forests. The detailed LULC for each catchment is given in the Table 7 and the land cover images are given in the Fig. 19. The dendrogram of sites based on LULC obtained by Ward's method is shown in the Fig. 20. Three well differentiated clusters

Table 7 Percentage LULC classes for each catchment in the study area

	Forest/ vegetation	Agriculture/ cultivation	Open scrub/ barren land	Water bodies	Built up	Others
CHI	52.5	34.24	10.9	1.18	0.14	1.04
MEL	83.58	10.88	0.57	2.84	1.52	0.61
KEL	85.83	8.19	1.4	3.03	0.92	0.62
BEE	90.41	2.55	0.16	5.11	1.16	0.61
ANG	81.54	12.67	1.38	0.08	0.18	4.14
MAK	95.45	3.02	0.38	0.01	0.13	1.01
HUR	52.84	28.62	11.89	3.91	0.1	2.64
MAV	48.85	36.26	10.79	2.94	0.43	0.73
YEN	56.15	24.49	10.47	5.61	0.16	3.12
BAI	70.85	23.49	0.99	0.58	0.2	3.89
DEE	64.34	28.64	3.62	0.51	0.2	2.69
YAN	90.83	6.52	0.56	0.02	0.08	1.98
SAP	42.8	50.61	4.5	0.97	0.31	0.81
BAD	88.36	7.29	0.24	0.11	0.06	3.94
NAI	67.43	17.89	3.65	1.03	0.44	9.58
SAK	80.08	14.94	0.26	0.92	0.24	3.58
AND	68.1	24.87	3.36	0.93	0.98	1.77
DAA	86.29	10.84	0.58	1.26	0.41	0.63
HAS	88.6	5.77	0.42	3.96	0.88	0.37
KAM	88.8	5.31	0.6	4.01	0.89	0.39
MAN	23.46	50.42	20.69	0.67	0.52	4.25
KAL	0.53	59.6	30.22	0.02	0.84	8.79
SAN	0.13	63.63	31.48	0.02	0.16	4.59
GUN	36.82	51.72	10.52	0.52	0.35	0.07

can be seen, with forest cover decreasing and agriculture/cultivable land cover increasing from top to bottom. The third cluster from top includes sites SAN, KAL, MAN, SAP and GUN, which are characterized with intensive agricultural activities (>50 %). The group located in the center of the dendrogram is characterized by more forest cover (>50 %) with moderate amount of agricultural land. The topmost group is dominated by forest land cover of more than 80 %.

4.9 Relationship of LULC with Water Chemistry and Diatom Assemblages

A PCA bi-plot of water quality variables and LULC for all sample sites is given in Fig. 21. The two-dimensional bi-plot describes 65 % of the variation in data, where 52 % displayed on the first axis and 13 % is displayed on the second axis. Among

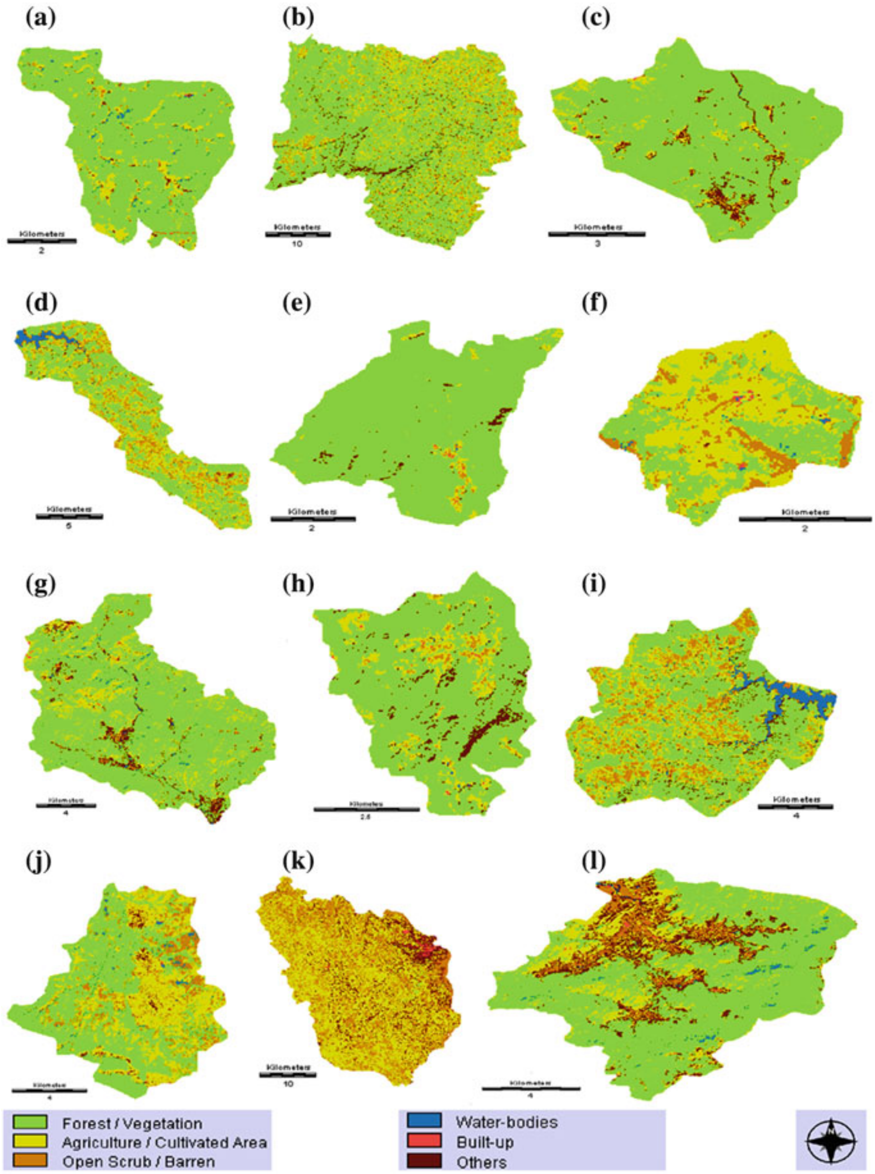


Fig. 19 Land use of study catchments in central Western Ghats.**a** Daanandhi,**b** Deevalli, **c** Badapoli, **d** Mavinahole, **e** Makkegadde, **f** Gunjavathi, **g** Sakathihalla, **h** Angadibail, **i** Hurlihole, **j** Chitgeri, **k** Kalghatghi, *l* Naithihole land use of study catchments in central Western Ghats. **m** Beegar, **n** Andhalli, **o** Yennehole, **p** Kammani, **q** Sangadevarakoppa, **r** Machikere, **s** Melinakeri, **t** Yanahole, **u** Sapurthi, **v** Bailalli, **w** Kelaginakere, **x** Hasehalla

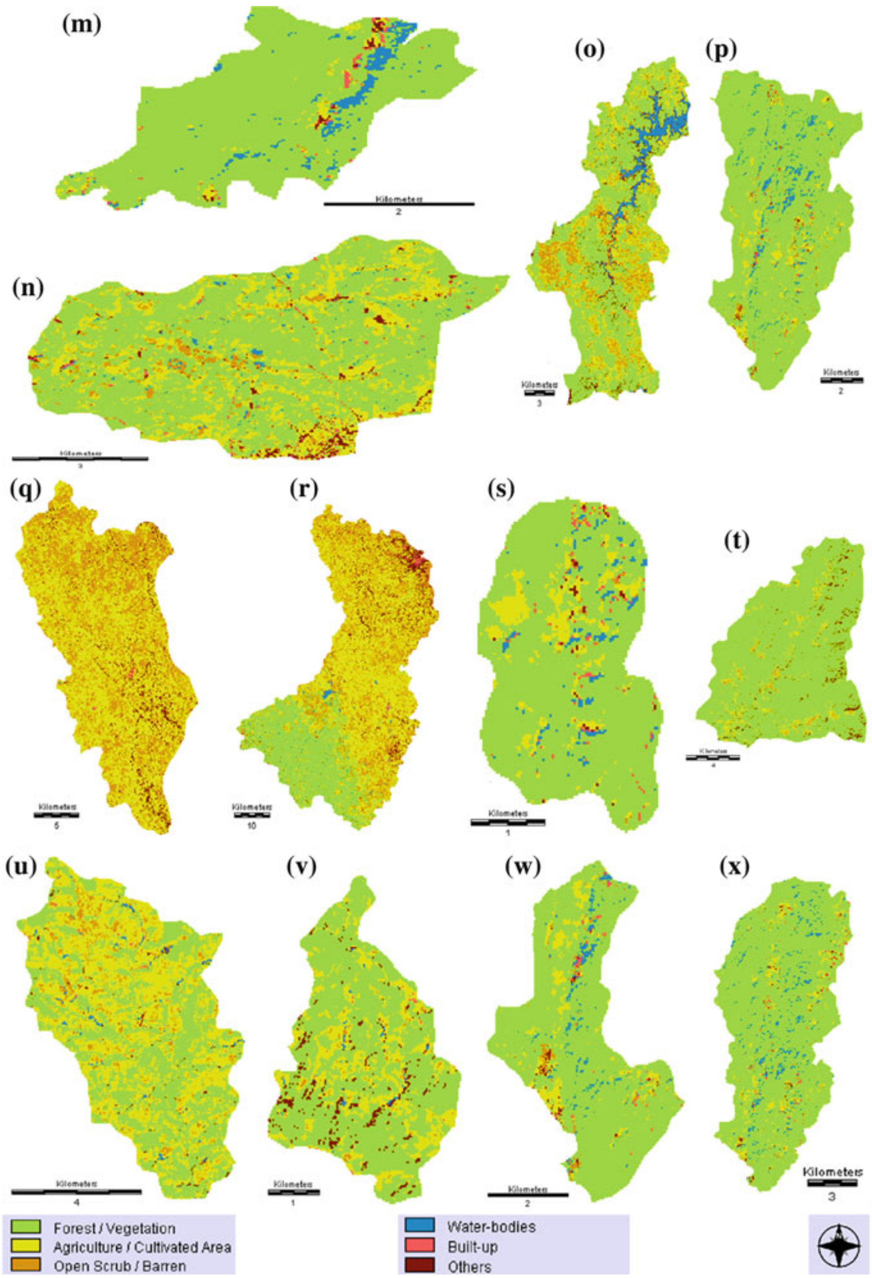


Fig. 19 (continued)

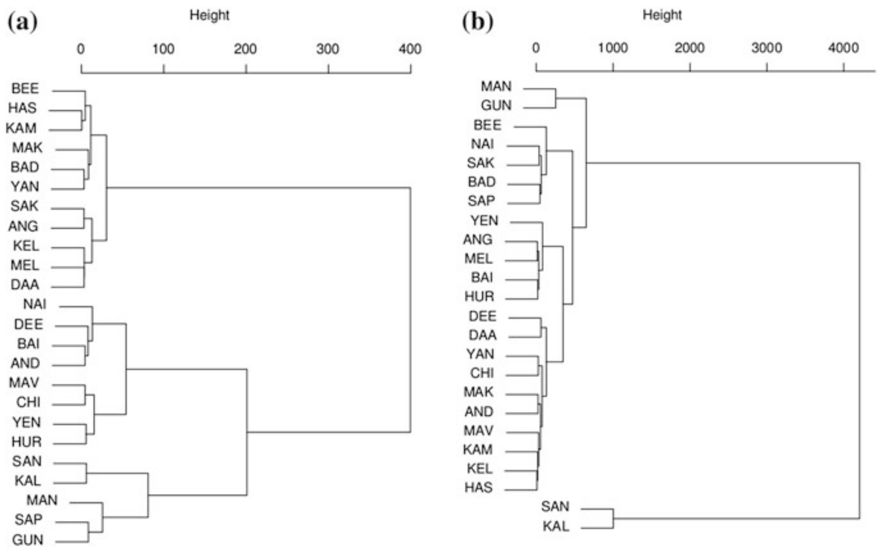
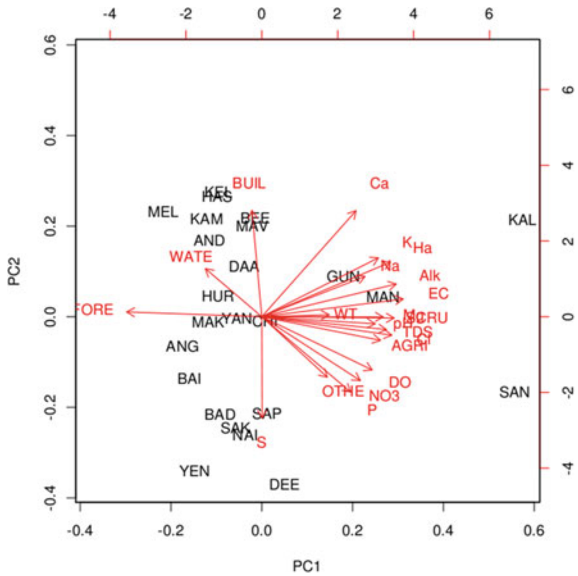


Fig. 20 Dendrogram of the cluster analysis based on **a** LULC and **b** water quality in the 24 sampling sites of the central Western Ghats

Fig. 21 PCA bi-plots of water chemistry and LULC variables in study sites in central Western Ghats Streams



water chemistry variables, ionic variables were positively correlated with first axis and among the LULC variables percentage agriculture and scrub land cover were positively related to the first axis. Sites with more than 50 % of agriculture land cover were separated from other sites on the PC2 axis indicating trends in water quality may be related to land use. Agriculture dominated sites were placed due to the higher conductivity, ionic and nitrates levels relative to the forest dominated sites, which are characterized by low ionic and nutrient in nature.

Correlation between percentage agricultural land cover with water chemistry variables and diatom autecological indices revealed the role of landscape (Hegde et al. 1994). Previous studies reported agricultural expansion as one of the major driver for deforestation (Menon and Bawa 1998) in Western Ghats and thereby determine the environmental condition of streams and diatom assemblages (Fig. 22). The gradient of percentage agriculture land cover were positively correlated with water chemistry variables like electrical conductivity (r = 0.67), total dissolved solids (r = 0.62), nitrates (r = 0.60) and pH (r = 0.52). Gradient of percentage agriculture land cover were positively correlated with percentage pollution tolerant diatoms (r = 0.65, Fig. 23). Relation between the diatom

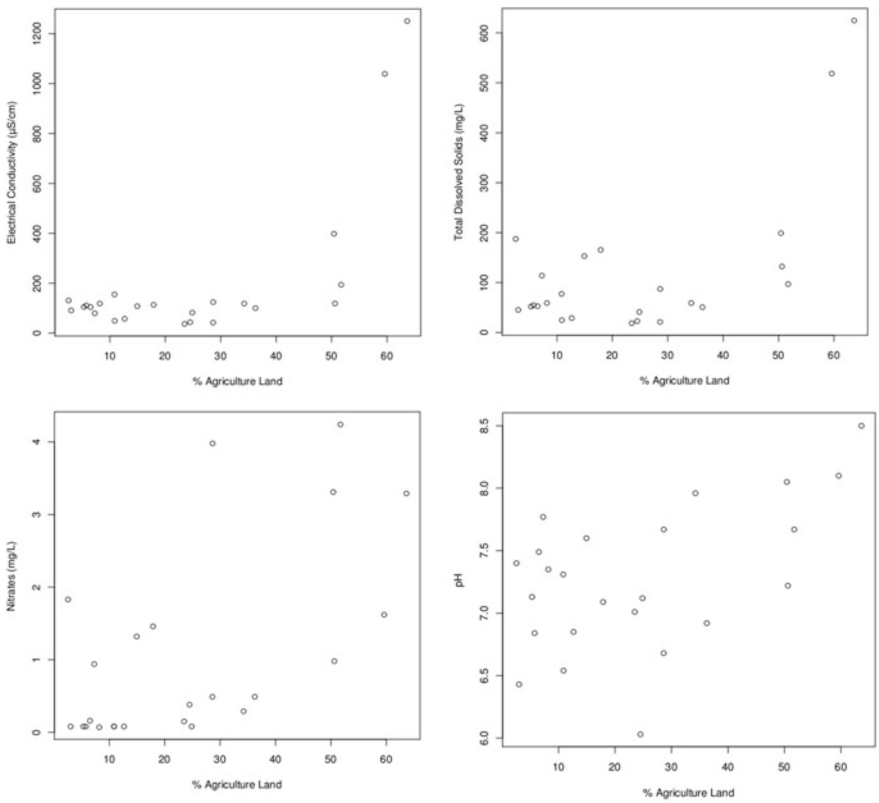


Fig. 22 Changes in water quality variables along a gradient of percentage agricultural land cover in central Western Ghats

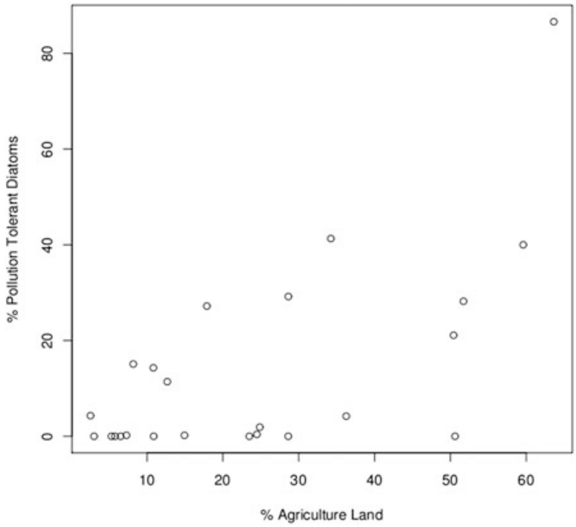


Fig. 23 Pollution tolerant diatoms with gradient of agricultural land cover (%) in central Western Ghats

autecological indices with land cover and water chemistry variables are given in Tables 7 and 8 respectively. Most of the diatom autecological parameters were positively correlated with forest/vegetative cover and negatively correlated with agriculture/cultivable and scrub land cover. All the diatom indices were normalized to a range of 0–20, where <9 indicates bad water quality, 9–12 indicates poor water quality, 12–15 indicates moderate water quality, 15–17 indicates good quality and >17 indicates high quality. The present study shows that within a similar eco-region, the diversity and community composition of diatoms changes with LULC pattern. Among all the 24 catchments, most of the catchments were dominated by forest/vegetation land cover. However, forest cover in the leeward side catchment was very low owing to anthropogenic activities. Hydro power projects commenced in the study area since 1960s seem to have lost.

The streams draining the catchments with agriculture and scrub land cover were characterized with ionic and nutrient rich waters, which highlight that the water chemistry variables are driven by the composition of land cover. Many studies have reported that urban and agricultural land use play a primary role in degrading water quality in adjacent aquatic systems by altering the soil surface conditions, increasing the impervious area and generating pollution (Tong and Chen 2002; White and Greer 2006). The results suggest better water quality tendencies in watersheds having less urbanization with more natural vegetation region. Percent agriculture in the catchment ranged from 2 to 63 % with an average of 24.27 %.

Table 8 Water chemistry variables of the sampling sites in central Western Ghats

Water chemistry variables (units)	Mean ± S.D	Range
pH	7.28 ± 0.58	6.03–8.50
Water temperature (°C)	26.09 ± 2.52	22.10–35.43
Electrical conductivity (μScm^{-1})	199.00 ± 301.44	37.17–250.67
Total dissolved solids (mg L^{-1})	120.26 ± 149.68	18.67–624.67
Alkalinity (mg L^{-1})	70.44 ± 111.46	12.00–421.07
Chlorides (mgL^{-1})	35.25 ± 62.36	4.99–255.92
Hardness (mg L^{-1})	69.49 ± 96.94	12.00–376.00
Calcium (mg L^{-1})	14.76 ± 17.33	1.60–84.97
Magnesium (mg L^{-1})	15.72 ± 18.58	1.17–71.01
Dissolved oxygen (mg L^{-1})	7.58 ± 1.77	4.81–11.52
Phosphates (mg L^{-1})	0.18 ± 0.36	0.01–1.30
Sulphates (mg L^{-1})	19.94 ± 18.07	2.91–67.91
Sodium (mg L^{-1})	52.92 ± 201.09	1.05–996.03
Potassium (mg L^{-1})	11.01 ± 35.01	0.41–168.33
Nitrates (mg L^{-1})	1.06 ± 1.33	0.07–4.24

Thus the sites selected for the present study covered a good range of the land-use gradient and hence the inferences drawn from the statistic may not have been influenced by skewed sampling. An aggregated measure of LULC such as percentage agriculture in catchments may only represent the potential of LULC effects on streams. Percentage agriculture lands in catchments were positively correlated with the ionic and nutrient variables. Studies have shown that the percentage of agriculture at watershed scale is a primary predictor for nitrogen and phosphorus (Ahearn et al. 2005).

Diatom community structure in streams of the central Western Ghats was found to be strongly related to the land use practices as could be observed elsewhere (Stevenson et al. 2009; Walsh and Wepner 2009). The nutritional changes in the streams triggered by the LULC changes stands as a determining factor in structuring the diatom species composition. Effects of nutrient are commonly identified as one of the most important determinants of diatom species composition in lentic and lotic ecosystems (Pan and Stevenson 1996). However, the diatom species composition at CWG streams were controlled more by the ionic variables than the nutrient concentration. More of pollution tolerant species were seen in the streams in agriculture dominated catchments. Blinn (1993, 1995) found that higher salinities (≥35 mScm^{-1}) tend to override other water quality parameters in structuring diatom communities in salt lakes. Agriculture dominated sites represented high pH, TDS and nutrient loads, (Figs. 22 and 23) which is also supported by positive correlation between percentage of agriculture land with percentage of pollution tolerant diatoms (Fig. 23).

5 Conclusions

- The results indicate that (a) the water quality regimes show seasonal variations, (b) diatom species assemblages change accordingly in all the water quality regimes, due to seasonal water quality conditions and (c) the species distribution across the sites followed the satellite-mode due to the specific ecological niches of the diatoms.
- This study concludes that the environmental quality of the Western Ghats streams can be monitored by biomonitoring ventures and compared to other water monitoring programs. This study also suggests that the diatom community in this region is rich with possible endemic taxa; hence considerable amount of importance has to be given for the taxonomy of the lesser-known species before commencing the biomonitoring programs.
- The analyses and results provided insights into the linkages between land use practices and water quality in the streams and the relative sensitivity of water quality variables to alterations in land use. The relationships between the diatom indices and water chemistry variables relation showed the impact of land use on the stream ecosystem.
- It has been evident that the causes and sources of water pollution in the five river basins are due to agricultural land use, anthropogenic activities and industrialization. The major occupation in the study area is agriculture, which is main source of increase in nitrates and ionic components in streams. Domestic and industrial sewage discharges into the rivers are responsible for the observed high concentration of electrical conductivity, total dissolved solids, total hardness and other ionic components. Proper treatment of effluent from the industrial processes to the acceptable levels and discouraging stagnation of water through small dams are the two major recommendations to minimize the damages on the river ecosystem in the central Western Ghats. Table 9 lists the threats and remedial measures.

Table 9 Threats and mitigation measures

River basin	Region	Problem	Remedial measures
Kali	Dandeli	Paper mill effluent	Enforce effluent treatment by the industry (implementation of the control of water pollution, Polluter pays principle)
Kali	Ramnagar	Non-point source pollution in streams and rivers from Agriculture fields	Avoiding intense use of chemical fertilizers and pesticides
Kali	Honkon (Brackish)	Mechanized sand mining	Stopping of sand mining in certain ecologically sensitive region and regulated sand mining in selected localities
Bedthi	Sangdevarkoppa	Non-point source pollution	Avoiding intense use of chemical fertilizers and pesticides
Bedthi	Kalghatghi	Urban domestic sewage, non-point source pollution	Implementation of sewage treatment plant in Hubli town. Sewage should be treated before letting into the river
Bedthi	Kalghatghi	Solid Waste Disposal in River	Setting up Solid waste disposal facility in outskirts of Hubli town
	Manchikeri	Urban domestic sewage, non-point source pollution	Implementation of sewage treatment plant in Hubli town. Sewage should be treated before letting into the river
Sharavathi	Gerusoppa and downstream	Mechanized sand mining	Stopping of sand mining in certain ecologically sensitive region and regulated sand mining in selected localities

Acknowledgment We are grateful to the NRDMS division, the Ministry of Science and Technology (DST), Government of India, The Ministry of Environment and Forests (MoEF), Government of India and Indian Institute of Science for the financial and infrastructure support.

Appendix

Appendix 1 Checklist of epilithic diatoms of Rivers of Uttara Kannada, Karnataka

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Achnanthes sp. J.B.M. Bory de St. Vincent		+			
Achnanthes minutissima Kützing*v. minutissima* Kützing (*Achnanthidium*)	+	+	+	+	+
Achnanthes sp.		+			
Achnanthidium sp.	+	+	+	+	+
Actinocyclus sp.	+				
Amphora montana Krasske	+				
Amphora pediculus (Kützing) Grunow	+				+
Amphora species		+			
Aulacoseira ambigua (Grunow) Simonsen	+	+		+	
Aulacoseira granulata (Ehr.) Simonsen		+			
Aulacoseira granulata (Ehr.) Simonsenmorphotype *curvata*		+			
Bacillaria paradoxa Gmelin	+				
Brachysira neoexilis Lange-Bertalot	+	+	+	+	+
Brachysira sp.	+	+	+	+	+
Brachysirawygaschii Lange-Bertalot	+		+	+	+
Brassierea sp Hein and Winsborough		+			
Caloneis bacillum (Grunow) Cleve	+	+		+	
Caloneis hyalina Hustedt	+				
Caloneis silicula (Ehr.) Cleve	+	+			+
Caloneis species		+			
Cocconeis placentula Ehrenberg *var.euglypta* (Ehr.) Grunow	+	+	+		+
Craticula sp A. Grunow		+			
Craticulaacco modiformis Lange-Bertalot		+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Craticula molestiformis (Hustedt) Lange-Bertalot		+			
Craticula submolesta (Hust.) Lange-Bertalot	+	+			+
Craticula vixnegligenda Lange-Bertalot		+			
Cyclostephanos sp F.E. Round		+			
Cyclostephanos species	+	+			+
Cyclotella sp F.T. Kützingex A de Brébisson		+			
Cyclotella meneghiniana Kützing	+	+			
Cyclotella ocellata Pantocsek		+			
Cyclotella species		+			
Cymbella kolbei Hustedt var. *kolbei*	+	+		+	+
Cymbella species	+	+	+	+	+
Cymbella tumida (Brebisson) van Heurck	+	+			
Cymbopleura (Krammer) Krammer					+
Cymbopleura sp.	+			+	+
Diadesmis contenta (Grunow ex V. Heurck) Mann	+	+			+
Diploneis elliptica (Kützing) Cleve		(+)			
Diploneis oblongella (Naegeli) Cleve-Euler		(+)			
Diploneis ovalis (Hilse) Cleve		+			
Diploneis subovalis Cleve	+	+			+
Encyonema mesianum (Cholnoky) D.G. Mann	+				+
Encyonema minutum (Hilse in Rabh.) D.G. Mann	+	+			+
Encyonema species	+				+
Entomoneis alata Ehrenberg		+			
Eolimna subminuscula (Manguin) Moser Lange-Bertalot and Metzeltin	+	+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Eunotia sp C.G. Ehrenberg		+			
Eunotiabi lunaris (Ehr.) Mills var. *bilunaris*					+
Eunotia incisa Gregoryvar. *incisa*	+	+			
Eunotia minor (Kützing*)* Grunow	+	+	+	+	+
Eunotia rhomboidea Hustedt	+		+	+	+
Eunotia sp.	+	+		+	
Fallaciainsociabilis (Krasske) D.G. Mann		+			
Fallacia pygmaea (Kützing) Stickle and Mann sp. *pygmaea* Lange-Bertalot	+	+			
Fallaciatenera (Hustedt) Mann in Round		+			
Fragilaria biceps (Kützing) Lange-Bertalot	+	+	+	+	+
Fragilaria species		+			
Fragilaria ulna (Nitzsch.) Lange-Bertalotvar. *ulna*	+	+	+	+	+
Fragilari aungeriana Grunow	+				
Frustulia saxonica Rabenhorst				+	
Frustulia species	+			+	+
Geissleriadecussis (Ostrup) Lange-Bertalot and Metzeltin		+			
Gomphonema acuminatum Ehrenberg	+				
Gomphonema difformum Karthick and Kociolek		+	+	+	
Gomphonemadi minutum Karthick and Kociolek	+	+	+		
Gomphonema gandhii Karthick and Kociolek	+	+	+	+	+
Gomphonema parvulum (Kützing) Kützingvar. *parvulum f. parvulum*	+	+	+	+	+
Gomphonema pseudo augur Lange-Bertalot		+			
Gomphonema species	+	+	+	+	+
Gyrosigma acuminatum (Kützing) Rabenhorst	+	+			

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Gyrosigma scalproides (Rabenhorst) Cleve	+				
Gyrosigma species		+			
Hantzschia distincte punctata Hustedt in Schmidt et al.				+	
Hippodontaavittata (Cholnoky) Lange-Bert. Metzeltin and Witkowski	+				+
Luticola species	+	+			
Luticola species (*aff. mutica*)	+				
Navicula species		+			
Navicula antonii Lange-Bertalot		+		+	
Navicula cincta (Ehr.) Ralfs in Pritchard	+				
Navicula cryptocephala Kützing	+	+	+	+	+
Navicula cryptotenella Lange-Bertalot	+				
Navicula elginensis (Gregory) Ralfs in Pritchard					+
Navicula erifuga Lange-Bertalot	+	+			
Navicula gracilis Ehrenberg	+			+	
Navicula hustedtii Krasske					
Navicula hustedtii Krasskevar. *obtusa* Hustedt	+			+	
Navicula leptostriata Jorgensen	+	+	+	+	+
Navicula peregrina (Ehr.) Kützing	+				
Navicula reinhardtii (Grunow) Grunow in Cl. and Möller				+	
Navicula riediana Lange-Bertalot and Rumrich	+			+	+
Navicula rostellata Kützing	+	+		+	+
Navicula sp.	+	+	+	+	+
Navicula symmetrica Patrick	+	+	+	+	+
Navicula viridula (*Kützing*) Ehrenberg	+				
Navigiolum species.					
Neidium affine (Ehrenberg) Pfitzer	+				+

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Nitzschia sp. A.H. Hassall		+			
Nitzschia amphibia Grunowf. *amphibia*	+	+			+
Nitzschia clausii Hantzsch	+	+		+	+
Nitzschia compressa (J.W. Bailey) Boyer		+			
Nitzschia dissipata (Kützing) *Grunowvar.media* (Hantzsch.) Grunow				+	
Nitzschia fonticola Grunow in Cleve et Möller	+	+			
Nitzschia frustulum (Kützing) Grunow var. *frustulum*	+	+			
Nitzschia gracilis Hantzsch				+	
Nitzschia linearis (Agardh) W.M. Smith var. *linearis*					
Nitzschia nana Grunow in Van Heurck	+				
Nitzschia obtusa W.M. Smith var. *kurzii* (Rabenhorst) Grunow	+	+		+	+
Nitzschia palea (Kützing) W. Smith	+	+		+	+
Nitzschia reversa W. Smith	+	+		+	+
Nitzschia sigma (Kützing) W.M. Smith		+		+	+
Nitzschia species	+	+			+
Nitzschia umbonata (Ehrenberg) Lange-Bertalot		+			
Pinnularia acrospheria W.M. Smith var. *acrospheria*		+			+
Pinnularia brebissonii (Kütz.) Rabenhorst var. *brebissonii*	+	+		+	
Pinnularia divergens W.M. Smith. var. *undulata* (M. Perag. and Herib.) Hustedt				+	
Pinnularia gibba Ehrenberg				+	
Pinnularia species		+		+	+
Placoneis sp.	+	+		+	
Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	+	+	+	+	+

(continued)

Appendix 1 (continued)

Taxa	Kali (KRB)	Bedthi (BRB)	Aghan ashini (ARB)	Shara vathi (SRB)	Venkat apura (VRB)
Planothidium rostratum (Oestrup) Round and Bukhtiyarova	+	+			+
Planothidium sp. Round and Bukhtiyarova		+	+	+	
Pleurosigma salinarum (Grunow) Cleve and Grunow	+				
Pseudostaurosira brevistriata (Grun. in Van Heurck) Williams and Round		+			
Rhopalodia gibba (Ehr.) O.Mullervar.gibba					+
Rhopalodia operculata (Agardh) Hakansson	+				+
Sellaphora species	+	+			
Sellaphora americana (Ehrenberg) D.G. Mann	+			+	+
Sellaphora laevissima (Kützing) D.G. Mann				+	
Sellaphora nyassensis (O. Muller) D.G. Mann	+	+			
Sellaphora pupula (Kützing) Mereschkowksy	+	+		+	+
Seminavis sp. D.G. Mann		+			
Seminavis species		+			
Skeletonema species					
Stauroneis species	+	+			+
Surirella angusta Kützing	+	+		+	+
Surirella species	+	+		+	+
Synedra sp.		+			
Tryblionella calida (grunow in Cl. and Grun.) D.G. Mann	+	+			
Tryblionella levidensis W.M. Smith		+			
Total	83	95	22	51	55
Total number of taxa reported from all river basins	140				

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Hydrological importance of sacred forest fragments in Central Western Ghats of India

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Abstract: Sacred groves are patches of forests of special spiritual significance to humans, offering also a diverse range of ecological and environmental services. We have attempted here to understand the local hydrological dynamics of a sacred forest, in terms of the benefits the village community derive, in central Western Ghats region of India. A comparative assessment has been made between two small watersheds in terms of their landscape structure (woody species composition) with soil water properties and availability of water in the respective downstream villages. The result shows that, sacred site with more primeval vegetation has close association with soil moisture in comparison to non-sacred site during dry spell of the year. The higher soil moisture ensures year long availability of water in the downstream village of the sacred site which facilitates farming of commercial crops with higher economic returns to the farmers, unlike the farmers in the other village where they face water crisis during the lean season. The study emphasizes the need for conservation endeavour on sacred groves highlighting its potential for water conservation at local and regional levels.

Resumen: Los bosques sagrados son fragmentos de bosques de especial significado espiritual para los seres humanos, los cuales también ofrecen una amplia gama de servicios ecológicos y ambientales. Hemos intentado aquí entender la dinámica hidrológica de un bosque sagrado, en términos de los beneficios derivados para una comunidad aldeana en la porción central de los Gates Occidentales de la India. Se hizo una evaluación comparativa entre dos cuencas pequeñas en términos de su estructura del paisaje (composición de especies leñosas) con las propiedades del agua del suelo y la disponibilidad de agua en las respectivas aldeas río abajo. Los resultados muestran que el sitio sagrado con más vegetación primaria tiene una relación estrecha con la humedad del suelo en comparación con el sitio no sagrado durante la temporada seca del año.Una humedad del suelo mayor asegura la disponibilidad de agua a lo largo del año en el poblado situado río abajo del sitio sagrado, y esto facilita el desarrollo de cultivoscomerciales y mayores ingresos económicos para los agricultores, a diferencia de los agricultores en el otro pobladoquienes se enfrentan a crisis de agua durante la temporada de carestía. El estudio enfatiza la necesidad de haceresfuerzos de conservación en los bosques sagrados, destacando su potencial para la conservación del agua tanto local como regionalmente.

Resumo: Os bosques sagrados são manchas de florestas de significado espiritual especial para os seres humanos, oferecendo também uma gama diversificada de serviços ecológicos e ambientais. Tentámos aqui entender as dinâmicas hidrológicas locais de uma floresta sagrada, em termos dos benefícios que a comunidade da aldeia obtém, na região central dos Gates Ocidentais da Índia. Uma avaliação comparativa foi feita entre duas pequenas bacias hidrográficas em termos da estrutura da paisagem (composição de espécies lenhosas) com as

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propriedades da água no solo e a disponibilidade da mesma nas respectivas aldeias a jusante. O resultado mostra que o local sagrado com mais vegetação primitiva apresentou uma associação estreita com a humidade do solo, em comparação com local não-sagrado, durante o período seco do ano. A maior humidade do solo garante, no ano, maior disponibilidade de água na aldeia a jusante do local sagrado o que facilita a produção de culturas comerciais com maiores retornos económicos para os agricultores, ao contrário dos agricultores na outra aldeia onde enfrentam crise da água durante o período de escassez. O estudo enfatiza a necessidade de esforço de conservação em bosques sagrados destacando seu potencial para a conservação da água a nível local e regional.

Key words: Ecosystem service, native forest, sacred grove, water conservation, watershed.

Introduction

Landscape constitutes a heterogeneous area comprising of different interacting ecosystems, including land (mountains, hills, soil, forests) and water (streams, rivers, oceans, lakes, etc.). These interactions among the components of ecosystems result in the flow of nutrients, minerals and energy, which contribute to the functioning of the landscape. Watershed, an integral part of any landscape, can be defined as an area that supplies water by surface or subsurface flow to a given drainage system or body of water, be it a stream, river, wetland, lake or ocean (World Bank 2001).

Forests and water are intrinsically intertwined as forested watersheds have significantly different behaviour from non-forested watersheds as the former is more helpful in infiltration of rainfall. The nature of vegetation in the catchment is important in ground water recharge, runoff and soil moisture conditions, soil erosion and soil quality (Biao *et al.* 2010; Bruijnzeel 2004). Despite the fact that the forest-water relationship is not all that simplistic, being an outcome of many factors of climatic, edaphic, geological and biological nature, the importance of forests in water conservation has been accepted globally (Bradshaw *et al.* 2007; Makarieva *et al.* 2006).

India has a well established ancient tradition, more in the highlands, of protection of patches of forests as sacred. Though these forests are devoted to gods with many taboos associated with tree felling in such areas, the intimate association of such sacred forests or sacred groves with water bodies, in the form of streams, rivers, ponds and lakes, swamps or springs, is a well acknowledged fact. Hydrological services to village communities from well preserved sacred groves are highlighted in several studies (Chandran & Gadgil 1998; Gokhale & Pala 2011; Malhotra *et al.* 2001). Based on studies in the Himalayan states of Himachal Pradesh and Meghalaya, Khiewtam & Ramakrishnan (1993) and Singh *et al.* (1998) reported the role of groves in reducing run-off and soil erosion, preventing landslides and in conferring ecosystem stability. Vertical stratification in the untrammelled humid tropical forests along with the extensive root network covered with leaf litter are linked to increased soil percolation, recharge of ground water (Khiewtam & Ramakrishnan 1993). The stored precipitation in the underlying strata (saturated and vadoze zone) are released to the streams making them flow perennially. Natural forest soils with greater porosity and low bulk density retain more moisture for longer duration even after the stoppage of seasonal rains. This fact is evident from the relatively less disturbed sacred groves which are often sources of fresh and clean water for many village communities (Godbole & Sarnaik 2004). The watershed values of especially swampy sacred forests, dominated by members of Myristicaceae, occurring in isolation in Western Ghats of Kerala and Karnataka, are home to several rare and threatened floristic and faunal elements that prefer aseasonal tropical forest conditions (Chandran & Mesta 2001; Chandran *et al.* 2008, 2010). Chandran & Gadgil (1993) emphasized the role of sacred groves as safety forests in otherwise human impacted landscapes of Uttara Kannada district of Karnataka, especially on account of their hydrological and biological importance. The British rulers had shown some consideration of the preservation of the evergreen *kan* forests of Uttara Kannada, on account of their hydrological importance, as reflected in the pronouncement of the Government of Bombay (1923).

All such studies associating perennial water sources with sacred groves were of more of general nature, without any quantifications or evaluations involving local water cycles with biodiversity and livelihoods.

The Western Ghat mountain chain, one of the 34 global hotspots of the world, running parallel to the west coast of the country, is home to numerous sacred groves. Their ecological characters range from evergreen to dry deciduous forests, semi-deciduous and swamp areas thus providing varied ecosystem services (Bhagawat *et al.* 2005; Chandran *et al.* 2010; Gunaga *et al.* 2013; Rajendraprasad *et al.*1998; Ray *et al.* 2012). A large scale land cover change in recent times is altering the ecosystem structure influencing the respective ecosystem's goods and services. Quantification of linkages of ecosystem structure with hydrological and other concurrent services helps in mitigating land cover changes and hence the conservation of ecosystems. In this context, a comparative assessment of two watersheds (with and without sacred forests) through ecological, hydrological and socio-economic parameters was undertaken to understand the linkages of landscape structures of watersheds with hydrological services and also local livelihood.

Methods

Study area

The field investigations were carried out in two neighbouring watersheds with similar topography, one with a sacred grove and the second without a sacred grove, in the Honavar taluk of Uttara Kannada district in the central Western Ghats of Karnataka State. The Karikan hill with a maximum height of about 450 mt. (14° 20.25" - 14° 22.95" N and 74° 29.40" - 74° 31.50" E), covered with a sacred forest of primeval dipterocarps is at the source of a stream that recharges the ground water in the Bangarmakki village in the valley below. In the vicinity of the grove is the Karikanamman temple, a popular place of mother goddess worship in the district. The Karikan watershed is spread over 460 ha, of which about ~178 ha is forest, including the sacred grove. The grove is today part of the State Reserved Forest of Karnataka, and as such has no sharp boundaries to distinguish it from the secondary forest surrounding it.

The second study area was Sambegadde, A hill, also with maximum height of about 450 mt. with a village by same name towards its base (14° 21.54" 14° 22.77" N and 74° 30.50" - 74° 31.58" E). The forest cover on the hill is of secondary nature, and less evergreen than Karikan with several deciduous trees. The forest turned secondary due to slash and burn cultivation in the past and no taboos associated with it regarding resource extraction (Chandran 1997, 1998). A stream draining the watershed enters the Sambegadde village. The total drainage basin covers an approximate area of ~1004 ha of which forest cover is ~239 ha. Both the study areas receive average rainfall 3713.4 mm and the temperature ranges from 15 - 32 °C.

Table 1. Land use under major cultivated crops in the study area.

	Bangarmakki (ha)	Sambegadde (ha)
Areca nut (*Areca catechu*) garden	20.123	10.491
Rainfed agriculture paddy (*Oryza sativa*)	0.111	25.398
Sugarcane (*Saccharum officinarum*)		0.082
Ragi (*Eleusine coracana*)		0.044
Total cultivated land	20.234	36.015

Major land use types in the Bangarimakki village are areca nut (*Areca catechu*) gardens with black pepper (*Piper nigrum*), betel leaf (*Piper betel*), banana (*Musa paradisiaca*) and coconut. Sampegadde has rain-fed rice (*Oryza sativa*) as main crop followed by ragi (*Eleusine coracana*) and sugarcane (*Saccharum officinarum*) as seasonal field crops (Table 1). Garden crops are grown in lesser areas compared to Bangarmakki. The study areas were digitized from Survey of India 1:50,000 toposheets (Fig. 1.)

Vegetation study

Study of the forests covering the drainage basins of the two streams, has been carried out using transect - cum - quadrat method. Each catch-ment was divided into three altitudinal zones viz. low (< 200 m), middle (200 - 400 m) and high (> 400 m). A line transect of 180 m was laid in each altitudinal zone. Five quadrats of 20 m × 20 m for tree (30 cm gbh or more) inventory were laid at equal distances from each other alternately along left and right of this transect covering a total of 2000 m^2 forest area. 5 m × 5 m quadrats, two each

Fig. 1. Study area details (Toposheet (SOI) 48_J_7, 48_J_11). Continuous line indicating watershed boundary and dotted line indicates study forest boundary.

within a tree quadrat, for shrub layer including tree saplings (< 30 cm gbh) and 1 m × 1 m nested quadrat for herbs, two each within a shrub layer quadrat, were laid along the line transect.

Soil study

Soil in the study area is broadly classified under clayey, kaolinitic and ustic kandihumults category (Anonymous 1998). Soil samples (at 0 - 20 cm) were collected for moisture content, bulk density and total carbon. For moisture content, five samples were collected from every altitudinal zone month-wise covering the post- and pre monsoon period (January - May). Therefore, a total of 75 samples were collected from each watershed (5 samples × 3 altitudes × 5 months). Moisture content was analysed through gravimetric method, organic carbon using Walkley-Black method and bulk density through core method (Baruah & Barthakur 1997).

Ground water monitoring

The study period was divided into pre-monsoon (April-May), monsoon (June-September) and post-monsoon (October-March) according to local weather and water availability scenario. The Sambegadde village stream dries up from late post-monsoon in January to May end in pre-monsoon, making villagers entirely depending on open wells for irrigation. The Bangarmakki stream experiences intermittent flows during the pre-monsoon. As ground water level is high villagers better use open wells for water. Therefore, we measured ground water levels in open wells and the quantum of water pumped out of them for farming and domestic needs. We selected 15 wells

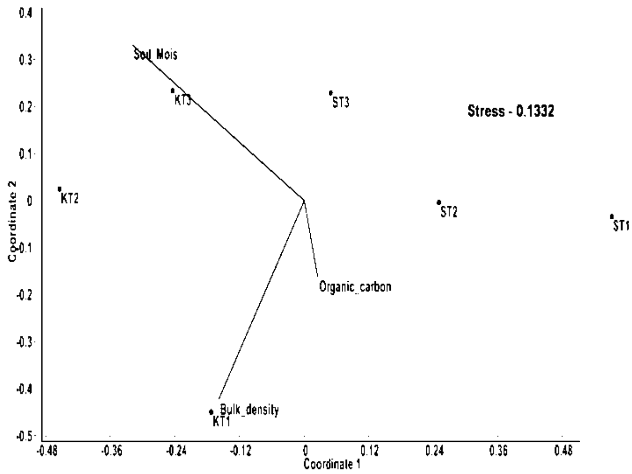
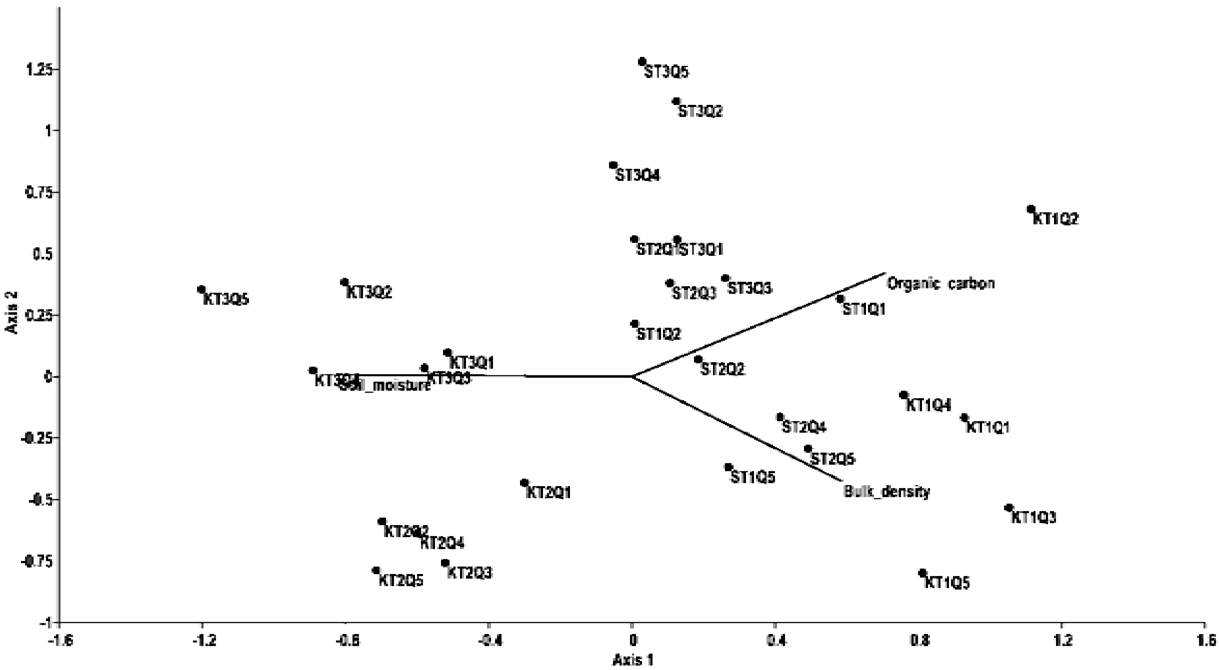


Fig. 2. Non-Metric Multidimensional Scaling (NMDS) result of vegetation-site characteristics (sacred and non-sacred forest sites). KT1, KT2 and KT3 denote sampling groups from Karikan; ST1, ST2 and ST3 denote sampling groups from Sambegadde.

A



B

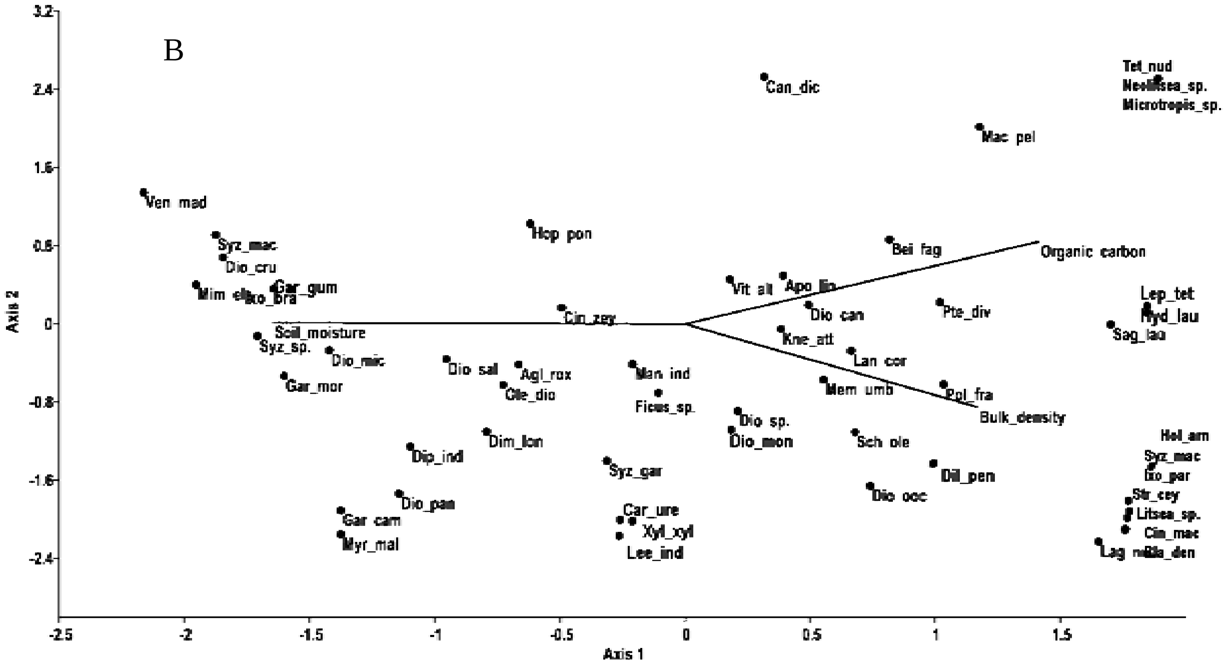


Fig. 3(A). Canonical Correspondence Analysis (CCA) result related to sampling sites and studied soil parameters. Sites prefix with "K" from Karikan and prefix with "S" from Sambegadde. (B) Canonical Correspondence Analysis (CCA) result related to association of species with studied soil parameters.

Table 2. Woody species diversity profile in studied watersheds.

	Karikan	Sambegadde
No. of species observed	44	27
Endemism (%)	38	22
No. of species estimated (% captured)		
Jackknife 1	58.93 (74.66)	38.2 (70.68)
Chao 2	54.18 (81.21)	45 (60)
Diversity index		
Fischer's alpha	13.21	10.11
Shannon	3	2.54
Simpson	12.92	7.57
Three most dominant species (IVI)	*Dipterocarpus indicus* (52.95)	*Hopea ponga* (71.27)
	Hopea ponga (33.03)	*Diospyros candolleana* (29.53)
	Knema attenuata (27.62)	*Aporosa lindleyana* (24.02)

each in Bangarmakki and Sambegadde villages for monitoring ground water for 18 months from January 2009 to May 2010. All these wells were at an average altitude of ~50 - 55 m. The depth to water table was measured manually following standard techniques suggested by World Meteorological Organisation (Anonymous 1994). Data on quantities of water pumped for irrigation and domestic use, was collected through interviews.

Socio-economic survey

Socio-economic survey was conducted in the two villages using structured questionnaire and market price method was used to estimate the cost and benefits of the ecosystem goods i.e. mainly of agricultural and horticultural crops.

Data analysis

Data related to ground water, soil moisture and water usage were analysed for central tendency and t-test was done for comparative analysis. Vegetation data was analysed through multivariate statistical techniques (PAST version 2.14.) (Hammer *et al.* 2001) included Nonmetric Multi Dimensional Scaling (NMDS), Analysis of similarity (ANOSIM) and similarity percentage analysis (SIMPER) for understanding the differences in species composition between the sites. Species richness was estimated through non-parametric richness estimators viz., ACE, ICE, Chao1, Chao2, Jack1 and Jack2 and species diversity-dominance was calculated through several indices like Fischer's alpha, Shannon-Wiener, and Simpson (Estimate S version 8.2) (Colwell 2009). Girth class distribution was compared through Kolmogrov-Smirnov test. Canonical Correspondence Analysis (CCA) was performed with vegetation and soil data to explore the site-species relationship with soil characters. For cost - benefit analysis, expenses related to cost and profit were calculated on data collected from twenty respondents from each site, which was then summed up and averaged. Total cost and benefit were calculated by multiplying this average value with total area under horticultural and crops and the value was expressed in terms of hectare.

Results

Vegetation analysis

Vegetation studies in the focal watershed areas revealed two distinct species composition patterns (Fig. 2.). Whereas 44 tree species were recorded from Karikan forest, only 27 occurred in Sambegadde. The nonparametric species richness estimators, captured 75 - 80 % of species diversity from the study sites (Table 2). Shannon index of diversity was significantly higher for Karikan (3.001) in comparison to Sambegadde (2.54) (P - value < 0.000). Girth class distribution is identical reverse "J" shaped in both the areas (K-S test D=0.53333; $D_{critical\ \alpha}$ at 0.05 = 0.6027; $p_{(permutated)}$ = 0.0218), but Karikan shows a good number of high girth class individuals and taller trees, in comparison to Sambegadde. Stark difference was in the average basal area -(53.6 m^2 ha^{-1} in Sambegadde). There are 94 % and 86 % of evergreen tree members and 38.6 % and 22.2 % of endemism in Karikan and Sambegadde respectively.

The overall dissimilarity between the sites is 84.1 % as per ANOSIM analysis (r value 0.342). SIMPER analysis highlighted the major contribution of wet evergreen species like, *Dipterocarpus indicus, Polyalthia fragrans, Syzygium gardneri, Diospyros crumenata, Myristica malabarica, Lepisanthes tetraphylla* etc. in Karikan. Canonical Correspondence Analysis (CCA) with vegetation and soil parameters (pre-monsoon soil moisture, organic carbon and bulk density) has shown distinct groupings in study sites. CCA axes 1 and 2 have explained 70.45 % and 29.54 % variation respectively (Fig. 3 A, B). Species like *Diospyros saldanha, Dipterocarpus indicus, Aglaia roxburghiana, Cinnamomum malabathrum, Myristica malabarica* and *Hopea ponga* are closely associated with high soil moisture, whereas, *Aporosa lindleyana, Vitex altissima, Knema attenuata, Lannea coromandelica* etc., mostly of Sampegadde, form a separate cluster opposite to soil moisture factors. Karikan middle and upper region showed greater association with soil moisture than the very disturbed lower region closer to the Bangarmakki village in the valley. On the other hand, all sampling sites in Sambegadde clustered around bulk density and organic carbon.

Soil analysis

Soil samples collected in three altitude ranges throughout the dry period (January to May) were analysed. In low altitude range (0 - 200 m), Karikan forest has shown gradual reduction in soil moisture from 18.6 % in January to 8.7 % in May. In Sambegadde, soil moisture dropped from 14.4 % to 11.7 % in the same period. In middle altitude range (200 - 400 m), soil moisture content was higher in Karikan than Sambegadde throughout the study period. It was always > 20 % in sacred forest whereas in non-sacred forest it gradually decreased from 17 % in January to 8.8 % in May. In the higher altitude range (> 400 m) of Karikan, soil moisture was 19 - 25 % throughout the study period in comparison to 18 - 20 % in Sambegadde. On the whole sacred forest was found to have more soil moisture in entire study period (Jan - May) 17 - 22 % than non-sacred one 13 - 17 %.

Soil organic carbon in Karikan low altitude was higher (3.79 %) than Sambegadde (2.54 %); but for middle and high altitudes, Sambegadde showed higher value than Karikan. These localities show more or less same bulk density values in all three altitude levels (Fig 4A, B and C).

Ground water monitoring

Ground water monitoring during 18 months (Jan 2009 to May 2010) showed marked differences in two areas (Fig. 5). Bangarmakki, associated with Karikan forest showed lesser decline in water table depth in comparison to Sambegadde during dry spell. However, both the villages showed similar water table profile during monsoon and early post-monsoon periods (July - Dec 2009). The water table at Sambegadde was at its lowest in May 2009 (5.97 m ± 1.60; peak summer) and highest in July 2009 (0.74 m ± 0.72; monsoon). Bangarmakki showed gradual changes in ground water level in comparison to drastic changes in Sambegadde (rising and receding faster during wet and dry seasons). The maximum difference between these two areas was found during March 2009, when the mean water table was 2.46 m. lower in Sambegadde than in Bangarmakki.

Crop pattern

Bangarmakki, the hamlet near Karikan sacred forest has dominance of horticultural crops (99.4 %) in its land under cultivation. Mainly higher income yielding cash crops like areca nut, coconut, banana, beetle leaf and pepper vines are grown there. In contrast to that horticultural crops cover only 29 % of total cultivated area in Sambegadde, while the rest was mainly under rain fed paddy and to a smaller extent sugarcane and ragi cultivation. Land holdings are small in both the study areas (mean 0.8 ha ± 0.424) (Table 1).

Water usage

Pumping schedule during late post- and pre-monsoon season showed more liberal usage of water in Bangarmakki than in Sambegadde. In the former average of 1862 Kilolitres ha^{-1} of water was pumped in January, which got reduced to 136 Kilolitres ha^{-1} in May, the peak of summer. Similar data for Sambegadde (947 Kilolitres ha^{-1} in January to 37 Kilolitres ha^{-1} in May) were significantly lower (Fig. 6). Withdrawal of water during lean seasons (non-monsoon) is linked to the quantum of recharged water at regular interval. Geology of the terrain (of both regions) are similar and there is no scope for further deepening of wells as in Sambegadde village compelling farmers to restrict to rain-fed rice than water demanding garden crops.

Cost-benefit analysis of plantation and agriculture products

Both plantation and agricultural crops have been considered for the valuation. In Bangarmakki, plantation crops (viz. areca nut, coconut, banana, beetle leaf and pepper) are the major income generating products. A total amount of Rs. 3,11,701 ha^{-1} $yr.^{-1}$ (year 2009-10) gross average income was generated from the plantation crops against an average expenditure of Rs. 37,043 ha^{-1} yr^{-1}, (mainly for plantation maintenance), yielding a net profit of Rs. 2, 74,658 ha^{-1} yr^{-1}. On the contrary, for Sambegadde, (where both plantation and rice

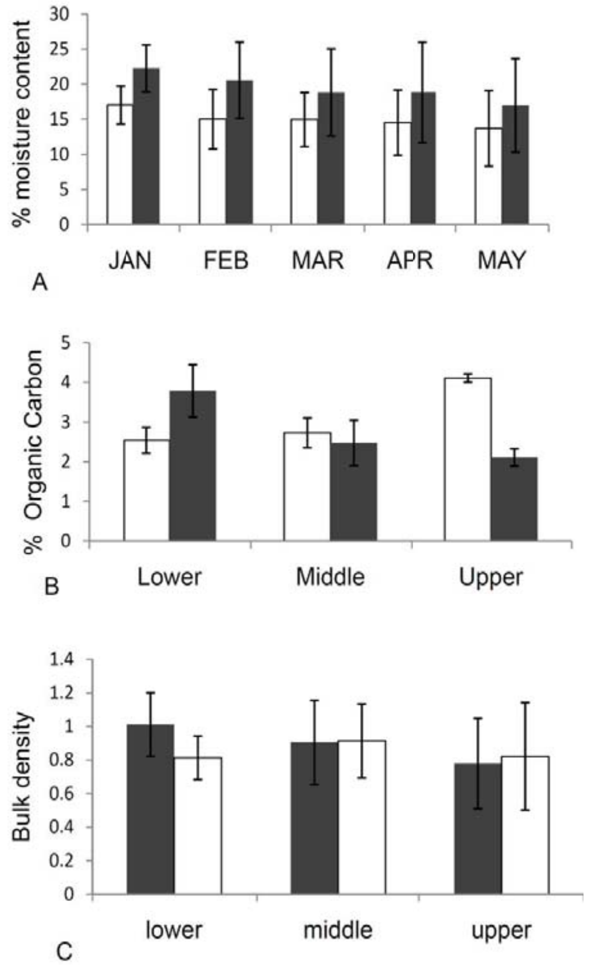


Fig. 4. Soil analysis result from sacred and non-sacred sites.

(Karikan ▇ Sambegadde □)
A = soil moisture at dry period (Jan-May)
B = % of organic carbon at three altitudes
C = Bulk density at three altitudes.

fields were considered for income calculation) the average gross income generated was Rs. 1, 50,679 ha^{-1} yr^{-1} against expenditure of Rs. 6474.10 ha^{-1} yr^{-1} for plantation maintenance and field preparation. The maintenance cost was lower here as major land use was rain-fed rice. Therefore, net profit per hectare of cultivated land was only Rs.1,44,204 ha^{-1} yr^{-1}, against a sum of over Rs. 2,74,658 ha^{-1} yr^{-1} from Bangarmakki.

Discussion

The importance of forested catchment area in hydrological cycle is a well explored topic which has been under extensive reviewing from time to time (Bruijnzeel 2004; Chomitz & Kumari 1998;

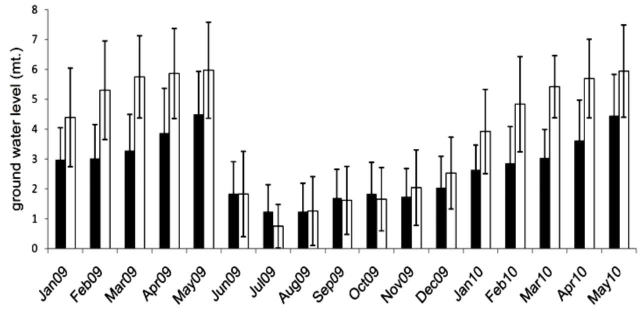


Fig 5. Groundwater profile at two sites (January 2009 - May 2010).

Hamilton 2008; Makarieva *et al.* 2006). Forest type (native/ plantation / primary / secondary), edaphic factors and ground water recharges are some of the major factors which have been investigated by many workers (Brauman *et al.* 2011; D'Odorico *et al.* 2010; Kagawa *et al.* 2009; Muñoz-Villers *et al.* 2011; Smerdon *et al.* 2009). Forest cover has defi-nite role in water conservation by soil moisture retention (through humus and thick litter layer) and maintaining microclimate thus reducing evapo-transpiration demand (Sikka & Selvi 2006; Thomas & Sankar 2006). Similarly studies have also addressed the effect of afforestation and land conversion in relation to hydrological cycle (Purandara *et al.* 2006; Sikka & Selvi 2006).

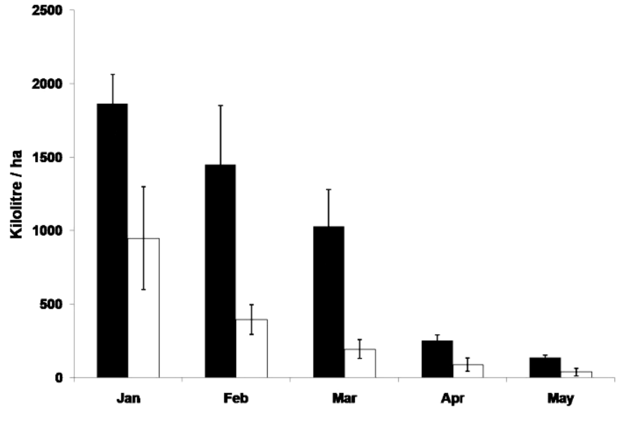


Fig. 6. Water usage in study areas during dry period (January-May).

Ecologically, the sacred groves in central Western Ghats region often represent relic primary forests or other old growth forests, usually characterised by large trees (higher basal area), rich litter cover and less compact soils. However, their ecological status is too much varied as per management condition and changing land use practices in the region from British colonial time period (Chandran & Gadgil 1998). Both sacred and non-sacred hill slopes of the current study sites, separated from each other by a single hill, are part of the central Western Ghats. Therefore, overall temperature, precipitation and gross geological pattern are similar for both the study areas. However, differences would certainly exist in microclimate level as reflected in plant species diversity, endemism, periodic soil moisture level and ground water recharge.

Karikan sacred grove occupies south-west slope of the hill and is the source of perennial streams in the locality. The old growth evergreen to semi-evergreen nature of the Karikan forest is in sharp contrast to its neighbouring forested areas which are secondary with more deciduous tree elements. These deciduous elements in a heavy rainfall zone are the results of slash and burn cultivation system of the past. Ever since this system was prohibited by the British over a century ago, the practice of setting fire to the forests diminished in the region, favouring the return of the evergreens in a big way as is evident from the greater numbers of the endemic evergreen trees like *Hopea ponga* and *Diospyros candolleana.* Nevertheless, the tree basal areas in the secondary forests of Sambegadde are far less from that of the Karikan hill. NMDS analysis also reveals distinct species composition pattern in two areas. Tree population study in Karikan shows considerable presence (31 %) of high girth class members (> 90 cm GBH) and upper strata at ≥ 30 mt, typical structural characteristic of tropical old growth forest as reported from other parts of Western Ghats and elsewhere in tropics (Chandrashekara & Ramakrishnan 1994; Pascal & Pelissier 1996; Uuttera *et al.* 2000). Although not saturated, the diversity study has captured 74.66 % and 81.21 % (Jackknife 1 and Chao1) of species diversity from the study area. High species richness among trees with 38 % Western Ghats endemism indicates favourable microclimate especially for diverse endemic species. Presence of typical wet evergreen species like, *Dipterocarpus indicus, Polyalthia fragrans, Diospyros saldanha, Knema attenuata, Myristica malabarica* etc. (Western Ghats endemics), in Karikan also confirms this contention. Although the non-sacred forest site in the Sambegadde hill has shown less species richness and endemism (22 %), estimators assume more species to be found. Tree population structure shows dominance of younger members (86 %) i.e. girth class < 90 cm GBH and lower height level (~20 - 25 mt) which indicates comparatively younger age of the forest stand, in contrast to the large girth trees with several reaching 30 - 40 m in Karikan. The dominant species are *Hopea ponga, Diospyros candolleana, Aporosa lindleyana, Schleichera oleosa* etc. (as per IVI value) of which *Hopea ponga* (though an ever-green dipterocarp) and *Aporosa lindleyana* are well recognised disturbance indicators of the forests of the high rainfall areas of South Indian Western Ghats (Gokhale 2005; Pascal & Ramesh 1997).

CCA has found close association between Karikan middle and upper region with soil moisture which could be justified by presence of undisturbed interior, large sized evergreen trees and litter covered forest floor whereas, the difference in lower region is mainly due to disturbances like, widespread tree cutting, lopping and encroachment (for plantation crop establishment) etc. Although this lower region has some wet evergreen species like *Sageraria laurifolia, Hydnocarpus laurifolia, Polyalthia fragrans* and *Pterospermum diversifolium* they are more restricted to adult population with minimal representation in the juvenile group. Non-sacred sampling sites in Sambegadde forest are present in close association with each other in relation to factors like bulk density and soil organic carbon but standing apart in soil moisture conditions. Similarly, tree species also form separate clusters corresponding to soil moisture. Wet evergreen species like *Diptero carpus indicus, Myristica malabarica, Dyospyros saldanha, Cinnamomum macrocarpum,* are clustered in the vicinity of soil moisture variable which confirms their inclination towards moist microclimatic conditions of Karikan. These species are more abundant in southern Western Ghats which enjoy more rainy months (usually 7 to 9) than in the central Western Ghats of Uttara Kannada with 5 - 7 rainy months (Pascal & Ramesh 1997).

Dry season soil moisture profile for top soil layer (0 - 20 cm) was analysed as it is one of the important determinant factors for species composition in any area (D'Odorico *et al.* 2010; Jirka *et al.* 2007). Moisture level at top soil layer is an indicator of water retention potential of entire soil mass especially at lean season. In clayey soil, the top soil layer (10 - 30 cm) is considered as soil moisture control section which plays important role in maintenance of above ground biomass (Anonymous 1999). As long as the top soil layer is wet there is a clear indication of water availability in the area. The study shows significantly higher soil moisture profile throughout the pre-monsoon season in Karikan which could be attributed to its dense canopy cover of evergreen trees and rich litter cover on the soil, not tampered with at least in the sacred grove proper. Many studies have established linkages of old growth trees in tropical forests as adapted to several physiological changes like less water usage, decreased stomatal conductance and protection of soil from direct solar radiation which promote water conservation in the nearby localities (Kagawa *et al.* 2009; Macfarlane *et al.* 2010; Singh & Mishra 2012; Vertessy *et al.* 2001).

The typical old growth forest structure (i.e. higher basal area, height, high evergreenness and endemism) and soil moisture profile in Karikan have obviously combined effect on water availability in downstream area. Bangarmakki shows comparatively slower decline in water table in dry months than Sambegadde indicating higher recharging capacity. The landscape with good vegetation cover allows higher infiltration of water and groundwater recharge. This also helps in sustaining water in the streams during lean seasons due to lateral flow from vadoze zone and from aquifer. The partial presence of water in stream bed in May in the Bangarmakki valley indicates stable presence of ground water in the area even in dry summer period, despite having heavy use for horticultural crops. Increment in water table is more drastic in Sambegadde compared to Bangarmakki due to its completely dry stream bed and sharp decline in the ground water table during summer.

Here we find the hydrological significance of a natural sacred site (Karikan) benefitting immensely the farming community in the valley downhill. The predominance of water demanding plantation crops at Bangarmakki indicates year long water availability in the region whereas, Sambegadde shows dominance of rain-fed cultivation mainly of paddy, (64 % of total cultivable area) with less plantation crops (29 % of total cultivable area). The availability of water for longer period (lean seasons) is also reflected in water usage pattern. Monthly water utility in dry period (January to May) shows that Bangarmakki has more water availability as reflected in the usage (1862 - 136 Kilolitres ha^{-1}) than Sambegadde (947 - 37 Kilolitres ha^{-1}). Similarly, a conservative monetary assessment on farm production has also highlighted the contrast between the areas. Constant availability and higher market prices of horticultural products keeps the Bangarmakki farmers in better economic situation in comparison to Sambegadde farmers. The farmers in Sambegadde, obviously, not backed to that extent by supporting forests like a primeval sacred grove, have to subsist mainly on rainfed rice. They are also required to grapple with fast depleting water table in the dry months throwing challenges for maintenance of cash crops in their gardens.

Conclusions

Comparative analysis of water yields from the watersheds of sacred forest dominated Karikan hill of Bangarmakki village and secondary forest dominated Sambegadde hill fortifies the contention of many investigators alluding to the intimate linkages between sacred groves and water conservation. Despite the smallness of this empirical study, confined to merely two forested watersheds, it illustrates the possible link of water availability in the watershed with the preservation of native primary forests to some extent. The retention of native forests as sacred groves, as reflected in their vegetation dominated by relic species, has added significance in the form of better status of soil moisture and ground water. That such forests were protected as integral to the cultures of the region highlights the need for more studies on the eco-centric societies and their conservation practices in the Western Ghats, one of the global biodiversity hotspots.

This finding has also much bearing on conservation and management of the last remains of primeval forests of the Western Ghats. Many of these forests, the sacred groves which had greater ecological and cultural roles in the rural land-scapes of the bygone days, are being increasingly targeted for development of hydroelectric projects or being reclaimed for cultivation and other alternative land uses by the local communities themselves who are under the throes of a cultural change that is distancing them from their age old traditions of worship associated with natural sacred sites. It is time that the waning sacred groves of central Western Ghats, which once con-stituted major landmarks of the pre-colonial villages, and functioned as decentralised water conservation systems, are resurrected through an active conservation program designed to ensure their long term survival and benefit to local liveli-hood.

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Research Article Open Access

Environmental Flow Assessment in a Lotic Ecosystem of Central Western Ghats, India

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Abstract

Environmental/Ecological flow refers to the minimum flow of water to be maintained in a water body (river, lake, etc.) to sustain ecosystem services. Understanding environmental flow is important to ensure the local ecological and social (people, agriculture and horticulture, etc.) needs in a sustained and balanced way, while designing large scale projects (such as hydro-electric, river diversion, etc.). Western Ghats are the mountain ranges extending from southern tip of India (Tamil Nadu-Kanyakumari) to Gujarat. These mountain ranges are rich in biodiversity with diverse and endemic flora and fauna, and is birth place to numerous perennial rivers namely Netravathi, Sita, Sharavathi, Aghanashini, Krishna, Cauvery, etc. Western Ghats is often referred as water tower of peninsular India, due to the water and food security provided by the ecosystem through array of services. The region is also one among 35 global biodiversity hotspots. However, deforestation due to large scale land cover changes has affected the water sustenance in the region evident from the quantity and duration of water availability during post monsoon period. Forests in the Western Ghats along with the soil characteristics and precipitation plays a major role in storing water in sub-surface (vadoze and groundwater) zones during monsoon, and releases to the streams during post monsoon periods catering to the needs of the dependent biota including humans. Some of these undisturbed/ unaltered natural flow conditions in rivers and streams have proved their worth with the presence of rich and diverse species and array of ecosystem services, which also has helped in sustaining the livelihood of dependent populations. The undisturbed flow conditions guarantees the natural flow as well as minimum flow in streams to sustain the ecosystem services, which helps in meeting the social and ecological needs. Growing demand to cater the demands of burgeoning human population coupled with accelerated pace of deforestation due to unplanned and senseless developmental projects in the ecologically fragile regions have led the water scarcity even in regions receiving high amount of rainfall. In the current communication an attempt is made to understand the linkages between the hydrological dynamics across varied landscape with the anthropogenic and ecological water needs. If the available water resource meets the societal and environmental demands across seasons, the catchment is said to achieve the minimum flow requirements. The federal government has plans to divert the water from rivers in Western Ghats region to the dry arid regions in Karnataka. In this regard, environmental flow assessment of Yettinaholé river in Central Western Ghats is carried out to understand the feasibility of river diversion through the assessment of hydrologic regime with the analysis of land use dynamics (using remote sensing data), meteorological data (rainfall, temperature, etc. from IMD, Pune), hydrological data (from gauged streams) apart from field investigations in the catchment. The catchments receive annual rainfall of 3000-5000 mm (Department of Statistics, Government of Karnataka). Land use analyses reveal that Major portion of the catchment is covered with evergreen forest (45.08%) followed by agriculture plantations (29.05%) and grass lands (24.06%). Water yield in the catchment computed for each of sub-catchments based on the current land use and other related hydrological parameters using empirical method. The total runoff yield from the catchments is estimated to be 9.55 TMC. About 5.84 TMC is required for domestic purposes including agriculture, horticulture and livestock rearing. The quantum of water required to sustain fish life in the streams is about 2 TMC, computed based on hydrological discharge monitoring and fish diversity in streams during 18 months (covering all seasons) in select streams in Western Ghats. Considering the available water is sufficient only to meet the anthropogenic and ecological needs in the region, the sustainable option to meet the water requirements in dry arid regions would be through (i) decentralized water harvesting (through tanks, ponds, lakes, etc.), (ii) rejuvenation or restoration of existing lakes/ponds, (iii) reuse of waste water, (iv) recharging groundwater resources, (v) planting native species of grasses and tree species in the catchment (to enhance percolation of water in the catchment), (vi) implementation of soil and water conservation through micro-watershed approaches. Implementation of these location specific approaches in arid regions would cost much less compared to the river diversion projects, which if implemented would help the section of the society involved in decision making, construction and implementation of the project.

Keywords: Ecological flow; Yettinaholé River; Watershed; Land cover; Fresh water ecosystem

Introduction

The Western Ghats is a series of hills located in the western part of peninsular India stretching over a distance of 1,600 km from north to south and covering an area of about 1,60,000 sq.km and one among the

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35 global hotspots of biodiversity [1-3]. It harbors very rich and rare flora and fauna and there are records of over 4,500 species of flowering plants with 38% endemics, 330 butterflies with 11% endemics, 156 reptiles with 62% endemics, 508 birds with 4% endemics, 120 mammals with 12% endemics, 289 fishes with 41% endemics and 135 amphibians with 75% endemics [4-7].

Western Ghats has numerous watersheds that feed perennial rivers of peninsular India [2]. It encompasses series of west and east flowing rivers that originates from the Western Ghats, supporting as source of sustenance for existing life forms in the environment. One such source of perennial waters is Yettinaholé originating at an altitude of 950 m in Sakaleshpura taluk of Hassan district, and tributary of river Gundia, which joins Kumaradhara and finally drains to Netravathi River The region with a repository of endemic and rare biodiversity is ecologically sensitive and large scale degradation of catchment landscape have influenced the availability of water and has also affected the sustenance of biodiversity. Changes in landscape structure and the regional climate [8,9] have altered the hydrologic regime [10,11] in many lotic ecosystems in the tropical regions, affecting the potential of the catchment to retain water in the surface and sub surfaces. Various studies carried out in Western Ghats [12-14] and across the globe show the relevance of landscape on surface and subsurface hydrological regime [12-19]. Few studies carried out in Western Ghats also emphasize on the role of hydrological regime on the habitats, ecology, biodiversity, quality of water, soil and ecosystem etc. [20-23]. In the current communication an attempt has been made to understand the linkages between the hydrological dynamics across varied landscape of Yettinaholé catchment with the societal and environmental water needs. In this regard, the study investigates land use dynamics, hydrological yield, fish diversity in select streams and linkages with the flow during lean season and drivers of hydrological regime impairment.

Materials and Methods

Study area

Yettinaholé catchment has a pristine ecosystem with rich biodiversity (Figure 1 and Table 1), extend from 12044'N to 12058'N Latitude and 75037'E to 75047'E longitude encompassing total area of 179.68 km^2. The terrain (Figure 2) is undulating with altitude varying from 666 m above MSL to 1292 m above MSL leading to higher density of stream network (Figure 3). Geologically, rock types consist of Gneiss, the soils are loamy ranging from sandy loamy to clay loamy. Soils (Figure 4) in the region are fertile and highly permeable, hence allowing the precipitated water to percolate easily into the subsurface recharging ground water and storing water in the sub surfaces and hence keeping the water source perennial to the catchment and the downstream users during and post monsoon.

Decadal population in Sakleshpura Taluk (spatial extent 1034 sq. km) of Hassan district is given in Figure 5 and Table 2 shows a declining trend due to migration to cities during post 2001. Population dynamics of the catchments also follows the dynamics of Sakleshpura taluk. Total Population of all the catchments with respect to census data [24,25] was estimated as 17005 in 2001, has declined to 16345 in 2011 at a decadal rate of 3.88%. Population for the year 2014 was calculated as 16156 based on the temporal data. Population density for each of the sub catchments are as depicted in Figure 6 and Table 3.

Sub basin id	Stream Name	Area (Ha)
1	Yettinaholé	4878.7
2	Yettinaholé T2	781.1
3	Yettinaholé T1	991.1
4	Kadumane holé 2	761.4
5	Kadumane holé 1	1362.4
6	Hongada halla	5676.6
7	Keri holé	2198.3
8	Yettinaholé lower reach	1319.1

Table 1: Study Area.

Census Year	1921	1931	1941	1951	1961
Population	44115	44300	43765	53398	77522
Census Year	**1971**	**1981**	**1991**	**2001**	**2011**
Population	91175	114008	124753	133657	128633

Table 2: Population Growth of Sakleshpura Taluk [24,25].

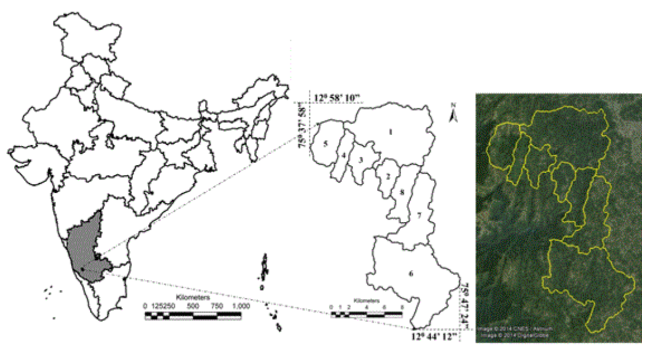

Figure 1: Study Area-Yettinaholé catchment, Karnataka, India.

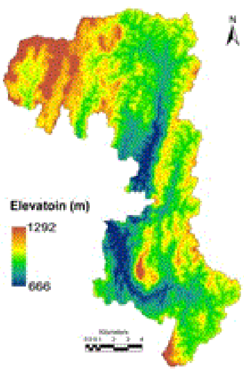

Figure 2: Digital Elevation Model.

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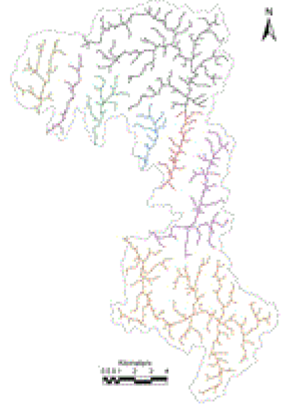

Figure 3: Stream Network.

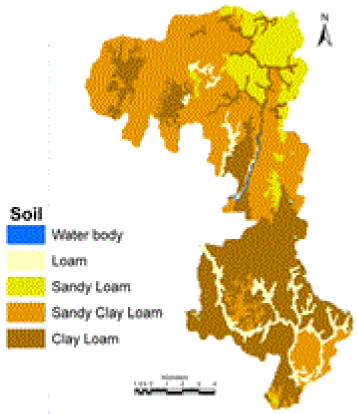

Figure 4: Soil.

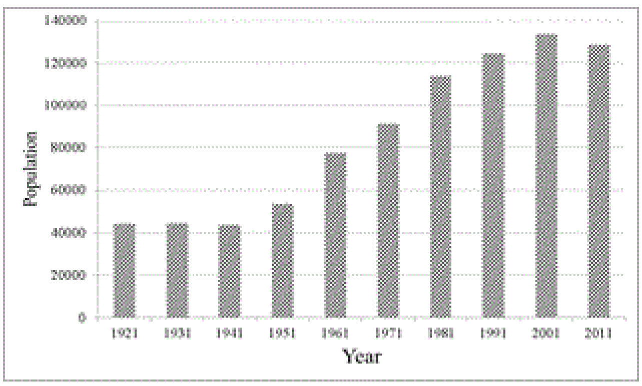

Figure 5: Population Growth of Sakleshpura Taluk.

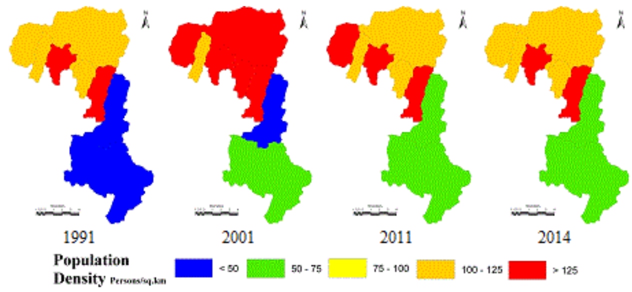

Figure 6: Population Density in Sub Catchments.

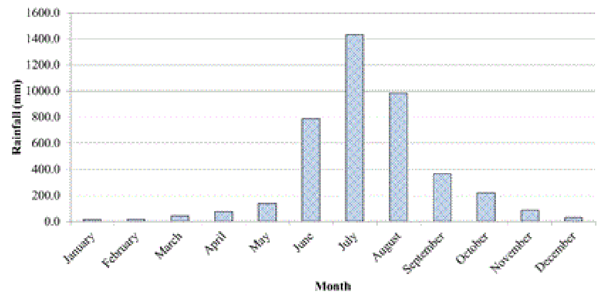

Figure 7: Rainfall in mm.

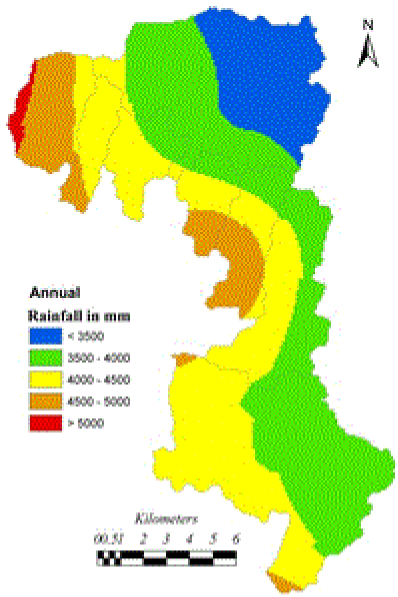

Figure 8: Rainfall distribution.

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Sub Basin Id	Sub basin	1991	2001	2011	2014
1	Yettina holé	117.86	126.92	122	120.59
2	Yettina holé T2	116.12	125.08	120.22	118.81
3	Yettina holé T1	126.52	136.31	130.96	129.45
4	Kadumane holé 2	108.36	116.76	112.17	110.98
5	Kadumane holé 1	121.33	130.65	125.58	124.12
6	Hongadahalla	47.26	50.89	48.92	48.36
7	Keri holé	32.71	35.25	33.89	33.48
8	Yettina holé lower reach	151.46	163.14	156.85	155.03

Table 3: Population density (persons per sq. km).

The region receives an annual rainfall of 3500 to 5000 mm across the catchment. Precipitation in the catchment during June to September is due to the southwest monsoons, with July having maximum rainfall over 1300 mm. Monthly variation in rainfall is depicted in Figure 7. Spatial variation of rainfall across the catchments was assessed based on 110 years data [26] (1901 to 2010) from the rain gauge stations in and around the catchment (Figure 8). Figure 9 depicts monthly temperatures [27] variations, which ranges from 14.7°C (January) to 31.6°C (in March).

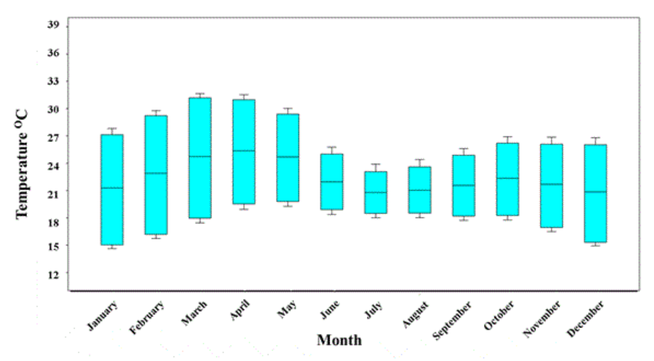

Figure 9: Monthly temperature variations.

Data

Data required for hydrological and land use analyses were (i) social and demographic data from the government agencies, (ii) temporal remote sensing data from public archive and (iii) primary data through field investigations. Latest remote sensing data used is of Landsat 8 series (2014). Rainfall data was acquired from the Directorate of Economics and Statistics, Government of Karnataka [26], Temperature data was sourced from World Clim-Global Climate Data [27] of 1 km resolution. Census data collected from government of India, state and district census departments [24,25]. These data was supplemented with secondary data compiled from various sources as tabulated in Table 4. Primary data is compiled through field investigations and through structured questionnaire (household survey).

Method

The method for the evaluation of the environmental flow and hydrological status is given in Figure 10. Hydrologic assessment in the catchment involved 1) delineation of catchment boundary 2) land use analysis, 3) assessment of the hydro meteorological data, 4) analysis of population census data, 5) compilation of data through public interactions for assessing the water needs for livestock, agriculture/ horticulture and cropping pattern, and 6) evaluation of hydrologic regime.

Delineation of catchment boundary: Catchment boundaries (Figure 1) and the stream networks (Figure 3) were delineated considering the topography of the terrain based on CartoSat DEM using the QSWAT module-Quantum GIS 2.10 32 bit. These catchment boundaries were overlaid on the extracted boundaries from the Survey of India topographic maps for validations. Corrected catchment boundaries were further overlaid on Google earth in order to visualize the terrain variations (Figure 2).

Data	Description	Source
Remote sensing data-spatial data	Remote sensing data of 30 m spatial resolution and 16 bit radiometric resolution were used to analyse land uses at catchment levels.	[28]
Rainfall	Daily rainfall data of 110 years (1901-2010), to assess the trends in rainfall distribution and variability across basins.	[26,29]
Crop Calendar	To estimate the crop water requirements based on the growth phases	[30-35]
Crop Coefficient	Evaporative coefficients used to estimate the actual evapotranspiration.	[33,36]
Temperature (max, min, mean), Extraterrestrial solar radiation	Monthly temperature data (1 km spatial resolution) and monthly extra-terrestrial solar radiation (Every 1° North latitude) available	[27,36-38]

	across different hemispheres to estimate the potential evapotranspiration.	
Population data	Population census data available at village level (2001, 2011), used to estimate the population at sub basin level for the year 2014, and estimate the water requirement for domestic use at sub basin levels.	[24,25]
Livestock Census	Taluk level data was used to estimate the livestock population and estimate water requirement at each of the river basins.	[39]
Digital Elevation data	Carto-DEM of 30 m resolution in association with Google earth and the Survey of India-Topographic maps (1:50000) was used to delineate the catchment boundaries, stream networks, contours, etc.	[40]
Secondary Data	Collateral data from government agencies regarding agriculture, horticulture, forests, soil, etc. for land use classification, delineation of streams/rivers/catchment, geometric correction (Remote sensing data).	[40-44]
Field data	Geometric Corrections, training data for land use classification, crop water requirement, livestock water requirement, etc.	GPS based field data, data form public (stratified random sampling of households)
Flow data	Evaluation of minimum flow requirements to sustain ecology (fish, etc.) and downstream dependent population's livelihood	Flow measurements at Hongadahalla, Kadumanehalla, and select streams of Sharavathi river [45,46]
Fish diversity	Understanding fish ecology in relation to water quantity and duration of flow to determine EF	Selected stream catchments and dams Sharavathi river [47]

Table 4: Data used for land use and assessment of hydrologic regime.

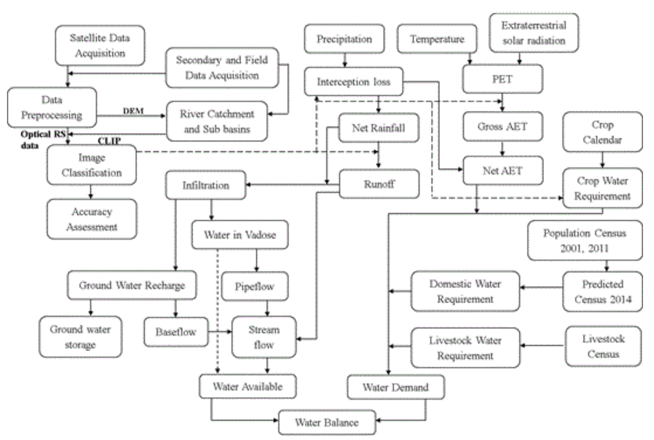

Figure 10: Method for computing environmental flow based on hydrologic variables.

Land use assessment: Large scale land-use land-cover (LULC) changes leading to deforestation is one of the drivers of global climate changes and alteration of biogeochemical cycles. This has given momentum to investigate the causes and consequences of LULC by mapping and modelling landscape patterns and dynamics and evaluating these in the context of human-environment interactions in the riverine landscapes. Human induced environmental changes and consequences are not uniformly distributed over the earth. However their impacts threaten the sustenance of human-environmental relationships. Land cover refers to physical cover and biophysical state of the earth's surface and immediate subsurface and is confined to describe vegetation and manmade features. Thus, land cover reflects the visible evidence of land cover of vegetation and non-vegetation. Land use refers to use of the land surface through modifications by humans and natural phenomena. Heterogeneous terrain in the landscape with the interacting ecosystems is characterized by its dynamics. Human induced land use and land cover (LULC) changes have been the major driver of the landscape dynamics at local levels. Land use assessment was carried using the maximum likelihood classification technique [48,49]. Understanding of landscape dynamics helps in the sustainable management of natural resources.

Land use analysis involved i) generation of FCC-False Colour Composite (Figure 11) of remote sensing data (bands-green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) 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, iv) supplementing this information with Google Earth v) 65% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land uses were categorized into 8 classes namely. i) water bodies (lakes/tanks, rivers, streams, ii) built up (buildings, roads or any paved surface, iii) open spaces iv) evergreen forest (evergreen and semi evergreen), v) deciduous forest (Moist deciduous and dry deciduous) vi) scrub land and grass lands, vii) agriculture, (viii) private plantations (coconut, arecanut, rubber) and forest plantations (Acacia, Teak, etc.)

Assessment of the hydro meteorological data: This involved assessment of the spatial and temporal variations in rainfall [26,29,50] in and around the study region. Long term precipitation data helped in understanding the rainfall variability over decades. Along with rainfall, temperature (minimum, maximum and average), extra-terrestrial solar radiation across the catchment were used to hydrological behaviors of the catchments which enables to understand the hydrological status.

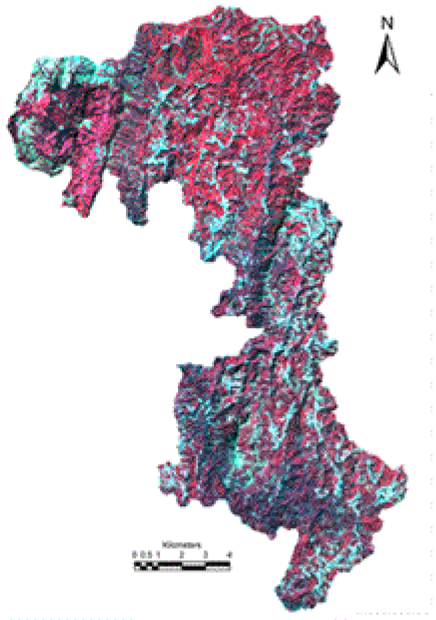

Figure 11: False Colour Composite of Study area.

Rainfall: Point data of daily rainfall from rain gauge stations for the period 1901-2010 [26,29,50] were used for the analysis. Some rain gauge stations had incomplete records with missing data for few months. The average monthly and annual rainfall data were used to derive rainfall map throughout the study area and was used to derive the gross yield (RG) in the basin (equation 1). Net yield (RN) was quantified (equation 2) as the difference between gross rainfall and interception (In).

$RG = A \times P$ ……. (1)

$RN = RG - In$ …… (2)

Where, RG: Gross rainfall yield volume; A: Area in Hectares; P: Precipitation in mm, RN: Net rainfall yield volume; and In: Interception volume

*Interception*During monsoons, portion of rainfall does not reach the surface of the earth; it remains on the canopy of trees, roof tops, etc. and gets evaporated. Field studies in Western Ghats show that, losses due to interception is about 15% to 30%, based on the canopy cover. Table 5 shows the interception loss across various rainy months and land uses.

Vegetation types	Period	Interception
Evergreen/semi evergreen forests	June-October	I=5.5+0.30 (P)
Moist deciduous forests	June-October	I=5.0+0.30 (P)
Plantations	June-October	I=5.0+0.20 (P)
Agricultural crops (paddy)	June	0
	July-August	I=1.8+0.10 (P)
	September	I=2.0+0.18 (P)
	October	0
Grasslands and scrubs	June-September	I=3.5+0.18 (P)
	October	I=2.5+0.10 (P)

Table 5: Interception loss.

Runoff: Portion of rainfall that flows in the streams after precipitation [2,8,10,11] are (i) surface runoff or direct runoff and (ii) sub surface runoff.

Surface runoff: Portion of water that directly enters into the streams during rainfall, which is estimated based on the empirical [9,10,11] relationships given in equation 3.

$Q = \Sigma(Ci \times PR \times Ai)/1000$……(3)

Where, Q: Runoff in cubic meters per month; C: Catchment/Runoff coefficient, depends on land uses as given in Table 6 [36]; PR: Net rainfall in mm; i: Land use type; Ai: Area of Landscape i as square meters.

Land Use	Catchment Coefficient
Urban	0.85
Agriculture	0.6
Open lands	0.7
Evergreen forest	0.15
Scrub/Grassland	0.6
Forest Planation	0.65
Agriculture Plantation	0.5
Deciduous Forest	0.15

Table 6: Catchment coefficients.

Infiltration: The portion of water enters the subsurface (vadoze and groundwater zones) during precipitation depending on land cover in the catchment. During field monitoring of streams in the forested catchment, overland flow is noticed in streams only after couple of days rainfall. This means that overland flow in the catchment with vegetation cover happens after the saturation of sub surfaces. The water stored in sub-surfaces will flow laterally towards streams and contributes to stream flow during non-monsoon periods, which are referred as pipe flow (during post monsoon) and base flow (during summer).

$Inf = RN - Q$…..…(4)

Ground water recharge: This is the portion of water that is percolated below the soil stratum (vadoze) after soil gets saturated. Recharge is considered the fraction of infiltrated water that recharges the aquifer after satisfying available water capacity and pipe flow. Krishna Rao equation, (equation 5) [19] was used to determine the ground water recharge.

$GWR = RC \times (PR - C) \times A$ …… (5)

Where, GWR: Ground water recharge; RC: Ground water recharge coefficient (Table 7); C: Rainfall Coefficient (Table 7); A: Area of the catchment. The recharge coefficient and the constant vary depending land uses with the annual rainfall.

Annual Rainfall	R_C	C
400 to 600 mm	0.2	400
600 to 1000 mm	0.25	400
>2000 mm	0.35	600

Table 7: Ground water recharge coefficients.

Sub surface flow (Pipe flow): Part of the infiltrated effective rainfall circulates more or less horizontally (lateral flow) in the superior soil layer and appears at the surface through stream channels is referred as subsurface flow. The presence of a relatively permeable shallow layer favors this flow. Subsurface flows in water bearing formations have a drainage capacity slower than superficial flows, but faster than groundwater flows. Pipe flow is considered to be the fraction of water that remains after infiltrated water satisfies the available water capacities under each soil. Pipe flow is estimated for all the basins as function of infiltration, ground water recharge and pipe flow coefficient, given by equation 6

PF=(Inf-GWR) × KP ……. (6)

Where, PF: Pipeflow; Inf: Infiltration volume; KP: Pipe flow coefficient [2]

Groundwater discharge: Groundwater discharge or base flow is estimated by multiplying the average specific yield of aquifer under each land use with the recharged water. Specific yield represents the water yielded from water bearing material. In other words, it is the ratio of the volume of water that the material, after being saturated, will yield by gravity to its own volume. Base flow appears after monsoon and receding of pipe-flow. This water generally sustains flow in the rivers during dry seasons. A portion of recharged water flows to the streams as ground water discharge which is dependent on the topography, geology and the land use conditions. Equation 7 defines Ground water discharge as product of specific yield and the portion of ground water recharged.

GWD=GWR × YS…..…(7)

Where, GWD: Ground water discharge; GWR: Ground water recharge; YS: Specific yield [2].

Estimation of water demand evapotranspiration

Evaporation is a process where in water is transferred as vapour to the atmosphere. Transpiration is the process by which water is released to the atmosphere from plants through leaves and other parts above ground. Evapotranspiration is the total water lost from different land use due to evaporation from soil, water and transpiration by plants. Some of the important factors that affect the rate of evapotranspiration are: (i) temperature, (ii) wind, (iii) light intensity, (iv) Sun light hours, (v) humidity, (vi) plant characteristics, (vii) land use type and (viii) soil moisture. If sufficient moisture is available to completely meet the needs of vegetation in the catchment, the resulting evapotranspiration is termed as potential evapotranspiration (PET). The real evapotranspiration occurring in specific situation is called as actual evapotranspiration (AET). These evapotranspiration rates from forests are more difficult to describe and estimate than for other vegetation types.

Potential evapotranspiration (PET) was determined using Hargreaves method (Hargreaves [2,36]) an empirical based radiation based equation, which is shown to perform well in humid climates. PET is estimated as mm using the Hargreaves equation is given by equation 8.

PET=0.0023 × (RA/λ) × √(Tmax-Tmin) × ((Tmax+Tmin)/2+17.8) …..…(8)

Where, RA: Extra-terrestrial radiation (MJ/m^2/day) [36]; Tmax: Maximum temperature [42]; Tmin: Minimum temperature [42]; λ: latent heat of vapourisation of water (2.501 MJ/kg)

Actual evapotranspiration is estimated as a product of Potential evapotranspiration (PET) and Evapotranspiration coefficient (KC) (Table 8), given in equation 9. The evapotranspiration coefficient is a function of land use varies with respect to different land use. Table 8 gives the evapotranspiration coefficients for different land use

AET=PET × KC……(9)

Land use	K_C
Built-up	0.15
Water	1.05
Open space	0.3
Evergreen forest	0.95
Scrub and grassland	0.8
Forest Plantation	0.85
Agriculture Plantation	0.8
Deciduous forest	0.85

Table 8: Evapotranspiration coefficient.

Note: the crop water requirement was estimated for different crops and different seasons based on land use, assumption is individual crop water requirement and different growth phases (need different quantum of water for their development inclusive of evaporation).

Domestic water demand: Understanding the population dynamics in a region is necessary to quantify and also to predict the domestic water demand. Population census for villages during 2001 and 2011 [24] were considered in order to compute the population of the basin level. Based on the rate of change of population (equation 10), the population for the year 2014 was predicted as given in equation 11.

r=(P2011/P2001-1)/n ……(10)

Where, P2001 and P2011 are population for the year 2001 and 2011 respectively; n is the number of decades which is equal to 1; r is the rate of change

P2014=P2011 × (1+n × r) ……(11)

Where, P2014 is the population for the year 2014; n is the number of decades which is equal to 0.3.

Domestic water demand is assessed as the function of water requirement per person per day, population and season. Water required per person includes water required for bathing, washing,

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drinking and other basic needs. Water requirements across various seasons are as depicted in Table 9.

Season	Water lpcd
Summer	150
Monsoon	125
Winter	135

Table 9: Seasonal water requirement.

	Water Requirement in lpcd (Liters per animal per day)							
Season\Animal	Cattle	Buffalo	Sheep	Goat	Pigs	Rabbits	Dogs	Poultry
Summer	100	105	20	22	30	2	10	0.35
Monsoon	70	75	15	15	20	1	6	0.25
Winter	85	90	18	20	25	1.5	8	0.3

Table 10: Livestock water requirement.

Livestock water requirement: Household surveys were conducted with the structured questionnaires to understand the agricultural and horticulture cropping pattern and water needed for various crops in the catchment. Livestock population details were obtained from the district statistics office and water requirement for different animals were quantified based on the household interviews. Table 10 gives the water requirement for various animals.

Crop water requirement: The crop water requirement for various crops was estimated considering their growth phase and details of the cropping pattern in the catchment (based on the data compiled from household surveys and publications such as the district at a glance, department of agriculture). Land use information was used in order to estimate the cropping area under various crops. Figure 12 provides the information of various crop water requirements based on their growth phase as cubic meter per hectare.

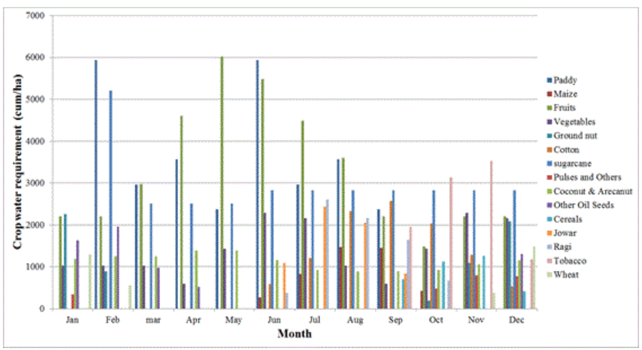

Figure 12: Crop water requirement (as cum per hectare per month).

Evaluating hydrological status: The hydrological status in the catchment is analysed for each month based on the water balance which take into account the water available to that of the demand. The water available in the catchment is function of water in the soil, run off (streams and river) and water available in the water bodies (Lentic water bodies such as lakes, etc.). Water demand in the catchment is estimated as the function of societal demand and terrestrial ecosystem (AET from forested landscape) crop water demand, domestic and livestock demand and the evapotranspiration. The catchment is considered hydrological sufficient, if the water available caters the water demand completely else the deficit catchment, if the water demand is more than the water available in the system.

Quantification of the environmental flow: Ecological investigations include the investigations of fish diversity across seasons. Habitat simulation method [51-56] was adopted to assess flows on basis of quantity and suitability of physical habitat available to target species under different flow regimes. In order to evaluate the natural flow regime [53,54], 18-24 months field monitoring of select streams in Sharavathi river basin and at Hongadahalla and Kadumanehalla (of Yettinaholé catchment) was carried out. This field data was compared with the long term flow measurements data at Hongadahalla and Kadumanehalla [45]. The natural flow that sustains native biota during lean season is accounted as the ecological or environmental flow [57-60] for the respective lotic system. In the current study, hydrologic assessment and investigations on the occurrence of native fish species (with diversity) helped in ascertaining the minimum flow required to sustain the native fish biota.

Results

Land use analysis

Land use analysis was carried out using remote sensing data of 2014, for Yettinaholé catchment (a tributary of Gundia River) and results are given in Figure 13 and Table 11. Major portion of the catchment is covered with evergreen forest (45.08%) followed by agriculture plantations (29.05%) and grass lands (24.06%). The valleys along the stream are dominated by agriculture lands and horticulture plantations, the hill tops dominated by grass lands, slopes covered with forest cover. The accuracy of the land use classification is 87% with kappa of 0.82. Temporal land use in the Gundia river catchment during 2000, 2006, 2010 and 2014 are depicted in Figure 14 and details are provided in Table 12. Results reveal that area under forests has reduced from 70.74% (in 2000) to 61.15% (in 2014).

Land use	Area (%)
Built up	0.07
Agriculture Plantation	29.25

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Evergreen	45.08
Forest Plantation	0.001
Water	0.002
Open land	0.91
Agriculture	0.62
Grassland	24.06

Table 11: Land use in Yettinaholé catchment.

The region receives annual rainfall ranging from 3000 mm to 4500 mm. Variability of rainfall was assessed based on 11 rain gauge stations in the catchment and is given in Figure 15.

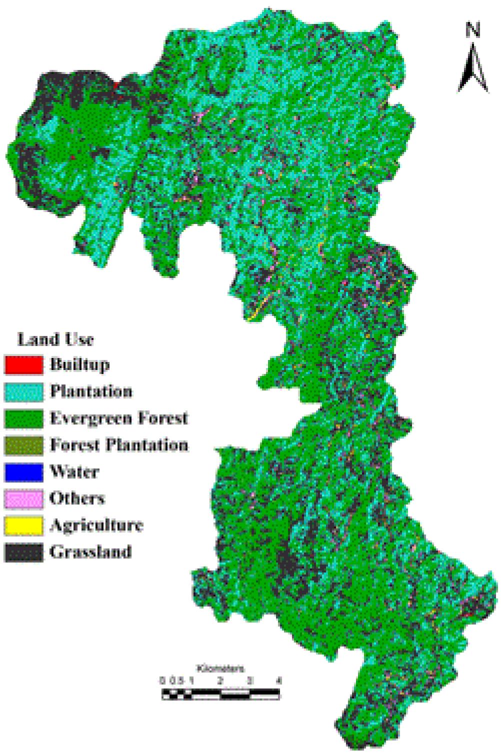

Figure 13: Land use in Yettinaholé catchment (eastern part of Gundya river basin).

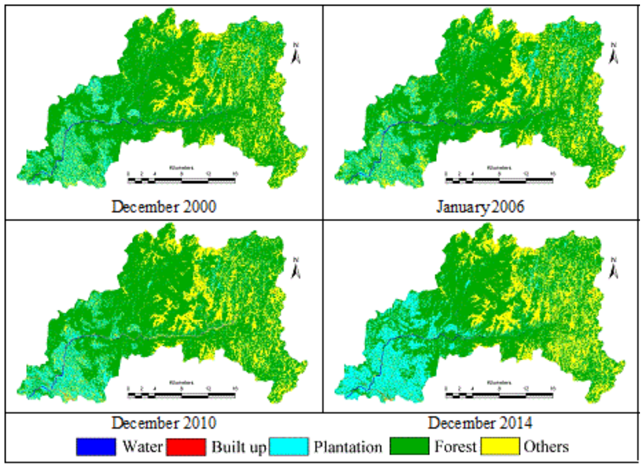

Figure 14: Land use dynamics-Gundia river basin.

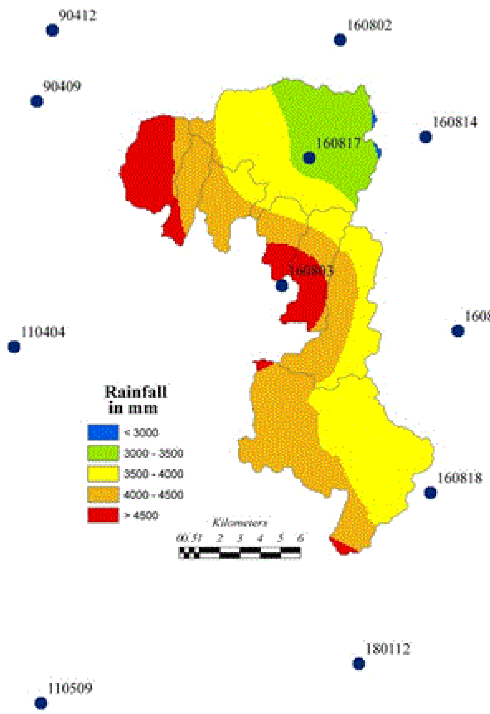

Figure 15: Spatial patterns of rainfall and rain gauge stations.

Land use	2000 December		2006 January		2010 December		2014 December	
	Area (sq.km)	% Area	Area (sq.km)	% Area	Area (sq.km)	% Area	Area (sq.km)	% Area
Water	4.05	0.63	3.61	0.56	2.96	0.46	3.11	0.49
Built up	0.44	0.07	0.17	0.03	2.41	0.38	2.72	0.43
Plantation	74.61	11.66	77.55	12.11	79.29	12.39	121.29	18.95

Forest	452.8	70.74	443.36	69.26	443.27	69.25	391.43	61.15
Others	108.22	16.91	115.44	18.03	112.18	17.53	121.56	18.99

Table 12: Land use dynamics - Gundia River basin.

Figure 16 provides the annual variability of hydrological parameters for understanding the hydrological regime. Gross rainfall, estimated as product of catchment area and rainfall. The gross rainfall varies from 33232 kilo.cum (in Kadumane holé 2 and Yettinaholé 2) and over 2000000 kilo.cum (in Yettinaholé and Hongada halla catchments). Portion of the water doesn't reach the earth surface, but is intercepted by the earth features namely the tree canopy, building tops, pavements etc., which gets evaporated. Runoff in the basin is estimated as a function of catchment characteristics along with rainfall. Yettinholé, catchment is covered predominantly by evergreen forests, has aided in recharging groundwater zone and sub surfaces. Infiltration of significant amount of precipitation to underlying layers, has reduced the overland flow and thus retarded the flash floods. The infiltration of water to sub-surface takes place during monsoon, and overland flow (surface runoff) happens during the monsoon (rainfall>50 mm per month) and quantity depends on the catchment characteristics namely land use/land cover in the catchment, soil porosity, texture, presence of organic matter (leave debris, decayed matter etc.). The portion of water percolates through the sub surfaces and thus recharges ground water resources. Water stored in vadoze zone (sub-surface) and groundwater zone moves laterally to streams with cessation of rain. Forests in the catchment have played a prominent role in maintaining stream flow, water holding capacity of soil, ground water, which also plays a pivotal role in catering the ecological and environmental demand of water. Sub basin wise yields are listed in Table 13; the surface runoff during the monsoon is estimated to be 9.55 TMC.

Sub basin	Average Annual Rainfall mm	Gross Rainfall TMC	Runoff yield as TMC
Yettina hole	3539.73	5.98	2.62
Yettina holé T2	4311.44	1.23	0.58
Yettina holé T1	4109.99	1.33	0.57
Kadumane holé 2	4364.85	1.2	0.53
Kadumane holé 1	4725.54	1.79	0.7
Hongadahalla	4000.77	6.7	2.68
Keri holé	4013.09	2.69	1.17
Yettina holé lower reach	4385.25	1.81	0.69
GROSS Yield (TMC)			9.55

Table 13: Catchment yield.

Evapotranspiration in the catchment depends on the land use, solar radiation, variations in temperature, precipitation, etc. Potential evapotranspiration was estimated using Hargreaves method. PET indicates the maximum possible water that can evaporate, PET varies between 160 mm/month (March) to 85 mm/month (monsoon season). Considering the various land use characteristics in the catchments, actual evapotranspiration was estimated in the catchments show variation of 40 mm/month (monsoon) to 120 mm/month (March).

Crop water demand was calculated in each catchment based on cropping pattern, area under each crop, and water required across the growth phases of the crops, which were compiled from various literatures (local, national and international) and discussion with the public regarding cropping practices and experiences. Table 9 and Figure 12, details season-wise crop water requirements and growth phases. The agricultural water demand of 2.6 TMC in the catchments is for horticultural and paddy cultivation. Livestock water demand given in Table 10 was estimated based on the livestock population (compiled from District at a glance of Hassan 2012-13).

Census data for the year 2001 and 2011 with the decadal rate of change in population was used compute the population for 2014 and water demand. Population for the year 2014 was estimated as 16156 persons. Catchment had a population of 17005 (in 2001), which decreased to 16345 (in 2011) at a decadal decline of 3.88%. The population density in the catchments varies from 33 persons per sq.km (in Keriholé) to about 150 persons per sq.km (Yettinaholé lower reach).

Ecological Flow Assessment: Flow measurements during the study period at two basins namely Hongadahalla and Kadumaneholé of Yettinaholé namely and based on the long term monitoring data [45] is given in Figures 16 and 17 respectively. This illustrates that flow during the lean season is about 10% of the annual flow, which is lower than the minimum flow requirement to sustain the ecosystem services in the water body.

Monthly monitoring of select streams in Sharavathi River basin over 24 months (covering all seasons) revealed the linkages of fish diversity with the duration of water flow in the respective stream. Table 14 lists the fish diversity across monitored streams. The current assessment confirm the requirement of 24 to 30% of annual flow during lean

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seasons to sustain the native fish diversity of endemic species [46,47]. Based on this, the ecological flow in Yettinaholé catchment (during the lean seasons) is 2.8 TMC.

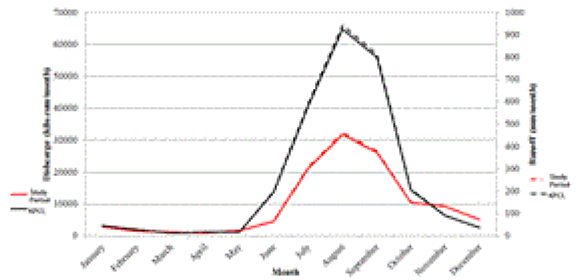

Figure 16: Hongadahalla.

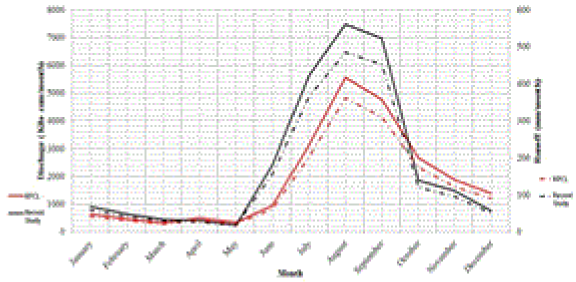

Figure 17: Kadumaneholé.

Fishes (Scientific Name)	Hill streams									
	Huruli River	Nagodi River	Birer River	Yenne River	Kouthi Stream	Sharavathi	Hilkunji	Sharmanavathi	Haridravathi	Nandihole
Amblyphyrngodon mola										
Aplocheilus lineatus	*	*	*	*	*	*	*	*		
Barilius canarensis			*		*					
Catla catla										
Chanda nama	*						*			
Channa marulius						*				
Cirhina fulungee						*		*		
Cirhina mrigala										
Cirrhinus reba								*		
Clarius byatracus										
Cyprinus carpio						*				
Danio aequipinnatus	*	*	*	*	*	*	*	*	*	*
Garra gotyla stenorynchus	*					*		*		*
Glossogobius giurus										
Heteropneustis fossilis										
Labeo fimbriatus										
Labeo rohita						*				
Lepidocephalichthys thermalis			*		*					
Mastacembalus arnatus						*				
Mystus cavesius	*									
Mystus keletius	*									
Mystus malabaricus	*									

Namacheilus rueppelli		*	*							
Ompok bimaculatus						*				
Ompok sp.										
Oreochromis mossambica										
Pseudambasis ranga	*									
Pseudeutropius atherenoides	*									
Puntius arulius					*					
Puntius dorsalis										
Puntius fasciatus	*	*	*	*	*					
Puntius filamentosis				*	*					
Puntius kolus										
Puntius narayani										
Puntius parrah										
Puntius ticto										
Rasbora daniconius	*	*	*	*	*	*	*		*	*
Salmostoma boopis						*	*		*	

Table 14: Fish diversity in select streams of Sharavathi River basin.

	Description	Quantity
1	Gross Area	179.68 sq.km
2	Average Annual Rainfall	3500 - 4500 mm
3	Water Yield in Yettinaholé catchment	9.55 TMC
4	Ground Water Recharge	0.49 TMC
5	Evapotranspiration	3.16 TMC
6	Irrigation Water Requirement	2.64 TMC
7	Domestic Water Requirement	0.03 TMC
8	Livestock Water Requirement	0.01 TMC
9	Total Water Demand (anthropogenic)	5.84 TMC
10	Ecological or environmental flow	2.8 TMC

Table 15: Hydrological assessment in Yettinaholé catchment.

The water demand and availability are listed in Table 15 and Figure 18 depicts the spatial variability of resources. Total water demand (5.84 TMC of water) across the catchments (accounting anthropogenic and evapo-transpiration of terrestrial ecosystems) was obtained as a function of evaporation, livestock, and domestic and agriculture demands. Availability of water in the catchment was assessed as a function of runoff during all seasons. The assessment showed that most streams in the forested catchment are perennial compared to steams in the catchment predominantly covered with monoculture plantations (6-9 months) or the streams in catchment dominated by open area or barren area (4 months). The available water in Yettinaholé catchment is sufficient to cater the existing water demand (social, ecological and environmental) throughout the year.

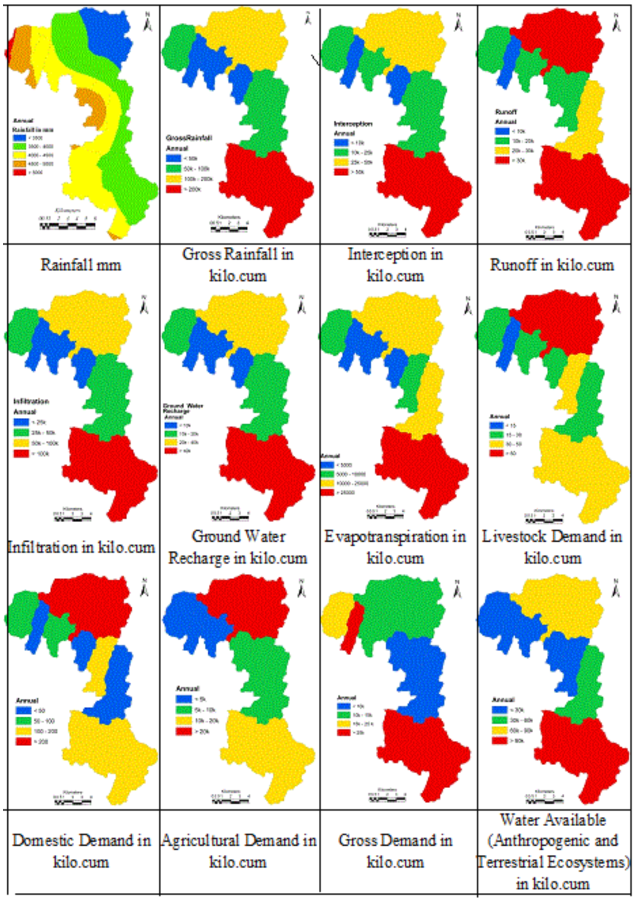

Figure 18: Hydrologic assessment in Yettinaholé catchment.

Conclusion

Yettinaholé River is currently catering to the anthropogenic and ecological water needs in the catchment. Higher discharge of water during monsoon has helped in the transport of nutrients, silt, etc., which has helped in sustaining the riparian's vegetation and aquatic life apart from meeting the anthropogenic demand (for horticulture, agriculture etc.). Many streams of Yettinaholé are perennial, which has helped in sustaining the rich and diverse aquatic life apart from sustaining horticultural, agricultural activities (3 crops per year) and fishery.

Hydrological yield computation shows the water yield in the catchment is about 9.5 TMC, About 5.84 TMC is required for domestic purposes including agriculture, horticulture and livestock rearing and the quantum of water required to sustain fish life in the streams is about 2 TMC. This highlights that water available in the catchment is sufficient to sustain the current ecological and anthropogenic (agricultural, horticultural) demand. Alterations in the catchment integrity (land cover) or water diversions would result in the variation in the natural flow regime affecting the biodiversity of riparian's and aquatic habitats and more importantly people's livelihood who are dependent on fisheries, etc. in the downstream. In this contyext, The federal government's plan to divert Yettinaholé River water to the dry arid regions in Karnataka is neither technically feasible, economically viable nor ecologically sound apart from depriving the anthropogenic demand in the Yettinaholé River catchment. The sustainable option to meet the water requirements in arid regions is through (i) decentralized water harvesting (through tanks, ponds, lakes, etc.), (ii) rejuvenation or restoration of existing lakes/ponds, (iii) reuse of treated waste water, (iv) recharging groundwater resources, (v) planting native species of plants in the catchment, (vi) implementation of soil and water conservation through micro-watershed approaches.

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