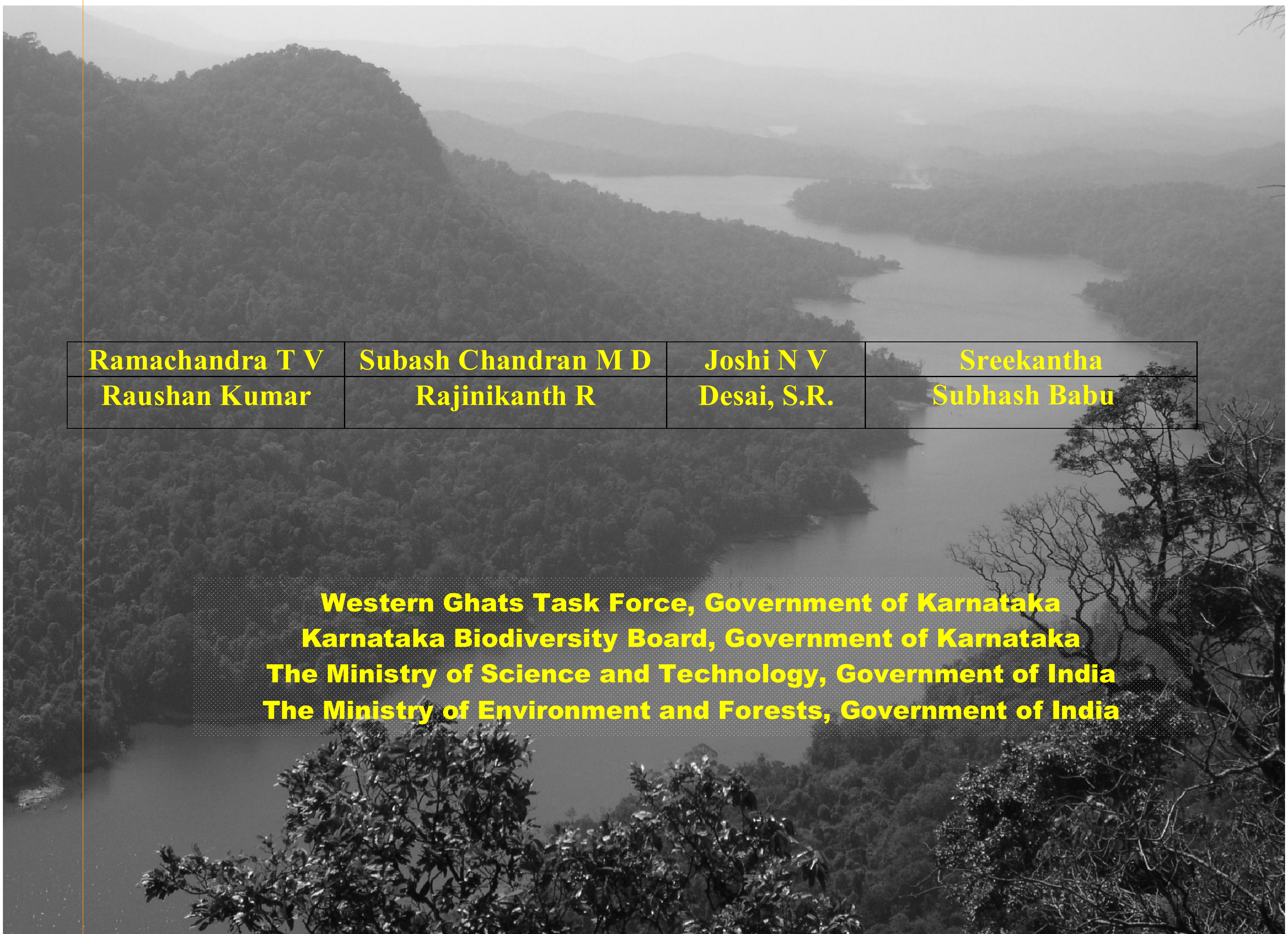
ECOLOGICAL PROFILE OF SHARAVATHI RIVER BASIN



Ramachandra T V	Subash Chandran M D	Joshi N V	Sreekantha
Raushan Kumar	Rajinikanth R	Desai, S.R.	Subhash Babu

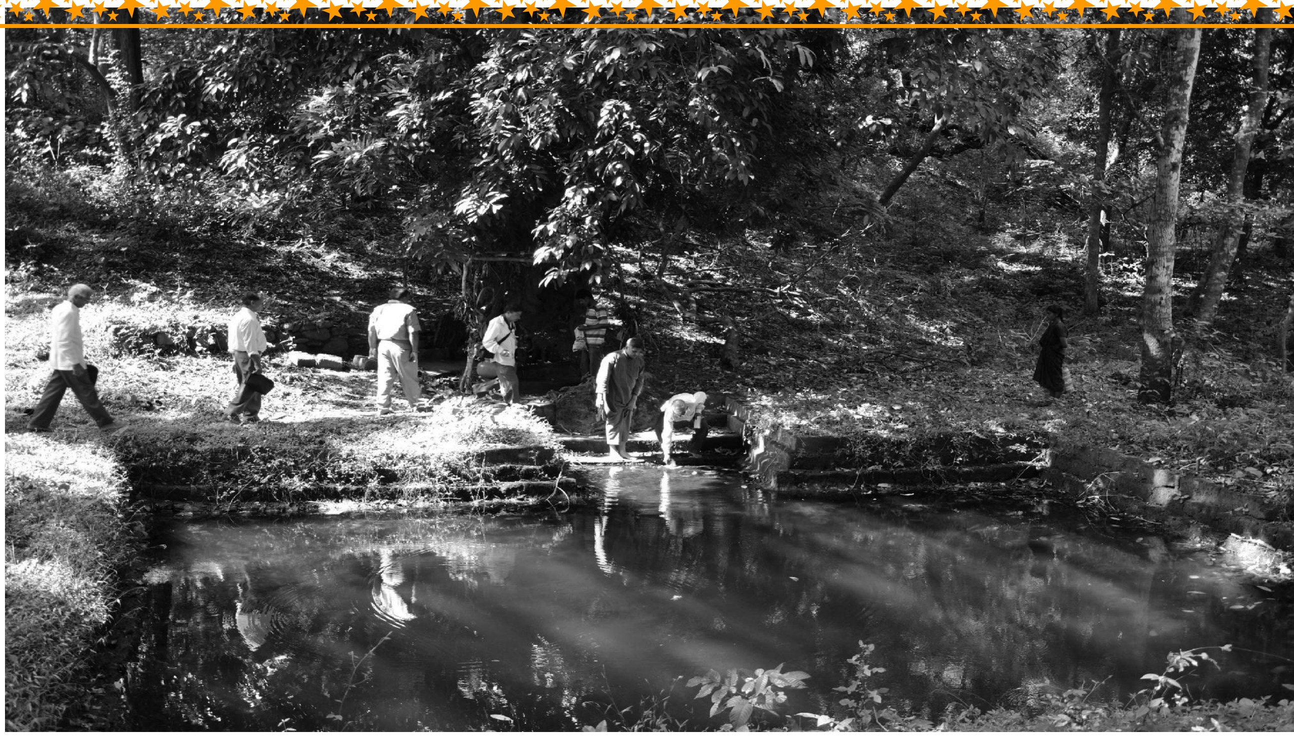
Western Ghats Task Force, Government of Karnataka
Karnataka Biodiversity Board, Government of Karnataka
The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forests, Government of India

ENVIS Technical Report: 52

November 2012

Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA

Web: **http://ces.iisc.ernet.in/energy/**
http://ces.iisc.ernet.in/biodiversity
Email: cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in



ENERGY AND WETLANDS RESEARCH GROUP
CENTRE FOR ECOLOGICAL SCIENCES
INDIAN INSTITUTE OF SCIENCE
BANGALORE 560 012
Telephone : 91-80-23600985/22932506/22933099
Fax : 91-80-23601428/23600085/23600683[CES-TVR]
Email : cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in
Web: http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity
Open Source GIS: http://ces.iisc.ernet.in/grass

ECOLOGICAL PROFILE OF SHARAVATHI RIVER BASIN

Ramachandra T V	**Subash Chandran M D**	**Joshi N V**	**Sreekantha**
Raushan Kumar	**Rajinikanth R,**	**Desai, S.R.**	**Subhash Babu**

Western Ghats Task Force, Government of Karnataka
Karnataka Biodiversity Board, Government of Karnataka
The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forests, Government of India

ENVIS Technical Report**: 52**

November 2012

Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA

Web: http://ces.iisc.ernet.in/hpg/envis
http://ces.iisc.ernet.in/energy/
http://ces.iisc.ernet.in/biodiversity

Email: cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in
sahyadri@ces.iisc.ernet.in

ECOLOGICAL PROFILE OF SHARAVATHI RIVER BASIN

Ramachandra T V	**Subash Chandran M D**	**Joshi N V**	**Sreekantha**
Raushan Kumar	**Rajinikanth R,**	**Desai, S.R.**	**Subhash Babu**

Content

AQUATIC ECOSYSTEMS

Freshwater river systems are among the most diverse and productive ecosystems in the world. Much of the biodiversity associated with the riverine landscapes is attributable to heterogeneity at the habitat scale. From a holistic landscape perspective, riverine habitats comprise running and standing waters, permanent and temporary waters, wetlands and groundwater (Ward, 1998). At the same time, the biodiversity of most microbial, plant, and animal groups of stream, lake, and wetland ecosystems is very poorly known (Wetzel, 2001).

Human evolution exhibited repeated speciations from *Australopithecus* to *Homo habilis, H. erectus,* and *H. sapiens;* and from their hominoid ancestor to orangutans, gorillas, chimpanzees, and humans (Ayala and Ananias, 1996) and this event spanned approximately 4 million years. This emergence from a position of a social ape of the savannas to its present position of global dominance has been a key in the changes that already took place and those still happening world over. Such changes are the clever manipulation of the environment, deflecting energy from other parts of the natural food webs into the support of one species (Cox and Moore, 2000). Part of the success of the human species has been their ability to influence the hydrological cycle: storing water for drinking, growing food and driving industrial processes and harnessing its power to generate power and fight against natural hazards, such as floods and droughts (Acreman, 2001). Our overall activities and their side effects have shaped the natural resource base as human-modified ecosystems.

Human interaction with the physical environment has increasingly transformed Earth-system processes (Dillehay and Kolata, 2004). Wherever human land use is located near sensitive natural areas, such as wetlands, it had significant impacts on biodiversity in such areas (Eppink et. al 2004). These ecosystems share a common set of traits including simplified food webs, landscape homogenization, and high nutrient and energy inputs. Ecosystem simplification is the ecological hallmark of humanity and the reason for our evolutionary success. However, the side effects of our profligacy and poor resource practice are now so pervasive as to threaten our future no less than that of biological diversity itself (Western, 2001). The magnitude of the resulting change is so large and so strongly linked to ecosystem processes and society's use of natural resources that biodiversity change is now considered an important global change in its own right (Sala, et. al 2000). At present, species are going extinct at a rate 100 times the natural background rates (Pimm and Lawton, 1998).

Beginning of the human civilization is believed to on the banks of world's major rivers. Due to this, river basins are renowned as the cradles of civilization and cultural heritage. Ancient and modern communities alike have depended on rivers for livelihood, commerce, habitat and the sustaining ecological functions they provide. Throughout the history alterations to rivers – have affected riverine communities in one-way or other (WCED 2000). Human pressures have now reached a state where the continental aquatic systems can no longer be considered as being controlled by only Earth system processes, thus defining a new era, the Anthropocene (Maybeck 2003).

Riverine ecosystems are critical components of the global environment. In addition to being essential contributors to biodiversity and ecological productivity, they also provide a variety of services for human beings, including water for drinking and irrigation, recreational opportunities, and habitat for economically important fishes. However, aquatic systems have been increasingly threatened, directly and/or indirectly, by human induced activities. Aquatic ecosystems, in addition to the challenges posed by land-use change, environmental pollution, and water diversion, are expected to experience the added stress of global climate change.

Available information suggests that over the past 30 years, freshwater biodiversity has declined much faster than either terrestrial or marine biodiversity. The ever-increasing demands placed on freshwater resources in most parts of the world has led to the uneven and continued loss of biodiversity. Pollution, siltation, canalization, water abstraction, dam construction, over-fishing, and introduced species will all play a part, although their individual impacts will vary regionally. The greatest effects will be on biodiversity in fresh waters in highly diverse and densely populated parts of the tropics, particularly South and Southeast Asia, and in dry-land areas, although large-scale hydro-engineering projects proposed elsewhere could also had catastrophic impacts (Jenkins 2003).

River ecosystems of India

The Indian sub-continent is traversed by a large number of rivers, which played a major role in shaping the history of human civilization in the sub-continent. It has very rightly been said that River Ganga has been the cradle of civilization in the Indian sub-continent. The rivers have been extensively used for various purposes, including irrigation, drinking water, recreation, fishing, transport, etc (Venkataraman, 2003). There is a dense network of rivers all over India, constituting the most important water resources for the country. The river systems are grouped on the basis of their drainage - basin area into major (more than 20,000 km^2), medium (2000 – 20,000 km^2) and minor (<200 km^2) rivers. Accordingly, 15 major, 45 medium and 120 minor systems, besides numerous ephemeral streams in the western arid region drain the mainland. The rivers of the Indian mainland can be grouped according to their origin, into Himalayan and peninsular rivers (Sinha and Sinha 2003).

Human population in India has reached 102.8 crores in 2001, which was 84.6 crores in 1991 with 21.3% increase (Census of India, 2001). Major portion of the water requirement of this population is met from the rivers. Consequently, human impacts on rivers throughout the country extend well beyond direct use of water to all activities in the floodplain and the entire catchment. Uncontrolled discharge of untreated (or partly treated) muncipal sewage and industrial effluents has reduced many river stretches into wastewater drains (Gopal, 2000). Now India is determined to go ahead with its single-point agenda of economic growth, the proposal to link major rivers for combating local water deficits. Over the next 10 years, it is envisaged that 37 major rivers in India will be linked through 12,500 km of canals and requiring the construction of at least 400 reservoirs (Daniels, 2004).

Western Ghats' scenario

Western Ghats that lies in the western part of peninsular India is a series of hills stretching over a distance of 1,600 km from north to south and covering an area of about

1,60,000 Sq. km. Western Ghats' extraordinary biological heritage makes the region one of the highest priorities for international conservation efforts and is recognized as one of the 25-biodiversity hotspots of the world (Myers *et al.,* 2000). These Ghats are known for exceptional species richness and endemism in angiospers, amphibians, reptiles and freshwater fishes. About 38-east flowing and 37 west flowing river systems of the region inhabit over 288 species of freshwater fishes of which about 118 are endemic to the region (Dahanukar *et al.,* 2004).

Major threats acting upon the freshwater ecosystems of the Western Ghats are deforestation, impoundments, and water diversion. Many people depend on the water in the Western Ghats Rivers and Streams for agriculture. Steep and undulating terrain of the region has provided the optimum differential head required for the hydroelectric power generation. Because of these, several development projects have diverted water for irrigation, which dries up streams and brooks. Dams built on the rivers have changed the natural flow of water and destroyed habitats.
(http://www.worldwildlife.org/wildworld/profiles/g200/g171.html#intro).

However, there is relatively small amount of published information in scientific journals that is available for river conservation in Western Ghats. The bulk of the literature is unpublished grey literature. Published information on freshwater biota of the Western Ghats is largely of a taxonomic nature and is sporadic throughout the systematic literature. However, in many regions, basic taxonomic information for most groups of organisms is lacking. Among the many westflowing rivers of the Western Ghats, a few of them have been extensively harnessed for hydro-electric powers, irrigation, and fisheries. Sharavathi River, one of the earliest exploited rivers amidst Western Ghats, and its ecosystem status are discussed in this report.

Sharavath River – Environmental setting

Sharavathi River is one of the west flowing rivers of Karnataka. The river basin comes under the two districts namely Shimoga and Karwar (called Uttara Kannada till recently). Two taluks in Shimoga district (*viz.,* Sagar, Hosanagara) and three taluks in Karwar district (*viz.,* Honnavar, Kumta, Siddapur) constitute the study area of the basin. The river rises at Ambuthirtha near Kavaledurga in Thirthahalli and flows in a northwesterly direction and receives Haridravathi river on the right (below Patterguppe) and Yenneholé on the left above Bharangi. Of a due course of 131 km in journey, the river receives a series if small tributaries like Nagodi, Kalkatte hole, Mavinahole, Hadinabal, Bhaskeri, Gudankatte hole, etc. Near the border of the Shimoga district, it bends to the west and hurls down near Jog from 255 m height. This river has a catchment area of approximately 2,784 sq. km. The river confluences the Arabian Sea at Honnavar in Uttara Kannada district (Figure 1).

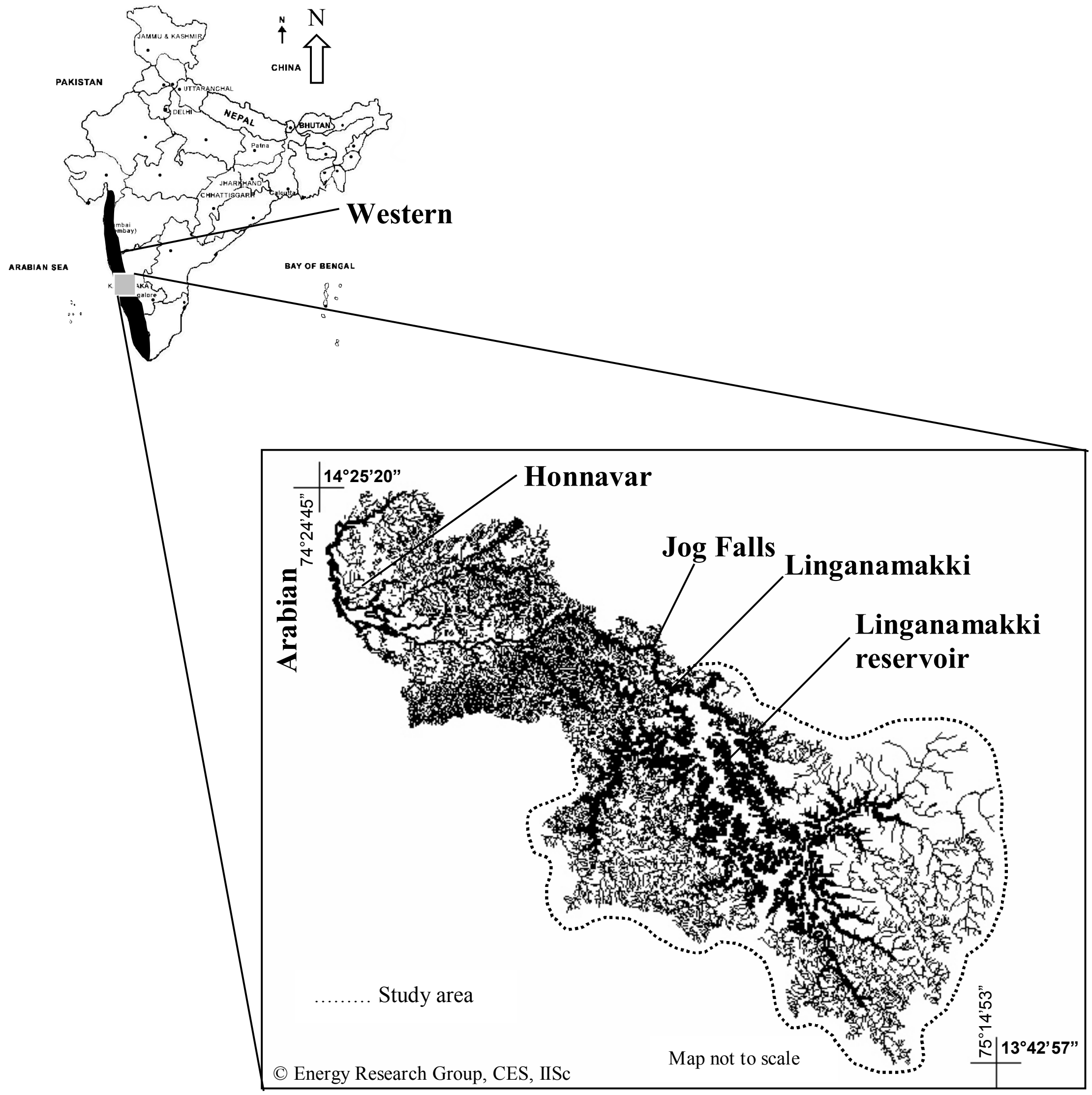


Figure 1. Drainage network and study area of River Sharavathi.

Ecological Significance of Sharavathi River Basin

The Sharavathi River in the Central Western Ghats, Karnataka is recognized as a hot speck in the biodiversity hotspot. Sharavathi Valley forms the northern limit of many endangered ecosystems, flora and fauna such as *Myristica* Swamps, *Gymnacranthera canarica* and Lion-tailed Macaque (*Macaca silenus*). These features illustrate the ecological significance, and the conservation importance of the region. The river basin has a vegetation cover that ranges from evergreen to semi-evergreen forest along with moist deciduous type of forests. Along with this, scrub savanna, grasslands, marshy areas and plantations are the major land covers of the region. Rare evergreen and endemic species belonging to the genera *Dipterocarpus*, *Calophyllum, Lophopetalum, Myristica, Gymnacranthera, Syzygium, Diospyros, Aglaia, Poeciloneuron*, *Palaquium*, etc. and *Semicarpus kathalekanensis*, a rare and endemic tree species that is restricted to

Kathalekan of this river basin make Sharavathi river basin an ecologically sensitive region. Presence of around 140 islands in the reservoirs of Sharavathi wherein almost all islands covered with semievergreen to moist deciduous forests represents the fragile ecosystem. Mammals like Gaur, Sambhar, Spotted deer, Boars, Pangolins and Porcupines are also present. The upper catchment of the study area is a habitat for endangered Grey headed Bulbul, Great Indian Hornbill, and endemic species as Black necked stork, White Ibis, Blue bearded Bee-eater, Great Black Woodpecker and Slatyheaded Scimitar babbler (http://wgbis.ces.iisc.ernet.in/energy/sharavathi/svati.htm). Sharavathi River is the dwelling place for a rare freshwater fish, *Batasio sharavatiensis*, a species reported from this river and yet the distribution is limited to this river.

Developmental Activities in Sharavathi River Basin

Sharavathi River has witnessed a series of alterations during the last century.Construction of Madenur (Hirebhaskar) dam across this river in 1932 is the first large-scale alteration in the river basin. Subsequently, another dam constructed near Linganamakki in 1964 is one of the oldest hydroelectric power projects in. Several small-scale reservoirs like Talakalale, balancing reservoirs for Mahathma Gandhi hydro-electric power generation were also commissioned soon after the completion of Lingnamakki Dam. In total, there are three major reservoirs in the Sharavathi river basin, Linganamakki, Talakalale and Gerusoppa. Gerusoppa, also known as Sharavathi Tail Race Project is the latest hydro-electric power project established on the Sharavathi river in 2001. To cope up the water requirement of huge power generation plant of Linganamakki dam, River Chakra, an adjacent river was diverted and connected to Sharavathi River through manmade canals. For the river Chakra, two dams were constructed at Chakra and Savehaklu. Madenur dam has submerged an area of about 27.52 km^2, where as Talakalale about 7.77 km^2 and Gerusoppa reservoir submerged 7.11 km^2 The Linganamakki reservoir has submerged about 326.34 sq. km. of prime forest area rich in biodiversity. Similar to most of the river valley projects in India, these projects in Sharavathi river basin were also evolved considering only the developmental aspects . Thus, these developmental activities have resulted population influx into the river basin especially in western hilly region of fragile forests and perennial streams, consequent on spurt of other developmental activities such as agriculture, increase in built up areas, etc. In this connection present study has been carried out in the catchment area of Sharavathi River to understand the cumulative effects of the changes on the aquatic ecosystem of the river basin.

Objectives: Objectives of the current investigations are:

- Assess the status of water and sediment by physico-chemical and biological characterization.
- Phytoplankton studies for species composition and their differences between the stations of reservoir and streams, population and bloom of phytoplankton, species diversity, richness, and dominance and to assess the trophic status of the river basin using phytoplankton group, genera and species
- Zooplankton studies to acquire the information on their diversity and distribution over the river basin.
- Freshwater fishes dealing with ichthyo-diversity and the existing pattern of commercial fishery.
- Explore suitable watershed management and conservation strategies for their long-term sustenance.

WATER AND SEDIMENT CHARACTERIZATION TO ASSESS THE PHYSICOCHEMICAL STATUS OF AQUATIC ECOSYSTEMS IN SHARAVATHI RIVER BASIN

Summary

Based on physico-chemical and biological analyses of the water in the river, Sharavathi River basin is categorized into most disturbed (Sharmanavathi, Haridravathi, Keshavapura, Gazni, Sampakai, Gudankatteholé), moderately disturbed (Muppanae, Talakalale Dam, Reservoir, Dabbe falls, Hosagadde) and least disturbed (Yenneholé, Hurliholé, Nittur, Valagere, Dobbod) zones. The disturbance is due to anthropogenic activities in the catchment, mainly agriculture. Presence of coliform bacteria at Sharmanavathi, Haridravathi, Keshavapura and Nandiholé indicates faecal contamination. Before construction of a dam at Gerusoppa, reports indicated that salinity concentration fell rapidly reaching a zero value at Hosad (about 5-6 km from the sea). Field measurements revealed salinity ingress up to Mutta, Balkur (about 15 km from sea). The concentration is highest during the high tide occurring in the morning. It would be desirable to maintain a discharge (*i.e.* release from the power stations) to limit the salinity ingress. Soil samples were collected from 78 locations distributed all over the upper catchment and subjected to physico-chemical analyses. Soils are rich in organic matter and low in phosphate, nitrate and sulphate concentration, while pH ranged between 5.5-6.8. The sediments have low sulphate (0.19-0.68 mg/gm), nitrate (0.0-0.0007 mg/gm) and phosphate (0.00024-0.001 mg/gm) indicating close correlation between sediment and catchment soil. The sediment samples are rich in organic carbon and the elements like Na, K, Ca, Mg are found well within the prescribed standards. Bulk density of sediments in streams of the western region indicates porous condition (0.783-0.983 gm/cm^3) while in the eastern side they are less porous (1.23-1.475 gm/cm^3).

Introduction

Water is essential for life and plays a vital role in the proper functioning of the earth's ecosystem. The pollution of water has serious impact on living creatures and can negatively affect the use of water for drinking, household need, recreation, fishing, transportation and commerce. Many factors affect the chemical, physical and biological characteristics of a water body. They may be either natural like geology/ weather or anthropogenic, which contribute to the point and non-point source of pollution. Developmental projects like construction of dams may change the quality of water as it involves blocking the natural flow. It impacts aquatic organisms and changes the nature of the stream itself. As water slows down and backs up behind a dam, various changes in its physico-chemical and biological characteristics take place. Water quality monitoring involves recording data about these various characteristics and usually involves analysing and interpreting these data. Monitoring helps to ensure that a particular water body is suitable for its determined use.

Rivers in the world carry as much as three billion tonnes of material in solution and ten billion tonnes of sediment every year. The characterisation of sediments reflects the quality of the catchment area, through which the rivers flow. Sedimentation of a river, lake or reservoir is associated with its flow and also disturbs the water quality and aquatic ecosystem. Runoff from different sources result in different qualities of sediment and ultimately various changes take place. The sediment content may also vary from month to month depending on the season, while it may be negligible during the winter and summer months, it is maximum during the monsoon months.

Higher sediment delivery ratio (ratio between the amount of sediment yield and the gross erosion in watershed) is associated with smaller catchments. As one moves upstream, the drainage basin area decreases and the topographic factors that promote sediment delivery becomes more intensified resulting in higher sediment - delivery ratio. The actual rate of silting of a reservoir depends on many other factors, in addition to the rate of sediment production in the catchment area. They are, trap efficiency of the reservoir, ratio of reservoir capacity to total runoff, gradation of silt, method of reservoir operation etc. The trap efficiency of a reservoir is defined as the ratio of sediment retained in the reservoir and sediment brought by the stream. Damming the water also deposits the sediments that they carry. This causes sediment build up behind the dam, often changing the composition of the river.

The following factors affect sedimentation -

a) Extent of catchment area and the friable nature of the different zones.
b) Amount of sediment load in the rivers.
c) Type of rainfall and snowfall in each zone.
d) Mean monthly and annual run-off from catchment or sub-catchment.
e) Slope of each zone of catchment.
f) Vegetation in each zone of catchment.
g) Geological formation of each zone, estimated relative weathering and erosion with due regard to climatic conditions.
h) Presence of upstream reservoirs and extent of trapping of sediment therein.
i) Amount of sediment flushed out through sluices.
j) Degree of consolidation of accumulated sediment depending upon the extent of exposure to air, sun and wind.
k) Operation schedule of reservoir.

River Systems and Water Resources of Karnataka

The state has very good water resources in its numerous rivers, lakes and streams and to a certain extent groundwater. Seven river basins drain the whole state (The names and the areas drained are given in Table 1).

Table 1. River basins of Karnataka State.

Name of the Basin	Catchment Area (sq. km)	Total Area of the State (%)	Estimated Average Flow (Million m^3)
Krishna	1,13,271	59.06	27,500
Godavari	4,405	2.30	1,400
Cauvery	34,273	17.87	11,000
West-flowing rivers	26,214	13.68	57,000
North Pennar		3.61	
South Pennar	13,610	1.95	900
Palar		1.54	

The total catchment area of these rivers is 1,91,773 sq. km. and the estimated average flow is 97,800 million m^3 (M cum). The Krishna and Cauvery river basins drain about 77% of geographical area of the state. Sharavathi, Netravathi, Varahi, Bedti (Gangavathi) and Aghanashini are the more important rivers, all of which have considerable hydroelectric potential. They arise in the west of the Ghats and flow into the Arabian Sea. The area of forests and hills has a rugged topography, characterised by deep ravines and steep hills rising to heights of 1,250 to 1,890 m, which are the source of all the east and west-flowing rivers of the state.

Objectives

- Assess the status of water and sediment by physico-chemical and biological characterization.
- Explore suitable watershed management and conservation strategies for their long-term sustenance.

Sampling and Analysis of Water: Water is a dynamic system and hence its characteristic quality changes with time and place. Water samples were collected at regular intervals to identify their characteristics and the changes in their quality. A total of 40 water samples (16 in the upstream and 24 in the downstream) were collected from various locations encompassing the entire catchment area. Precautions were taken while handling the collected samples to ensure its integrity.

Sampling Sites - Upper catchment: For physico-chemical and biological characterisation, monthly samples were collected at (numbers in the square brackets indicate sampling sites):

- Area where principal feeder tributaries Sharavathi [1] (Nagara), Sharavathi [2], Sharmanavathi or Mavinaholé [3], Haridravathi [4] and Yenneholé [10] that meet the reservoir.
- Central part of reservoir near Holébagilu [8] to get a general quality of the water.
- Outlet [7] from the Linganamakki dam.
- Other minor tributaries like Hurliholé [9] and Keshawapura [14] and Nandiholé [15], Valagere [11], Nittur [13] and Sampekai [16].
- At Talakalale dam, a balancing reservoir [6], Muppane [5] and Madenur dam [12] to get a comparative water quality status over the other sampling sites.

Table 2 gives the water sampling sites and their respective co-ordinates in the upper catchment of Sharavathi river basin.

Table 2. Water sampling representative sites of the Sharavathi upper catchment.

Sub-basin	Sampling Sites	Latitude (°N)	Longitude (°E)
Hilkunji (US8)	Sharavathi (Nagara) [1]	13.8267	75.0601
Sharavathi (US4)	Sharavathi [2]	13.8789	75.065
Mavinaholé (US3)	Sharmanavathi [3]	13.9855	75.0822
Haridravathi (US2)	Haridravathi [4]	14.0384	75.1207
Yenneholé (US5)	Muppane [5]	14.1083	74.7902
Mavinagundi (US5)	Talakalale [6]	14.1853	74.7863
Mavinagundi (US5)	Dam outlet [7]	14.1917	74.8268
Linganamakki (US9)	Reservoir [8]	14.0756	74.8977
Hurliholé (US6)	Hurliholé [9]	13.9914	74.8672

Yenneholé (US5)	Yenneholé [10]	14.0417	74.759
Linganamakki (US9)	Valagere [11]	14.0624	74.8452
Linganamakki (US9)	Madenur Dam [12]		
Linganamakki (US9)	Nittur [13]	13.9371	74.9139
Haridravathi (US2)	Keshawapura [14]	14.0191	75.1215
Nandiholé (US1)	Nandiholé [15]	14.0426	75.1254
Linganamakki (US9)	Sampekai [16]	14.048	75.0467

Note: Numbers in the square brackets indicate sampling sites.

Sampling sites - Lower catchment: In the lower catchment among the 7 sub-basins, 20 localities were selected for water sampling (Table 3).

Table 3. Water sampling representative sites of the downstream catchment.

Sub Basin	Sampling locations	Latitude (°N)	Longitude (°E)
Dabbe falls (DS4)	Hebbankeri [2]		
Dabbe falls (DS 4)	Dabbe falls [1]	14.13747	74.74158
Magod (DS 3)	Hosagadde [3]	14.17009	74.54848
Magod (DS 3)	Dabbod [4]		
Magod (DS 3)	Magodholé [5]	14.22377	74.59595
Magod (DS 3)	Gazni/ Hennur [6]	14.21883	74.53471
Magod (DS 3)	Heggar [7]	14.23294	74.52602
Chandavar (DS 1)	Chandavar [21]		
Chandavar (DS 1)	Gudankatteholé [22]	14.38152	74.44321
Chandavar (DS 1)	Badagani [23]	14.35294	74.42194
Gudankattehole (DS 7)	Bhaskeri [8]	14.3027	74.48524
Haddinabal (DS 2)	Chandubana [9]	14.32452	74.58300
Haddinabal (DS 2)	Haddinabal [10]	14.28523	74.51153
Haddinabal (DS 2)	Mavinaholé [11]	14.24546	74.61644
Haddinabal (DS 2)	Mahasathi [12]	14.26296	74.68116
Haddinabal (DS 2)	Vatehalla [13]	14.27035	74.69153
Magod (DS 3)	Upponi location 1 [14]	14.23432	74.60058
Magod (DS 3)	Upponi village loc 2 [15]	14.23167	74.58934
Kathlekan (DS 6)	Kathlekan [16]	14.27267	74.74788
Mavinagundi (DS 5)	Mavinagundi [17]	14.24380	74.81250
Mavinagundi (DS 5)	Jog lower [18]	14.22767	74.8120
Mavinagundi (DS 5)	Jog upper [19]	14.22973	74.81355
Mavinagundi (DS 5)	Joginamatha [20]	14.23024	74.82361

Note: Numbers in the square brackets indicate sampling sites.

Sampling Procedure

- Polyethylene containers
- The container was rinsed with HCl followed by distilled water.
- Before being filled with the sample, the container was first rinsed with the sample.
- The samples were collected by directly immersing the container in the water, and it was closed properly using appropriate stoppers.
- A number of parameters like pH, temperature, colour, and dissolved oxygen were measured at the sampling sites immediately after collection of the sample.
- After the addition of preservatives like Toluene (to check microbial action) the samples were transported to the laboratory for further analysis (physico-chemical and biological).

Physico-Chemical and Biological Analysis

Physico-chemical and biological parameters for monthly samples were analysed according to the standard methods provided by National Environmental Engineering Research Institute NEERI and American Public Health Association (APHA) and the values were compared with World Health Organization and Indian Standard Specifications (IS: 1050-1983; IS: 2490 –1982).

The following physico-chemical and biological parameters were measured at various representative sites within the Sharavathi catchment area at one-month intervals. Table 4 gives physico-chemical and biological parameters and its respective method of analysis.

Table 4. Water quality parameters and its method of analysis.

Physical Parameter	Method of Analysis
Temperature (°C)	Mercury Thermometer
Transparency (cm)	Secchi Disk
Total Dissolved Solids (mg/L)	Electrometric
Total Suspended Solids (mg/L)	Gravimetric
Turbidity (NTU)	Jal Tara Water Testing Kit
Colour	Visual Comparison
Odour	Olfactory sensing
Chemical Parameter	
pH	Electrometric
Conductivity (mS/cm)	Electrometric
Acidity (mg/L)	Titrimetric
Alkalinity (mg/L)	Titrimetric
Chloride (mg/L)	Argentometric
Residual chlorine (mg/L)	Visual Colour Comparison
Total Hardness (mg/L)	Titrimetric
Calcium hardness (mg/L)	Titrimetric
Magnesium hardness (mg/L)	Titrimetric
Dissolved oxygen (ppm)	Electrometric
Fluoride (mg/L)	Jal Tara Water Testing Kit
Ammonia (mg/L)	Visual Colour Comparison
Sodium (mg/L)	Flame Photometer
Potassium (mg/L)	Flame Photometer
Sulphates (mg/L)	Spectrophotometer
Iron (mg/L)	Visual Colour Comparison
Nitrates (mg/L)	Phenoldisulphonic Acid
Phosphates (mg/L)	Ammonium molybdate
Biological Parameter	
Coliform	Visual Comparison

Note: Parts per million (ppm) is equivalent to mg/L

Significance of Various Physico-chemical Parameters

Physical Parameters

Temperature: The rate of chemical and biological processes in surface water, especially oxygen levels, photosynthesis and algal production, are strongly influenced by temperature. Temperature readings are used in the calculations of various forms of alkalinity and salinity. In limnological studies, water temperature is often taken as a function of depth. Increase in temperature over 40°C in natural water tends to accelerate chemical reactions, lower solubility of gases like oxygen, carbon dioxide, nitrogen and methane, amplify taste and odour, and increase metabolic activity of organisms.

Impinging solar radiation and atmospheric temperature brings about spatial and temporal changes in water temperature setting up convection currents and thermal stratification. Temperature has direct influence on various parameters like alkalinity, salinity, dissolved oxygen, electrical conductivity etc. In an aquatic system, these parameters affect the chemical and biological reactions such as solubility of oxygen, carbon-dioxide, carbonate-bicarbonate equilibrium, increases in metabolic rate and affect the physiological reactions of organisms, etc. Water temperature is important in relation to fish life. The temperature of drinking water has an influence on its taste.

Transparency (Light Penetration): Transparency is a characteristic of water that varies with the combined effect of colour and turbidity. It measures the light penetrating through the water body.

Total Dissolved Solids: Dissolved solids are in dissolved state in solution (having particle size less than 10^{-9}m). Low concentrations of dissolved substances have no significant influence on the water quality but at high concentrations impair the water quality and suitability of water for various applications such as domestic, industrial and agricultural purposes. It has an overall effect on the living creatures like humans, aquatic and terrestrial organisms. Excessive concentrations increase water turbidity, affects photosynthesis, absorbs more heat, enrich nutrient status of water etc. It helps in understanding level of turbidity and hardness of water. They cause laxative effects in humans and when present in irrigation water enrich the soil making it saline.

Total Suspended Solids: Solids that remain in suspension like silt, sand, clay and phytoplankton etc., form the total suspended solids. Similar to TDS, it interferes in the quality of the water.

Turbidity: The substances not present in the form of true solution can cause turbidity in water. True solution have a particle size of less than 10^{-9} m and any substances having more than this size will produce turbidity. Suspended solids and colour are the main interference for transparency. The clarity of a natural water body is a major determinant of the condition and productivity of the system. Turbidity value above 10 NTU would affect these processes and transparency. It restricts the penetration of light giving rise to reduced photosynthesis and affects the aesthetics. High levels of turbidity can protect microorganisms from the effects of disinfection and can stimulate bacterial growth. The transparency and turbidity are inversely related to each other, if turbidity is more, transparency is less and vice versa.

Turbidity is an expression of optical property; wherein light is scattered by suspended particles present in water (Tyndall effect). Suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms cause turbidity in water. Turbidity affects light penetration, absorption properties and aesthetic appearance of a water body. Increase in the intensity of scattered light results in higher values of turbidity.

Increased turbidity associated with reduction in suspended matter and microbial growth makes water unfit for drinking and other purposes. High turbidity levels in natural waters makes water warmer as suspended particles absorb more heat from the sunlight resulting in low dissolved oxygen concentrations. Turbidity also restricts light penetration for photosynthesis and hence a major determinant of the condition and productivity of the natural water body.

Colour: In natural water, colour is due to the presence of humic acids, fulvic acids, metallic ions, suspended matter, plankton, weeds and industrial effluents. Colour is removed to make water suitable for general and industrial applications.

Odour: Odour is an *in situ* parameter and temperature dependent. It impairs the water quality creating unhygienic conditions and is a pollution indicator. Odour is imparted to water due to the presence of volatile and dissolved organic and inorganic components such as organic matter, phytoplankton, contamination due to domestic sewage and industrial effluents, dissolution and presence of gases in water like NH_3, H_2S etc.

Chemical Parameters

pH: pH has its great influence on the chemical and biological properties of liquids, hence its determination is very important. In natural water, pH is governed by the equilibrium between carbon dioxide/bicarbonate/carbonate ions and ranges between 4.5 and 8.5 although mostly basic. It tends to increase during day largely due to the photosynthetic activity (consumption of carbon dioxide) and decreases during night due to respiratory activity. Wastewater and polluted natural waters have pH values lower or higher than 7 based on the nature of the pollutant.

Electrical Conductivity: Conductivity (specific conductance) is the ability of water to conduct an electric current. It is measured in milli-Siemens per cm and depends on the total concentration, mobility, valence of ions and the temperature of the solution. Electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply.

Acidity: Acidity of a liquid is its capacity to denote H^+ ions. Since most of the natural waters and sewage are buffered by carbon dioxide - bicarbonate system, the acidity present due to free CO_2 has no significance from public health point of view. Water containing mineral acidity (due to H_2SO_4, HNO_3 and HCl) is unacceptable. Further, acid waters pose problems of corrosion and interfere with water softening.

Alkalinity: The alkalinity of water is the measure of its capacity to neutralise acids. The alkalinity of natural waters is due to the salts of carbonates, bicarbonates, borate, silicates and phosphates along with the hydroxyl ions in the free state. However, hydroxide, carbonate and bicarbonate cause the major portion of the alkalinity in the natural water, which may be ranked in the order of their association with high pH values.

Chlorides: The presence of chlorides in natural waters can mainly be attributed to dissolution of salt deposits in the form of ions (Cl^-). Otherwise, high concentrations may indicate pollution by sewage or some industrial wastes or intrusion of seawater or other saline water. It is the major form of inorganic anions in water for aquatic life. High chloride content has a deleterious effect on metallic pipes and structures, as well as agricultural plants. In natural fresh waters, high concentration of chlorides is regarded as an indicator of pollution due to organic wastes of animal origin (animal excreta have higher chlorides along with nitrogenous wastes). Domestic sewage and industrial effluents also bring chlorides into the water. Chloride content above 250 mg/L makes water salty. However, a level up to 1000 mg/L is safe for human consumption. High level results in corrosion and non-palatability.

Residual Chlorine: Free chlorine reacts readily with ammonia and certain nitrogenous compounds to form combined chlorine. With ammonia, chlorine reacts to form the chloroamines; monochloroamine, dichloroamines and nitrogen trichloride. The presence and concentrations of these combined forms depend chiefly on pH, temperature, initial chlorine to nitrogen ration, absolute chlorine demand and reaction time. Both free and combined chlorine may present simultaneously. Combined chlorine in water supplies may be formed during the treatment of raw water containing ammonia or ammonium salt. Chlorinated wastewater effluents as well as certain chlorinated industrial effluents, normally contain combined chlorine.

Total Hardness: Hardness is due to the presence of multivalent metal ions, which come from minerals dissolved in the water. In fresh water the primary ions are calcium and magnesium; however iron and manganese may also contribute. Depending on pH and alkalinity, hardness of about 200 mg/L can result in scale deposition, particularly on heating. Soft waters with a hardness of less than about 100 mg/L have a low buffering capacity and may be more corrosive to water pipes.

Calcium Hardness: The presence of calcium (fifth most abundant) in water results from passage through or over deposits of limestone, dolomite, gypsum and other calcium bearing rocks. Calcium contributes to the total hardness of water and is an important micronutrient in aquatic environment and is especially needed in large quantities by molluscs and vertebrates.

Magnesium Hardness: Magnesium is a relatively abundant element in the earth's crust, ranking eighth in abundance among the elements. It is found in all natural waters and its source lies in rocks, generally present in lower concentration than calcium. It is also an important element contributing to hardness and a necessary constituent of chlorophyll. Its concentration greater than 125 mg/L can influence cathartic and diuretic actions.

Dissolved Oxygen: Oxygen dissolved in water is a very important parameter in water analysis as it serves as an indicator of the physical, chemical and biological activities of the water body. The two main sources of dissolved oxygen are diffusion of oxygen from the air and photosynthetic activity. Diffusion of oxygen from the air into water depends on the solubility of oxygen, and is influenced by many other factors like water movement, temperature, salinity, etc. Photosynthesis, a biological phenomenon carried out by the autotrophs, depends on the plankton population, light condition, gases, etc. Oxygen is considered to be the major limiting factor in water-bodies with organic materials. If its value is less than 3 mg/L, the metabolic processes that produce energy for growth and reproduction get affected. Oxygen levels that remain below 1-2 mg/L for a few hours can result in large fish kills.

Fluoride: Fluorides have dual significance in water supplies. High concentration causes dental fluorosis and lower concentration (< 0.8 mg/L) causes dental caries. A fluoride concentration of approximately 1 mg/L in drinking water is recommended. They are frequently found in certain industrial processes resulting in fluoride rich wastewaters. Significant sources of fluoride are found in coke, glass and ceramic, electronics, pesticide and fertiliser manufacturing, steel and aluminium processing and electroplating industries.

Ammonia: Ammonia is produced by the microbial degradation of organic matter. It appears therefore, in many grounds as well as surface waters. Concentrations of ammonia above a certain level in water; polluted either due to sewage or industrial wastes, is toxic to fish.

Sodium and Potassium: Sodium is one of the most abundant and a common constituent of natural waters. The sodium concentration of water is of concern primarily when considering their solubility for agricultural uses or boiler feed water. The concentration ranges from very low in the surface waters and relatively high in deep ground waters and highest in the marine waters.

Potassium is found in low concentrations (<10 mg/L) in natural waters since rocks, which contain potassium, are relatively resistant to weathering. It is usually found in ionic form and the salts are highly soluble. Though found in small quantities it plays a vital role in the metabolism of fresh water environment.

Sulphates: Sulphates are commonly found in all natural waters, particularly those with high salt content. Besides industrial pollution and domestic sewage, biological oxidation of reduced sulphur also adds to sulphate content. It is soluble in water and imparts hardness with other cations. Sulphate causes scaling in industrial water supplies, and odor and corrosion in wastewater treatment processes due to its reduction to H_2S. Its main source is industrial discharge that contains sulphate salts and domestic wastes (heavy use of detergents). When water containing magnesium sulphate at levels about 1000 mg/L acts as a purgative in human adults, lower concentration (below 150 mg/L) may still affect new users and children. Taste threshold concentration for the most prevalent sulphate salts are 200 to 500 mg/L for sodium sulphate, and 400 to 600 mg/L for magnesium sulphate.

Iron: Iron is the fourth most abundant element by weight in the earth's crust. In water it occurs mainly in the divalent and trivalent state. Iron in surface water is generally present in the ferric state. The concentration of iron in well-aerated water is seldom high, but under reducing condition, which may exist in some ground water, lake and reservoir and in the absence of sulphate and carbonate, high concentration of soluble ferrous iron may be found. The presence of iron in natural water can be attributed to the dissolution of rocks and minerals, acid mine drainage, landfill leachates, sewage or engineering industries. Iron is an essential element in human nutrition. It is contained in a number of biologically significant proteins, but ingestion in large quantity results in hemochromatosis where in tissue damage results from iron accumulation.

Nitrates: The nitrate ion is the common form of combined nitrogen found in surface waters. By denitrification process, it may be bio-chemically reduced to nitrite under anaerobic conditions. The significant sources of nitrates are chemical fertilizers from cultivated lands, drainage from livestock feeds, as well as domestic and industrial sources. Natural waters in their unpolluted state contain only minute quantities of nitrates. The stimulation of plant growth by nitrates may result in eutrophication, especially due to algae. The subsequent death and decay of plants produce secondary pollution. Nitrates are most important for biological oxidation of nitrogenous organic matter. Certain nitrogen fixing bacteria and algae have the capacity to fix molecular nitrogen in nitrates. The main source of polluting nitrates is the domestic sewage let into water bodies. Nitrates may find their way into ground water through leaching from soil and at times by contamination. Waters with high concentrations (>45mg/L) can represent a significant health risk. Beyond this value methemoglobinemia takes place.

Phosphates: Phosphate's role in promoting plant growth actually makes it a dangerous pollutant when dumped in excessive quantities into aquatic ecosystems. The rate at which plants can grow and reproduce is limited by the amount of usable phosphate in the soil or water (for aquatic plants). When extra phosphorous was added to water due to anthropogenic activities, it creates a condition called eutrophication that can wipe out aquatic ecosystems. Eutrophication is characterized by a rapid growth in the plant population (an algal bloom). The bacteria that decompose the dead plants use oxygen, and eventually burn up so much that not enough remains to support fish, insects, mussels, and other animals, leading to a massive die-off. The presence of phosphates in virtually every detergent, including household cleaners and laundry soap, fertilizer run-off from agriculture and landscaping, decomposition of organic matter continues to be a major source of phosphate pollution. Animal wastes can also add significant amounts of phosphate to water. In most surface waters, concentration of phosphorus ranges from 0.005 to 0.020 mg/L PO^4- P.

Biological Parameters

Biological Coliform: Storm water combined with sanitary sewers can flush bacteria laden water into streams. Total coliform bacteria are a collection of relatively harmless microorganisms that live in large number in the intestine of man and warm and cold-blooded animals. They aid in the digestion of food. A specific sub-group of this collection is the faecal coliform bacteria, the most common member being *Escherichia coli* (*E. coli*). These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated with the fecal material of warm-blooded animals. The presence of faecal coliform bacteria in aquatic environment indicates that the water has been contaminated with the faecal material. At the same time the pathogens or diseases producing bacteria or virus that are co-existing with faecal material might also contaminate the water. This results in the outbreak of water born diseases like typhoid, dysentery, diarrhoea, viral and bacterial gastroenteritis and hepatitis A.

Sampling and Analysis of Sediments

The sediment from water bodies is usually collected by dredge and scoop and for deeper layer special boring machine is used. In this study samples were collected in polyethylene bags by means of scoop and immediately transported to the laboratory for further physico-chemical analysis.

The sediment sampling sites were (1) Sharavathi 1 (Nagara), (2) Sharavathi 2, (3) Sharmanavathi, (4) Haridravathi, (5) Muppane, (6) Linganamakki reservoir, (7) Hurliholé, (8) Yenneholé, (9) Valagere, (10) Nittur, and (11) Sampekai with corresponding longitude and latitude as given for water sampling sites (Table 2).

Results and Discussion of Water Analysis

Physical Parameters

Temperature: The temperature of water in upper catchment ranged from 22°C to 34.5°C. In sampling site 8 (Linganamakki Reservoir), water temperature was higher than any other site (Min: 24.0°C Max: 34.5°C). This is a characteristic feature of a lacustrine ecosystem (Table 5).

Table 5. Temperature (°C) in the water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	24.5	29.5	29	28			31	34.5		28.9						
Mar-01	30.1	30.5	30.1	31.6	30.6	28	26.5	34	27.9	29.2	29.6	28.3	29.1			
Apr-01	28.1	26.5	26.5	29	29	29.5	31	31.5	28	31	29	30.5	30.5			
May-01	30.1	30.5	30.1	31.6	31	30.5	29.2	34	29	27.5	31	28.9	30			
Jul-01	23.8	24	23.9	24.3	23.3	24.1	24.8	26	24.5	23.4	25.5	24.5		24.1	24.4	25
Aug-01	23.4	27	26	26	25.9	26	25.8	26	24.5	24	26	25		27	26.5	26
Sep-01	26	29	25.5	26.5	27	25.5	27	26.5	27.5	28	27	28	27.5	27.5	27	27
Oct-01	28	31	27	28	27	25	28.5	27	27	28	27.5	27.5	28	29	28	26
Nov-01	26	26	25	29	28	26	28	27	26	29	28	28	28	26	28	28
Dec-01	25.5	24	22	24	26	25	24	25	24	25	25	25.5	26	24	24	27
Jan-02	24	25	23	25	26	25	24	25	25	27	25		25	22	25	29
Feb-02	25	27	29	30	27	25	26	27	27	27	28		28			28
Mar-02	29	29	27	28	26	23	25	24.5	27	26	25		27			
Apr-02	30	29	28	28	27	25	27	26	28	27	26		28			

In downstream, water temperature ranged from 20°C - 36°C (Table 6). Values obtained are well within the limits provided by Indian Standards Specifications (NEERI).

Table 6. Water temperature in downstream localities.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02			28	29	28	28		27	27	27	26
Dec-02			28	27	28	28		27	27	27	24
Jan-03			28	26	28	28	27	29	27	29	28
Feb-03				30	30	29	28	29	29	31	32
Mar-03				33	33	32	30		31	34	33
April-03				33	34	33	31		31	31	34
May-03				32	32	31	30		35	31	33
Jun-03			29	29	29	29	28	28		28	28

Table 6. Water temperature in downstream localities (cont...).

Months	**Sampling sites**											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	29	26	27	28	22	22	22			29	28	30
Dec-02	28	24	28	28	20					27	28	30
Jan-03	29	27	28	30	21	28		27		30	29	26
Feb-03	33	35	30	30	27	28		32	26		30	31
Mar-03	32	30	30		28	28		32	26		29	31
April-03	34	36	32		26	30		32	27		30	32
May-03	32	33	31		26			30	28		30	32
Jun-03	30	28	28		24			25	24		34	27

Transparency and Turbidity

In the upper catchment, transparency varied from 3 cm to 284 cm and turbidity value fluctuated from <5 –125 NTU (Table 7 and 8). Turbidity exceeded NEERI limits, mainly in Hosanagara and some part of Sagar due to agricultural runoff during monsoon.

Table 7. Transparency (cm) in the water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	85	80	40	80			27.5	65		76						
Mar-01	80	100	124	74	92	59	73	98	73	93	57	47	56			
Apr-01	64	65	76	56	67	55	60	75	67	67	43	70	45			
May-01	65	43	89	65	92	59	73	70	73	65	67	60	56			
Jul-01	23	16	14	8	50	45	50	43	34	53	45	42		8	8	4
Aug-01	12	12	8	5	30	50	30	37	32	50	42	40		5	3	3
Sep-01	18	15	12	6	25	35	20	75	45	30	45	30	30	7	5	4
Oct-01	53	35	38	3	50	150	65	160	80	80	80	75	32	8	3	35
Nov-01	58	58	38	15	112	166	82	148	70	39	39	39	82	18	15	38
Dec-01	58	38	38	13	97	130	70	280	97	80	148	24	80	10	10	58
Jan-02	80	65	58	23	90	284	82	284	90	35	90		145	20	35	35
Feb-02	82	75	42	12	82	284	80	284	90	35	70		125			15
Mar-02	72	48	15	15	82	284	72	72	58	72	10		130			
Apr-02	75	50	18	15	80	284	70	75	45	70	12		110			

Table 8. Turbidity (NTU) in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	<10	<10	<10	25			<10			<10						
Mar-01	<10	<10	<10	>50	<10	<10	<10	<10	<10	<10	<10	<10	<10			
Apr-01	<10	<10	<10	>50	<10	<10	<10	<10	<10	<10	<10	<10	<10			
May-01	25	<10	<10	>50	<10	<10	<10	<10	<10	<10	<10	<10	<10			
Jul-01	50	35	30	60	<10	<10	<10	<10	<10	<10	<10	<10		75	75	50
Aug-01	75	50	20	75	<5	<5	12	<5	<10	<10	<10	<10		125	100	50
Sep-01	25	25	20	75	<10	<10	<10	<10	<10	<10	<10	<10	<10	60	75	45
Oct-01	<10	15	20	20	<5	<5	<5	<5	<5	<5	<5	<5	<5	50	70	<10
Nov-01	<10	12	15	20	<5	<5	<10	<5	<5	<5	<5	<5	<5	30	30	15
Dec-01	<10	<10	15	20	<5	<5	<10	<5	<5	<5	<5	<5	20	25	20	15
Jan-02	20	<5	15	30	<10	<10	<10	<10	<10	<10	<10		<10	25	10	20
Feb-02	10	5	20	40	7	<5	5	<10	<5	<10	<10		<10			45
Mar-02	10	5	20	40	7	<5	5	<10	<5	<10	<10		<10			45
Apr-02	10	10	15	25	7	<5	<5	<10	<5	<10	<10		<10			

In lower catchment, turbidity was in the range of 10 - 100 NTU. At Dabbe [DS4], Joginamutt [DS5] and Jog upper [DS5] it was 25-50 NTU, <100 NTU and 10 – 25 NTU respectively and exceeded the standard limit of 10 NTU. It was due to runoff from the catchment area and also due to the obstruction of water for agriculture leading to the increased sediment loads and phyto-productivity in the stream.

Total Dissolved Solids and Total Suspended Solids

In Sharavathi upstream regions, the total suspended solids ranged from 21.3 to 110 mg/L and total dissolved solids 13.77 – 84.03 mg/L (Table 9 and 10). The results showed that TSS concentration exceeds the limits, due to siltation from storm and agricultural runoff (mainly at Hosanagara region) whereas TDS values are within the limits provided by NEERI.

Table 9. Total Suspended Solids (mg/L) in the water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	62	41.3	21.3	52			52	40		38.6						
Mar-01	40	54	30	41	32	50	26	32	40	64	60	35	40			
Apr-01	54	39	68	37	32	37	68	35	46	52	40	52	27.1			
May-01	82	80	74	67	40	26	67	74	32	48	71	57	85			
Jul-01	65	78	76	110	40	35	65	55	65	45	55	55		102	108	58
Aug-01	80	80	82	110	45	40	70	58	68	50	58	60		100	106	55
Sep-01	82	83	80	108	50	50	75	55	70	55	60	65	55	101	105	60
Oct-01	81	83	81	106	49	51	72	51	69	53	62	62	51	101	102	58
Nov-01	85	85	82	108	55	55	75	55	75	55	65	65	55	105	105	65
Dec-01	75	80	80	100	52	50	72	52	72	53	59	60	54	100	98	61

Table 10. Total Dissolved Solids (mg/L) in the water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Aug-01	26.12	36.76	35.8	46.24	20.99	23.85	27.3	16.32	16.12	17.2	18.59	20		44.3	18.16	18.5
Sep-01	28.14	30.95	37	45.3	14.5	15.95	17.85	17.9	18	15	18.9	18	20	57	36	18.5
Oct-01	28.38	30.69	36.97	46.4	17.5	15.2	20.3	17.65	17.6	14.25	17.5	20.56	22.48	44	42.65	41.71
Nov-01	31.27	32.98	41.38	53.56	15.37	16.63	21.31	18.12	18.38	15.41	18.19	40.72	16.62	60.58	60.93	42.2
Dec-01	33.1	35.1	41.85	56.13	16.11	17.39	18.75	19.09	19.05	21.8	19.1	19.23	17.99	64.03	64.45	42.18
Jan-02	26.95	22.95	42.15	57.1	15.55	16.9	17.8	21.07	21.65	27.5	24.9		20.37	52.95	54.9	45.5
Feb-02	21.85	27.83	41.75	59.94	13.77	14.47	15.07	15.08	21.73	25.5	17.96		16.25			40.13
Mar-02	26.85	33.05	78.34	84.03	19.2	20.34	20.09	22.29	30.51	26.29	24.17		30.25			
Apr-02	27.4	80.8	110	60.83	20.02	21.6	22.52	23.68	32.38	32.38	24.49	26.54	33.96			

In downstream, however, except in the sites near to confluence of Sharavathi into Arabian sea (Haddinabal, Gudankateholé and Badagani), all other localities had TDS values in the stipulated USEPA range of 500mg/L (Table 11). In Haddinabal, Gudankateholé and Badagani, TDS ranges between 24.81 – 15,090 mg/L. This indicated the brackish quality of water in the region.

Table 11. Total Dissolved Solids (mg/L) in the water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	18.83		22.27	20.26	21.72	20.62		24.31	22.22	24.81	25.95
Dec-02	19.99	30.22	21.78	20.38	21.68	21.22		26.01	23.83	26.34	25.04
Jan-03	24.52	30.9	24.33	29.32	24.26	36.14	23.95	29.53	31.64	1.21*	26.66
Feb-03	29.44			38.29	22	38.89	20.78	41.92	36.86	2.17*	28.53
Mar-03	25.97	36.3		37.26	25.97	39.9	20.93		45.81	1.43*	27.85
April-03	28.11	38.71		36.79	26.89	38.17	21.8		41.26	1.79*	25.7
May-03	29.22	57.95		42.93	23.36	40.44	24.2		77.37	2.20*	26.3
Jun-03	21.24		26.22	25.75	28.23	27.92	30.72	34.91		79.23	32.02

Table 11. Total Dissolved Solids (mg/L) in the water samples of the Sharavathi downstream (cont…).

Months	***Sampling sites***											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	18.77	27.77	17.71	17.51	19.6	26.36	22.19			19.05	25.24	1.56*
Dec-02	18	30.2	16.2	16.8	21.4					19.71	27.04	6.35*
Jan-03	19.91	41.77	19.49	19.83	27.34	38.42		27.89		21.46	56.5	14.42*
Feb-03	21.14	51.28	20.13	21.45	28.13	43.3		31.95	30.44		95.31	14.32*
Mar-03	20.33	67.82	23.71		36.2	46.21		33.75	32.1		547.2	14.42*
April-03	20.34	72.88	21.23		33.51	46.88		34.07	31.41		1.047 *	15.09*
May-03	21.04	87.98	22.45		33.51			34.83	29.78		11.1 *	14.89*
Jun-03	20.53	39.34	22.32		25.36			31.71	21.45		224.3	5.04*

* expressed as parts per thousand or g/L

Colour

Pure water has no colour, but the presence of soluble or insoluble, organic or inorganic matter will impart greenish blue, green, greenish yellow, yellow or brown colour to water. Different species of phytoplankton and zooplankton also impart colour. A dark or blue green colour can be caused by blue green algae, yellow-brown by diatoms or dinoflagellates and red and purple by zooplankton such as Daphnia or Copepods. Colour must be removed to make water suitable for general and industrial applications.

In upstream, the water was colourless to brownish green. Brown and brownish green colours were recorded during monsoon due to colloidal suspension of silts from erosion (Table 12). Similar colouration was also observed in the downstream. In streams like Chandubanu, Vatahalla, Hennur, Hossagadde, Bhaskere, it was transparent, colourless and odourless, whereas in Haddinabal it was greenish due to stagnation. In Dabbod, generally water was transparent and colorless, but during agricultural activities it turned slightly turbid and exceeded the permissible limits for turbidity (February, March and April).

Table 12. Coloration of water samples from the Sharavathi upstream.

Months	**Sampling sites**				
	1	**2**	**3**	**4**	**5**
Feb-01	Colour less	Colour less	Colour less	Colour less	Colourless
Mar-01	Colour less	Colour less	Colour less	Colour less	Colourless
Apr-01	Colour less	Colour less	Colour less	Colour less	Colourless
May-01	Colour less	Colour less	Colour less	Colour less	Colourless
Jul-01	Brownish	Brownish	Brownish	Brownish	Colourless
Aug-01	Brownish	Brownish	Brownish	Brownish	Colourless
Sep-01	Brownish	Brownish	Brownish	Brownish	Colourless
Oct-01	Colourless	Brownish	Light brown	Brownish	Colourless
Nov-01	Colourless	Colourless	Light green	Brownish green	Colourless
Dec-01	Colourless	Light Brown	Light Brown	Brownish	Colourless
Jan-02	Greenish	Colour less	Light Brown	Brownish green	Colourless
Feb-02	Light Brown	Colour less	Light Brown	Brownish	Colourless
Mar-02	Slight Green	Light Brown	Brownish Green	Slight green	Colourless
Apr-02	Light Brown	Light Brown	Light Brown	Slight green	Colourless

Table 12. Coloration of water samples from the Sharavathi upstream. (Cont...)

Months	**Sampling sites**				
	6	**7**	**8**	**9**	**10**
Feb-01	Colour less	Colour less	Colour less	Colour less	Colour less
Mar-01	Colour less	Colour less	Colour less	Colour less	Colour less
Apr-01	Colour less	Colour less	Colour less	Colour less	Colour less
May-01	Colour less	Colour less	Colour less	Colour less	Colour less
Jul-01	Colour less	Light brown	Light brown	Light brown	Colour less
Aug-01	Colour less	Light brown	Light brown	Light brown	Colour less
Sep-01	Colour less	Light brown	Light brown	Light brown	Colour less
Oct-01	Colourless	Colourless	Green	Colourless	Colourless
Nov-01	Colourless	Colourless	Bluish green	Colourless	Colourless
Dec-01	Colourless	Light Green	Light Green	Colourless	Light Green
Jan-02	Slight green	Greenish	Colour less	Colour less	Brownish
Feb-02	Slight green	Light brown	Colour less	Colour less	Brownish
Mar-02	Greenish	Greenish brown	Light Green	Brownish green	Brownish
Apr-02	Slight green	Light brown	Light Green	Brownish green	Light brown

Table 12. Coloration of water samples from the Sharavathi upstream. (Cont...)

Months	**Sampling sites**					
	11	**12**	**13**	**14**	**15**	**16**
Feb-01	Colour less	Colour less	Colour less			
Mar-01	Colour less	Colour less	Colour less			
Apr-01	Colour less	Colour less	Colour less			
May-01	Colour less	Colour less	Colour less			
Jul-01	Light brown	Light Brown		Brownish	Brownish	Brownish
Aug-01	Light brown	Light Brown		Brownish	Brownish	Brownish
Sep-01	Light brown	Light Brown	Light brown	Light Brown	Brownish	Light Brown
Oct-01	Colourless	Colourless	Light brown	Brownish	Brownish	Brownish
Nov-01	Colourless	Colourless	Colourless	Green	Brownish green	Brownish green
Dec-01	Colourless	Colourless	Light brown	Brownish green	Brownish	Light Brown
Jan-02	Light Green		Light brown	Green	Green	Brownish green
Feb-02	Brownish		Colourless			Brownish green
Mar-02	Brownish		Colourless			
Apr-02	Light brown		Colourless			

Electrical conductivity

The electrical conductivity in the upper catchments of Sharavathi River ranged from 0.003 to 0.44 mS/cm (Table 13). Values obtained are well within the limits provided by Indian Standards Specifications (NEERI).

Table 13. Electrical conductivity (mS/cm) in the water samples of the Sharavathi upstream.

Months	**Sampling sites**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Feb-01	0.042	0.039	0.070	0.077			0.022	0.034
Mar-01	0.064	0.089	0.089	0.089	0.025	0.032	0.025	0.032
Apr-01	0.064	0.096	0.076	0.070	0.057	0.034	0.031	0.283
May-01	0.058	0.040	0.102	0.005	0.096	0.440	0.063	0.003
Jul-01	0.030	0.044	0.040	0.061	0.021	0.027	0.029	0.025
Aug-01	0.027	0.043	0.042	0.055	0.018	0.023	0.027	0.025
Sep-01	0.041	0.042	0.051	0.060	0.202	0.022	0.024	0.026
Oct-01	0.042	0.044	0.052	0.064	0.024	0.022	0.029	0.026
Nov-01	0.042	0.045	0.056	0.070	0.021	0.022	0.028	0.025
Dec-01	0.044	0.048	0.056	0.070	0.058	0.014	0.024	0.025
Jan-02	0.046	0.035	0.064	0.09	0.024	0.025	0.028	0.028
Feb-02	0.035	0.048	0.070	0.09	0.026	0.026	0.025	0.028
Mar-02	0.039	0.051	0.115	0.122	0.031	0.027	0.029	0.032
Apr-02	0.058	0.066	0.22	0.11	0.044	0.041	0.042	0.045

Table 13. Electrical conductivity (mS/cm) in the water samples of the Sharavathi upstream (cont...).

Months	**Sampling sites**							
	9	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01		0.023						
Mar-01	0.03	0.025	0.032	0.032	0.032			
Apr-01	0.03	0.044	0.44	0.096	0.32			
May-01	0.12	0.045	0.064	0.037	0.12			
Jul-01	0.023	0.02	0.025	0.026		0.06	0.067	0.029
Aug-01	0.022	0.02	0.025	0.026		0.028	0.054	0.027
Sep-01	0.026	0.02	0.026	0.023	0.020	0.038	0.064	0.049
Oct-01	0.249	0.02	0.025	0.023	0.021	0.063	0.061	0.059
Nov-01	0.024	0.021	0.024	0.031	0.022	0.077	0.077	0.059
Dec-01	0.023	0.028	0.026	0.024	0.023	0.077	0.09	0.058
Jan-02	0.029	0.033	0.03		0.016	0.083	0.09	0.064
Feb-02	0.038	0.032	0.031		0.028			0.064
Mar-02	0.039	0.037	0.035		0.043			
Apr-02	0.062	0.053	0.048		0.067			

In downstream regions, some localities were recorded with higher electrical conductivity. This is due to the salt-water intrusion by the Arabian Sea in these localities. Table 14 details the electrical conductivity of water samples from the downstream.

Table 14. Electrical conductivity (mS/cm) in the water samples of the Sharavathi downstream

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	0.04		0.05	0.04	0.05	0.04		0.05	0.05	0.05	0.05
Dec-02	0.04	0.06	0.04	0.04	0.04	0.04		0.05	0.05	0.05	0.05
Jan-03	0.05	0.06	0.05	0.06	0.05	0.07	0.05	0.06	0.06	2.35	0.05
Feb-03	0.06			0.08	0.04	0.08	0.04	0.08	0.08	4.35	0.06
Mar-03	0.05	0.07		0.08	0.05	0.08	0.04		0.09	2.84	0.06
April-03	0.06	0.08		0.07	0.05	0.08	0.04		0.08	3.56	0.05
May-03	0.06	0.12		0.09	0.05	0.08	0.05		0.16	4.41	0.05
Jun-03	0.04		0.05	0.05	0.06	0.06	0.06	0.07		0.16	0.06

Table 14. Electrical conductivity (mS/cm) in the water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	13	14	15	16	17	18	19	20	21	22	23
Nov-02	0.04	0.06	0.04	0.04	0.04	0.06	0.05			0.04	0.05	3.28
Dec-02	0.04	0.06	0.03	0.03	0.04					0.04	0.05	12.65
Jan-03	0.04	0.08	0.04	0.04	0.05	0.07		0.05		0.04	0.11	27.91
Feb-03	0.04	0.1	0.04	0.04	0.06	0.09		0.06	0.06		0.19	28.61
Mar-03	0.04	0.13	0.05		0.07	0.09		0.07	0.06		1.1	28.82
April-03	0.04	0.15	0.04		0.07	0.09		0.07	0.06		2.1	30.2
May-03	0.04	0.18	0.05		0.07			0.07	0.06		22.15	29.77
Jun-03	0.04	0.08	0.05		0.05			0.06	0.04		0.44	10.06

pH, Acidity and Alkalinity

In the upstream, pH ranged from 6.53 - 8.25 (Table 15). Acidity 2.5 –40 mg/L (Table 16) and alkalinity value ranged from 8 – 75 mg/L (Table 17), results well within the limits (NEERI and WHO standards).

Table15. pH in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	7.4	6.9	7.3	7.5			7.5	6.53		6.7						
Mar-01	6.85	6.53	6.78	7.2	6.85	6.8	6.9	7.4	6.9	6.94	6.75	6.55	6.65			
Apr-01	7	7.2	7	7.4	6.72	6.94	6.94	6.94	6.55	7	7.4	7	6.72			
May-01	7.4	6.9	7.74	7	6.94	6.55	6.72	6.59	6.75	7	7	7.4	6.94			
Jul-01	7.09	6.89	6.97	6.98	6.95	7.22	6.94	6.65	6.6	6.93	6.8	6.99		7.01	6.98	6.85
Aug-01	6.98	7.03	7.15	7.05	7.24	7.07	7.21	7.06	6.69	6.99	6.85	7.03		7.03	6.94	6.83
Sep-01	7.3	7.12	7.17	7.03	7.01	6.64	7.01	7.13	6.75	6.53	6.88	7.27	6.88	7.02	7.53	7.07
Oct-01	7.5	7.43	7.85	7.58	7.12	6.9	7.21	7.38	7.33	7.34	7.33	7.45	7.02	7.9	7.7	7.83
Nov-01	7.35	7.25	7.26	7.55	7.19	7.01	7.27	7.1	7.06	6.99	7.03	6.56	6.96	7.2	7.5	7.34
Dec-01	7.4	7.71	7.59	7.86	6.98	7.76	7.36	7.26	7.01	7.45	7.46	7.43	7.45	7.55	7.81	7.28
Jan-02	7.25	7.2	7.1	7.38	7.08	7.09	7.07	7.01	7.9	7.05	6.69		7.03	7.25	7.48	7.18
Feb-02	7.62	7.7	8.25	7.75	7.7	7.47	7.13	7.38	7.36	7.01	6.93		7.04			7.25
Mar-02	7.27	7.25	7.01	7.73	7.45	7.45	7.58	7.62	7.48	7.38	7.32		7.25			
Apr-02	7.41	8.41	7.05	7.15	6.54	6.55	6.77	7.02	7.76	6.52	6.57		6.63			

Table 16. Acidity (mg/L) in the water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	16	20		8			8	8		12						
Mar-01	8	8	12	12	20	20	12	12	12	16	8	16	12			
Apr-01	6	12	8	12	8	8	8	8	12	8	8	12	12			
May-01	12	16	12	9	12	20	8	12	6	12	20	12	12			
Jul-01	5	5	5	5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		2.5	2.5	12
Aug-01	10	5	5	10	10	5	10	10	10	5	10	10		10	15	10
Sep-01	15	15	15	20	20	10	15	30	15	10	15	15	10	15	20	20
Oct-01	12	12	10	15	18	8	12	15	12	8	12	12	8	12	18	18
Nov-01	12	12	12	12	15	10	12	12	12	10	15	12	8	12	15	15
Dec-01	17.5	17.5	17.5	17.5	10	12.5	12.5	12.5	12.5	12.5	15	15	12.5	25	30	20
Jan-02	20	17.5	20	20	12.5	15	15	12.5	12.5	15	15		12.5	25	30	25
Feb-02	20	20	20	20	10	20	10	10	20	30	20		10			30
Mar-02	30	30	40	30	20	30	30	20	30	30	30		30			
Apr-02	25	25	35	22	21	25	23	21	32	25	25		27			

Table 17. Alkalinity (mg/L) in the water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	48	40	28	68			24	38		34						
Mar-01	44	56	52	48	32	40	26	44	52	64	60	35	40			
Apr-01	60	40	44	48	36	44	38	32	49	48	36	32	48			
May-01	56	52	48	52	42	50	48	52	52	40	52	48	50			
Jul-01	35	30	35	45	20	20	20	30	20	20	25	25		55	50	32
Aug-01	45	45	50	45	45	45	30	35	20	20	25	24		30	30	30
Sep-01	40	40	45	40	45	35	35	35	20	20	24	28	24	28	30	28
Oct-01	45	40	50	20	20	25	30	30	25	20	25	25	25	55	55	60
Nov-01	45	45	55	25	25	30	30	35	30	25	25	30	30	60	65	55
Dec-01	48	48	59	30	30	30	35	35	32	28	26	32	35	55	68	58
Jan-02	16	12	8	20	8	8	16	8	8	12	8		8	24	8	20
Feb-02	32	16	12	20	16	12	24	20	8	12	8		12			12
Mar-02	75	50	50	50	25	25	50	25	25	25	25		25			
Apr-02	50	45	52	50	33	31	48	28	22	25	30		32			

In the downstream, pH value was generally in circum neutral condition of 6.5 – 7.5 and rarely exceeded 8.0 (Vatahalla: 8.67 in May 2003). Apart from this individual observation, all other localities had pH level within the permissible level of NEERI (Table 18). Tables 19and 20 show corresponding alkalinity and acidity values of Sharavathi downstream. They were also observed within the permissible level of 100 – 250mg/L.

Table 18. pH in water samples of the Sharavathi downstream.

Months	Sampling sites										
	1	2	3	4	5	6	7	8	9	10	11
Nov-02	7.26		7	6.98	6.84	6.75		7.14	7.13	6.97	7.01
Dec-02	7.13	7.4	6.72	6.93	7.01	6.98		7.04	7.05	6.95	6.99
Jan-03	7.25	7.59	7.22	7.1	6.94	7.36	6.94	7.31	7.52	7.42	7.35
Feb-03	7.11			6.76	6.78	7.19	6.99	6.91	7.74	7.68	6.93
Mar-03	7.35	7.26		6.36	6.61	6.62	6.9		7.07	7.23	6.37
April-03	7.1	7.28		6.55	6.67	6.76	6.92		6.88	7.17	6.58
May-03	7.29	7.05		6.71	6.68	6.66	6.83		6.92	7.18	6.44
Jun-03	6.66		6.8	6.62	6.51	6.79	6.88	7.13		6.71	7.07

Table 18. pH in water samples of the Sharavathi downstream (cont...).

Months	Sampling sites											
	12	13	14	15	16	17	18	19	20	21	22	23
Nov-02	7.5	7.63	7.05	6.94	7.21	7.54	7.27			6.74	6.68	7.07
Dec-02	7.07	7.52	7.06	7.01	7.13					6.78	6.81	7.46
Jan-03	7.07	7.84	6.9	7.23	7.3	7.8		7.3		6.98	7.27	7.38
Feb-03	7.22	7.88	7.21	7.12	7.3	7.6		7.3	6.5		7.16	7.61
Mar-03	6.84	7.85	6.56		7.5	7.4		6.9	6.7		6.84	7.54
April-03	7.16	7.72	6.96		7.2	7.6		7	6.6		6.61	7.51
May-03	7.08	8.67	6.89		7.17			6.84	6.81		6.53	7.54
Jun-03	7.3	7.49	7.5		7.33			6.55	6.68		6.21	7.18

Table 19. Alkalinity (mg/L) in the water samples of the Sharavathi downstream.

Months	Sampling sites										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	13.93		16.87	13.2	16.87	16.87		19.8	15.4	19.07	21.27
Dec-02	15.4	24.2	17.6	15.4	16.13	16.5		19.07	18.7	19.8	19.8
Jan-03	15.4	26.4	15.4	19.8	13.2	22	11	17.6	24.2	26.4	17.6
Feb-03	21.6			31.2	16.8	28.8	14.4	26.4	33.6	38.4	21.6
Mar-03	21.6	36		28.8	19.2	31.2	14.4		40.8	45.6	21.6
April-03	24	38.4		28.8	21.6	33.6	19.2		38.4	45.6	19.2
May-03	24	40.8		36	19.2	26.4	16.8		74.4	48	19.2
Jun-03	14.4		14.4	16.8	19.2	16.8	19.2	9.6		19.2	21.6

Table 19. Alkalinity (mg/L) in the water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	13.2	24.2	12.1	15.4	13.2	22	17.6			13.2	14.67	25.7
Dec-02	15.4	30.8	11	13.2	14.3					13.93	17.6	46.2
Jan-03	13.2	28.6	11	11	17.6	28.6		17.6		11	30.8	73.7
Feb-03	16.8	45.6	14.4	14.4	21.6	38.4		24	24		33.6	76.8
Mar-03	16.8	60	19.2		33.6	40.8		26.4	24		26.4	79.2
April-03	16.8	67.2	16.8		28.8	45.6		28.8	26.4		24	72
May-03	16.8	74.4	19.2		26.4			24	21.6		43.2	74.4
Jun-03	19.2	26.4	19.2		16.8			12	12		9.6	28.8

Table 20. Acidity (mg/L) in the water samples of the Sharavathi downstream.

Months	Sampling sites										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	1.8		2.1	2.7	1.8	1.8		1.8	1.8	2.4	3.6
Dec-02	2.7	2.7	2.7	2.25	2.7	2.7		3	1.8	2.4	2.7
Jan-03	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.9	3.6	1.8	0.9
Feb-03	1.8			5.4	1.8	1.8	1.8	5.4	3.6	3.6	3.6
Mar-03	3.6	3.6		5.4	3.6	3.6	3.6		5.4	3.6	3.6
April-03	4	6		2	2	4	2		2	4	2
May-03	4	4		6	4	8	4		8	6	6
Jun-03	4		2	4	4	4	4	4		4	4

Table 20. Acidity (mg/L) in the water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	1.8	2.7	1.8	1.8	2.7	2.7	1.8			1.8	2.7	2.7
Dec-02	2.7	2.7	2.7	2.4	2.25					2.7	4.5	1.8
Jan-03	1.8	1.8	1.8	2.7	1.8	1.8		1.8		1.8	1.8	2.7
Feb-03	3.6	5.4	3.6	1.8	1.8	1.8		3.6	3.6		3.6	3.6
Mar-03	3.6	5.4	3.6		3.6	3.6		3.6	3.6		3.6	9
April-03	2	4	2		2	4		4	4		2	4
May-03	4	0	6		4			4	6		12	6
Jun-03	4	4	2		4			4	2		4	8

Dissolved Oxygen

In the upstream region, dissolved oxygen ranged from 5 to 8.0 ppm (Table 21). This in the range of NEERI standards.

Table 21. Dissolved oxygen (ppm) in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	5	5.4	5.7	5.6			5.2	6		5.9						
Mar-01	6	5.6	5.8	4.8	6.2	5	6.4	5.2	6.4	4.9	5.3	6	5.2			
Apr-01	6.3	5	5.5	5.3	5.8	6	6.3	5.6	5.4	5.8	6.3	6	6.4			
May-01	6.5	4.9	6	6	6.8	6.4	7	7	7	6	7	6.5	7			
Jul-01	7.7	7.5	7.6	7.7	7.7	7.8	7.7	7.7	7.9	8	7.7	7.8		7.3	7.4	7
Aug-01	7.8	8	7.9	7.6	7.8	8	7.7	7.8	7.8	7.9	7.7	7.8		7.7	7.8	7
Sep-01	7.3	7	7.3	7.2	7.4	7.2	7	7.3	7	7.2	7.4	7.1	7.2	7.1	7.3	6.5
Oct-01	7.6	6.9	7.1	6.9	7.3	7.4	6.6	7.3	7	7	7.2	7	7.1	6.4	6.6	6.9
Nov-01	8	7.9	7.7	6.7	7.5	7.5	7.5	7.3	7.5	7.3	6.6	7.5	7	6.8	7.3	7.5
Dec-01	7.8	7.5	7.2	6.5	7.4	7.2	7.5	7	7.1	6.8	7	7.6	7.3	6.5	6.9	7.4
Jan-02	7.2	7.1	6.9	6.3	7	7	7.4	7.3	7.2	7	7.4		7.5	5.8	6.6	6.9
Feb-02	6.7	6.8	6.8	6.5	6.9	7	6.8	7	7.1	7.1	6.7		6.9			6.8
Mar-02	6.1	6.2	6.5	6.4	6.9	7.2	7.1	7.2	6.6	6.5	7.2		6.5			
Apr-02	6	6.3	6.2	6.1	6.3	6.5	6.4	6.5	6.1	6.2	6.5		6.3			

In downstream, DO at Chandavar [16.3 ppm], Gudankateholé [13 ppm], Dabbod [12.2 ppm], Hossagadde [12.2 ppm], Hennur [12.2 ppm] showed comparatively higher values due to high inflow and increased water turbulence in the region. Apart from these extremities, DO range was very much similar to upstream catchment (Table 22).

Table 22. Dissolved oxygen (ppm) in water samples of the Sharavathi downstream.

Months	Sampling sites										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02											
Dec-02	8.1	7.3	12.2	12.2	11.4	12.2		9.7		7.3	6.5
Jan-03			6.5	5.2	6.2	5.9	6.8	8.6	7.9	7.5	6.9
Feb-03	6.3			4.1	6.1	4.5	6.9	5.1	7.7	5.3	6
Mar-03	6.2	6.8		4.2	6.4	5.8	6.9		6.6	6.7	5.5
April-03	6.8	7.1		4.6	5.6	6.7	6.9		6.6	5.9	5.5
May-03	7.4	6.6		4.7	6	6.8	7.1		6.2	6.1	4.9
Jun-03	7.2			6	6.6	6.4	6.7	6.7		6.5	6.6

Table 22. Dissolved oxygen (ppm) in water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02												
Dec-02	8.9	8.1	11.4		7.3					16.3	13	7.31
Jan-03	7.1	8	8.2	7.3	9.6	6.4		6.3		7.4	5.6	
Feb-03	7.1	6.8	7.1	8.1	7.4	6.4		5.3	6.7		4	
Mar-03	6.9	6.7	7.9	6.6	7.2	6.3		5.5	6.8		5.7	
April-03	6.5	6.8	6.9		6.4	6.5		6.6	6.9		5.9	
May-03	6.9	9.1	6.9		6.6			6.5	7		6.1	
Jun-03	6.6	8.4	6.7		7.4			7.4	7.6		7.2	

Chloride

The chloride concentration fluctuated from 4.9 to 63.9 mg/L in the upstream region, well within the limits of NEERI (Table 23).

Table 23. Chloride concentration (mg/L) in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	17.9	12.9	14.9	13.9			10.9	8.9		9.99						
Mar-01	4.9	6.9	12	11	6.9	7.5	6.9	7.9	7.1	5	10.9	8.9	12			
Apr-01	15	9.9	10.9	8.9	9.9	11	8.9	9.9	8.9	11.9	12.9	9.9	12			
May-01	33	23	21.8	23	16	22	18	23	14	18.5	20.8	19.7	21.2			
Jul-01	19.9	14.9	14.9	14.9	14.9	19.9	14.9	14.9	14.9	19.9	14.9	14.9		19.9	24.9	12.99
Aug-01	14.99	19.99	14.99	9.99	14.99	9.99	14.99	14.99	14.9	19.9	14.9	13.9		9.99	14.99	14.99
Sep-01	14.99	14.99	14.99	12.99	12.49	14.99	14.99	14.99	9.99	14.99	9.99	12.9	14.99	12.9	19.99	14.99
Oct-01	24.9	19.99	19.99	24.9	14.99	24.99	14.99	19.99	19.99	19.99	19.99	14.99	19.99	14.99	19.99	19.99
Nov-01	24.99	14.99	14.99	14.99	9.99	14.99	9.99	14.99	14.99	14.99	9.99	14.99	14.99	14.99	14.99	14.99
Dec-01	24.9	24.9	29.99	34.98	34.98	29.99	29.99	29.99	29.99	29.99	29.99	24.9	39.98	34.98	34.98	34.98
Jan-02	17.04	22.72	22.72	25.56	25.56	22.76	25.56	22.72	25.56	25.56	28.4		25.56	28.4	31.24	25.56
Feb-02	19.88	25.56	19.88	22.72	19.88	17.04	17.04	17.04	25.56	31.24	17.04		19.88			19.88
Mar-02	42.6	63.9	63.9	56.8	42.6	56.8	35.5	42.6	49.7	49.7	49.7		42.6			
Apr-02	17.49	42.48	22.47	24.99	14.99	22.49	17.49	19.99	19.99	22.49	19.99		24.99			

In Haddinabal, Gudankateholé and Badagani of downstream, Chloride concentration was comparatively higher (range: 3.19 – 13320.9 mg/L; Table 24) than other sites (both in upstream as well in downstream). Intrusion of salt-water in the above regions is the main reason for higher chloride concentration.

Table 24. Chloride concentration (mg/L) in Sharavathi downstream water samples.

Months	Sampling sites										
	1	2	3	4	5	6	7	8	9	10	11
Nov-02	1.91		2.87	4.47	3.19	3.51		3.83	2.55	3.19	5.1
Dec-02	2.87	2.39	4.79	4.79	4.15	4.31		4.47	4.31	4.79	2.87
Jan-03	6	6	6	8	6	8	6	16	6	655.8	6
Feb-03	7			11	6	8	6.5	11	7	50.98	7
Mar-03	7	7		8	7	10	6		7	782.75	7
April-03	7	6		9	6	8	6		7	1017.68	7
May-03	7	6		9	6	11	7		31	3049.1	7
Jun-03	5		9	7	8	8	10	9		37.99	8

Table 24. Chloride concentration (mg/L) in Sharavathi downstream water samples (cont…).

Months	Sampling sites											
	12	13	14	15	16	17	18	19	20	21	22	23
Nov-02	2.87	4.15	2.87	1.91	3.19	3.83	3.83			3.19	4.47	871
Dec-02	2.87	3.35	3.83	2.9	3.35					4.79	6.7	5344.1
Jan-03	4	6	6	6	6	6		8		6	16	12371.2
Feb-03	6	8	5	6	7	7		8	7			
Mar-03	6	7	7		7	7		9	9			
April-03	6	8	5		7	7		9	8		570.82	13320.9
May-03	6	9	6		8			10	8		364.89	523.8
Jun-03	5	34.99	5		7			9	6		130	3573.9

Sulphate

The sulphate concentration in the representative samples from the upstream catchment ranged from 0.34 to 32.02 mg/L, within the limits given by NEERI (Table 25).

Table 25. Sulphate concentration (mg/L) in water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	19.42	16.05	20.12	32.02			15.28	17.2		16.4						
Mar-01	14.22	16.22	14.89	25.77	13.17	23.35	18.62	14.89	24.81	14.89	20.5	18.29	16.65			
Apr-01	11.3	22.32	24.52	14.65	6.99	12.5	7.15	20.11	14.5	11.87	10.05	10.05	13.79			
May-01	13.27	9.52	15.23	9.24	10.04	15.23	12.4	9.32	12.51	7.39	10.93	12.4	14.21			
Jul-01	4.96	11.28	9.47	22.1	7.44	2.93	4.51	11.28	10.15	7.44	7.66	6.76		21.2	20.07	24.36
Aug-01	13.26	10.38	6.34	15.86	0.86	0.86	0.86	7.86	8.99	6.34	6.53	5.86		19.86	29.9	32
Sep-01	4.76	11.9	9.52	14.86	2.3	4.28	3.33	2.38	3.8	3.33	4.76	3.33	4.76	17.86	15.7	4.76
Oct-01	1.76	4.47	1.76	11.94	1.49	1.19	2.38	2.69	6.86	1.79	1.19	1.49	1.79	9.25	22.3	3.88
Nov-01	7.46	8.06	8.65	9.55	8.06	8.06	9.55	8.36	8.65	10.15	9.85	10.44	11.64	12.53	14.92	13.13
Dec-01	10.46	9.69	11.59	12.56	7.58	9.25	10.25	11.25	12.58	13.01	9.89	11.49	12.59	17.58	18.59	16.48
Jan-02	5.07	1.33	4.53	8	5.87	2.67	2.67	2.13	7.2	22.66	9.33		4.27	7.466	12	13.66
Feb-02	2.99	2.45	4.89	4.89	0.54	3.53	5.17	4.35	2.18	8.16	9.25		5.44			9.25
Mar-02	2	4	9.33	5	0.34	0.67	0.34	0.67	0.67	3.33	0.67		0.67			
Apr-02	2.51	3.24	8.99	6.21	1.24	1.25	1.65	1.22	1.54	2.13	2.01		0.99			

In downstream, apart from Haddinabal, Gudankateholé and Badagani, all other sites had low sulphate concentration, but within NEERI's specification (Table 26).

Table 26. Sulphate concentration (mg/L) in water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	3.78		3.62	2.5	2.18	2.57		2.07	1.87	3.2	3.43
Dec-02	1.93	1.29	1.47	1.64	1.6	2.52		1.33	2.05	1.68	1.35
Jan-03	4.44	2.46	2.22	4.33	2.57	2.34	3.63	2.46	2.22	79.29	3.51
Feb-03	1.99			2.69	1.64	1.87	1.29	1.87	1.75	117.53	1.29
Mar-03	2.34	2.57		2.69	2.81	3.39	4.56		1.52	84.2	1.52
April-03	1.87	2.11		1.87	1.52	1.99	1.99		1.64	113.21	1.05
May-03	2.22	2.46		1.64	1.52	2.46	2.57		2.34	93.56	1.87
Jun-03	5.61		13.57	1.52	1.99	1.99	1.05	3.51		3.63	2.11

Table 26. Sulphate concentration (mg/L) in the Sharavathi downstream (cont…).

Months	**Sampling sites**											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	3.39	2.73	3.12	1.64	3.08	2.69	3.98			2.77	2.49	123.8
Dec-02	1.52	1.82	1.64	1.29	1.41					1.75	2.34	224.2
Jan-03	2.11	2.22	3.74	1.99	2.34	2.69		4.44		3.51	3.16	837.4
Feb-03	1.64	2.22	1.4	1.87	1.75	2.69		1.99	1.99		2.92	
Mar-03	1.4	2.57	1.75		2.22	2.57		2.34	1.29		38.13	456.1
April-03	2.46	3.63	1.52		1.75	2.22		2.69	1.64		48.89	1765.9
May-03	2.11	3.98	1.64		2.11			3.39	2.57		1090.6	1754.3
Jun-03	1.4	3.51	1.4		1.75			5.15	8.07		12.16	321.6

Total Hardness

In the water samples of upstream, total hardness ranged from 27.25 to 148.29 mg/L (Table 27). Except four incidences from Sharamanavathi, Haridravathi, Keshawapura and Sampekai, where total hardness reached beyond 120mg/L, all other sites had very low hardness. The reason for higher concentration could not be substantiated.

Table 27. Total Hardness (mg/L) in water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	59.95	27.25	49.05	27.25			30.12	30.35		32.7						
Mar-01	54.4	49.05	81.7	76.3	49.05	43.6	49.5	76.3	54.5	49.5	38.15	40.9	54.5			
Apr-01	43.6	43.3	39.24	52.32	37.5	49.7	43.6	30.52	50.7	43.6	48.8	39.24	34.48			
May-01	52	43.6	56.6	56.6	50.2	54.3	60.9	65.4	58.2	56.6	58.9	58.2	54.3			
Jul-01	59.5	59.9	76.3	82.2	82.3	49.5	40.9	38.15	54.5	49.5	49.05	43.6		54.5	54.5	40.6
Aug-01	39.24	39.24	43.6	43.6	47.96	34.88	30.52	30.52	46.32	46.35	45.63	40.56		56.68	78.48	39.24
Sep-01	61.04	43.6	56.68	56.6	43.6	52.32	30.52	61.04	39.24	47.96	69.76	78.48	47.9	78.89	122.08	78.48
Oct-01	65.4	49.05	49.05	54.5	43.6	54.5	49.05	49.05	59.95	59.95	43.6	59.95	49.05	70.85	59.95	59.95
Nov-01	78.48	52.32	143.88	122.08	78.48	52.32	87.2	61.04	43.6	39.24	47.96	52.32	56.68	148.24	82.84	65.4
Dec-01	43.6	39.24	47.96	52.32	43.6	30.52	30.52	56.68	65.4	52.32	61.04	43.6	65.4	126.44	95.92	47.96
Jan-02	28	36	68	80	40	32	32	36	32	28	28		32	76	76	44
Feb-02	60	32	52	88	40	20	32	36	44	22	92		32			64
Mar-02	60	50	50	60	50	50	30	30	70	40	30		40			
Apr-02	58	42	55	55	48	50	35	38	68	54	28		38			

Similar to upstream, generally all the sites in downstream exhibited low hardness concentration (Table 28). The reason for higher concentration in Haddinabal, Gudankateholé and Badagani could be due to salt-water intrusion in these regions.

Table 28. Total Hardness (mg/L) in water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	16		19.33	14.67	17.33	16.67		18	17.33	21.33	22
Dec-02	17	23	17	15	18.67	19		20	19	18.67	20
Jan-03	16	24	16	20	16	24	12	24	24	232	18
Feb-03	18			24	12	22	12	20	26	400	18
Mar-03	14	24		24	14	20	10		32	272	14
April-03	18	26		24	14	22	10		28	336	14
May-03	18	28		28	12	18	12		64	400	6
Jun-03	12		14	14	18	16	16	20		28	20

Table 28. Total Hardness (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	**Sampling sites**											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	14	22	16.67	16	16	22	16			14	14.67	1676.7
Dec-02	12	23	16	13.33	16					12.67	18	1866.7
Jan-03	12	26	12	12	22	32		16		16	32	
Feb-03	12	34	10	10	16	30		18	16		32	3800
Mar-03	10	44	10		26	32		16	18		116	4100
April-03	10	52	10		36	36		20	16		196	4300
May-03	6	52	6		8			6	10		3050	4200
Jun-03	12	22	14		16			16	12		52	1250

Calcium Hardness

In downstream sites, Calcium hardness ranged between 4 – 38 mg/L (excluding Haddinabal, Gudankateholé and Badagani). Table 29 details the Calcium hardness in Sharavathi downstream.

Table 29. Calcium hardness (mg/L) in water samples of the Sharavathi downstream.

Months	Sampling sites										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	8		8	8	8	8		8	8.67	9.33	10
Dec-02	8	12	8	8	8	8		10	10	10	9
Jan-03	8	12	8	12	8	12	6	12	12	48	8
Feb-03	10			14	6	14	6	10	14	100	8
Mar-03	8	16		14	8	12	6		18	58	10
April-03	10	18		14	10	12	8		16	68	8
May-03	10	18		16	8	12	6		38	100	8
Jun-03	8		8	8	10	8	8	12		12	10

Table 29. Calcium hardness (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	8	11.33	8	6	7.33	12	8			6	7.33	66.7
Dec-02	8	12	6	6.67	8					6.67	8	366.7
Jan-03	6	16	6	4	8	14		10		8	14	
Feb-03	6	24	6	6	10	16		10	10		16	600
Mar-03	6	36	6		18	18		10	10		36	700
April-03	8	42	8		20	18		8	10		56	700
May-03	8	50	8		10			8	12		500	700
Jun-03	8	16	10		8			10	8		16	200

Magnesium Hardness

In downstream, magnesium hardness was within the permissible level (30 mg/L) in almost all sites (except sampling site 10, 22 and 23). Table 30 shows the magnesium hardness recorded from the downstream localities.

Table 30. Magnesium hardness (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	Sampling sites										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	8		11.33	6.67	9.33	8.67		10	8.67	12	12
Dec-02	9	11	9	7	10.67	11		10	9	8.67	11
Jan-03	8	12	8	8	8	12	6	12	12	184	10
Feb-03	8			10	6	8	6	10	12	300	10
Mar-03	6	8		10	6	8	4		14	214	4
April-03	8	8		10	4	10	2		12	268	6
May-03	8	10		12	4	6	6		26	300	
Jun-03	4		6	6	8	8	8	8		16	10

Table 30. Magnesium hardness (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	13	14	15	16	17	18	19	20	21	22	23
Nov-02	6	10.67	8.67	10	8.67	10	8			8	7.33	1610
Dec-02	4	11	10	6.67	8					6	10	1500
Jan-03	6	10	6	8	14	18		6		8	18	
Feb-03	6	10	4	4	6	14		8	6		16	3200
Mar-03	4	8	4		8	14		6	8		80	3400
April-03	2	10	2		16	18		12	6		140	3600
May-03											2550	3500
Jun-03	4	6	4		8			6	4		36	1050

Sodium and Potassium

Sodium concentration in upstream sites fluctuated between 2.1 to 101.4 mg/L (Table 31) and potassium values ranged between trace amounts to 9.5 mg/L (Table 41). The observed values are well within the limits given by NEERI. Concentration of potassium was much less compared to sodium, as it is not very abundant in natural waters.

Table 31. Sodium concentration (mg/L) in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	16.05	11.74	16.4	16.4			14.28	15.25		17.21						
Mar-01	7.81	9.99	10.44	15.57	12.53	9.8	11.4	12.3	11.5	12.34	12.64	12.97	13.5			
Apr-01	18	18	17	17.4	17.21	14.28	15.25	16.5	13.9	19	32.02	21	16.4			
May-01	12.52	12.64	12.25	11.4	12.3	17.5	15.75	11.5	12.4	9.99	10.53	10.44	7.3			
Jul-01	8.31	13.77	11.33	17.66	4.43	5.63	5.92	5.82	5.24	4.46	5.71	6.04		18.46	29.22	9.23
Aug-01	6.9	11.73	9.27	9.49	2.1	2.61	2.67	2.80	2.53	4.12	5.10	4.03		9.82	9.41	8.24
Sep-01	10.58	12.6	14.07	10.49	3.68	4.22	4.34	4.28	4.38	3.53	4.68	4.7	3.53	10.25	24.5	14.24
Oct-01	9.86	12.36	13.95	15.28	4.15	5.2	4.99	5.69	4.56	4.28	5.1	4.86	4.12	15.6	28.8	20.1
Nov-01	8.63	11.64	14.5	38.08	4.73	5.19	5.73	6.13	5.5	4.61	6.14	6.32	4.64	39.04	40.04	28.04
Dec-01	8.95	10.76	10.54	65.4	4.58	5.15	5.10	5.59	4.96	5.50	5.56	5.48	4.79	85	101.4	34.5
Jan-02	11.23	10.8	15.99	55.36	5.47	6.04	6.46	6.52	5.82	6.68	6.49		5.81	85.27	89.64	35.01
Feb-02	13.33	16.78	12.30	43.54	6.53	7.10	7.31	2.3	9.13	8.53	4		8.07			30.49
Mar-02	9.20	4.36	4.00	49.25	6.68	9.49	9.30	9.39	9.59	8.52	8.91		9.29			
Apr-02	10.21	5.321	3.68	47.86	5.69	10.25	10.25	9.37	9.46	8.65	8.64		10.25			

Table 32. Potassium concentration (mg/L) in water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	0.4	0.8	0.7	0.8			ND	ND		ND						
Mar-01	0.039	0.039	0.156	ND	ND	ND	ND	0.078	0.039	ND	0.039	ND	0.039			
Apr-01	0.08	1.4	1.2	0.84	0.43	0.67	0.34	0.43	0.34	1.4	0.91	1.2	0.67			
May-01	0.039	0.56	1.4	0.91	0.22	1.4	0.43	0.1	1.2	1.2	0.84	0.91	0.34			
Jul-01	1.134	2.151	1.564	2.151	0.195	0.743	0.86	0.743	0.391	0.235	0.704	0.899		1.447	2.503	0.169
Aug-01	0.116	0.232	0.116	0.232	ND	0.116	0.116	1.96	0.291	0.203	0.502	0.775		0.155	0.193	0.193
Sep-01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.013	0.03	0.04	0.01
Oct-01	0.95	0.98	0.88	1.1	0.099	0.098	0.15	0.2	0.298	0.258	0.35	0.42	0.199	0.56	0.33	0.99
Nov-01	1.076	1.35	1.35	1.55	0.3	0.478	0.59	0.59	0.478	0.3	0.59	0.59	0.398	1.435	1.91	1.395
Dec-01	0.3	0.348	0.503	0.465	0.077	0.116	0.116	0.15	0.116	0.116	0.15	0.15	0.077	0.54	0.69	0.348
Jan-02	2.7	2.156	4.156	4.274	0.919	1.216	2.039	1.647	1.176	1.294	1.686		0.941	2.94	4.039	3.25
Feb-02	0.883	0.803	1.225	3.214	0.281	0.361	0.401	0.401	0.321	0.562	0.321		1.285			4.416
Mar-02	3.518	2.345	7.818	9.508	5.863	1.564	4.691	1.173	0.782	0.782	0.782		1.564			
Apr-02	1.025	1.365	4.256	8.25	4.35	2.317	3.214	2.154	1.255	1.256	2.351		2.155			

In downstream localities, the lowest concentration of 0.1 mg/L of sodium was recorded at Dabbe falls and Joginamutt and was highest with 36.60 mg/L at Chandubanu (Table 33). High sodium concentrations were attributed to seawater intrusion. The permissible range of sodium concentration for surface water is <1 - > 300 mg/L. Similarly, potassium concentration in the downstream sub-basins ranged between 0.09 – 6.4mg/L (0.7 – 1.80 mg/L [DS 4], 0.09– 2.50 mg/L [DS 3], 0.09 – 6.4 mg/L [DS 2], 0.46 – 2.6 mg/L [DS 5]).

Table 33. Sodium concentration (mg/L) in water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	5.46		6.57	6.53	6.38	6.52		7.08	6.73	6.92	6.98
Dec-02											
Jan-03											
Feb-03	17.79			17.59	17.88	15.75	17.88	5.73	17.5		17.3
Mar-03	17.88	16.52			17.69	11.86	17.79		17.4		17.3
April-03	17.59	17.01		16.33	17.3	14	17.88		17.3		17.5
May-03				5.03	3	11.9	3.8		36.6	5356.8	3.87
Jun-03	0.1		0.6	0.7	0.8	0.7	2.29	1.6		20.54	1.1

Table 33. Sodium concentration (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	**Sampling sites**											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	5.8	7.38	6.07	5.57	6.19	6.38	6.95			7.16	8.53	1339.8
Dec-02										7.16		1339.8
Jan-03												1339.8
Feb-03	17.69	10.11	17.69	17.79	17.5	17.2		14.29	17.3		53.36	
Mar-03	17.79	6.12	17.59		16.72	17.2		12.44	15.75			
April-03	17.79	3.6	17.88		16.33	16.62		7.78	15.84			
May-03	2.42	13.6	2.5		4.5			12.08	4.06			
Jun-03	0.02	2.19	0.4		0.8			1.2	0.1		70.58	1908

Table 34. Potassium concentration (mg/L) in water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	0.51		0.07	0.24	0.13	0.44		0.31	0.33	0.24	0.4
Dec-02											
Jan-03											
Feb-03	1.8			1	0.9	1.5	0.9	2.2	1		0.7
Mar-03	0.9	0.7			0.9	1.6	0.8		1		0.9
April-03	1	1.3		1.2	1.3	2.5	0.8		1.2		0.9
May-03				0.09	0.09	0.09	0.09		0.09	0	0.09
Jun-03	1.29			0.89	1.09	0.8	0.89	1.49		1.89	0.89

Table 34. Potassium concentration (mg/L) in water samples of the Sharavathi downstream (cont…).

Months	**Sampling sites**											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	0.4	0.84	0.81	0.79	0.31	0.46	0.4			0.04	0.22	186.9
Dec-02										0.04		186.9
Jan-03												186.9
Feb-03	1.1	4.5	0.8	0.8	1	2.2		1.7	2.3		4.7	
Mar-03	0.9	5.8	1.2		1.3	2.6		2	1.7			
April-03	0.9	6.4	1		1.3	2.6		2.4	1.7			
May-03	0.09	1.74	0.09									
Jun-03	0.6	2.09	0.6		0.8			1.79	1.69		3.18	82

Nitrate Nitrogen

In Sharavathi upstream, Nitrate nitrogen concentration in water samples ranged from trace to 1.622 mg/L (Table 35).

Table 35. Nitrate concentration (mg/L) in the water samples of the Sharavathi upstream.

Months	**Sampling sites**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Feb-01	0.161	0.167	0.12	0.154			0.147	0.141		0.134						
Mar-01	0.004	0.024	0.007	0.014	0.012	0.01	ND	ND	0.024	0.028	ND	ND	0.012			
Apr-01	0.013	0.073	0.213	0.34	0.01	0.04	0.06	0.006	0.067	0.033	0.053	0.06	0.006			
May-01	0.1	0.14	0.02	0.42	0.012	0.01	ND	0.14	0.024	0.16	0.13	0.4	0.14			
Jul-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	ND	0.099
Aug-01	0.015	0.05	0.01	0.01	0.015	0.075	0.01	0.095	0.1	0.015	0.075	0.074		0.11	0.12	0.095
Sep-01	0.045	0.075	0.15	0.15	0.022	0.15	0.12	0.15	0.15	0.03	0.105	0.095	0.095	0.14	0.157	0.105
Oct-01	0.052	0.079	0.155	0.168	0.066	0.099	0.085	0.13	0.056	0.098	0.256	0.099	0.101	0.169	0.561	0.589
Nov-01	0.055	0.086	0.162	0.199	0.092	0.087	0.098	0.092	0.105	0.159	0.361	0.134	0.198	0.235	0.942	0.789
Dec-01	0.061	0.101	0.188	0.254	0.15	0.025	0.056	0.075	0.213	0.312	0.587	0.857	0.534	0.654	1.023	0.954
Jan-02	0.083	0.139	0.251	0.307	0.279	ND	ND	0.008	0.335	0.587	0.979	0.712	0.979	0.979	1.259	1.623
Feb-02	0.042	0.063	0.021	ND	ND	ND	0.056	ND	ND	0.416	0.071		ND			ND
Mar-02	0.09	0.128	0.308	0.142	0.160	0.038	0.257	0.039	0.071	0.192	0.769		0.026			
Apr-02	0.076	0.099	0.125	0.125	0.099	0.036	0.354	0.047	0.075	0.231	0.564		0.055			

In downstream sites, nitrate concentration was higher at Hossagadde, Bhaskere and Mavinaholé with 1.011 mg/L, 1.208 mg/L and 1.114 mg/l respectively (Table 36). Comparatively, downstream sites had low nitrate concentration than upstream sites.

Table 36. Nitrate concentration (mg/L) in the water samples of the Sharavathi downstream.

Months	**Sampling sites**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Nov-02	0.149		0.203	0.146	0.134	0.173		0.094	0.113	0.153	0.097
Dec-02	0.144	0.146	0.12	0.178	0.15	0.142		0.153	0.165	0.12	0.142
Jan-03	0.231	0.231	0.206	0.343	0.253	0.793	0.326	0.253	0.279	0.206	0.214
Feb-03	0.317			0.308	0.214	0.27	0.24	0.249	0.219	0.206	0.236
Mar-03	0.27	0.279		0.176	0.21	0.227	0.244		0.223	0.249	0.219
April-03	0.047	0.099		0.06	0.064	0.06	0.051		0.039	0.06	0.021
May-03											
Jun-03	0.63		1.011	0.716	0.908	0.951	0.176	1.208		0.788	1.114

Table 36. Nitrate concentration (mg/L) in the Sharavathi downstream (cont…).

Months	Sampling sites											
	12	13	14	15	16	17	18	19	20	21	22	23
Nov-02	0.103	0.103	0.21	0.2	0.13	0.1				0.12	0.32	0.13
Dec-02	0.13	0.12	0.17	0.183	0.155					0.13	0.18	0.11
Jan-03	0.27	0.3	0.39	0.43	0.24	0.26		0.3		0.21	0.29	0.25
Feb-03	0.29	0.21	0.27	0.21	0.27	0.24		0.27	0.28		0.24	0.19
Mar-03	0.2	0.2	0.19		0.24	0.21		0.23	0.24		0.27	0.19
April-03	0.05	0.04	0.12		0.13	0.09		0.09	0.06		0.14	0.04
May-03												
Jun-03	0.154	0.24	0.206		0.163			0.514	0.65		0.48	0.18

Phosphate

The values ranged from non-detectable (ND) to 0.0929 mg/L (Table 37). The occasional rise in concentration can be attributed to the agricultural runoff getting into that water.

Table 37. Phosphate concentration (mg/L) in the water samples of the Sharavathi upstream.

Months	Sampling sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-01	0.007	0.009	0.009	0.008			0.006	0.018		0.007						
Mar-01	0.008	ND	0.012	0.009	0.004	ND	0.002	ND	ND	0.005	ND	0.012	0.004			
Apr-01	0.004	0.01	ND	0.004	0.004	ND	0.002	0.005	0.002	0.003	0.003	0.001	ND			
May-01	0.002	0.003	0.001	0.01	ND	0.004	0.004	0.004	0.002	ND	0.004	0.014	ND			
Jul-01	0.014	0.014	0.014	0.02	0.005	0.01	0.011	0.019	0.01	0.015	0.01	0.02		0.018	0.032	0.003
Aug-01	0.017	0.008	0.012	0.018	0.012	0.009	0.02	0.005	0.012	0.015	0.010	0.02		0.013	0.017	0.002
Sep-01	0.004	0.007	0.004	0.005	0.003	0.002	0.01	0.001	0.004	0.007	0.005	0.01	0.005	0.005	0.005	0.004
Oct-01	0.022	0.015	0.053	0.012	0.025	0.008	0.008	0.032	0.008	0.028	0.023	0.011	0.007	0.092	0.003	0.036
Nov-01	0.009	0.005	0.008	0.007	0.012	0.011	0.014	0.008	0.016	0.014	0.010	0.01	0.011	0.014	0.013	0.014
Dec-01	0.014	0.010	0.017	0.005	0.004	0.003	0.014	0.038	0.022	0.07	0.014	0.017	0.007	0.048	0.051	0.021
Jan-02	0.001	0.005	ND	0.009	0.008	0.003	0.007	0.004	0.003	0.004	ND		ND	0.004	0.001	0.002
Feb-02	ND	0.046	ND	0.057	ND	ND	0.009	ND	ND	ND	ND		ND			ND
Mar-02	0.003	0.002	0.006	0.018	0.006	0.017	0.017	0.014	0.005	0.001	0.004		0.001			
Apr-02	0.002	0.002	0.004	0.026	0.005	0.021	0.015	0.015	0.005	0.002	0.004		0.002			

Contrasting to upstream, the downstream localities generally had low phosphate concentration (trace to 0.025 mg/L) and fluctuations were also very less (Table 38).

Table 38. Phosphate concentration (mg/L) in the water samples of the Sharavathi upstream.

Months	Sampling sites										
	1	2	3	4	5	6	7	8	9	10	11
Nov-02	0.01		0.01	0.01	0.01	0.02		0.01	0.01	0.01	0.01
Dec-02	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01
Jan-03	0.017	0.014	0.016	0.016	0.016	0.016	0.015	0.015	0.017	0.014	0.016
Feb-03	0.016			0.014	0.013	0.012	0.014	0.012	0.016	0.009	0.014
Mar-03	0.017	0.02		0.025	0.015	0.018	0.022		0.017	0.016	0.015
April-03	0.003	0.004		0.003	0.003	0.006	0.003		0.003	0.003	0.003
May-03	0.004	0.004		0.003	0.003	0.006	0.003		0.003	0.003	0.003
Jun-03	0.014		0.016	0.013	0.015	0.015	0.016	0.012		0.014	0.014

Table 38. Phosphate concentration (mg/L) in the Sharavathi upstream (cont…).

Months	Sampling sites											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Nov-02	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.01	0.01	0.01
Dec-02	0.01	0.01	0.01	0.01	0.01					0.01	0.01	0.01
Jan-03	0.016	0.017	0.015	0.012	0.016	0.016		0.016		0.01	0.02	0.01
Feb-03	0.014	0.018	0.013	0.013	0.013	0.021		0.014	0.014		0.013	0.01
Mar-03	0.01	0.02	0.03		0.01	0.02		0.02	0.02		0.02	0.01
April-03	0.003	0.003	0.003		0.003	0.004		0.003	0.003		0	0
May-03	0.003	0.003	0.003		0.003			0.004	0.003		0.003	0
Jun-03	0.009	0.013	0.01		0.014			0.012	0.015		0.013	0.013

Iron

Iron concentration in all upstream sampling points was <0.3 mg/L, within the limits of NEERI and APHA (drinking water 0.3mg/L and freshwater bodies 1.0mg/L).

Ammonia

In upstream sites, concentration of ammonia ranged between <0.2 to 3 mg/L.

Fluoride

In downstream, fluoride concentrations in all sub-basins were 0.6 mg/L which falls within the standard limit of 0.6 – 1.2 mg/l for drinking water.

Coliform Bacteria

In upstream, water samples taken during monsoon had coliform bacteria at Sharavathi 1 and 2, Sharmanavathi, Haridravathi and its nearby streams (Keshawapura and Nandiholé). This is due to human or animal interference with the water bodies of the region. Other sampling sites showed occasional presence of coliform bacteria.

In downstream localities, coliform bacteria were found in almost all the samples. This could be due to human faecal matter or due to aquatic or terrestrial animal wastes. As per the permissible limits for drinking water, there should not be any coliform bacteria in the water.

Comparison with NEERI and WHO Standards

Table 39 details the comparison of the study with NEERI and WHO standards. Only those parameters having permissible levels according to NEERI are considered here. A few parameters have exceeded the stipulated limits, but they require continued monitoring.

Table 39. Obtained values vs. standard values of NEERI and WHO

Variables	Permissible Limits	Upstream	Downstream
Turbidity (NTU)	Not more than 10	<5 – 125	10 – 100
Total Dissolved Solids (mg/L)	100	13.77 – 110	16.2 – 15,090 mg/L
Colour	Colourless	Colourless – Brownish green	Colourless – Brownish green
pH	6.5-8.5	6.52-8.41	6.21-8.67
Conductivity (mS/cm)	0.05-1.5	0.003-0.44	0.03-30.20
Alkalinity (mg/L)	200	8 -75	9.6-79.2
Dissolved oxygen (ppm)	Not less than 3.0	4.8-8	4.0-16.3
Total Hardness (mg/L)	300	27.25 - 148.29	6-4300
Sulphate (mg/L)	150	0.34-32.02	1.05-1765.3
Chloride (mg/L)	250	4.9-63.9	1.91-13320.9
Sodium (mg/L)	200	2.1 - 101.4	0.1-1908
Potassium (mg/L)	-	Trace - 9.508	0.09-186.9
Nitrates (mg/L)	45	Trace - 1.623	0.021-1.114
Phosphates (mg/L)	0.03	Trace - 0.092	Trace – 0.025
Coliform Bacteria	Should be nil	Nil - Present	Nil – Present

Comparison between Sampling Sites in Upstream

The upper catchment area was divided in to three categories based on their disturbance level. Group A was classified under most disturbed area (agricultural activities, siltation process etc), whereas Group B and Group C come under comparatively less disturbed area. Table 40 gives the classification of groups based on their disturbance level.

Table 40. Classification of study area (upstream)

Group A	Group B	Group C
Sharavathi [1] and [2]	Muppane [5]	Linganamakki Reservoir [8]
Sharmanavathi [3]	Talakalale dam [6]	Valagere [9]
Haridravathi [4]	Dam outlet [7]	Yenneholé [10]
Nandiholé [14]		Hurliholé [11]
Keshavapura [15]		Nittur [12]
Sampekai [16]		Madenur [13]

Table 41 gives the comparison of water quality variables between sampling sites under each group.

Table 41. Comparison between sampling sites.

Variables	Group A	Group B	Group C
Transparency (cm)	3 – 124	20 – 284	24 - 284
Turbidity (NTU)	10 – 125	<5 – 12	5 - 20
Colour	Light Brown - Brownish green	Colourless - Brownish green	Colourless - Brownish
Total Dissolved Solids (mg/L)	18.16 – 84	13.77 - 27.3	14.25 - 40.72
Total Suspended Solids (mg/L)	21.3 – 110	26 – 75	26 - 85
PH	6.53 - 8.25	6.54 - 7.757	6.53 - 7.76
Ammonia (mg/L)	<0.2 - >3.0	<0.2 – 3.0	<0.2 - 3.O
Total Hardness (mg/L)	27.25 - 143.88	20 – 87.2	22 - 78.48
Sulphate (mg/L)	1.76 - 32.02	0.34 – 23.35	0.67 - 17.2
Nitrates (mg/L)	ND - 1.6229	ND - 0.279	ND - 0.979
Phosphate (mg/L)	ND - 0.0929	ND - 0.0174	ND - 0.0699
Coliform Bacteria	Almost Present in all sampling sites	ND- Slightly Present	ND-Slightly Present

The results show that the physico-chemical and biological variables under group A is comparatively polluted than group B and group C in terms of transparency, turbidity, suspended solids, phosphate and coliform bacteria.

The tributaries flowing through the sub-basins Nandiholé (US1), Haridravathi (US2), Sharavathi (US4), Mavinaholé (US3) and Hilkunji (US8) (Group A) are relatively more polluted (in terms of transparency, turbidity, suspended solids, phosphates and coliform) than the tributaries in the sub-basins Yenneholé (US5), Linganamakki (US9), and Hurliholé (US6) (Group B and C) in the Sharavathi upper catchment. The reason for higher pollution in the above said sub-basins is due to the agricultural and other anthropogenic activity in the catchment area. Secondly, the less water flow during lean seasons leads to increased concentration of pollutants in these regions.

Comparison between Sampling Sites in Downstream

Stagnant waters especially at Dabbod, Gudankateholé show low DO values in comparison to flowing waters of Vatahalla, Chandubanu. Drastic changes were observed in the water quality during the months of January, February, March and April in the Haddinabal stream due to seawater intrusion as evident by high conductivity and total dissolved solids with corresponding increase in values for all other parameters. Generally the water is saline only upto Badagani. The seawater intruded backwards upto Hablikapu nearly one and a half km away from Gudankateholé passing through 4 dams/obstructions. Farmers in the nearby areas have noticed crop damage *i.e.* stunted growth due to saline water usage.

Badagani showed high salinity during all months. Gudankateholé showed fresh water characteristics during November, December, and January. But during the months February, March and April the water turned saline. This has led to the contamination of nearby wells and rendered them unfit for drinking.

Turbidity levels at Dabbod a stream located at the southern end of Sharavathi downstream catchment exceeded the limits during the months of January and April. The reason for this abnormality can be attributed to the damming of this stream for agricultural purposes. Alkalinity levels have also shown substantial increase in the values similar to TDS values. All streams except Chandavar started flowing in the month June due to rains. There are natural variations and trends in the water quality that the water bodies are usually bound to experience over a period of time or season. Apart from Haddinabal, Gudankateholé and Badagani, all other sites had the water parameters within the stipulated range of Indian standards for drinking and agriculture except for turbidity and coliform bacteria.

PHYTOPLANKTON DIVERSITY IN SHARAVATHI RIVER BASIN

The study was undertaken in 32 localities (16 in the upper catchment and 16 in the lower catchment) of the Sharavathi River Basin to assess the phytoplankton composition.

In the upper catchment, 216 species belonging to 59 genera (belonging to Bacillariophyceae, Desmidials, Chlorococcales, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae) were recorded. During the sampling, 100, 117 and 110 species of phytoplankton were recorded in collection I, II and III respectively. Species composition was almost uniform in all the three collections, whereas species diversity and species richness varied across stations and collections. Species compositions as well as population of diatoms were more in streams, while that of desmids was more in reservoir water. Various pollution indices applied showed oligotrophic nature of the reservoir waters with slight organic pollution in stream waters.

In the lower catchment, 86 species belonging to 38 genera (belonging to Bacillariophyceae, Desmidials, Chlorococcales, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae) were recorded . In I-collection 44, II-collection 47 and in III-collection 45 phytoplankton species were recorded. Diatom species as well as population predominated in almost all the streams. Pollution indices showed oligotrophic nature of down stream region.

Introduction

Population pressure, urbanization, industrialisation and increased agricultural practices have significantly contributed to the pollution and toxicity of aquatic ecosystems. Pollutants bring about a change not only in physical and chemical quality of water but also modify the biotic components resulting in the elimination of some, probably valuable species. Attempts have been made by many workers to decide the trophic status of water bodies based on phytoplankton groups or species. Microscopic suspended algae or phytoplankton occur in different forms such as unicellular, colonial or filamentous, which are mainly photosynthetic in nature.

Phytoplanktons are among the rapid detectors of environmental change. This is because of their quick response to toxins and other chemicals. A marked change in algal community severely affects the species diversity (Biligrami, 1988). Eutrophication or organic pollution of aquatic ecosystem results in replacement of algal groups. It has been observed that many species are sensitive to the nutritional loading but equally good numbered are pollution tolerant.

Certain species of phytoplankton grow luxuriantly in eutrophic waters while some species cannot tolerate waters that are contaminated with organic or chemical wastes. Some of the species that indicate clean waters are *Melosira islandica, Cyclotella ocellata* and *Dinobryon*. The pollution indicating plankton includes *Nitzschia palea*, *Microcystis aeruginosa* and *Aphanizomenon flosaquae*. The latter two species have been found to produce toxic blooms and anoxic conditions. Some algae were found to cause noxious blooms in polluted water that tastes bad with intolerable odour. Plankton adapt quickly to the environmental changes because of their short life cycles. Their standing crop and species composition indicate water quality. Plankton influence on factors such as pH, colour, taste and odour. This is mainly because of the small size and great numbers. Often their scant distribution along with their transient nature cannot be totally relied upon for assessing the water quality (APHA, 1985).

In the present work an attempt has been made to assess the distribution pattern of phytoplankton in Sharavathi River Basin. Comparative study of various stations of the reservoir (lacustrine ecosystem) and streams (lotic ecosystem) is unique.

In the present work an attempt has been made to assess the distribution pattern of phytoplankton in Sharavathi River Basin. Comparative study of various stations of the reservoir (lacustrine ecosystem) and streams (lotic ecosystem) is unique.

Objectives -

1. To study species composition and variations between the stations of reservoir, up and downstreams.
2. To study the population and bloom of phytoplankton among these stations.
3. To study species diversity, richness, and dominance.
4. To assess the trophic status of the river basin using phytoplankton group, genera and species as a measure.

For this purpose phytoplankton sampling was made on monthly basis for three months during October-December 2002 at the following respective stations.

Sampling sites

Station	Upstream	Downstream
1	Sharavathi-I	Hebbankere
2	Sharavathi-II	Dabbefalls
3	Sharmanavathi	Hossagadde
4	Keshavapur	Dabbod
5	Haridravathi	Magodholé
6	Nandiholé	Gazni/hennur
7	Muppane	Chandavar
8	Talakalale	Gudankatehole
9	Dam outlet	Bhaskere
10	Reservoir centre	Chandubanu
11	Valagere	Haddinabal
12	Yenneholé	Mavinahole
13	Huruliholé	Mahasati-reservoir
14	Sampekai	Hennehole/watahalla
15	Madenur	Upponi/loc 1
16	Nittur	Upponi village loc 2

Materials and Methods

In each sampling station phytoplankton collection was made by towing a net, made up of bolting silk net No.25, for 5 minutes. Sedimentation of phytoplankton was made in 4%

formaldehyde. For identification of phytoplankton algal monographs on Bacillariophyceae by Hustedt (1976) and Algae (Desmidials, Chlorococcales, Cyanophyceae, Euglenophyceae, Dinophyceae, Chrysophyceae) by Prescott (1982) were followed. For counting of phytoplankton drop count method (Trivedy and Goel, 1984) was followed. The results are expressed as organisms per ml (O/mL). For the trophic status study, different indices given by Biligrami (1988) and Palmer (1980) were applied.

Trophic status assessment

In order to apply biological means of determining the trophic status Shannon and Weiner's species diversity values, Nygaard's phytoplankton Quotient and Palmer's pollution indices of phytoplankton were calculated for the three collections of phytoplankton.

Nygaard (1949) has given ratios for plankton communities to decide the trophic status. For oligotrophic lakes, the values for Cyanophycean, Chlorococcales, Diatom, Eugleninae and Compound quotients are 0.0-0.4; 0.0-0.7; 0.0-0.0; 0.0-0.2 and 0.0-1.0 respectively and for eutrophic lakes they are 0.8-3.0; 0.7-3.5; 0.2-3.0; 0.0-0.2 and 2.0-8.75 respectively. The ∞ value indicates the absence of algal quotient representing groups in that collection.

$$CyanophyceanQuotient = \frac{Cyanophyceae}{Desmidials}$$

$$ChlorococcaleanQuotient = \frac{Chlorococcales}{Desmideae}$$

$$DiatomQuotient = \frac{Centricdiatoms}{Pennatediatoms}$$

$$EuglenophyceanQuotient = \frac{Euglenophyta}{(Cyanophyceae + Chlorococcales)}$$

$$CompondQuotient = \frac{(Cyanophyceae + Chlorococcales + Centricdiatoms + Euglenophyta)}{Desmideae}$$

Biligrami's pollution values

Biligrami (1988) has given the degrees of pollution based on the ranges of Shannon and Weiner's species diversity. The pollution status based on this are, 'slight' (species diversity 3.0 – 4.5), 'light' (species diversity 2.0 – 3.0), 'moderate' (species diversity 1.0 – 2.0) and 'heavy' (species diversity 0.0 – 1.0).

Palmer's Algal Genera and Algal Species Indices

Palmer (1980) has listed top 8 pollution tolerant genera, the *Euglena, Oscillatoria, Chlamydomonas, Scenedesmus, Chlorella, Nitzschia, Navicula* and *Stigeoclonium* and top 9 species *Ankistrodesmus falcatus, Euglena viridis, Nitzschia palea, Oscillatoria limnosa, Oscillatoria tenuis, Pandorina morum, Scenedesmus quadricauda, Stegioclonium tenue* and *Synedra ulna*. Further he has given the algal pollution indices developed for use in rating water samples for high or low organic pollution (based on 20 genera and 20 species). In analysis of a water sample, all of the 20 genera and species of algae that are present are recorded separately. An alga is called 'present' if there are 50 or more individuals per mL. The pollution index factors of the algae present are then totalled. A score of 20 or more for a sample is taken as evidence of high organic pollution while a score of 15-19 is taken as probable evidence of high organic pollution. Low figures indicate that the organic pollution of the sample is not high.

Results and Discussion

Upstream

Different aquatic ecosystems of Sharavathi River basin showed rich and diverse phytoplankton population (Appendix-I). Phytoplankton in the collections belonged to Bacillariophyceae (diatoms), Desmidials (desmids), Chlorococcales, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae. During the study, 216 species belonging to 59 genera were recorded. List of phytoplankton of all the three collections are given in Appendix-II.

Collection – I

During first sampling, 100 species belonging to 37 genera were recorded. Of these 48 species belonged to Bacillariophyceae, 38 to Desmidials, 8 to Chlorococcales, 3 to Cyanophyceae, 2 to Euglenophyceae and one to Dinophyceae. Qualitative dominance of the phytoplankton in this collection was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Euglenophyceae > Dinophyceae. In this collection population of Desmidial member *Staurastrum multispiniceps* was highest (58,944/mL) in Station-7 (Muppane) of the reservoir. Among streams population of Bacillariophyceae member *Synedra ulna* was highest (35,136/mL) in Haridravathi main tributary.

Collection – II

In this collection 117 species were recorded from 49 genera. Bacillariophyceae dominated with 49 species followed by Desmidials with 44; Chlorococcales with 14; Cyanophyceae with 5; Chrysophyceae with 3; and Dinophyceae with 2 species. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Chrysophyceae > Dinophyceae. Among streams population of *Gomphonema longiceps* a Bacillariophycean was highest (21,568/mL) in Nandiholé, while among reservoir waters in Nittur, population of *Dinobryon sertularia* was highest (4752/mL).

Collection - III

During this collection 110 species of phytoplankton belonging to 48 genera were recorded. Of these 41 species belonged to Bacillariophyceae, 39 to Desmidials, 16 to Chlorococcales, 9 to Cyanophyceae, 2 species each to Dinophyceae and Chrysophyceae and a single species to Euglenophyceae. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Dinophyceae = Chrysophyceae > Euglenophyceae. Between both the waters of streams and reservoir, population of *Navicula viridula* was highest in Sharavathi-I, 27,728/mLand Yenneholé, 5,648/mL.

The distribution pattern of phytoplankton was almost similar in all the collections. However, highest species were recorded in collection-II with 117 species and lowest in collection-I with 100 species. During collection-III, 110 species were recorded. From

Tables 2.1, 2.2 and 2.3 it is clear that, in general in all the streams (Station 1-6 and 14) Bacillariophyceae (Diatoms) species dominated while in all the waters of reservoir (Station 7-13, 15, and 16) Desmidials predominated during all the collections. From the stationwise list of diatoms (Appendix-II) it is clear that, *Gomphonema longiceps*, *Navicula viridula*, *Synedra ulna*, *Surirella ovata* and many species of diatoms almost commonly occurred in all the streams. Similarly, species of desmids like *Staurastrum limneticum, S. freemanii, S. multispiniceps, Arthrodesmus psilosporus, Triploceros gracile* and *Xanthedium perissacanthum* almost commonly occurred in all the stations of the reservoir during all the three collections. Thus, the distribution pattern of diatoms and desmids indicates that during all the collections species composition was almost similar in streams and reservoir waters.

Cyanophyceae and Chlorophyceae members distributed uniformly in streams and reservoir waters, but Dinophyceae and Euglenophyceae were scantly distributed. Chrysophyceaen members did not occur during collection-I. During collection II and III, they were recorded from reservoir waters with 2 species of *Dinobryon*.

Bacillariophycean members *Anomoeoneis sphaerophora, Gyrosigma attenuatum, G. gracile, Gomphonema lanceolatum, G. longiceps, Navicula viridula, Nitzschia obtusa, N. palea, Pinnularia lundii, P. maharashtrensis, Surirella ovata, Synedra acus* and *S. ulna* were common to all the three collections. Desmidial members common to all the three collections were *Arthrodesmus psilosporus, Closterium ehrenbergii, Cosmarium decoratum, Desmidium baileyi, Staurastrum limneticum, S. freemanii, S. multispinceps, S. peristephes, S. tohopekaligense* and *Triploceros gracile.*

Chlorococcalean members *Eudorina elegans, Muogeotia punctata*, *Pediastrum simplex*, and *Spirogyra rhizobrachialis* were common in all the three collections. One Dinophycean member *Ceratium hirundinella* and one Cyanophycean member *Microcystis aeruginosa* were common in all the three collections.

Most of the other species of Diatoms, Desmids, Cyanophycean and Chlorococcalean were common to either collection-I and II or I and III or II and III indicating almost similar species composition in all the three collections.

Species Diversity

Tables 42, 43, and 44 reveal the diversity status of phytoplankton during I, II and III-collection. Species diversity is not uniform in any station in any of the collections, mainly due to the non-uniformity in the occurrence of species and their population.

Table 42 Diversity status of phytoplankton in I-Collection.

Parameter	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total individual	371	390	169	108	3879	355	10339	2770	1218	3414	1845	820	1298	101
Total species	21	13	14	10	12	9	21	13	11	14	18	23	16	5
Species richness	3.25	2.01	2.53	1.92	1.33	1.36	2.16	1.51	1.4	1.59	2.26	3.27	2.09	0.86
Shannon-diversity	2.44	2	1.67	2.03	1.27	1.37	1.96	1.85	1.84	2.24	2.37	2.69	2.15	1.09
Simpson-dominance	0.11	0.19	0.33	0.16	0.39	0.31	0.2	0.22	0.21	0.12	0.12	0.09	0.17	0.47
Simpson-diversity	0.88	0.8	0.66	0.83	0.6	0.68	0.79	0.77	0.78	0.87	0.87	0.9	0.82	0.52

Table 43 Diversity status of phytoplankton in II-Collection.

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individual	187	220	108	50	263	1552	49	96	79	33	29	437	610	1303	74	397
Total species	17	22	13	14	14	18	15	18	9	18	13	19	16	18	24	20
Species richness	3.05	3.89	2.56	3.32	2.33	2.31	3.59	3.72	1.83	4.86	3.56	2.96	2.33	2.37	5.34	3.17
Shannon-diversity	0.86	2.29	1.99	1.97	1.79	0.66	2.43	2.11	1.08	2.75	2.42	1.97	1.19	0.93	2.85	1.16
Simpson-dominance	0.66	0.17	0.17	0.2	0.2	0.75	0.11	0.23	0.55	0.07	0.09	0.24	0.48	0.62	0.07	0.56
Simpson-diversity	0.33	0.82	0.83	0.79	0.79	0.24	0.88	0.76	0.44	0.92	0.9	0.75	0.51	0.37	0.92	0.43

Table 44 Diversity status of phytoplankton in III-Collection.

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individual	1858	301	204	31	35	166	232	59	52	88	146	585	223	1133	175	617
Total species	19	14	13	12	16	17	21	17	24	15	18	20	14	12	19	22
Species richness	2.39	2.27	2.25	3.2	4.21	3.12	3.67	3.92	5.82	3.12	3.41	2.98	2.4	1.56	3.48	3.26
Shannon-diversity	0.41	1.37	1.94	2.01	2.59	2.17	1.57	2.45	3.07	2.21	1.69	1.57	1.66	0.15	2.21	2.46
Simpson-dominance	0.87	0.45	0.17	0.21	0.09	0.14	0.4	0.12	0.05	0.14	0.35	0.38	0.34	0.95	0.15	0.11
Simpson-diversity	0.12	0.54	0.82	0.78	0.9	0.85	0.59	0.87	0.94	0.85	0.64	0.61	0.65	0.04	0.84	0.88

From Table 42 it is clear that in general, total individuals are low in almost all the streams and high in almost all the waters of reservoir. Among all the stations total individuals are highest in Station-7 (10339) and lowest in Station-14 (101). Total species is high (23) in Station-12 with highest species richness (3.27) and Shannon diversity values (2.69), which is evident from the low Simpson dominance value and high evenness index value in Station-12. On the other hand in Station-14 species richness and Shannon diversity values are low (0.86 and 1.09 respectively) with high Simpson dominance (0.47) and low evenness index value (0.52).

From Table 43 it is clear that in general, in the waters of streams and reservoir total individuals are almost low as compared to collection - I. Total individuals are lowest (49) in Station-7 where it was high during I collection. Highest individuals were recorded in Station-6 (1552). Total species is high (24) in Station-15 with highest species richness (5.34) and Shannon diversity values (2.85), which is evident from the low Simpson dominance and high evenness index values. Total species is lowest (9) in Station-9 with lowest species richness (1.83) and almost lower Shannon diversity value (1.08). However, lowest (0.66) Shannon diversity is in Station-6 with highest Simpson dominance (0.75) and lowest evenness index values (0.24).

Table 44 indicates that the total individual value is highest (1858) in Station-1 and lowest (31) in Station-4. Total species is high (24) in Station-9 with highest species richness (5.82) and Shannon diversity (3.07) values. Lowest species richness value is in Station-14 (1.56) with lowest Shannon diversity (0.14), which is evident from the higher Simpson dominance (0.95) and lower evenness index (0.04) values. Vice versa was true with Station-9 where the Shannon diversity is high (3.07) with low Simpson dominance (0.05) and high evenness index values (0.94).

Table 45 reveals the average diversity status of phytoplankton of all the three collections. This table shows the highest population (3540) in Station-7 and lowest (63) in Station-4.

Highest number of species is in Station-15 (22) with highest species richness (4.41) and highest Shannon diversity (2.53) values, which are indicated by low Simpson dominance (0.11) and high evenness index values (0.88). Lowest number of species is in Station-14 (12) with lowest species richness (1.59) and Shannon diversity (0.72) and with the highest Simpson-dominance (0.68) and lowest evenness index values (0.31). From Table 7d it is also clear that species richness and species diversity values are almost high in the waters of reservoir as compared to waters of streams. This might be due to the higher number of species (24 species) of *Staurastrum,* a desmidial member, which might have resulted in higher species diversity value in reservoir waters.

Table 45 Average diversity status of phytoplankton in all the three Collections

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individual	805	304	160	63	1392	691	3540	975	450	1178	604	614	710	846	124	507
Total species	19	16	13	12	19	15	19	16	15	16	16	21	15	12	22	21
Species richness	2.94	2.72	2.44	2.81	2.62	2.26	3.14	3.05	3.01	3.19	3.07	3.07	2.66	1.59	4.41	3.21
Shannon-diversity	1.23	1.88	1.86	2	1.88	1.4	1.98	2.32	1.99	2.88	2.16	2.07	1.66	0.72	2.53	1.81
Simpson-dominance	0.54	0.27	0.22	0.19	0.22	0.4	0.23	0.19	0.27	0.37	0.18	0.23	0.33	0.68	0.11	0.33
Simpson-diversity	0.44	0.72	0.77	0.8	0.76	0.59	0.75	0.8	0.72	0.88	0.8	0.75	0.66	0.31	0.88	0.65

From the Tables 42, 43 and 44 it is clear that the Stations 7 and 1, which harboured highest and lowest total individuals respectively during I collection had almost low and high total individuals during II and III-collection. Similarly during collection – II, Station-6, which harboured highest total individuals, showed lower population during I and III collection. This indicates that the growth and distribution patterns of phytoplankton are not uniform during all the collections. Further as compared to II and III-collections total individuals were high during I-collection. It might be because of the rains during the month of September just prior to I-collection during October, which might have added nutrients to the waters along with run-off water from surrounding catchment areas.

Thus, from the above discussion about species diversity of phytoplankton in various stations of streams and reservoir it is clear that diversity and species richness were not uniform in any stations during all the three collections. However, during I collection total population was highest in reservoir waters as compared to streams. It might be because of the higher nutrient load in stagnant waters of reservoir (due to rain just before I collection), which might have resulted in higher population of Desmidials in these waters.

In general the requirement of dissolved oxygen for the growth of many diatom species is well documented. In the present study, in stream waters higher population of diatoms coincided with the higher dissolved oxygen, as oxygen is generally high in stream (flowing) waters compared to reservoir waters. The studies of Venkateshwarlu (1970) and Sheavly and Marshal (1989) who found that diatoms prefer well-aerated waters that are rich in dissolved oxygen is in support of present observation. Rao (1977) has observed dissolved oxygen favouring different species of diatoms, which is also found true for diatoms in the present study.

On the other hand reservoir waters showed lower species composition as well as population of diatoms. It may be due to their slight stagnant nature where dissolved oxygen content is less as compared to streams. However, in reservoir waters desmid species predominated. Generally, paucity of desmids is seen in the organically polluted waters. Waters supporting luxuriant growth of Desmidials have been found to be chemically distinct from those harbouring other members of algae (Hegde, 1985). The present study is on par with these observations, since desmids predominated in reservoir waters, which might have had lower organic pollution. On the other hand stream waters harboured lower desmid population indicating probable evidence of organic pollution as compared to the waters of reservoir.

Trophic Status

Table 46, 47 and 48 indicate the Nygaard's phytoplankton quotient values. From Table 6.1 it is clear that almost all the values are very low to represent the eutrophic nature of the water. However, in some Stations (1, 3, 4, 5 and 6), the values were above the values given by Nygaard for oligotrophic waters. In Station-1, Chlorophycean and Compound quotient values, in Station-2 Compound quotient value, in Station-3 and 4 Euglenophycean quotient values, in Station-5 Chlorophycean, Euglenophycean and Compound quotient values and in Station-6 Cyanophycean, Chlorophycean and Compound quotient values exceeded the values given for oligotrophic nature of water. Interestingly all these Stations represents the streams. All the waters of reservoir show the oligotrophic nature as their quotient values are in between the values given by Nygaard for oligotrophic water. Similarly from Table 3b it is clear that, stream waters are slightly eutrophicated, as in Station-1 Cyanophycean, Chlorophycean and Compound quotient values, in Station-3 Chlorophycean and Compound quotient values and in Station-4 and 5 Cyanophycean and Chlorophycean quotient values exceeded the values given for oligotrophic nature of water. Similar to I-collection, in II-collection also in all the reservoir waters the Nygaard's phytoplankton values are in the range of oligotrophic nature.

Table 46. Nygaard's Phytoplankton Quotient for the I collection

Family	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cyanophycean Quotient	∞	0.5	∞	∞	∞	1	0.05	0.1	∞	0.09	∞	0.08	0.08	∞
Chlorophycean Quotient	2	∞	∞	∞	1	1	∞	0.1	∞	∞	0.06	0.16	∞	∞
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	1	1	1	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	2	1.5	0.5	1	2	2	0.05	0.2	∞	0.09	0.06	0.25	0.08	∞

Table 47. Nygaard's Phytoplankton Quotient for the II collection

Family	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cyanophycean Quotient	2	0.5	∞	1	1	0.33	0.11	0.11	0.33	0.09	0.16	0.09	0.14	0.5	0.18	0.07
Chlorophycean Quotient	2	2	2	1	1	0.33	0.11	0.11	0.66	0.9	0.16	0.09	0.14	2	0.18	0.07
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	4	1.5	3	2	2	0.66	0.22	0.22	1	0.18	0.18	0.33	0.28	2.5	0.36	0.15

Table 48. Nygaard's Phytoplankton Quotient for the III collection

Family	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cyanophycean Quotient	1	1	0.5	1	2	0.2	0.076	0.12	0.062	0.166	0.1	0.18	0.25	0.2	0.1	0.33
Chlorophycean Quotient	1	1	0.5	3	2	0.2	0.076	0.375	0.062	0.33	0.1	0.09	0.5	0.2	0.1	0.66
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	2	2	1	4	4	0.4	0.153	0.5	0.125	0.5	0.2	0.27	0.75	0.4	0.2	1

Table 48 almost confirms the findings of I and II–collections, as the stream waters in III-collection are also eutrophic in nature. In Station-1 Cyanophycean, in Station-2 Chlorophycean, in Station-4 Cyanophycean, Chlorophycean and Compound quotient values and in Station-5 Cyanophycean, Chlorophycean and Compound quotient values have exceeded above the oligotrophic values. On the other hand waters of the reservoir are in between the values given for oligotrophic waters. Thus, it is clear from Nygaard's pollution index that stream waters are slightly eutrophic in nature as compared to reservoir waters. Generally, waters of streams with rapid flow carry organic matter from the soil. In the present study, stream waters might have carried the organic matter from the soil and decomposed dried leaves of surrounding trees and resulted in the slight eutrophic nature of the waters. It is quite natural that in reservoir waters, the organic matter brought from runoff water during rains will settle down to the bottom in the winter season. This might be the reason for the lower organic pollution and oligotrophic nature of the reservoir waters as the collections of phytoplankton were made during the winter season.

From Table 49 it is clear that in general species diversity values of almost all the stations are in the range of moderate or light pollution level. As per the pollution ranges given by Biligrami (1988), waters of Stations 1, 2, 4, 10, 11, 12 and 13 during I-collection, waters of Stations 2, 7, 8, 10, 11 and 15 during II-collection and waters of Stations 4, 5, 6, 8, 9, 10, 15 and 16 during III-collection show light pollution level with species diversity ranging between 2.0 – 3.0. While waters of Stations 3, 5, 6, 7, 8, 9 and 14 during I-collection, waters of Stations 3, 4, 5, 9, 12, 13 and 16 during II-collection and waters of Stations 2, 3, 7, 11, 12 and 13 during III-collection show moderate pollution level (Species diversity ranges between 1.0-2.0).

Table 49. Shannon–Weiner's diversity values.

Stations	Phytoplankton collections		
	I	II	III
1	2.44	0.86	0.41
2	2	2.29	1.37
3	1.67	1.99	1.94
4	2.03	1.97	2.01
5	1.27	1.79	2.59
6	1.37	0.66	2.17
7	1.96	2.43	1.57
8	1.85	2.11	2.45
9	1.84	1.08	3.07
10	2.24	2.75	2.21

11	2.37	2.42	1.69
12	2.69	1.97	1.57
13	2.15	1.19	1.66
14	1.09	0.93	0.14
15	-	2.85	2.21
16	-	1.16	2.46

In II and III-collections stream waters show heavy pollution load in some stations. In II-collection waters of Stations 1, 6 and 14 and in III-collection waters of Stations 1 and 14 had heavy pollution load with the species diversity ranging between 0.0-1.0. Only the waters of Station-9 in III-collection had slight pollution level with the species diversity 3.07.

From the average species diversity values it is clear that almost all the waters of streams show moderate pollution level, while almost all the reservoir waters show light pollution level.

Thus, from the above discussion it is clear that waters of only Station-3 and 10 show uniformity i.e., moderate and light pollution level from I-collection to/and III-collection. Remaining waters during different collections show either light or moderate pollution level. Thus, the pollution level was not uniform in almost all the stations. It is in between the light and moderate pollution level with heavy pollution load in few stations of streams.

Tables 50, 51 and 52 reveal the Palmer's genera index values. From Table 5a it is clear that all the stations with a score of less than 10 except Stations 5 and 13 are said to be less polluted. Stations 5 and 13 with score of 12 and 13 come nearer to the point of suspected pollution. Similarly, II collection and III-collection with scores less than 10 are indicating low organic pollution in all the stations. Thus, Palmer's pollution index values of all the three collections are not exceeding the score given by Palmer (1960) for the high organic pollution or the probable evidence of organic pollution. Thus, the waters of all the stations during I, II and III-collections showed low organic pollution.

Table 50. Palmer's pollution index of algal genera in I-Collection.

Genera	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gomphonema	1	1	1	1	1	-	-	-	1	1	1	1	1	1
Navicula	3	3	3	3	-	3	3	-	-	3	-	3	-	3
Nitzschia	3	3	-	3	3	3	3	-	-	-	-	3	-	3
Synedra	2	2	2	2	2	2	-	-	2	-	2	2	-	-
Closterium	-	-	-	-	1	-	-	-	-	-	-	1	-	-
Euglena	-	-	-	-	5	-	-	-	-	-	-	-	-	-
Microcystis	-	-	-	-	-	-	-	-	-	-	-	1	1	-
Ankistrodesmus	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Total Score	9	9	6	9	12	8	6	0	3	4	3	13	2	7

Table 51. Palmer's pollution index of algal genera in II-Collection.

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gomphonema	1	1	1	1	1	-	-	1	1	1	1	1	1	1	1	-
Navicula	3	-	3	-	-	3	3	3	3	-	-	-	-	3	3	3
Nitzschia	-	3	-	-	3	3	-	-	-	-	-	-	-	3	-	-
Synedra	-	2	2	2	2	2	-	2	-	-	-	-	-	2	-	-
Closterium	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Microcystis	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Ankistrodesmus	-	-	-	-	-	-	-	-	-	-	-	2	-	2	-	-
Scenedesmus	-	-	-	-	-	-	-	4	-	-	-	4	-	-	-	-
Melosira	-	-	-	-	-	-	1	-	1	-	1	-	1	-	-	1
Total Score	4	6	6	3	6	8	4	10	5	1	2	8	3	11	4	4

Table 52. Palmer's pollution index of algal genera in III-Collection.

	Stations															
Genera	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gomphonema	1	1	1	1	1	1	-	-	1	1	-	-	-	-	1	1
Navicula	3	3	3	-	3	3	-	-	-	3	3	-	3	3	3	3
Nitzschia	3	-	3	3	-	3	-	-	-	-	-	-	-	-	-	3
Synedra	2	2	2		2	2	-		-	-	-	-	-	2	-	2
Closterium	-	-	-	-	-	1	-	-	-	-	-	-	1	1	-	-
Microcystis	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-
Pandorina	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Melosira	-	-	-	-	-	-	1	1	1	1	1	1	1	-	1	1
Total Score	9	6	9	5	6	11	1	1	2	5	4	2	5	6	5	10

Out of the 20-algal species reported by Palmer, *Synedra ulna* and *Nitzschia palea* occurred in some of the stations of I and III-collections. In II-collection along with these two species *Ankistrodesmus falcatus* also occurred in some stations. Some other species like *Pandorina morum* and *Scenedesmus quadricauda*, even though occurred in some of the stations, are discarded due to their lower number (less than 50 per ml.).

Tables 53, 54 and 55 reveal the Palmer's species index values. From these Tables it is clear that the total score of none of the stations of all the three collections exceeded the total score given by Palmer for high organic pollution or even probable high organic pollution. This indicates that waters of all the stations during sampling had low organic pollution.

Table 53. Palmer's pollution index of algal species in I-Collection.

Genera	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Synedra ulna	3	3	3	3	3	3	-	-	3	-	-	-	-	-
Nitzschia palea	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Total Score	3	3	3	3	3	3	-	-	3	-	-	-	-	5

Table 54. Palmer's pollution index of algal species in II-Collection.

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ankistrodesmus falcatus	-	-	-	-	-	-	-	-	-	-	-	3	-	3	-	-
Synedra ulna	-	3	3	-	3	3	-	3	-	-	-	-	-	3	-	-
Nitzschia palea	-	5	-	-	-	5	-	-	-	-	-	-	-	-	-	-
Total Score	-	8	3	-	3	8	-	3	-	-	-	3	-	6	-	-

Table 55. Palmer's pollution index of algal species in III-Collection.

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Synedra ulna	3	-	3	-	3	3	-	-	-	-	-	-	-	-	-	3
Nitzschia palea	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	5
Total Score	3	0	3	0	3	8	0	0	0	0	0	0	0	0	0	8

From the species composition and growth of phytoplankton in various streams and reservoirs it is clear that waters of both streams and reservoir were below the level of high organic pollution. High pollution indicating organisms were very less in these aquatic ecosystems and the score of those present did not show the range of Palmer's total score of high organic pollution.

By applying various pollution indices, it is clear that in general waters of both streams and reservoir are oligotrophic in nature, as there is no high organic pollution load in these waters. However, there is slight difference in the results of different pollution indices. Nygaard's pollution index showed slight eutrophic quality for stream waters and oligotrophic for reservoir waters. While pollution index based on Shannon diversity showed no difference between streams and reservoir waters on the basis of oligotrophic and eutrophic natures. Results of this index indicated the slight eutrophication and oligotrophication in both the waters of streams and reservoir. Palmer's genera as well as species pollution index showed no heavy load of organic pollution in any of the waters of both the streams and reservoir. According to Palmer (1980) *Melosira islandica* and species of *Dinobryon* are clean water indicators. The occurrence of *Melosira islandica* in stream waters and *Dinobryon calciformis* and *D. sertularia* in reservoir waters clearly indicate that both the waters are clean. Thus, there is no heavy organic pollution load in any of the waters of both streams as well as reservoir of Sharavathi River basin.

As all the stations of streams and reservoir are away from disturbances from cities and industries, presently there is no heavy organic pollution in these water-bodies. However, in future if there would be any pollutants like domestic and industrial wastes, there is a threat to the indigenous phytoplankton. Phytoplanktons are primary producers, on which many higher-level organisms like zooplankton and other aquatic higher animals are directly or indirectly dependent. So these contaminations may change their environment and affect the food chain. Due to this the organisms, which were in equilibrium with habitat earlier, will be unable to cope up with the changed environment and may disappear slowly.

Downstream

Analysis of phytoplankton sampling in Sharavathi downstream revealed that all the three collections were represented by the members belonging to Bacillariophyceae (Diatoms), Desmidials (Desmids), Chlorococcales, Cyanophyceae (Blue-green algae), Dinophyceae, Euglenophyceae and Chrysophyceae. A total of 86 species belonging to 38 genera were recorded during the study period.

Collection - I

During first sampling a total of 44 species belonging to 23 genera were recorded. Of these 23 belonged to Bacillariophyceae, 12 to Desmidials, 4 to Chlorococcales, 3 to Cyanophyceae, and one each to Euglenophyceae and Chrysophyceae. Qualitative dominance of the phytoplankton in this collection was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Euglenophyceae = Chrysophyceae. In this collection population of Bacillariophyceaen member *Navicula viridula* was highest (1664 O/mL) in Stream-6 (Gazni-Hennur stream).

Collection - II

A total of 47 species were recorded in this collection. These belonged to 27 genera. Bacillariophyceae dominated with 25 species followed by Desmidials with 10, Chlorococcales with 8, Cyanophyceae with 2, Euglenophyceae and Dinophyceae with a single species each. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Euglenophyceae = Dinophyceae. During this collection population of *Synedra acus* a Bacillariophycean member was highest (1984 O/mL) in Stream-3 (Hosagadde stream).

Collection - III

During this collection 45 sps. of phytoplankton belonging to 29 genera were recorded. Of these 20 species belonged to Bacillariophyceae, 14 to Desmidials, 5 to Chlorococcales, 4 to Cyanophyceae, and a single species each to Dinophyceae, Chrysophyceae and Euglenophyceae. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Dinophyceae = Chrysophyceae = Euglenophyceae. In this collection population of *Synedra ulna*, a Bacillariophycean member was highest (1472 O/mL) in Stream-2 (Dabbefalls).

The distribution pattern of phytoplankton was almost similar in all the collections. However highest species were recorded in II-collection with 47 species and lowest in I-collection with 44 species. During III- collection 45 species were recorded. In general in all the streams Bacillariophyceae (diatoms) species dominated except the Stream –13 (Mahasati- reservoir main river) where desmids dominated during all the collections. Bacillariophyceae members like *Gomphonema longiceps, Eunotia praerupta, Melosira islandica, Synedra ulna* and *S. acus* were almost commonly occurred in all the streams of all the collections. Desmidial members like *Desmidium suboccidentale, Staurastrum freemanii* and *S. multispiniceps* were also almost common. However their species composition as well as number were drastically low compared to diatoms.

Species of Cyanophyceae and Chlorophyceae distributed uniformly, while distribution pattern of Euglenophyceae was scanty. Chrysophyceaen and Dinophycean members did not occur during II & I-collection respectively. During other collections only one Chrysophyceaen and two Dinophycean members occurred.

Bacillariophycean members *Eunotia praerupta, Gomphonema longiceps, G. viderbhense, Navicula laeta, N. viridula, N. cuspidata, Nitzschia palea, Melosira islandica, Pinnularia lundii, Synedra acus* and *S. ulna* were common to all the three collections. Desmidial members common to all the three collections were *Desmidium suboccidentale, Closterium ehrenbergii, Staurastrum freemanii and S. multispinceps.*

Chlorococcalean members *Ankistrodesmus falcatus*, *Muogeotia punctata*, *Spirogyra gratiana* were common in all the three collections. Two Cyanophycean members *Merismopedia glauca* and *Microcystis aeruginosa* and one *Euglenophycean* member *Euglena acus* were common in all the three collections.

Most of the other species of Diatoms, Desmids, Cyanophycean and Chlorococcalean were common to either I and II-collection or I and III-collection or II and III-collection indicating almost similar species composition in all the three collections.

Bacillariophyceae (diatoms) members were high in all the streams except in Stream-13 (Mahasati-reservoir main river), where desmidials dominated. However none of the phytoplankton representing either Bacillariophyceae or desmidials formed bloom during any of the collections. Their individual population was not enough to form a scum on the surface to give distinct colouration to the water. However *Navicula viridual* in Stream-6 (Gazni-Hennur stream), *Synedra acus* in Stream-3 (Hosagadde stream) and *Synedra ulna* in Stream-2 (Dabbefalls stream) dominated in I, II and III collection respectively. Population of Cyanophyceae and Chrorophyceae was very low. Dinophyceae, Euglenophyceae and Chrysophyceae occurrence was scanty with negligible population.

In present study ominance of diatoms in streams could be attributed to the well-oxygenated water as they were lotic. Higher desmid population in Stream-13 (Mahasati-reservoir-main river) could be due to addition from Linganamakki reservoir which might have had higher desmid population, as observed during upstream study of Sharavati river (October-December 2001).

Species diversity

Tables 56, 57 and 58 reveal the diversity status of phytoplankton. From the Table 56 it is clear that in general during I collection, species diversity is high (2.35) in Stream-15 (Upponi location-main river) and low (1.34) in Stream-2 (Dabbefalls stream). Among all the streams total individual is highest (5328) in Stream-6 (Gazani-Hennur stream) and lowest (768) in Stream-12 (Mavinhole stream). Total species is high (15) in Stream-15 (Upponi) with highest species rich ness (1.85) and Shannon diversity (2.35) values which are evident from the low Simpson dominance value (0.12) and high evenness index value (0.87).

Collection-II (Table 57)had low total individuals compared to collection-I. Total individual is lowest (256) in Station-6 (Gazani/Hennur stream) where it was high during I-collection. Highest individuals (6980) were recorded in Stream-7 (Chandavar stream). Species richness is high (1.44) in stream-14 (Hennehole/watahalla) with highest Shannon diversity values (2.16), which are evident from the low Simpson dominance (0.13) and high evenness index values (0.86). While species richness is lowest (0.49) in Station-11 (Haddinbal stream) with almost lowest Shannon diversity value (1.23). However, lowest

Shannon diversity value (1.08) is in Stream-3 (Hassagadde stream) with highest (0.50) Simpson dominance and lowest (0.49) evenness index values.

Table (58) indicates that the total individual value is highest (2944) in Stream-13 (Mahasati –reservoir main river) and lowest (224) in Stream-8 (Gudankatehole stream). Total species is high (13) in Stream-5 (Magodhole stream) with highest species richness (1.56) and Shannon diversity (1.94) values. Lowest species richness value (0.67) is in Stream-3 (Hossgadde stream) with lowest Shannon diversity (1.20), which is evident from the higher Simpson dominance (0.39) and lower (0.60) evenness index values. From Table 56, 57 & 58 it is clear that the Stream-6 (Gazani/hennur stream) and Stream-12 (Mavinhole stream) which harboured highest and lowest total individual respectively during I-collection had almost low and moderate total individuals during II and III-collection. Similarly during II collection, Stream-7 (Chandavar stream), which harboured highest total individuals showed lower population during collection-I and IIFurther as compared to II and III collections total individuals were high during I-collection. It might be because of the rains during the month of September just prior to the I-collection, which might have added nutrients to the waters along with run-off water from surrounding catchment areas.

Thus from the above discussion about species diversity of phytoplankton in various stations of streams it is clear that diversity and species richness were not uniform in any streams during all the three collections. However during I-collection total population was slightly highest in almost all the streams. This could be due to the increased population of *Gomphonema longiceps* and *Synedra ulna,* whose populations were more during this collection.

Table 56: Diversity status of Phytoplankton in I collection

Parameters	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individual O/ml	-	3552	-	-	-	5328	1936	-	2784	-	1376	768	1728	-	1887	-
Total Species	-	9	-	-	-	8	13	-	12	-	8	9	13	-	15	-
Species richness	-	0.97	-	-	-	0.81	1.58	-	1.38	-	0.96	1.20	1.60	-	1.85	-
Shannon Weiner's diversity	-	1.34	-	-	-	1.50	2.27	-	1.88	-	1.70	1.76	1.95	-	2.35	-
Simpson's dominance	-	0.36	-	-	-	0.27	0.12	-	0.22	-	0.23	0.23	0.24	-	0.12	-
Simpson's diversity	-	0.63	-	-	-	0.72	0.87	-	0.77	-	0.76	0.76	0.75	-	0.87	-

Table 57: Diversity status of Phytoplankton in II collection

Parameters	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individual O/ml	1824	960	2880	176	880	256	6980	384	2496	3616	416	1024	-	512	1792	2592
Total Species	9	9	10	5	7	5	11	7	11	10	4	9	-	10	8	11
Species richness	1.06	1.16	1.12	0.77	0.88	0.72	1.12	1.00	1.27	1.09	0.49	1.15	-	1.44	0.93	1.27
Shannon	1.64	1.51	1.08	1.36	1.52	1.49	1.98	1.58	1.75	1.32	1.23	1.59	-	2.16	1.35	1.60

Wiener's diversity																
Simpson's dominance	0.25	0.33	0.50	0.30	0.28	0.27	0.17	0.29	0.26	0.36	0.32	0.30	-	0.13	0.36	0.31
Simpson's diversity	0.74	0.66	0.49	0.69	0.71	0.75	0.82	0.70	0.73	0.63	0.67	0.69	-	0.86	0.63	0.68

Table 58: Diversity status of Phytoplankton in III collection

Parameters	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total individuals O/ml	-	2624	1728	576	2176	2016	544	224	832	800	448	2080	2944	2816	2080	1824
Total Species	-	7	6	7	13	9	6	6	9	8	8	7	11	7	9	8
Species richness	-	0.76	0.67	0.94	1.56	1.05	0.79	0.92	1.18	1.04	1.14	0.78	1.25	0.75	1.04	0.93
Shannon Wiener's diversity	-	1.21	1.20	1.72	1.94	1.48	1.48	1.74	1.72	1.68	1.90	1.67	1.64	1.54	1.65	1.41
Simpson's dominance	-	0.38	0.39	0.20	0.19	0.31	0.27	0.18	0.25	0.22	0.17	0.22	0.24	0.24	0.24	0.31
Simpson's diversity	-	0.61	0.60	0.79	0.80	0.68	0.72	0.81	0.74	0.77	0.82	0.77	0.75	0.75	0.75	0.68

Trophic status

Species diversity values of almost all the stations are in the range of moderate or light pollution level. As per the Biligrami's pollution ranges, waters of Stream-7 and 15 during I-collection and waters of Stream-14 during II-collection show the light pollution level with species diversity range between 2.0-3.0. While during I-collection waters of stream-2, 6, 9, 11, 12 & 13 and during II-collection waters of Stream-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15 and 16 and during III collection waters of all the streams show the moderate pollution level (Species diversity range between 1.0-2.0).

Thus waters of almost all the streams showed uniformity i,e moderate pollution from I-collection to III-collection. While the waters of only three streams (Stream-7, 14 and 15) during different collections showed either light or moderate pollution level. Thus the pollution level was uniform in almost all the streams. It was in moderate level through out the study period. However none of the waters of any streams during any collection showed the heavy pollution load indicating pollution level is low in down stream region.

Conclusion

The biological examination of the stream and reservoir ecosystems of Sharavathi River basin showed a rich and diverse phytoplankton population. Desmids predominated in reservoir waters while diatoms in streams. Species diversity is not uniform either in streams or reservoir waters.

From the Biligrami's and Palmer's pollution indices it is clear that, in general waters of all the streams of down stream region are oligotrophic in nature as there is no high organic pollution load in these waters. However Biligrami's (Shannon and Weaver's pollution index) showed waters of most of the streams had moderate pollution level.

According to Palmer (1980) *Melosira islandica* is a clean water indicator. The occurrence of *M. islandica* in these waters and least occurrence of Palmer's pollution indicating phytoplankton clearly indicate that there is no heavy pollution load in any of the waters of these streams of down stream region.

Both upstream and downstream regions of Sharavathi River showed low organic pollution. This could be due to least domestic and industrial pollutants in this region. Compared to upstream region, down stream region is less polluted as far as phytoplankton abundance is concerned. Phytoplankton number and species composition were very less in down stream region as compared to upstream region. According to Palmer (1980), higher organic pollution directly relates with higher eutrophication and phytoplankton population. This observation holds good with present study as the phytoplankton population was not so high, in any of the streams, to form the eutrophic condition indicating lower organic pollution (eutrophication). Further, Wielgolaski (1975) opines that, in freshwater most dinoflagellates are sensitive to eutrophication. Thus, in present study, occurrence of only two Dinophyceaen members, with very low number, clearly indicates the lesser organic pollution in this region.

From various pollution indices, it is clear that the waters of reservoir are in oligotrophic nature, even though the streams showed slight organic pollution. The study emphasises the requirement of proper conservation of phytoplankton-the primary producers, on which most of the higher aquatic organisms are dependent.

REFERENCES

American Public Health Association (APHA), American Water Works Association (AWWA) and Water Pollution Control Federation (WPCF), 1985. Standard Methods for the Examination of Water and Wastewater. Sixteenth Edition, Ed. by Arnold E.Greenberg, R. Rhodes Trussell and Lenore S. Clesceri, Washington DC.

Biligrami K. S., 1988. Biological monitoring of Rivers, Problems and Prospects in India. Aquat. Ectovicol. (*Proc. Indo. Dutch. Symp. Eds. de kruijf et. al*) 1988: 245-50.

Hegde, G. R. 1985. On the succession of algae in a temple tank at Dharwar, Karnataka State, India. Geobios, 12(6): 261-263.

Hustedt, F., 1976. *Bacillariophyta (Diatomaeae).* Otto Koeltz Science Publishers W-Germany.

Nygaard, G. 1949. Hydrobiological studies of some Danish ponds and lakes II. The quotient hypothesis and some new or little known phytoplankton organisms. K. Danske Vie dersk. Selsk skr., 7(1):1-293.

Palmer, C. M., 1980. *Algae and water pollution*. Castel House Publishers Ltd., England: 123pp.

Prescott G. W., 1982. *Algae of the Western Great lakes area*. Otto Koeltz Science Publishers W-Germany.

Rao, V. S. 1977. An ecological study of three fresh water ponds of Hyderabad-India IV-The phytoplanktons (Diatoms, Eugleninae and Myxophyceae). Hydrobiologia, 47(2): 319-337.

Sheavly, S. B. and H. G. Marshall., (1989). Phytoplankton and water quality relationships within the Euphotic zone of lake Trashmore, Virginia: A Borrow p: t Lake: *Castanea*, 54(3): 153-163.

Trivedy, R. K. and P. K. Goel., 1984. *Chemical and Biological methods for water pollution studies.* Environmental pub. Karad, 215pp.

Venkateshwarlu, V., 1970. An ecological study of the algae of the river Moosi Hyderabad (India) with special reference to water pollution IV. Periodicity of some common species of algae. *Hydrobiologia*, 35 : 45-64.

Wielgolaski, F. E., 1975. Biological indicators on pollution, *Urban Ecology*: 1(1): 63-79

List of Phytoplankton in I, II and III-Collections of the upper catchment

Desmidials	Collections		
	I	II	III
Arthrodesmus constrictus G. M Smith var.longispinus Gronbl.		+	+
A. curvatus Turn.var.latus var.nov	+		
A. psilosporus (Nodrdst. & Lofg.) De Toni Formae	+	+	+
Bambusina brebissoni Kuetz.	+	+	
Closterium calosporum Wittr		+	
C. ehrenbergii Menegh	+	+	+
C. lagoense Nordst.var.crassius Gutw			+
C. kuetzingii Breb var. vittatum Nordst		+	+
C. porrectum Nordst	+		
C. ralfsii Breb var.hybridrum Rab		+	+
C. setaceum Ehrbg.			+
Cosmarium askenasyi Schm.fa.latum Scott & Presc			+
C. contractum Kirchn		+	+
C. decoratum West & West	+	+	+
C. dubium Borge	+		
C. ordinatum (Borges) West & West var.borgei Scott Gronbl.	+		
C. lundellii Delp var circulare (Reinch) Krieg	+		
C. lundellii Delp			+
C. margaritatum (Lund) Roy & Biss var sublatum (Nordst.) Krieg		+	
C. pseudoconnatum Nordst	+		
C. punctulatum Breb.var.sub punctulatum (Nordst.) Borges	+		
C. retusiforme (Wille) Gutw. Fa	+		
C. scabrum Turn		+	
C. sexangulare Lund Fa		+	
C. spinuliferum West & West		+	+
C. subturgidum (Turn.) Schm. Fa. minus Schm		+	+
C. tumidium Lund		+	
Desmidium baileyi (Ralfs) Nordst fa.longiprocessum fa.nov	+	+	+
D. baileyi (Ralfs) Nordst fa. tetragonum Nordst		+	
D. bengalicum Turn	+		+
D. bengalicum Turn fa.quadratum fa. nov.		+	
D. quadratum Nordst		+	
D. suboccidentale Scott & Presc.	+		+
Euastrum acanthophorum Turn.		+	
E. ansatum Ehr. v. Triporum	+		
E. elegans (Breb) Kutz. fa.			+
E. gnathophorum West & West var.bulbosum var-nov		+	+
E. luelkemuelleri Ducell var. carniolicum (Lutkem.)	+		
E. sinuosum Lenorm. var. parallelum Krieg	+		

E. spinulosum Delp. Fa			+
Gonatozygon aculeatum Hastings		+	+
Hyalotheca dissiliens (Smith) Breb. var. hains Wolle	+		+
Micrasterias foliacea Bail var. quadrinflata var-nov		+	
M. mahabuleshwarensis Hobs.var.chauliodon var-nov	+		
M. quadridentata (Nordst.) Gronbl.fa, indonesinsis fa.nov			+
M. mahabuleshwarensis Hobs var, surculifera lagerh		+	
Netrium digitus (Ehrbg.) Itzigs & Rothe			+
Pleurotaenium ehrenbergi (Breb.) De Bary v. undulatum Schaarschm		+	+

Desmidials (continued ……)	Collections		
	I	II	III
Sphaerozosma granulatum Roy & Biss	+		
Spondylosium nitens (Wall.) Arch.fa.majus Turn		+	
S. planum (Wolle.) West & West	+		
Onychonema laeve Nordst. var. latum West & West			+
Staurastrum anceps Her.		+	
S. anceps Ehr. v. hyalina Brun. et.Perag			+
S. cerastes Lund. var. coronatum Krieg. fa. inflatus Scott.& Presc.	+		
S. cerates Lund var pulchrum Scott & Gronbl. fa		+	
S. euprepes sp.nov.	+		
S. emaciatum sp.nov.		+	
S. gralile Ralfs fa. Kriegeri fa .nov		+	+
S. freemanii West & West var.nudiceps Scott & Presc.	+	+	+
S. indentatum West & West Formae	+		
S. limneticum Schm. Var. burmense West & West	+	+	+
S. longibrachiatum (Borge) Gutw	+		
S. menggalense sp. Nov		+	
S. multispiniceps sp.nov.	+	+	+
S. peristephes sp.nov	+	+	+
S. prionotum sp.nov		+	+
S. rosei Playf. var. stemmatum var.nov		+	
S. sexangulare Lund var.productum Nordst	+		
S. sebaldi Reinsch var.ornatum Nordst		+	+
S. sebaldi Reinsch var.ventriverrucosum var .nov			+
S. tauphorum West & West	+	+	
S. thienemannii Krieg fa. triradiatum fa.nov		+	+
S. tohopekaligense Wolle var. insigne West & West Formae	+	+	+
S. wildmanii Gutw.		+	
S. zonatum Borges var.majus.var. nov.	+		
Triploceros gracile Bail fa. curvatum fa.nov.	+	+	+
T. gracile Bail fa. Undulatum Scott & Presc.			+
Xanthedium antilopaeum (Breb.) Kutz.var.laeve longispinum fa.nov.			+
X. freemanii West & West fa	+		
X. hastiferum Turn. Var. javanicum (Nordst.) Turn. fa. Planum Turn	+		
X. perissacanthum Scott. & Presc. Var. minus. Var-nov.	+	+	

Complete list of Phytoplankton in I, II and III-Collections

Chlorococcales	Collections		
	I	II	III
Ankistrodeimus falcatus (Corda) Ralfs		+	+
A. spiralis (Turner) Lemmermann	+		+
Gomphosphaeria aponina var. delicatula virieux		+	
Coelastrum microporum Naegeli	+		
Eudorina elegans Ehrenberg	+	+	+
Kirchnerilla lunaris (Krich.) Moebius	+		
K. obesa (W.West) Schmidle		+	+
Muogeotia punctata Wittrock	+	+	+
Oocystis submarina Lagerheim		+	+
Pandorina morum (Muell.) Bory		+	+
Pediastrum duplex var rugulosum Raciborski	+		
P. simplex Meyen	+	+	+
Pleudorina californica Shaw			+
Scenedesmus acuminatus (Lag) Chodat			+
S. bijuga (Turp.) Lagerheim		+	+
S. dimorphus (Turp.) Kuetzing		+	
S. opoliensis var contacta Prescott			+
S. quadricauda (Turp.) de Brebisson		+	+
Spirogyra gratiana Transeau		+	+
S. rhizobrachialis Jao	+	+	+
Stigeoclonium staganatile (Hazen) Collins			+
Zygnena pectinatum (Vauch.) C.A. Agardh		+	

Complete list of Phytoplankton in I, II and III-Collections

Cyanophyceae	Collections		
	I	II	III
Aphanocapsa rivularis (Carm) Rabenhorst		+	+
Chroococcus limneticus var.elegans G. M. Smith	+		+
C. turgidus (kuetz.) Naegeli		+	+
Coelosphaerium dubium Grunow		+	+
Gomphosphaeria aponina var. cordiformis Wolle			+
G. lacustris Chodat			+
Merismopedia elegans var.major G.M.Smith	+		
M. glauca (Ehrbg.) Naegeli		+	+
Microcystis aeruginosa Kuetz, emend, Elenkin	+	+	+
Oscillatoria anguina (Borg.) Gomont			+

Dinophyceae			
Ceratium hirundinella (O.F. Muell) Dujardin	+	+	+
Peridinium cinctum (Muell) Ehrenberg		+	+

Euglenophyceae			
Euglena acus Ehrenberg	+		+

E. acus var. rigida Huebner	+		

Chrysophyceae			
Dinobryon calciformis Bachmann		+	+
D. divergens Imhof		+	
D. sertularia Ehrbg.		+	+

APPENDIX II Complete list of Phytoplankton in I, II and III-Collections of the Sharavathi downstream region

Bacillariophyceae (Diatoms)	Collections		
	I	II	III
Anomoeoneis lanceolata Gandhi	+		
A. sphaerophora (Kuetz.) Ptitzer.	+	+	+
Caloneis silicula (Ehr.) Cleve v. intermadia Mayer		+	
C. bengalensis Grun		+	
Cymbella chandolensis Gandhi		+	
C. lata Grun v. nagpurensis v. nov.	+		
C. laevis Naeg		+	
C. leptoceros (Ehr.) Grum v. rostellata Hustedt f.India Gandhi		+	
C. osmanabadensis sp.nov	+	+	
C. powaiana Gandhi		+	+
C. ventricosa Kuetz.		+	+
C. vidarbhensis sp. Nov		+	
Eunotia praerupta Ehr.	+	+	
Frustulia jogensis Gandhi		+	
Gomphonema gracile Ehr. v. major Grun			+
G. intricatum Kuetz.		+	
G. intricatum Kuetz.v. virbio (Ehr.) Cleve	+		
G. lanceolatum Her	+	+	+
G. longiceps Ehr. v. subclavata Grun	+	+	+
G. speculoides Gandhi v. major Gandhi			+
G. sphaerophorum Her		+	
Gyrosigma acuminatum (Kuetz.) Rabh	+		
G. attenuatum (Kuetz.) Rabh.(Nordst & Lofg.) De Toni			+
G. attenuatum (Kuetz.) Rabh	+	+	+
G. distortum (W. Smith) Cleve v. porkeri Harrison			+
G. gracile Ehr. v. naviculoides (W. Smith) Grun		+	
G. gracile Ehr. v. intricatiforme Mayer	+	+	+
G. kuetzingii (Grun.) Cleve	+		+
G. sclalporoides (Rabh.) Cleve	+		
G. spenceri (W. Smith) Cleve. v. nodiferum (Grun.) A. Cl		+	
Hantzschia linearis (O. Muell) A. Cl			+
H. voigtii Gandhi		+	
Navicula cari Ehr.		+	+
N. cari Ehr. v. angusta Grun		+	
N. crysptocephala Kuetz.v.exilis Grun	+		
N. gastrum Ehr.	+		

N. gracilis Her	+		
N. cuspidata Kuetz.			+
N. cuspidata Kuetz.f.brevirostrata Gandhi	+	+	
N. cuspidata Kuetz. v. major Meister		+	
N. cuspidata Kuetz. v. amigua (Ehr.) Cleve			+
N. laeta A. Mayer	+		+
N. lanceolata Grun	+		
N. mutica Kuetz. v. linearis Gonz. et. Gandhi	+		
N. pygmaea Kuetz. v. indica Skv	+		
N. reinhardtii Grun. f. gracilis Grun	+		
N. rostellata Kuetz.		+	
N. subdapaliformis Gandhi	+		
N. tusculoides A. Cl. v. mayeri A. Cl.		+	
N. viridula Kuetz. V. capitata Mayer	+	+	+
N. viridula Kuetz.	+		
Bacillariophyceae (Diatoms)	Collections		
	I	II	III
Neidium dubium (Ehr.) Cleve		+	
N. indicum Gonzalves et Gandhi v. capitata Gonz.&Gandhi	+		
Nitzschia apiculata (Greg.) Grun	+		
N. closterium W. Smith	+	+	
N. lorenziana Grun v. subtilis Grun	+		+
N. kuetzingiana Hilse	+		
N. obtusa W. Smith v. scalpelliformis Grun	+	+	+
N. palea (Kuetz.) W. Smith	+	+	+
N. philippinarum Hustedt	+		+
N. radiosa Kuetz.		+	+
N. regula Hustedt v. fennica A. Cl.	+		
N. sublinearis Hustedt	+	+	
N. tryblionella Hantzsch v. victoriae Grun			+
Melosira islandica O. Muell v. helvetica O. Muell		+	+
M. granulata (Ehr.) Ralfs. v. mazzanensis Meister			+
Mastogoloea baltica Grun		+	
Pinnularia brevicostata Cleve v. indica Gandhi			+
P. divergense W. Smith v. capitata Mills		+	+
P. gracioloides Hustedt			+
P. interrupta W. Smith	+		
P. legumen Ehr. v. florentinu (Grun) Cleve			+
P. lundii Hustedt	+	+	+
P. kolhapurensis Gandhi			+
P. platycephala (Ehr.) Cleve		+	
P. maharashtrensis sp. nov.	+	+	+
P. stomatophoroides Mayer v. ornata A. Cl. f. erlangensis Mayer		+	
P. streptoraphe Cleve			+
P. vidarbhensis sp. nov.			+
Stauroneis anceps Ehr.			+
S. anceps Ehr. f. linearis (Ehr.) Cleve	+		
S. kirtikari sp. nov.		+	

S. phoenicenteron Ehr.		+	
Surirella capronii Breb		+	
S. capronioides Gandhi		+	
S. linearis W. Smith		+	
S. ovata Kuetz v. pinnata (W. Smith) Hustedt	+		
S. ovata Kuetz v. salina (W. Smith) Hustedt	+	+	+
S. robusta Ehr.	+		+
S. tenera Greg. v. nervosa A. S.	+		
Synedra acus Kuetz.	+	+	+
S. acus Kuetz. v. acula (Kuetz.) V. H.	+		
S. ulna (Nitz.) Ehr.	+		
S. ulna (Nitz.) Ehr. v. danica Kuetz. Grun.	+	+	+

ZOOPLANKTON OF THE SHARAVATHI RIVER BASIN

Zooplankton are tiny organisms in the aquatic ecosystem responsible for energy transfer from producers to higher trophic level. They occur in both lentic and lotic aquatic ecosytems. In the Sharavathi River Basin, a study was carried out to know the zooplankton diversity of the region. The study carried out in 13 localities recorded 37 species belonging to Rotifera, Copepoda and Cladocera groups.

Introduction

Zooplankton - so called “secondary producers” are the major components in the aquatic ecosystem, both in lotic and lentic. They are responsible for energy transfer from primary producers to other higher trophic levels and their importance in aquatic ecosystem has already been investigated (Edmondson, 1974; Hutchinson, 1957; Wetzel, 1975). Rotifera, Cladocera and Copepoda are the major groups among freshwater zooplankton. A detailed knowledge about zooplankton composition and their seasonal fluctuations is essential for proper management of water bodies.

In India, systematic studies on freshwater zooplankton were initiated by Baird (1860). Since then, numerous limnological investigations have been conducted, but the majority of them were in regional levels *viz.,* Rajasthan (Biswas, 1971; Nayar, 1971); Karnataka (Patil and Gauder, 1980), Kerala (Nair and Nayar, 1971), Punjab (Vashist and Batish, 1971); Kashmir (Quadri and Yousuf, 1978). Members of rotifera in India were relatively well studied (Segars *et al,* 1994) and enlisted 300 taxa. Recently Michael and Sharma (1988) reported 93 cladoceran taxa belonging to 8 families from inland waters of India. Copepoda are the least studied group among the three groups. The present systematic study on freshwater zooplankton deals with rotifers, cladocerans and copepods from 13 localities of Sharavathi River basin. Segers *et al.,* (1994) reported about 300 species of rotifers from Indian inland waters but the information about Rotifers from lotic water system is still far from complete. Cladocerans are the favorite prey of most of the fishes. The gut content analysis of some carp fishes revealed the fact that nearly 70% of food consumed by fish was Cladocera (Edmondson, 1974).

Materials and Methods

The samples were collected using plankton nets with a mesh size of 50 µm and 75 µm, and samples were fixed in 4% formaldehyde solution. Later zooplankton was sorted out using binocular microscope. Rotifera was mounted on glycerin medium and identified under a compound microscope based on its lorica morphology and trophi structure. Taxonomically important parts of Cladocera and Copepoda were dissected under the binocular microscope by means of two tungsten needles and mounted on slides for further identification. Measurements were carried out using calibrated ocular micrometers. Species identification was done using available literature of Dussart and Fernanto (1988), Flossner (1972), Golden (1968), Lindberg (1957), Michael and Sharma (1982), Reddy (1994) and de Vande (1984).

Study Area

The study was carried out in 13 selected localities (Table 59) of Sharavathi River basin. The details of the sampling localities are given below.

Table 59. Localities in the study area at Sharavathi River Basin.

Location
Nagara
Sharavathi
Mavinaholé
Haridravathi
Muppane
Talakalale dam
Dam out let
Holebagilae
Huliholé
Yenneholé
Valagere
Nagodiholé
Rocky pool in Jog falls

Results

Rotifera

Rotifera (Rotatoria) are pseudocoelomate, bilaterally symmetrical animals. They are mostly considered as a separate phylum (Hymann, 1951). Rotifers occur in nearly every water body *i.e.,* from trickles on rocks to rivers, from bogs to lakes. Majority of rotifers inhabit freshwater but some genera also occur in brackish water and marine environment. Most species are free-living while some are epizoic or parasitic. Generally the size of the rotifera range from 400 µm to 0.2 mm. Twelve species belonging to four families are recorded in the present study (Table 60). *Lecane bulla* is recorded from 10 sites.

Table 60. Rotifers recorded in the study.

Species	Sites												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Family- Brachionidae													
Brachionus quadridentatus Hemann, 1783								+					
B. calciflorus Pallas, 1776	+		+						+				
B. falcatus (Zacharias, 1898)	+		+	+	+								
Keratella tropica (Apsein, 1907)	+									+			
Plationus platulus (Muller, 1786)													+
Family: Trichotridae													
Macrochetus collinsi (Gosse, 1867)	+												
Family: Colurellidae													
Lepadella patella (O.F.Muller)													+
Family: Lecanidae													
Lecane bulla (gosse, 1888).	+	+	+	+	+	+	+	+	+	+			+
L. inopinata HarringandMayers, 1926.	+												
L. lateralis sharma, 1978.	+									+			
L. quadridentata (Ehrenberg, 1886)		+							+				
Lecane sp.				+		+			+	+			

Cladocera

Cladocera belongs to Class Crustacea and Sub-class Branchiopoda. They are commonly known as *'water fleas'* and are mostly found in freshwater habitat. They are ubiquitous in distribution, *i.e.,* they are found in the Arctic to Antarctic, in temperate and tropical latitudes. Recently they were also reported from ground water (Dumont, 1987; Negrea 1983). The size is ranging from 0.2 mm to 18 mm. Like other Zooplankton cladocerans are excellent food for Zooplanktivorous fish. Cladocerans are the major representatives in the present study with 18 species recorded from the 13 localities (Table 61).

Table 61. Cladocerans recorded in the study.

Species	Sites												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Family: Sididae													
Latonopsis australis (Sars, 1888)	+												
Diaphanosoma sarsi Richard, 1895		+			+								
Family : Daphniidae													
Ceriodaphnia cornuta Sars, 1885					+	+							
Simocephalus serrulatus (Koch, 1841)	+												
Scapholebris kingii sars, 1903				+									
Family: Moinidae													
Moina micrura Kurz, 1874			+	+	+			+					
Moinodaphnia macleayi (King, 1853)				+									
Family: Macrothricidae													
Macrothrix spinosa King, 1953.		+							+				
M. triserialis (Brady, 1886)		+											
M. odiosa (Gurney, 1907)										+			
Family: Ilyocryptidae													
Ilyocryptus spinifer Herrick, 1882.									+				
Family: Chydoridae													
Sub-family: Chydorinae													
Alonella excisa (Fischer, 1884)				+									
Chydorus sphaericus (Muller, 1776)	+		+										+
C. parvus (Daday, 1898)	+												
Ephimeroporus barrosi (Richard, 1894)				+	+								
Sub-family: Aloninae													
Alona verrucosa (Sars, 1901)	+									+			
A. affinis (Leydig, 1860)													+
Leydigia acanthocercoids (fischer, 1884)									+				

Copepoda

Copepods are the very ancient arthropods. Zoogeographical data suggest that the copepoda of continental waters were rich and diversified. Their habitat ranges from small ditches to large rivers and lakes. Majority of them are freshwater and some are marine. In freshwaters, they occur as free living, parasitic or semi-parasitic. Most of them are very small with size ranging from 0.3 mm to 5 mm. In inland waters copepods are well known up to family level, but numerous species are yet to be discovered. Of the three groups of zooplankton, Copepoda was least represented in terms of diversity with only seven species (Table 62).

Table 62. Copepodans recorded in the study.

Species	Sites												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Family: Cyclopidae Sub-family: Cyclopinae													
Mesocyclops ogunnus Onabamiro, 1943	+												
M. splendidus Lindberg, 1943.			+	+					+				
Microcyclops varicans Sars, 1863	+									+			
Thermocyclops decipiens (Kiefer, 1926b)													+
Family: Diaptomidae													
Heliodiptomus cinctus (Gurney, 1907)		+						+					
Allodiaptomus mirabilipes (Kiefer, 1936)	+				+	+	+						
Tropodiaptomus informis Kiefer, 1930													+

Discussion

In the present study, 39 species of zooplankton were recorded from different localities along the River Sharavathi. Compared to lentic ecosystem, the species richness was low in lotic ecosystem. This is mainly due to the extreme complex nature of the zooplankton (Throp and Covich, 1991). Being a secondary producer, these organisms are very much related to their specific algal food. Most of them feed on unicellular algae, while some feed on filamentous algae. The sporadic increase in density of zooplankton associated with algal bloom was observed by Lefevre (1950); Ruttner (1970) and Edmondson (1974). Phytoplankton like *Microcystis* sp. are toxic to some zooplankton.

In the present investigation, the Rotifers exhibited maximum diversity. Species richness was more in the genus *Lecane* and *Branchionous*. *Lecane bulla* was distributed evenly in all sampling sites. No large sized rotifers were recorded during the present study; this may be due to presence of predatory fishes in the reservoir. Further more, the lack of riparian vegetation along the margin of river may directly be able to influence the prey-predatory relationship in running water system.

Cladocerans and copepods were the second largest group in this study. During the study period 20 species of Cladocera belonging to 7 families were recorded. Most of them were smaller in size, ranged from 0.2 mm to 0.4 mm. The high-pressure perdition and turbulent flow of river water can shape the community structure of zooplankton. One of the important observations in the present study was the absence of any zooplankton in sites 11 and 12, which may be due to the complete absence of primary producers in that water. As far as Karnataka state is concerned, the freshwater copepods are the least studied group with only a few reported studies (Reddy, 1994). In the present study 7 species of copepods were recorded. *Tropodiaptomus informis* and *Thermocyclops decipiens* were reported from locality 13, *i.e.,* found only in rocky pools. Further more, a cyclopidae species *Mesocyclops ogunus* was restricted to locality 1, while other species were distributed to more than one locality (see species-locality list).

Conclusion

The freshwater zooplankton fauna of Sharavathi River is rich and highly diversified. They were showing a typical tropical assemblage. Large zooplankton species were absent in this river system, probably due to high predatory pressure. The alteration of the natural lotic system like construction of dam and bunds will lead to eutrophication and finally it eliminates some endemic species from the same ecosystem. So, the knowledge about the physico-chemical and biological factors of a lotic ecosystem becomes a prerequisite for better management of the ecosystem.

REFERENCES

Baird, W.C. 1860. Description of two new species of Entamostraca: Crustace from India. Proc. Zool. Soc. London. 213-234.

Biswas, S. 1971. Fauna of Rajasthan, India Part II, (Crustace: Cldocera) Rec. Zool. Survey. India. 63:95-141.

de Velde, I.V. 1984. Revision of the African species of the genus Mesocyclops Sars,1914 (Copepoda: Cyclopidae) Hydrobiologia 109:3-66.

Dumont, H. J. 1987. Ground water Cladocera: A synopsis, *Hydrobiologia*. 148:169-173.

Dussart, B. H and C. H. Fernanto. 1988. Sur quelgues *Mesocyclops* (Crustace: Copepoda), Hydrobiologia; 157: pp. 241-264.

Dussart, B. H and D. Defae. 1995. Introduction to the Copepoda. Guide to the identification of the microinvertibrate of continental waters of the world; SPB Academic Publishing. pp. 277.

Edmondson, W. T. 1974. Secondary production. Mitt. Internt. Verein. Limnol. 20:241-264.

Flossner, D. 1972. Krebstiere, Crustace. Kiemen-und Blattfusser, branchiopoda, fishause Brachiura. Die Tierwelt Deutschlands 60:501.

Golden, C. E. 1968. The systematics and evolution of the Moinidae, Trans. Am. Phil. Soc. Phinland., pp. 101.

Hutchinson, G. E. 1957. A Treatise on Limnology. Wiley, New York. pp. 1015.

Hymann, L. 1951. The Invertebrates. Vol II-MC Graw-Hill, New York:1-572.

Lefevre, M. 1950. Aphanizomenon gracil lemm., Cynophyte de favorable au Zooplankton. Ann. St.cent, hydrobiol.Appl.3: 205-208.

Lindberg, K. 1957. Cyclopoides (Crustace:Copepoda) De la cote d ivoire. Bull. De. II. F.A.N. 19 (Ser A): 134-179.

Michael, R. G and B. K. Sharma. 1982. Fauna of India. Indian Cladocera (Crustace: Branchiopoda: Cladocera) Zoological Survey of India, pp. 262.

Nair, K. K. N and C. K. G Nayar. 1971. A preliminary study of the rotifers of Irinjalakuda and neighbouring places J. Ker. Acad. Biol., 3: 31-43.

Nayar, C. K. G. 1971. Cladocera of Rajasthan. Hydrobiologia, 37: 509-519.

Negrea, S., 1983. Fauna, Repablica Socialiste Romania, Crustacea Vol.4, 12:399.

Patil, C. S and P. Gauder., 1980. Fauna of Dharwad; Karnataka State, India. Tvr. Zoo. In. 38:18-32.

Quadri, M. Y and A. R.Yousuf., 1978. Some new records of crustace from Kashmir. Curr. Sci, 46:859-860.

Reddy, Y.R. 1994. Copepoda: Calanoida: Diaptomidae, Guide to the identification of the Microinvertebrates of the continental waters SPB Academic Publishing bv. The Netherlands. pp. 221.

Ruttner, K. A. 1974. Plankton rotifers, Biology and Taxonomy. Geber uder Ranz., Dietenheim Suttgart, pp. 144.

Segars, H, S. S. Sharma, F. K. Kakkassery and C.K.G. Nayar. 1994. New records of rotifers from India. Hydrobilogia, 287:251-258.

Throp, J. H and Covich. 1991. Ecology and Classification of North American freshwater Invertebrates, Academic press Inc. pp. 911.

Vashist, H. S and B. K. Battish. 1991. The rotifer fauna of North India Brachionus Res. Bull (N.S) Punjab Univ., 22:189-192.

Wetzel, R.G. 1975. Limnology. W.B.Sauder. Philadelphia. pp. 525.

FRESHWATER FISH DIVERSITY AND FISHERIES IN SHARAVATHI RIVER BASIN

Summary

The aquatic communities and more specifically fish communities are very good indicators of disturbances, and since these communities play prominent role in the aquatic food chain, their study can effectively depict the comphrehensive account of aquatic ecosystemstructure and function. The present study of fish diversity in the Linganamakki Reservoir of the upper catchment has recorded 64 species from 32 genera and 16 families. From the lower catchment, 51 freshwater fish species have been recorded. The Sharavathi estuary has a total of 44 species of fishes. The annual fish yield of both the native and introduced fishes of the Sharavathi reservoir is estimated to be 200 ton. The decline in native fish stock necessitates the stocking of indigenous and endemic fishes of Western Ghats. Prevention of over-fishing, migrant fishermen and breeding season fishing can contribute to sustainable fishery in the reservoir. Strict practice of restricted mesh size utility can minimize the death of non-target fishes. Educating local fishermen and activating the inactive cooperative society can lead to sustainable fishery in Sharavathi River basin.

Introduction

Fishes are poikilothermic aquatic vertebrates, breathe through pharyngeal gills, propelling and balancing themselves by means of fins. Presently over 28,500 fish species are known throughout the world (Nelson, 1996); of these 40% are inhabitants of fresh and inland waters. A majority of these fishes are found in the tropical waters. For instance, it has been estimated that the river Amazon and its tributaries together harbour about 3000 or more species. Likewise, it is estimated that about 2500 fish species are found in India, of which 930 species are freshwater fishes, belonging to 20 orders, 100 families and 300 genera (Daniels, 2000).

Fish diversity investigations in rivers of southern India (Chandrashekhariah, 2000) show that in Krishna River basin, 101 fish species belonging to 19 Families and 5 Orders were recorded along with Indian gangetic carps and exotic fishes. Majority of the fish species in this riverine system are endemic and 20 species are under the threat of extinction. The Cauvery river basin has 96 fish species under 23 Families and 8 Orders. Studies show that 15 fish species are on the verge of total elimination and the carps such as *Puntius carnaticus, Hypselobarbus dubius* and the non-predatory catfish – *Pangasius pangasius* were not recorded in recent investigations in Cauvery riverine zone of the state. Sixty fish species belonging to 13 Families and 4 Orders were recorded in Godavari basin. Of these, *Thynnichthys sandkhol* has become extinct; in addition 15 more species are under the threat of elimination.

The west-flowing rivers of Karnataka (Kali, Bedthi, Aghnashini, Sharavathi and Netravathi, etc.) have recorded 83 species belonging to 19 Families and 7 Orders. *Hypselobarbus thomassi, Labeo nigerscens* and *Clarias dussumieri* have become extinct while 9 more species are on the verge of extinction.

A study of freshwater fish diversity in Aralam Wildlife Sanctuary of Kerala (Shaji *et al*., 1995) found 33 species belonging to 15 families. The study found *Garra mullya, Barilius bakeri* and *Danio aequipinnatus* were the commonest and uniformly distributed species. Whereas, river Periyar of Periyar Tiger Reserve has 35 species belonging to 21 genera and 11 families. Similar studies carried out in Kalakad – Mundanthurai Tiger Reserve, and rivers in Western Ghats of Kerala (Johnsingh, 2001) reported 33 species belonging to 9 families. During the 1993 – 95 survey of freshwater fishes in two east flowing and three west flowing rivers in Kerala part of the Nilgiri Biosphere Reserve 92 species were recorded. Individually, Kabini River has 59 species, followed by River Chaliyar with 50 species and Kunthi River with 11 species. The interesting observation made in this study is the east flowing rivers were more diverse than the west flowing rivers. But almost all the species found in west flowing rivers were endemic to Kerala.

The catchment of the Sharavathi river has bountiful natural resources and houses rich biodiversity as well as enormous hydro potential. The river receives many tributaries. The major tributaries are Haridravathi near Pattarguppe and Yenneholé near Bharangi. Along with them, the minor tributaries like Nagodiholé, Nandiholé, Mavinaholé, Hurliholé and Birerholé also join this river. The water from Chakra and Savehaklu reservoirs of Chakra River has been diverted to this reservoir. Present study has been undertaken in the upper catchment of Sharavathi River with the aim of documenting the ichthyo-diversity of the basin and to study the existing pattern of commercial fishery.

Materials and Methods

Fish sampling was carried out in the Linganamakki catchment area from January 2002 to August 2004. Collections were made using Gill nets, Cast nets, Drag nets and Hooks and Lines of varying dimensions. Stratified random sampling method was adopted to locate the 29 sampling sites. In these sites, 261 samplings were made with approximately 40 samplings per season (summer, winter and monsoon). The sampling sites are shown in Figure 2. Within each site, all microhabitats of aquatic habitat (riffle zone, pools, cascade, falls, embayment, run, plunge and backwater) were also sampled using various types of nets. Fish specimens collected were fixed initially in 30-35% formaldehyde and later transferred to 4% formaldehyde. Standard keys of Jayaram (1999), Talwar and Jhingran (1991) and Day (1889) were followed for species identification. Some specimens were identified with the help of experts at the Southern Regional Station, Zoological Survey of India, Chennai.

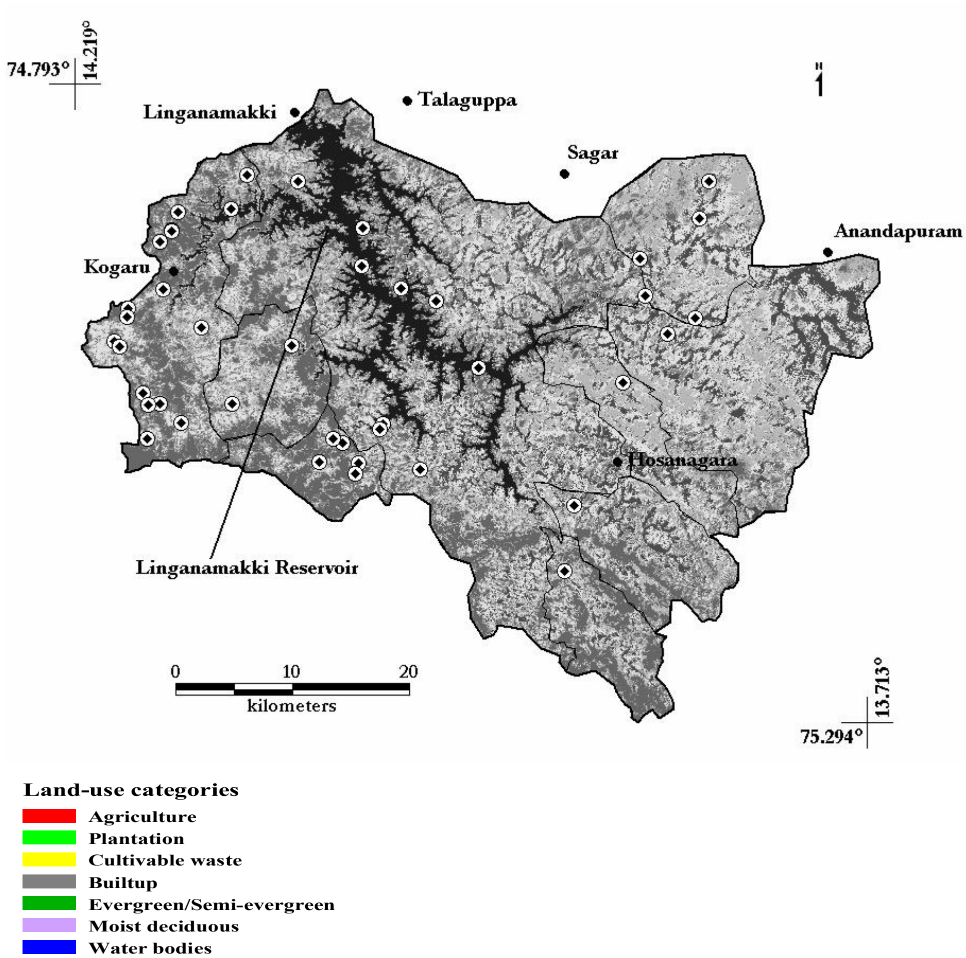


Figure 2. Classified image (supervised classification based on maximum likelihood classifier) of the study area with major sub-basins and sampling points

Gill nets of varying mesh sizes (2 x 1", 2 x 2", and 1 x 5" nets) were chosen and laid in an approximate area of 200×200 m. The lengths of the nets were maintained at 100 metres. The nets were put in the evenings and removed early in the morning. The total duration of netting was 12 – 14 hours.

In case of cast net sampling, transects with an approximate length of 100 meters along the banks were laid. In each location totally 20 castings were made. Dragnets were towed to a length of about 5 meters at each towing except at inaccessible localities. Finally, benthic habitats were sampled using hooks.

Historical Information

Systematic historical data regarding fish species of the reservoir were not available. However, experienced local fishermen with fishing history of more than 30 years helped us in this regard.. The knowledge of fishery in terms of historical and present status was evident from their continuous association with the fishing activities over a long period. Most of the fishermen participated enthusiastically in discussions and shared their views and experiences in fishing and social aspects. Market information such as location, channels, seasonal demand, etc., was collected from the fish merchants. The Fisheries Department provided all available statistical data regarding seeding methods, annual income to the department, licensing pattern, etc.

Results and Discussion

Fish diversity

In the present study 64 species from 38 genera and 17 families were recorded from the Linganamakki catchment of Sharavathi river basin. Annexure 1 details the species recorded from the region with their IUCN status. The total species collected from these basin alone accounts for 6.88 % of Indian fresh water fish (930 species) and 22.2 % of Western Ghats species (288). Based on the IUCN categories of the fish species, of the 51 species, 35.3 % (18 species) are endemic to Western Ghats, about 43.1 % (22 species) are threatened species and the remaining 19.6 % (10 species) are data deficient. This analysis excludes introduced and unidentified species.

Species composition, distribution and abundance
Considering the species richness at the family level, Cyprinidae dominated with 30 species, followed by Balitoridae and Bagridae with 7 and 6 species respectively. Among the genera, *Puntius* recorded 7 species followed by *Schistura* with 5 species. There are four introduced species and distribution of five species is unknown.

Reservoir fish composition

The native fishes like *Gonoproktopterus kolus, Cirhina fulungee, Ompok bimaculatus, Mystus cavesius, Mystus malabaricus, Mastacembelus armatus, Channa marulius,* etc, are largely found all over the reservoir. During the non-monsoon season these fishes form bulk of the catch in commercial fishery. Similarly, some of the catfishes like *Wallago attu, Heteropneustes fossilis* and *Clarias batrachus* are rare in the reservoir. Recently described species, *Batasio sharavatiensis*, from the downstream region (Bhat, 2004) of the Linganamakki dam has been collected from the upper catchment. Interestingly, the distribution of *Batasio sharavatiensis* is restricted to Sharavathi river basin and its occurrence seems to be occasional.

Among the four introduced species, three species (Common carp) were introduced into the reservoir. *Oreochromis mossambica,* a prolific breeder introduced accidentally is abundantly found in the central parts of the reservoir. During last few years, *O. mossambica* has spread all over the catchment including the hill streams. The translocated species like *Labeo rohita*, *Cirhina mrigala* and *Catla catla* contribute substantially towards fish yield especially from central parts of the reservoir only during the monsoon season.

Out of the 64 species, within the catchment, about 39 species are found in the reservoir. Of this, 25% (10 species) are endemic to Western Ghats and about 7.5% (3 species) are restricted to peninsular India. The introduced species in the reservoir accounts for 17.5% (7 species). Nearly 43.2 % (17 species) are non-endemics having distribution all over India.

Stream fish composition

The stream habitats of the river are very diverse and account for greater endemism. The perennial streams are associated with *Puntius fasciatus, P. arulius, P. sahyadriensis, P. filamentosus, Nemacheilus denisonii, Lepidocephalus thermalis, Garra gotyla stenorhynchus,* etc, many of which are restricted to the Western Ghats. The species of Balitoridae are commonly found in the Sharavathi River, the Nagodi tributary and the Yennehole tributary. *Schistura nilgiriensis* has been reported for the first time from Karnataka from this region (Sameer Ali, personal communication). The common species of the streams include *Rasbora daniconius, Danio aequipinnatus, Puntius filamentosus, P. sophore* and *Garra gotyla stenothynchus*. These species have wider distribution including in the reservoir. The glass fishes (*Parambassis ranga* and *Chanda nama*) are very common during the early monsoon season.

The streams of the study area have 33 species of which 42.4 % (12 species) are endemic to Western Ghats. About 21.2% (7 species) of the total species are restricted to peninsular India and 36.3% (11 species) has distribution all over India. The only introduced species in the streams is *Oreochromis mossambica*.

Comparison between the reservoir and stream fishes composition

The comparison between the ecological parameters between these two major habitats is given in Table 63. Species richness is more in reservoir (39 species), attributed mainly to the introduced and generally distributed species, than stream habitats (33 species). However, endemism and restrictedly distributed species are more in streams compared to reservoir.

Table 63: Ecological status of fish species in two major habitats of the catchment

Ecological Status	**Reservoir**	**Streams**
Species richness	39	33
Endemic species (%)	25.0	42.4
Restricted to peninsular India (%)	7.5	21.2
Distributed throughout India (%)	47.5	36.3
Introduced species (%)	17.5	3.0

Influence of Riparian Vegetation on Fish Distribution

During the field visits it is observed that riparian vegetation plays a determinant role in species composition. As the summer arrives there will be a great variation in day and night temperature. The rainwater dependent streams especially in the eastern part of the study area show considerable reduction in the flow. The less flow makes them sensitive to any variation in atmospheric temperature. The sparse riparian vegetations further worsen the condition by directly exposing the stream to sunlight. When this condition comes, most of the habitats for most of the fishes become unsuitable and they move to those places where there is considerable vegetation along the bank, which will maintain the stream temperature. The summer sampling in these hill streams confirmed these facts as no fishes other than *Danio aequipinnatus* and *Aplocheilus lineatus* were found in open areas. Where there is canopy cover, higher concentration of fishes both in terms of species and individuals were noticed. However, this effect was comparatively less in western part of the area as there is uniform canopy cover (throughout the year due to evergreen and semi evergreen vegetation) and more flow coupled with lower temperature (Table 64).

Table 64. Cast net summer sampling in eastern streams.

Locality	Species	Description with respect to Vegetation in sampling sites
Nandiholé	*Oreochromis mossambica, Danio aequipinnatus, Salmostoma boopis, Aplocheilus lineatus*	The sampled locality had absolutely no vegetation on both sides.
Haridravathi	*Danio aequipinnatus, Aplocheilus lineatus*	On one side paddy fields with two trees. On the other side small Acacia plantation.
Mavinaholé	*Aplocheilus lineatus, Mystus malabaricus, Puntius dorsalis, Garra gotyla stenorhynchus, Chanda nama, Cirhina* Sp., *Danio aequipinnatus*	*Lophopetalum wightianum*, *Hopea wightianum* and other trees covered over the river.
Sharavathi River	*Danio aequipinnatus, Aplocheilus lineatus, Garra gotyla stenorhynchus, Chanda nama, Salmostoma boopis*	No vegetation other than bamboo. But significant water flows in the river.
Hilkunji River	*Danio aequipinnatus, Aplocheilus lineatus, Rasbora daniconius, Salmostoma boopis, Chanda nama, Cirhina species*	*Hopea wightianum* and *Bambusa* Sp. on one side and paddy fields on other side. But significant water flows in the river.

People and Fishery

About 120 fishermen families reside in the reservoir catchment area with distinct social and cultural aspects. Among these, 70 families are permanent residents while remaining 50 families migrate from neighbouring southern states during monsoon. These families are restricted to these localities and are isolated from other localities and trade with merchants who visit this area. Generally these communities are very poor and uneducated. Their kids spend 3 – 4 years for basic education and then get into fishing.

Fishermen Communities

The communities such as Killakhyatha, Mada and migrated fishermen are engaged in fishing activities in these localities. Tamil fishermen from Tamilnadu state who were fishing in Mettur Dam of River Kaveri have migrated to Koluru area. The drawbacks in the licensing system (like one person gets the license for fishing in a family and no one else is allowed for fishing) at Mettur were one of the reasons for migration. Thus, about 20 families of fishermen have migrated about 30 years back and most of them are settled in the region.

'Killekyatha' or 'Burudebestha' communities with 50 families are found near Suttha Village of Hosanagara taluk. Some of these families migrated from the Anjanapura reservoir catchment of Shikaripura taluk. Even though these families have permanent houses in their village Suttha and reside there during festivals and other family occasions, most of the time they travel from place to place for fishing. There are five families of 'Mada' community engaged in fishing as seen near Malali village of Hosanagara taluk.

Management Structure

Three government agencies manage the water body based on its spatial extent. Water bodies with an area between 1 ha and 10 ha are under the control of Fish Farm Development Agency. This agency trains interested persons with a daily stipend of 25 rupees and gives the lake on a lease for 6 years. The trained person gets 50% subsidy on seeds, manure, restoration and other requirements for one year with compulsion to buy the seeds from the department and insurance;

Water bodies with area between 10 ha and 100 ha are regulated by the Zilla Panchayaths and are given for lease on cost basis; and The Deputy Director of Fisheries regulates water bodies with more than 100 ha. Linganamakki Reservoir falls under this category.

License Pattern

Obtaining yearly license is compulsory to all the fishermen for fishing in the reservoir. The fee structure for gill net with a length of 500 meters is Rs. 1000/- per year, cast net Rs. 300/- per year and hooks Rs. 100/- per year. The Fisheries Department data shows that at present there are about 200 license holders fishing in the reservoir area. Thus, the department is getting 1.65 lakh rupees of revenue annually from this source.

Facilities provided by the Department to the Fishermen

Fisheries Department provides housing to the fishermen at various places. Koluru village has fishermen colony of 20 houses. Under the department scheme, construction of 13 houses near Chikmathur village and 7 houses near Kippadi Village is in progress. In addition to this, iceboxes, measuring equipment, nets and bicycles to these families are provided free of cost.

Seeding Pattern

Seeds are introduced after the monsoon season in order to avoid overflow and washing, even though the seeds are to be introduced during the beginning of monsoon as per stipulations. Table 64 lists seeding pattern for the last 20 years and the quantity of seeds introduced depending on availability. The department gives least preference to the reservoir for seeding. It is seen that during the last two years, seeding quantity has reduced to a minimum.

Table 64. Yearly data on seeds introduced into the reservoir.

Year	**Seeds in Lakhs (0.1 million)**			
	Catla	**Rohu**	**Mrigal**	**Common Carp**
1983 – 1984	1.643	0	0	2.21
1984 – 1985	1.278	0	0	1.62
1985 – 1986	6.8	0	0	7.42
1986 – 1987	6.81	0	0	2.48
1987 – 1988	7.87	0	0	0
1988 – 1989	4.754	0	0	0
1989 – 1990	2.95	0	0	3.55
1990 – 1991	0.85	2.783	0.312	8.41
1991 – 1992	0	0	0	4.6
1992 – 1993	0	0.42	0	5.4
1993 – 1994	1.2	5.75	0	15.058
1994 – 1995	5.3345	7.0685	0	11.418
1995 – 1996	7.266	11.07	0.35	10.605
1996 – 1997	0	26.362	0.72	9.86
1997 – 1998	3	21.885	6.03	1.25
1998 – 1999	2.448	19.016	1.12	1.4
1999 – 2000	12.115	14.374	0	0
2000 – 2001	0	0	0	5
2001 – 2002	0	0	0	3

Fishermen Co-operative Society

Fishermen co-operative society, which is located in Sagar, has presently 412 members (fishermen and fish merchants) with their share being Rs. 13,895/- and Government's share being Rs. 10,000/-. But the fishing activities in the reservoir are more or less under the control of merchants. The Society's efforts to market through society without any middlemen is in vain as most fishermen sell fishes to merchants due to mutual dependence of fishermen and merchants with flexible credit and services. As the fish catch is highly fluctuating over the season, fishermen borrow loans from the merchants for their livelihood and reimburse in the form of fish. The loans are as huge as Rs.

60,000/-. Due to financial constraints the society is not in a position to help needy fishermen.

Marketing

Fresh-water fish decay earlier than marine fish necessitating transportation, proper storage mechanism and marketing network. The reservoir fish is marketed in Sagar and Hosanagara Taluks and parts of Soraba, Shikaripura, Shiralakoppa and Shimoga taluks. Besides, small open market outlets at various places are established to market the fishes, including door-to-door selling on two wheelers.

Harvesting Pattern

Craft: Most commonly used fishing craft is coracle (locally called *Ukkada*), constructed with bamboo thatches and covered by nylon sheets. The outer surface is pasted with tar to prevent water seeping into the coracle.

Usually gill nets with length varying from 300 m to 500 m and with different mesh sizes (depending on the type and size of fish) are used. Net placement at different levels is also a deciding factor in harvesting types of fishes. Usually Gill nets are used for covering large area while cast nets are used for a small area. The Department has banned the use of dragnets, but certain fishermen still use dragnets for capturing large quantity of fish with less effort, which results in capturing juvenile fish that ultimately affects the fish stock. The department with meagre resources and manpower is unable to monitor and control such unauthorized activities. Fishing with hooks and lines is a hobby to many people who are residing near the reservoir.

Seasonal Fluctuation in Demand and Supply

The regional supply fluctuates between freshwater and marine fish. Marine fish is imported extensively during non-monsoon seasons from the nearby coastal districts. During this period, the availability of freshwater fish is considerably less. During monsoon season, the supply of sea fish decreases with increased availability of freshwater fish. As such the region receives continuous supply of fish throughout the year either from marine or freshwater depending on seasons.

Reservoir Yield

A systematically managed database is highly useful in assessing the yield of any reservoir, which is not available either at the fisheries department or with any other government agencies. In the absence of any historical information from any sources, an attempt could be made through fish landing sources. However, unorganized market channels in this region have complicated the data collection. Yield of the reservoir is assessed based on sampling at five localities - Lingadakai, Hasaramakki, Muppane, Holebagilu and Madenur. Landing data was collected and quantified with the help of the fishermen without interfering in their routine way of collection. Multiple sampling in the same locality was carried out considering day-to-day variations (Table 65).

Table 65. Fish-catch (kg/person/day) during the year 2001-02.

Locality	During non-monsoon season	During monsoon season
Lingadakai	1.3	No fishermen
Hasaramakk i	1.75	4.3
Muppane	2.8	5.25
Holebagilu	2.1	8.4
Madenur	1.6	5.6

Table 66. Estimation of total fish yield of the reservoir.

Monsoon yield	
Total authorized fishermen during monsoon season	200
Considering 10 % extra as unauthorized fishermen, the total number of fishermen engaged in fishing are	220
The product of total number of fishermen and average individual fish catch gives the total monsoon fish catch per day (220×5.8875)	1,295.25 kg
Considering 3.5 months as monsoon period, total fish catch over this period becomes	1,36,001.25 kg
Non-monsoon yield	
Assuming 60 % of the total fishermen remain engaged in fishing activities and only 5 % of the total unauthorized fishermen remain for non-monsoon season, total fishermen engaged are	165
Total non-monsoon fish catch per day is (170×1.91)	324.7 kg
Total non-monsoon fish catch (Total non-monsoon period is 8.5 months from which 2 month are deducted for non-fishing days) is	63,316.5 kg
Total yearly fish catch from the reservoir is	1,99,317.75 kg

This data represent the fishing using gill nets and hooks as majority of the fish catch is carried out in this manner. Monsoon data collection was done considering higher sample size (10 % extra fishermen). During the field visits it is observed that migratory fishermen are always in a group of 10 or more and few of them had fishing licenses. Illegal fishing is accounted as 10 % in yield computation. After monsoon, most of these migratory fishermen move to other reservoirs, which considerably reduces unauthorized fishing. This is summarised in Table 66 and the total yearly catch is 1,99,317.75 kg.

Fishermen get Rs. 22 per kg of fish from merchants (who buy at shore) and the total gross income works out to Rs. 43,84,990.5 per year. Thus, a permanent fisherman earns annually about Rs. 22,042.

Based on the yield computations (Table 66), the reservoir fish yield per sq. km is 610.76 kg. at full reservoir level. About 68.23 % of the total fish-catch takes place during monsoon and this quantum includes breeding season. The increased catch is due to movement of bottom dwellers to the upper strata and higher yield of introduced fish and also due to turbidity. It is noticed that some fishermen practice destructive fishing by harvesting at breeding grounds. Fishermen shift to shallow areas as the water level rises during monsoon season and these are normally the breeding ground for fishes.

Localitywise and Seasonwise Species Distribution

During the field visits, it was observed that western river Yenneholé is mainly dominated with the native species. Fishes like *Cirhina reba* and *Labeo fimbriatus* dominate the fish catch along with other species like *Ompok bimaculatus,* and *Mystus* species. The *Tor* species were found in Hallibylu region of this river system. Thus, the season-wise species composition remains more or less same in this locality. Further, the southwestern part shows similar trends of Yenneholé. But here *Tor* species was not recorded. In both the cases, natural terrain is undulating with hills and valleys. Valleys being shallow areas are excellent localities for indigenous monsoon breeders.

The deeper regions of the reservoir like Holébagilu, Hasaramakki and Madenur have major fish catch of introduced species during monsoon season. As the monsoon season recedes the catch of indigenous species increases compared to introduced species and this condition prevails until there is water inflow into the reservoir.

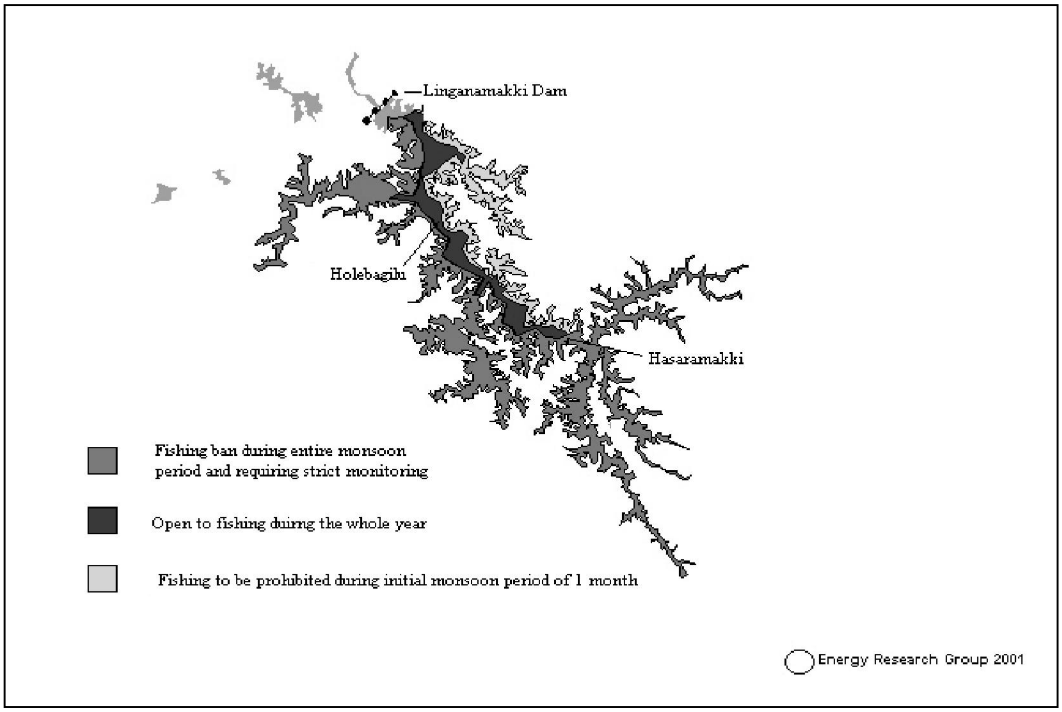


Figure 2. Sensitive fish breeding regions.

Discussions

Large number of Western Ghat endemics (18 species) in the region highlights the uniqueness of the region. About 55 % (28 species) of the fishes are found only in peninsular India. Similar comparisons were made with respect to the status of each species. The only critically endangered species, *Tor mussullah* is found in the western parts of the reservoir. Ten species are endangered and require immediate conservation measures, while 12 are vulnerable, 19 are with lower risk and remaining 10 are data deficient. This clearly emphasises the richness and ecological value of the region.

Comparison between the reservoir and streams shows that the species composition of the reservoir is dominated with non-endemic and introduced species. The reason for the flourishing of non-endemics/introduced species is due to development of commercial fishery in the Linganamakki reservoir, since 1969. On the other hand the streams have more number of endemics having narrow range of distribution, emphasizing the importance of streams as natural habitats for endemics. This in turn, accounts for high conservation value of the region.

The data on seeding (refer Table 64) reveals that no scientific approach was adopted. Without determining the carrying capacity and productivity of the reservoir enormous amounts of seeds were introduced during early 90s. The present condition reveals that the approach adopted in seeding has negatively affected the total fish fauna.

Introduction of Tilapia (*Oreochromis mosambica)*: Tilapia is a hardy, territorial and a powerful competitor in nature, and is has started dominating in Linganamakki reservoir. As per the local fishermen, the fish catch of *Tilapia* is increasing over years. The catch starts at the post monsoon period and during November, it dominates in the entire catch. Due to the least demand for this fish in local markets, fishermen treat this fish as unwanted catch. Ecologically these fishes have adverse effects on the native fish diversity. As per the fishermen, the maximum weight that this fish can attain is 0.5 kg in this reservoir.

Endangered Mahseers: *Tor khudree* and *Tor mussullah* are the two endangered species present in the reservoir. These fishes breed during post monsoon period and their habitat is rocky pools. Their commercial value and habitat destruction might be the factors contributing to their decline. In Linganamakki Reservoir, mahseers were recorded in Hallibylu of Sharavathi Wildlife Sanctuary area. In other areas also these fishes are found rarely. At present, the silt deposition at the bottom is slowly disturbing their habitat along with fishing pressure.

***Cyprinus carpio* (Common Carp) Fishery**: During monsoon period, Common carp is the major fish catch in deeper areas like Holébagilu, Madenur and Hasaramakki areas. During other seasons, this fish catch is almost nil. Since Common carp is a bottom dweller, high transparency of the reservoir makes it to move to the bottom surface. During monsoon season, transparency reduces and Common carp comes to the surface. *Cyprinus carpio* is regarded as one of the major competitors to the native species of fishes for food and habitat. In the present case, the fish may affect benthic fishes like *Wallago attu, Ompok bimaculatus* and *Channa striatus* indirectly. Since *Cyprinus carpio* is an herbivorous fish, and its growth is quite fast, it consumes lower level organisms like phytoplankton, zooplankton and other aquatic insects andmay in turn affect the food requirement of carnivorous fishes and result in decreasing their population.

Role of Predatory Fish in Total Fish Catch: Depending upon the fish catch composition it can be concluded that, predatory fishes like *Wallago attu* and *Channa striatus* are least in number. Only *Ompok bimaculatus* catch is quite encouraging. This could be due to excessive introduction of Gangetic carps like *Cyprinus carpio* during the last decade, which has led to competition among the bottom dwellers. Yenneholé tributary is the only place with considerable catch of predatory fishes with no introduced species. In this locality, 13 hooks were placed and out of six, 4 *Wallago attu* and 2 *Channa striatus* were caught. This indicates the presence of predatory fishes in this area.

Diseases - Epizootic Ulcerative Syndrome (EUS): The fishermen recall the widespread outbreak of a disease about 5 years back, featured by the severe ulcerative skin lesions over the body, which ultimately caused the death of the fish. Reports on the outbreak of EUS in Shimoga District show that during Dec 1993 – Jan 1994 the disease had caused mortality in the major and minor irrigation tanks. Even though initially the disease affected the bottom dwellers like *Channa* species slowly it spread to catfish and minor carps. Interestingly it has not affected the Indian major carps like Catla, Rohu, Mrigal and common carp in Karnataka (Mohan and Shankar, 1994). This disease might be one of the main reasons for extinction of many species. According to the local fishermen, fish species like *Wallago attu*, *Heteropneustes fossilis* and *Channa striatus* were severely affected by this disease and there was a remarkable decline in their population. Presently there are no such episodes of disease in the reservoir. Still one of the sampling at Lingadakai found a *Garra gotyla stenorhynchus* with lesions on the body.

Parasitic infection to *Mastacembelus armatus*: Recently parasitic infection to the species *Mastacembelus armatus* was observed in areas like Hasaramakki. The infection showed numerous lesions within the abdomen with approximately 1 – 2 cm diameter. After the death of the fish during fishing, nearly 2" long thread like worms (helminthes) were coming out of the abdomen. The infection was at its peak during summer season and affected almost all the fishes of the species. During this period, the commercial use of this fish had almost stopped in this area. However, the question of the suitability of the fish as food and the reason for the first time occurrence of this disease during June 2002 remains unanswered.

Destruction at the breeding ground: Species of *Garra, Puntius, Labeo, Cirhinus, Mystus, and Pseudeutropius* etc. are regarded as resident species. These fishes breed within the reservoir or migrate to smaller distances in search of shallow weedy areas for breeding. Most of the people residing along the bank go for fishing and capture them during monsoon season. Residents here adopt traditional techniques to capture these fishes. These are the localities where large congregations of the spawning fishes are caught and destroyed. Some fishermen even move to shallow upstream areas during monsoon to exploit the breeding grounds. Probably this is a prime factor that retards the population of these migratory fishes. Most of the streams along the western side are observed to be excellent breeding grounds for the native fishes.

Over exploitation and improper fishing system: The over exploitation of the reservoir plays a major role in extinction of the species. The department issues licenses to any number of fishermen. Many fishermen from Tungabhadra dam migrate to this area during rainy season and catch huge quantity of fish. This has adversely affected the livelihood of permanent local fishermen. Over exploitation of the reservoir for fishing has resulted in excessive mortality and reduction in effective population size of the fish. Monsoon is the breeding season for most of the fishes and the fishing activity is at its peak during this season.

The commercial fish catch of the reservoir is dominated by species belonging to Cyprinidae family (54%). The other major families are Bagridae (23%) and the Siluridae (15%). When biomass is considered, the fast growing Indo-gangetic carps, popularly known as Indian major carps, occupy a prominent place. Mainly *Catla catla* (21%), *Labeo rohita* (8.4%) and *Cirhina mrigala* (6.32%). These fishes are introduced to fulfill the commercial fish requirement along with the exotic species (*Cyprinus carpio* 21%). The native fishes with significant biomass are *Gonoproktopterus kolus* (11.5%), *Ompok bimaculatus* (10%) and *Wallago attu* (9%).

Table 67. Fish-catch observed at different locations during the year 2003-04

Locality	Catch per unit effort (Kg/boat/day)	
	Non-monsoon season	Monsoon season
Holebagilu	1.34	39.4
Muppane	7.93	16.5
Konjavalli	6.2	16.5
Melmanji	6.8	24.2
Kogar	8.2	28.5

Data on fish catch of the selected seven localities show that at the center of the reservoir (Holebagilu) the yield variation is very high compared to other regions (Table 67). During monsoon season, the central region yields the introduced species in bulk. In the peripheral localities (Muppane, Konjavalli, Melmanji and Kogar) variation in catch during two seasons is less.

Table 68. Percentage catch composition of various species during non-monsoon season

Species name	Percentage biomass				
	Holebagilu	Muppane	Konjavalli	Melmanji	Kogar
Introduced					
Catla catla	0.0	0.0	0.0	0.0	0.0
Labeo rohita	0.0	0.0	0.0	0.0	0.0
Cyprinus carpio	0.0	0.0	0.0	0.0	0.0
Native					
Gonoproktopterus kolus	0.0	28.4	28.9	13.3	11.0
Cirhina fulungee	5.6	8.5	8.4	2.2	4.6
Garra gotyla stenorhynchus	0.0	1.5	0.6	0.0	0.0
Mastacembelus armatus	0.0	25.2	19.3	17.8	19.5
Mystus cavecius	16.8	3.8	6.0	8.9	14.6
Mystus malabaricus	22.4	5.7	7.2	7.8	10.1
Ompok bimaculatus	32.8	8.3	14.1	39.1	29.5
Ompok pabo	0.0	13.9	10.6	9.8	10.7
Oreochromis mossambica	0.0	1.0	2.4	1.1	0.0
Puntius arulius	0.1	0.0	0.0	0.0	0.0
Puntius filamentosus	17.9	0.0	0.0	0.0	0.0
Tor khudree	0.0	3.8	2.4	0.0	0.0
Xenentodon cancilla	4.5	0.0	0.0	0.0	0.0

During summer season there is no role of introduced species in enhancing the fish catch of the reservoir (Table 68). The catch is mainly represented *by Mystus cavecius, Mystus malabaricus* and *Mastacembelus armatus* in almost all the localities. At the peripheral localities *Gonoproktopterus kolus* shows significant catch whereas its catch is negligible at the central region.

Table 69. Percentage catch composition of various species during monsoon season

Species name	Percentage biomass				
	Holebagilu	Muppane	Konjavalli	Melmanji	Kogar
Catla catla	25.4	0.0	0.0	0.0	0.0
Cyprinus carpio	12.7	0.0	0.0	0.0	0.0
Labeo rohita	10.1	0.0	0.0	0.0	0.0
Cirhina mrigala	7.6	0.0	0.0	0.0	0.0
Cirhina fulungee	0.0	12.7	5.4	2.5	3.2
Gonoproktopterus kolus	0.0	39.0	43.4	38.9	43.2
Mastacembelus armatus	8.1	9.7	12.1	4.9	8.4
Mystus bleekeri	0.0	0.3	0.0	0.0	0.0
Mystus cavecius	9.1	7.2	1.4	0.6	0.5
Mystus malabaricus	1.7	2.7	1.4	0.6	2.1
Ompok bimaculatus	24.0	23.9	15.9	8.1	37.1
Ompok pabo	0.0	1.3	2.6	0.9	1.5
Osteocheilus nashi	0.0	0.9	0.0	0.0	0.0
Pseudeutropius atherinoides	0.0	0.2	0.3	0.1	0.2
Puntius filamentosus	0.0	1.1	1.4	1.5	3.8
Tor khudree	0.0	0.9	0.0	0.0	0.0
Tor mussullah	0.0	0.0	0.9	0.6	0.0
Wallago attu	0.0	0.0	15.1	41.2	0.0
Xenentodon cancilla	1.2	0.0	0.0	0.0	0.0

During monsoon season, the fish biomass composition (Table 69) in the central region is dominated by introduced (Holebagilu - 55.8 %). Of the indigenous population, only *Ompok bimaculatus* has shown significant biomass in these localities. Whereas in other localities where there is no introduction, their catch is totally absent and substituted by indigenous commercial fishes like *Gonoproktopterus kolus, Wallago attu, Mastacembelus armatus* and *Ompok bimaculatus*. Apart from *G. kolus*, the market value for all other indigenous fishes is higher than the introduced species.

Variable fishing pressure: Monsoon is the peak fishing period and there will be 3.4 times increase in fish catch per person per day during this period compared to non-monsoon period. Even though the monsoon period being shorter than non-monsoon period, about 86.7 % of the total fish-catch takes place during monsoon. Nearly 63.5 % of the original fishermen population arrives here during the initial monsoon season from various parts of peninsular India. As the density of fishermen increases 2.75 times, the fishing pressure also increases. During the initial monsoon season, the reservoir attains the minimum water spread area. It is observed that most of the fishermen get concentrated in the central regions like Holebagilu in order to harvest huge catch. Obviously this results in overexploitation of resource. This is evident from the low fish catches of summer season from this region.

Loss at the breeding grounds: Monsoon is the breeding season for most of the fishes and the fishing activity is at its peak during this season. Muppane, Konjavalli, Melmanji and Kogar represent the peripheral localities of the western region. The biomass composition of this region shows that in these localities, the catch is formed by the native species. These are the flood plains where majority of the fish species breed during monsoon season. Huge quantities of fish catch in these localities during monsoon season poses huge threat to their population. It is evident that the catch per unit effort increases at the periphery than the other localities. Almost all the fishermen move to the extreme ends of the tributaries thereby destructing the breeding fish population.

Fish translocation from other basins: Details on the pattern of introduction clearly reveal that no scientific approach has been adopted before determining the quantity of introduction. Seeds have been introduced depending on the availability. This unscientific approach has resulted in an artificial system of fishing wherein the indigenous fishing population has to rely on an external source to increase the fishing stock. Declined native fish population is inefficient to cope up their livelihood. The low catches during non-monsoon season totally affects the permanent fishermen of the region who are totally relying on this resource for their livelihood. The biomass composition of this region also reveals that other than catfishes, no other native species has succeeded to form a stable population. Thus the fishermen are dependent on an artificial system in the form of introduction and harvest. It is implicative that the original fauna has been changed and hardy fish species has taken advantage of the vacant niches. Thus transplantation of fishes from other basins has led to radical changes in the species set up.

Conclusion

The present study of fish diversity in the Linganamakki Reservoir recorded 52 species from 32 genera and 16 families, where as lower catchment area harbours 51 freshwater species and Sharavathi estuary has 44 species. Altogether, entire basin has 112 species. For the first time a monotypic genus *Phylloneura westermanni* was recorded from a Myristica swamp of Kathalekan in Siddapur. The only earlier report on this species was from Nilgiris, Coorg and Wayanad in 1933 by Fraser. The presence of *Philorus* in the Vatehalla stream indicates its pristine nature and presence of primeval forests around. Some pollution sensitive genera have also been found in Kathalekan indicating the beginning of human disturbances.

The annual fish yield of the reservoir is estimated to be 200 ton with both native and introduced fishes. The decline in native fish stock necessitates the stocking of indigenous and endemic fishes of Western Ghats. Prevention of over-fishing, migrant fishermen and breeding season fishing can contribute to sustainable fishery in the reservoir. Strict practice of restricted mesh size utility can minimize the death of non-target fishes. Eliminating predatorial exotics and omnivores like tilapia and common carp is required to minimize the negative effects. Educating the local fishermen and activating the inactive co-operative society can lead to sustainable fishery in Linganamakki reservoir.

Management Approaches

Conserving the breeding areas: As discussed earlier, shallow and stream joining areas are the breeding grounds of most of the fish species. In this connection, fishing activities should be totally restricted in shallow areas during June to September. The breeding area should be demarcated and these areas should be kept under continuous monitoring. Monsoon fishing should be allowed only at the central part and limited to harvest transplanted species by operating large mesh sized gill nets.

***Permanently stopping the fishermen migration*:** The Fisheries Department should reconsider its revenue-oriented approach in issuing the licenses to the fishermen. Licenses should be issued to the permanent fishermen residing near the reservoir, who are solely dependent on this reservoir for their livelihood. In order to reduce the fishing pressure, it is advisable to avoid migratory fishermen from fishing. Since their fishing period is monsoon, large quantities of breeding fishes are destroyed by over fishing. These fishermen are highly mobile in nature, which complicates the authorities in monitoring. This provides sufficiently large fishing ground to the permanent fishermen thereby considerably retarding the stress on the aquatic system.

Strengthening the indigenous fish population: Culture techniques for endangered species should be developed to protect and rehabilitate the endangered species taking into account the critical need to conserve genetic diversity. The native commercial fishes like *Tor khudree, Tor mussullah, Labeo kontius,* etc., have tremendous potential in commercial fishery and their population need to be strengthened by external input. Specifically in the central part of the reservoir most of the cyprinids have poor population indicating the immediate requirement of their culture.

Proper introduction: Presently it is necessary to translocate the gangetic carps to share the fishing stress on the native fishes. However there is a great ecological concern over the introduction of exotic species. In this regard, carrying capacity of aquatic environments should be well studied and the quantification of introduction should be made in order to eliminate the adverse effect on native fish fauna.

Strict supervision: Presently the department is lacking trained staff to strictly and properly supervise the fishing activity. They should be strengthened through increasing their number and proper training. This can enlighten the scientific approach in them towards fisheries management.

Activating the Cooperative society: It is another major necessity to activate the Cooperative Society, which is presently passive. All fishing activities should be carried out through the society. Frequent meetings among the fishermen, merchants and the departmental staff can strengthen the society. Here once again banning the temporary fishermen can simplify the task of activating the Cooperative society.

Properly managed data: There is no scientific information available about fisheries in of Sharavathi Wildlife Sanctuary. This severely affects the decision-making. Without any statistical data, it is impossible to maintain the fishery activity in healthy condition. Thus it is the prime importance to maintain at least the data pertaining to total yield statistics, species-wise yield, physicochemical analysis of reservoir water representing the entire water body, disease episodes which is very useful during any planning stage.

Educating the local fishermen: Fishermen should be properly educated about the importance of fish diversity and the associated interconnections between different species. This can considerably decrease improper fishing practices by understanding their negative impacts on fish resources.

REFERENCES

Bhat, A. 2002. A study of the diversity and ecology of the freshwater fishes of four river systems of Uttara Kannada District, Karnataka, India. Ph. D Thesis. Centre for Ecological Sciences, Indian Institute of Science.

Canter, L. 1999. Cumulative Effects Assessment. Handbook of Environmental Impact Assessment - Vol. 1, Ed. Judith Pets, pp. 405 – 440.

Chandrashekhariah, H.N. 2000. Status of Fin Fishes in Karnataka, Workshop on Karnataka Bio-diversity Information System.

Daniels, R.J.R. 2000. Project Lifescape 6. Freshwater Fishes: Catfishes. Resonance Journal of Science Education, 5(4):95 – 107.

Daniels, R.J.R. and R. Abraham, 1995. Role of faunal bioindicators. *In:* Bioindicators – Identification and use in assessing environmental disturbances (Eds. M.S.S. Mohan, S. Nair and R.J.R. Daniels). M. S. Swaminathan Research Foundation. Chennai, India.

Easa, P.S. and Shaji, C.P. 1997. Freshwater fish diversity in Kerala part of Nilgiri Biosphere Reserve. Current Science, 73(2): 180 – 182.

Jayaram, K.C. 1981. The Freshwater Fishes of India, Pakistan, Bangladesh, Burma and Sri Lanka – A Handbook. The Director, Zoological Survey of India.

Jayaram, K.C. 1996. Manual for Field Identification – Common Freshwater Fishes of Karnataka. World Wide Fund for Nature – India, Biodiversity Conservation Prioritization Project – India (BCPP).

Jhingran, V.G. 1982. Fish and Fisheries of India. Hindustan Publishing Corporation (India), Delhi, pp 3-666.

Johnsingh, A.J.T. 2001. The Kalakad – Mundanthurai Tiger Reserve: A global heritage of biological diversity. Current Science, 80 (3): 378 – 388.

Leveque, C. 1997. Biodiversity dynamics and conservation – the freshwater fish of tropical Africa. Cambridge University Press. pp. 95 (438).

Nelson, J.S. 1996. Fishes of the world, 3rd edition. John Wiley and Sons, New York.

Shaji, C.P., Easa., P.S. and Basha, S.C. 1995. Freshwater Fish Diversity in Aralam Wildlife Sanctuary, Kerala, South India. Journal of the Bombay Natural History Society, 92 (3):360-363.

Talwar, P. K. and Jhingran, A.G. 1991. Inland Fishes of India and Adjacent Countries – Vol. 1 & Vol. 2. Oxford & IBH Publishing Co. Pvt. Ltd.

APPENDIX I

Annexure I: Fresh water fishes of Linganamakki catchment area with their distribution and IUCN status.

Species	IUCN status	Stream	Reservoir
ENDEMIC SPECIES			
Family: Cyprinidae			
Barilius bakeri	VU	+	-
Barilius canarensis	DD	+	-
Barilius gatensis	DD	+	-
Salmostoma boopis	LR	+	+
Osteocheilichthys nashii	VU	+	+
Gonoproktopterus dubius ?	EN	+	-
Gonoproktopterus kolus	EN	-	+
Puntius arulius	EN	+	+
Puntius sahyadriensis	DD	+	-
Labeo kontius	LR	-	+
Garra gotyla stenorhynchus	EN	+	+
Tor mussullah	CR	-	+
Family: Balitoridae		-	-
Nemacheilus anguilla	LR	+	-
Schistura nilgiriensis	EN	+	-
Schistura semiarmatus	VU	+	-
Family: Bagridae		-	-
Batasio sharavatiensis	DD	-	+
Mystus malabaricus	EN	-	+
Family: Sisoridae			
Glyptothorax lonah	LR	-	+
NON-ENDEMIC SPECIES			
Family: Cyprinidae			
Barilius bendelisis	LR	-	+
Amblypharyngodon mellettinus	LR	+	-
Danio aequipinnatus	LR	+	-
Brachydanio rerio	LR	+	
Rasbora daniconius	LR	+	-
Tor khudree	VU	-	+
Oreichthys cosuatis	DD	+	-
Puntius chola	VU	+	+
Puntius sophore	LR	+	-
Puntius ticto	LR	+	-
Puntius fasciatus	EN	+	-

Puntius filamentosus	DD	+	+
Cirrhinus fulungee	LR	-	+
Family: Balitoridae		-	
Schistura denisonii denisonii	VU	+	-
Acanthocobitis botia	LR	+	-
Family: Cobitidae			
Lepidocephalus thermalis	LR	+	-
Family: Bagridae			
Mystus keletius	DD	-	+
Mystus bleekeri	VU	-	+
Mystus cavesius	LR	-	+
Family: Siluridae			
Ompok bimaculatus	EN	-	+
Ompok pabo?	DD	-	+
Wallago attu	LR	-	+
Family: Schilbeidae			
Pseudeutropius atherinoides	EN	-	+
Family: Claridae			
Clarias batrachus	VU	-	+
Clarias dussumieri dussumieri	VU	-	+
Family: Heteropneustidae			
Heteropneustis fossilis	VU	-	+
Family: Belonidae			
Xenentodon cancilla	LR	-	+
Family: Aplocheilidae			
Aplocheilus lineatus	LR	+	-
Family: Chandidae			
Chanda nama	VU	+	+
Parambassis ranga	DD	+	+
Family: Gobiidae			
Glossogobius giuris	LR	+	+
Family: Belontidae			
Pseudophromenus cupanus	DD	+	-
Family: Channidae			
Channa orientalis	VU	+	-
Channa marulius	LR	-	+
Family: Mastacembelidae			
Mastacembelus armatus	LR	-	+
TRANSLOCATED SPECIES			
Family: Cyprinidae			
Cyprinus carpio communis		-	+
Cyprinus carpio sp.		-	+

Cyprinus carpio specularis	-	+
Catla catla	-	+
Cirhinus mrigala	-	+
Labeo rohita	-	+
Family: Cichlidae		
Oreochromis mossambica	+	+
SPECIES WITH STATUS UNKNOWN		
Family: Balitoridae	-	-
Schistura sp1	+	-
Schistura sp2	+	-
Schistura sp3		
Family: Bagridae	-	-
Aorichthys sp.	-	+

Note: CR – Critically Endangered, EN – Endangered, VU – Vulnerable, LR – Lower risk, DD – Data deficient, ? – Identification incomplete due to lack of multiple specimens, '+' Present, '–' absent.

APPENDIX - II

Checklist of Fish species recorded in Sharavathi River Basin

Linganamakki Dam up to Estuary (Bhat, 2002)	Sharavathi estuary (Nakadia)
Aplocheilus lineatus	*Ambassis commersoni*
Arius caelatus	*Arius arius*
Barilius canarensis	*Arius platystomus*
Brachydanio rerio	*Arius subrostratus*
Caranx carangus	*Austrobatrachus dussumieri*
Caranx ignobilis	*Belone cancilla*
Chanda nama	*Bothus pantherinus*
Cirrhinus fulungi	*Carangoides malbaricus*
Danio aequipinnatus	*Chrysophrys berda*
Eleotris canarensis	*Cyanoglossus sp.*
Garra gotyla stenorhynchus	*Drepane punctata*
Gerres (setifer) spp.	*Etroplus suratensis*
Gerres setifer	*Euryglossa pantherinus*
Gerres spp	*Gerres filamentosus*
Glossogobius giuris	*Gerres lucidus*
Gonoproktopterus dubius	*Gobius giuris*
Gonoproktopterus kolus	*Gobius ornatus*
Hyporhampus limbatus	*Hemiramphus xanthopterus*
Labeo boggut	*Johnius glaucus*
Labeo fimbriatus	*Lates calcarifer*
Labeo kawrus	*Leiognathus daura*
Labeo potail ?	*Leiognathus equulus*

Mastacembalus armatus	*Liza macrolepis*
Mystus cavesius	*Liza parsia*
Mystus malabaricus	*Lutjanus argentimaculatus*
Nemacheilus anguilla	*Lutjanus johni*
Nemacheilus botia	*Mugil cephalus*
Osteocheilus nashii	*Mugil poicilus*
Parabatasio sharavatiensis	*Nematolosa nasus*
Parambassis dayii	*Platycephalus indicus*
Parambassis thomassi	*Platycephalus scaber*
Periophthalmus weberi	*Pristipoma hasta*
Pristolepis marginata	*Scatophagus argus*
Puntius amphibius	*Sillago sihama*
Puntius bimaculatus	*Sphyraena jello*
Puntius dorsalis	*Stolephorus cummersonii*
Puntius fasciatus	*Stolephorus indicus*
Puntius filamentosis	*Strongylura strongylura*
Puntius jerdoni	*Terapon jarbua*
Puntius narayani	*Teuthis vermiculata*
Puntius sahyadrensis	*Teuthris oramin*
Puntius sarana sarana	*Thryssa hamiltonii*
Puntius sophore	*Trachynotus ovatus*
Puntius ticto	
Rasbora daniconius	
Salmostoma boopis	
Salmostoma clupioides	
Tor khudree	
Xenontodon cancilla	

Conclusions

The biological examination of the stream and reservoir ecosystems of Sharavathi River basin showed a rich and diverse aquatic fauna. The physicochemical and biological analysis of water samples in the upper catchment of the river and the phytoplankton sampling revealed that the river is in oligotrophic condition and there is no high organic pollution load. This could be due to least domestic and industrial pollutants in this region. Also the annual rainfall in the range of 2000 – 6000 mm contributes to the dilution of pollutants that enter into the river basin resulting in flushing effect of the pollutants. The freshwater zooplankton fauna of Sharavathi River is rich and highly diversified. They were showing a typical tropical assemblage. Large zooplankton species were absent in this river system, probably due to high predatory pressure. However these studies were unable to reflect the cumulative impacts resulted in the river basin. This could be mainly due to the fact that these communities along with physico-chemical analysis are the indicators of localized and short-term environmental changes. Fishes are good indicators of long-term effects and broad habitat conditions.

The study of freshwater fishes of the Sharavathi Upper catchment revealed that there are large numbers of Western Ghats endemics (18 species) in the region. The only critically endangered species, *Tor mussullah* is found in the western parts of the reservoir. Ten species are endangered and require immediate conservation measures, while 12 are vulnerable, 19 are with lower risk and remaining 10 are data deficient. This clearly emphasises the richness and ecological value of the region. The distribution pattern of fishes revealed that reservoir has supported the non-endemic and introduced species. On the other hand the streams have more number of endemics having narrow range of distribution, emphasizing the importance of streams as natural habitats for endemics. This in turn, accounts for high conservation value of the region. The study also found that the promotion of commercial fishery into the Linganamakki Reservoir has resulted in rapid depletion of native fish fauna.

References

Ayala, F.J. and Escalante, A. A. 1996. The Evolution of Human Populations: A Molecular Perspective. *Molecular Phylogenetics and Evolution.* Vol. 5, No. 1.: 188 – 201.

Census of India, 2001. http://www.censusindia.net/

Daniels, R.J.R. 2004. Interlinking of rivers: Ecologists wake up! *Current Science*, Vol. 87, No. 8: 1030 – 1031.

Dillehay, T.D. and Kolata, A.L. 2004. Long-term human response to uncertain environmental conditions in the Andes. *Proceedings of Natural Academy of Sciences.* Vol. 101. No. 12:4325 – 4330.

Dodds, W.K. 2002. Freshwater Ecology: concepts and environmental applications. Academic press. pp 1 (569).

Cox, C.B. and Moore, P.D. 2000. Biogeography an ecological and evolutionary approach, Sixth edition, Blackwell Science publication (298).

Eppink, F. V., Jeroen C.J.M. Bergh V. D. and Rietveld, P. 2004. Modelling biodiversity and land use: urban growth, agriculture and nature in a wetland area. *Ecological Economics* 51: 201– 216.

Gopal, B. 2000. River conservation in the Indian sub-continent. *In. Global perspectives on river conservation: science, policy and practice*, Boon P.J., Davies, B.R. and Petts, G.E. (eds.). John Wiley & Sons, Ltd. 233 – 262.

Jenkins, M. 2003. Prospects for biodiversity. *Science.* Vol. 302: 1175 – 1177.

Karr, J.R., Allan, J.D. and Benke, A.C. 2000. River conservation in the United States and Canada. In Boon, P.J, Davies, B.R. and Petts, G.E. *Global perspectives on river conservation.* John Wiley & Sons, Ltd. 3 – 40.

Meybeck, M. 2003. Global analysis of river systems: from Earth system controls to anthropogenic syndromes. *Philosophical Transactions of Royal Society of London: Bulletin of Biological Sciences.* 29-358:1935-55.

Pimm, S.L. and Lawton, J.H., 1998. Ecology: Planning for Biodiversity, *Science*, Vol. 279, Issue 5359, 2068-2069.

Sala, O.E., Chapin, S., Armesto, J.J, Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A, Leemans,R., Lodge,D.M., Mooney, H. A., Oesterheld, M., Poff, N.L. Sykes, M.T., Walker,B.H., Walker, M and Wall, D.H., 2000. *Science*, Vol 287: 1770- 1774.

Sinha, R.K. and Sinha, S.K. 2003. Lotic Ecosystems of India. *In. Venkataraman, K. (Ed). Natural aquatic ecosystems of India, Thematic Biodiversity Strategy and Action Plan, The National Biodiversity Strategy Action Plan, India* 1 – 275.

Venkataraman, K. 2003. Natural aquatic ecosystems of India, Thematic Biodiversity Strategy and Action Plan, The National Biodiversity Strategy Action Plan, India 1 – 275.

WCED. 2000. *Dams and Development: A new framework for decision-making*. 404.

Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation.* Vol 83. No. 3: 269 – 278.

Western, D. 2001. Human-modified ecosystems and future evolution. *PNAS*. Vol. 98, No. 10: 5458-5465.

Wetzel, R.G. 2001. Limnology – Lake and river ecosystems, third edition, Academic press
(http://www.worldwildlife.org/wildworld/profiles/g200/g171.html#intro)
http://wgbis.ces.iisc.ernet.in/energy/sharavathi/svati.htm

19. Ramesh, B. R. and Pascal, J. P., *Atlas of Endemics of the Western Ghats, India*, French Institute, Pondicherry, 1997.
20. Ved, D. K., Barve, V., Noorunnisa Begum and Latha, R., *Curr. Sci.*, 1998, **75**, 205–208.
21. Ganeshaiah, K. N., Kathuria, S. and Uma Shaanker, R., *Curr. Sci.*, 2002, **83**, 810–813.
22. Ganeshaiah, K. N., *Sasya Sahyadri*, Univ. Agric. Sci., Bangalore, CD-ROM, 2003.
23. Shaily Menon and Bawa, K. S., *Curr. Sci.*, 1997, **73**, 134–145.
24. Narendra Prasad, S., *Curr. Sci.*, 1998, **75**, 228–235.
25. Nagendra, H. and Gadgil, M., *Curr. Sci.*, 1998, **75**, 264–271.
26. Ganeshaiah, K. N. and Uma Shaanker, R., *Curr. Sci.*, 1998, **75**, 292–298.
27. Ramesh, B. R., Menon, S. and Bawa, K. S., *Ambio*, **26**, 529–536.
28. Nagendra, H. and Gadgil, M., *J. Appl. Ecol.*, 1999, **36**, 388–397.
29. Shi, H and Singh, A., *J. Indian Soc. Remote Sensing*, 2002, **30**, 105–112.
30. Neelakandan, V. N., Mohanan, C. N. and Sukumar, B., A Bio-Geographical Information System. *Indian Cartogra.*, 2001, **21**.
31. Neelakandan, V. N., Mohanan, C. N., Sukumar, B. and Baijulal, B., Role of geoinformatics in biodiversity studies. Proc. National Symposium on Resource Management with Special Reference to Geoinformatics and Decentralised Planning, Trivandrum, 9–12 Dec. 2003.
32. Neelakandan, V. N., Mohanan, C. N. and Sukumar, B., Development of a Biogeographical Information System for Kerala. Project Completion Report submitted to the State Council for Science, Technology and Environment, Govt of Kerala, 2004.
33. Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J., *Nature*, 2000, **403**, 853–858.
34. Pushpangadan, P. and Nair, K. S. S. (eds), *Biodiversity and Tropical Forests – The Kerala Scenario*, STEC, Govt of Kerala, 1997.
35. Nayar, M. P., Biodiversity challenges in Kerala and science of conservation biology. In *Biodiversity of Tropical Forests – The Kerala Scenario* (eds Pushpangadan, P. and Nair, K. S. S.), STEC, Govt of Kerala, 1997.
36. Nayar, M. P., Biodiversity and tropical forests – The Kerala Scenario. A compendium of background papers on the focal theme of the ninth Kerala Science Congress, 1997, The State Committee on Science, Technology and Environment, Kerala, 1997.
37. Sasidharan, N., Studies on the flora of Periyar Tiger Reserve. KFRI Research Report No. 128, KFRI, Peechi, 1997.
38. Sasidharan, N., Studies on the flora of Shendurney Wildlife Sanctuary. KFRI Research Report No. 150, KFRI, Peechi, 1998.
39. Nayar, M. P. and Sastry, A. R. K., *Red Data Book on Indian Plants*, *Vols I–III*, Botanical Survey of India, Calcutta, 1987, 1988, 1990.
40. Jain and Rao, Threatened plants of India. A state-of-the-art report, BSI, Calcutta, 1984.
41. Neelakandan, V. N. and Nair, M. M., Customization of Bio-Geographical Information System. *Indian Cartogr.*, 2002, **22**.
42. Nayar, M. P., Pushpangadan, P., Rajasekharan, S., Narayanan Nair, K. and Mathew Dan, *Jaivavaividhyam* (in Malayalam), State Institute of Language, Thiruvananthapuram, 2000.
43. Kathuria, S. and Ganeshaiah, K. N., *Curr. Sci.*, 2002, **82**, 76–81.
44. IUCN, *Red List Categories*, The World Conservation Union, Gland, Switzerland, 1994.
45. MoEF, National Biodiversity Strategy and Action Plan, October 2002, p. 53.

ACKNOWLEDGEMENTS. We thank Dr M. Baba, Director CESS, Thiruvananthapuram, for providing necessary facilities to carry out this work. We also thank Dr B. R. Ramesh, French Institute, Pondicherry, Drs N. Sasidharan, K. Vijayakumaran Nair and E. A. Jayson, Kerala Forest Research Institute, Trichur and Dr A. G. Pandurangan, Tropical Botanic Garden and Research Institute, Palode, for suggestions and useful information. We are grateful to Prof. M. Balakrishnan, Department of Zoology, University of Kerala; Dr M. Kunhikrishnan, University College, Trivandrum and Dr Radhakrishnan, ZSI, Calicut for help. We thank the project staff K. Sriraj, B. Baijulal, and C. Anish for support in the preparation of spatial and bioresources database, and individuals and agencies who provided necessary data. We are grateful to the State Council for Science, Technology and Environment, Govt of Kerala for financial support.

Received 19 March 2005; revised accepted 27 October 2005

Developmental mode in white-nosed shrub frog *Philautus* cf. *leucorhinus*

K. V. Gururaja and T. V. Ramachandra*

Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

Direct development in amphibians bypassing intermediary tadpole stage has behavioural evolutionary and ecological significance. This paper presents direct development in *Philautus* cf. *leucorhinus*, while comparing with other congeners of the Western Ghats.

Keywords: Amphibians, direct development, *Philautus* cf. *leucorhinus*, shrub frogs, Western Ghats.

AMPHIBIANS exhibit remarkable variations in development from egg to adult. One such extreme modification is direct development, wherein free-swimming tadpole stage is completely eliminated and eggs hatch into baby frogs, resembling the adults except for their size. Species adapted completely to terrestrial living generally exhibit direct development. The advantage of being adapted to such development includes avoidance of predation, which is prevalent in aquatic media, parental care and more importantly, dependency on water body for development and complex metamorphic processes[1].

Direct development bypassing an aquatic, free-swimming tadpole stage in amphibians seems to be the fastest reproductive mechanism adapted in vertebrates and specifically among anamniotes[2,3]. Based on site of egg development, as many as 29 breeding types have been recorded in amphibians[2]. Nevertheless, direct development has an evolutionary significance in adapting to non-aquatic habitats, resembling oviparous development of birds and reptiles.

The Western Ghats, a hill range on the west coast of India, with rich biodiversity harbours as many as 137 amphibian species. Among these, *Philautus* genus (Anura: Ranidae: Rhacophorinae), commonly known as Oriental shrub frog has direct development from egg to adult.

*For correspondence. (e-mail: cestvr@ces.iisc.ernet.in)

About 90 *Philautus* species have been recorded throughout the world and over 30 species have been described from India, among which 23 are from the Western Ghats[4–8]. Rao[9] has reported tadpole stages in '*Philautus leucorhincus*' or '*Philautus leucorhyncus*', *P. hypomelas*, *P. nassutus*, *P. pulcher* and *P. variabilis*. Later, Patil and Kanamadi[3] provided a detailed description of direct development in *P. variabilis*. Similarly, Bossuyt and Dubois[4] rejected the tadpole descriptions in *P. hypomelas* by Rao[9], which is supposed to be of the genus *Nyctibatrachus*. Subsequently, direct development was reported in *P. glandulosus*[10,11] and later in *P. bobingeri*, *P bombayensis*, *P. graminirupes*, *P. nerostagona*, and *P. tinniens*[4,6,7,12,13]. The present communication reports direct development in white-nosed shrub frog, *Philautus* cf. *leucorhinus* Lichtenstein and Martens, 1856, is contrary to earlier reports of tadpole stage in its development[9,8] and only the third species from the Western Ghats to be described completely.

Philautus cf. *leucorhinus* is a small-sized arboreal shrub frog, coloured pale to dark brown on the dorsum with varied black patches, and resembles the earlier description of the species[8,14–16], (S. K. Dutta, pers. commun.). It has a hexagonal white spot on the snout tip and a dark band between eyes passes through a distinct tympanum till the shoulder. Prominent supratympanic fold. Throat speckled with brown in male. Toes half-webbed. Calling male of *P.* cf. *leucorhinus* (SVL: 28.9 mm; Figure 1 *a*) was observed from a tree trunk at a height of 2 m facing down, whereas the female (SVL: 33.7 mm; Figure 1 *b*) was observed less than a metre away at 0.3 m from the ground on a *Myristica malabarica* tree stilt root. This was observed at 2015 h IST on 14 June 2004 with incessant rain (air temperature: 28.8°C and relative humidity: 97%) from Yenneholé, Sagar taluk, Shimoga (563 m amsl; 13°57′54″N, 74°43′37″E). Pairs got amplected axially at 2315 h (Figure 1 *c*) and female carried the male to ground level. All eggs were laid on a leaf of *Hopea ponga* less than 10 cm from the ground, between two rocky boulders by morning (0600 h). Male and female got separated after the spawning process. Later eggs were collected ($N = 51$) and developmental stages were observed in the laboratory (Figure 1 *d*) at an interval of 24 h.

Diameter of eggs was 3.5 ± 0.16 mm, with a thin gelly coat. Eggs were unpigmented with uniform cream colouration. Pole differentiations followed by the process of cleavage, gastrulation and neurulation were observed within 24 h. Neural folds were seen at 24 h (Figure 2 *a*). Neural fold and neural plate elongated and formed into neural tube and at 72 h, head and tail buds were formed at the anterior and posterior ends of the neural tube respectively (Figure 2 *b*). Hind limb and forelimb buds were seen as embedded beads on the surface of the egg near the neural tube attachment region. Head, tail and limb buds elongated and were more pronounced at 96 h and eyespots as a bulged region on the lateral positions on the head were observed (Figure 2 *c*). Tail was curved to the left in all the eggs. Pigmentation was observed on the mid-dorsal line at 120 h and it spread initially along the neural tube, then on upper and lower portions of the abdomen during the entire developmental process (Figure 2 *d*). At 144 h, head and tails further elongated and pigmentation intensity also increased. Tail was translucent, flat and membranous. During the same period, pigmentation of iris and heart beats were also observed. Tail and head region differentiated further during 168 h. Hindlimb bud elongated, with recognizable differentiation of femur, tibia and foot. At 240 h, mouth-

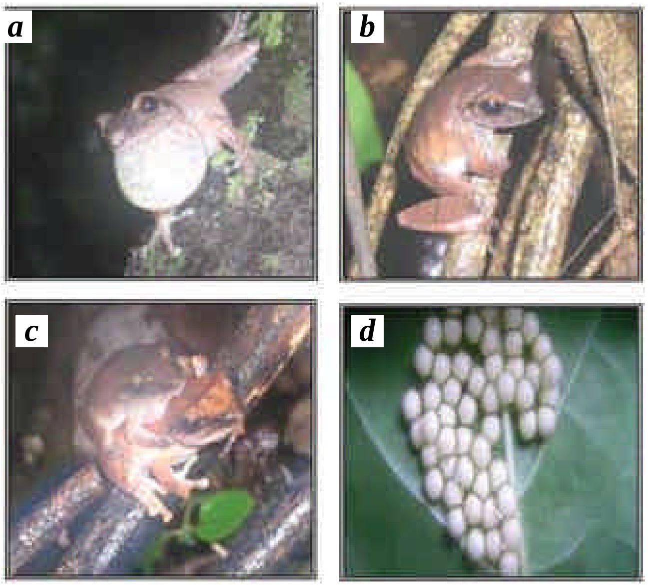


Figure 1. Amplexus and egg deposition of *Philautus* cf. *leucorhinus*. ***a***, Male (SVL: 28.9 mm); ***b***, Female (SVL: 33.7 mm); ***c***, Amplected pair and ***d***, Egg clutch (3.5 ± 0.16 mm, $N = 51$).

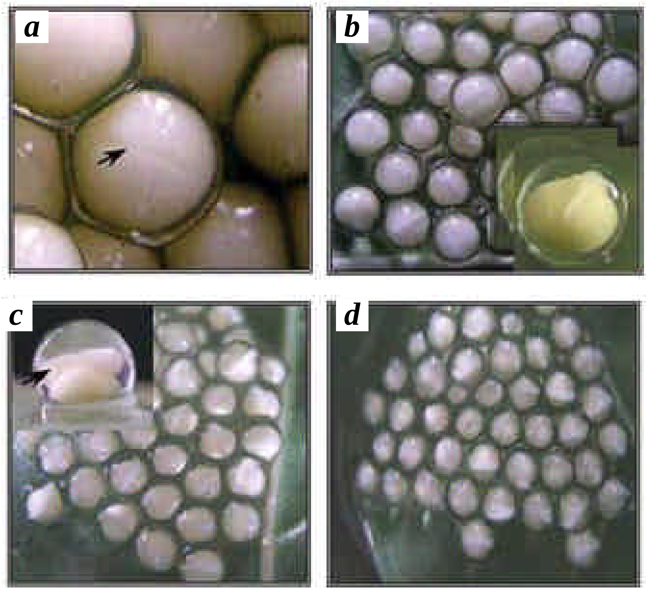


Figure 2. Developmental stages of *P.* cf. *leucorhinus* till day 5. ***a***, Neural fold at 24 h; ***b***, Head, limbbud and tail differentiation at 72 h; ***c***, Curved tail bud, bead-like limb buds at 96 h and ***d***, at 120 h.

Table 1. Various features of direct developmental pattern in *Philautus* of the Western Ghats

Species	SVL (mm)	Eggs	Days to hatch	Mode*	Habitat	Parental care	Egg diameter (mm ± SD) (*N*)	Locality	Geographic coordinates	Observation	Reference
Philautus cf. leucorhinus	♀: 33.7 ♂: 28.9	51	19	20	Above ground, (10 cm) on wet leaves, between rocks	Pair separates after spawning	3.5 ± 0.16 (51)	Yenneholé, Sharavathi River, Karnataka	13°57′54″N, 74°43′37″E, 563 m asl	14 June 2004	Present study
P. glandulosus	♀: 25; 24.5–26[#] ♂: 21; 20.4–22.9[#]	12–18; 48[#]	22; 28[#]	20	Above ground (1.5–3 m) on wet leaves	Pair separates after spawning	4.9 ± 0.9 (14); 4.4 ± 0.2 (48)[#]	Kudremukh, Karnataka; Kalpatta, Waynaad, Kerala[#]	13°10′–13°26′N, 75°05′–75°10′E, ~ 600 m asl; 11°38′N, 76°08′E, 1000 m asl[#]	12 August 2000 28 June 1997[#]	10, 11[#]
P. variabilis	♀ and ♂: 30.0 ± 4.5	54–62	12	20	Above ground	Eggs beneath abdomen of female, chasing intruding males	4.1 ± 0.2 (30)	Dharwad, Karnataka	15°17′N, 75°03′E, ~ 780 m asl	June–August 1994–96	3
P. nerostagona	♀: No report ♂: 30.1–34	41	20	20	In ~10 cm deep tree hole, 10 m above ground	–	4.5 ± 0.3 (41)	Kalpatta, Waynaad, Kerala	11°38′N, 76°08′E, ~ 1000 m asl	20 July 2000	6
P. tinniens	♀: 25 ♂: No report	–	–	17	On ground	–	–	Nilgiri hills, Tamil Nadu	11°24′N, 76°42′E, ~ 1800+ m asl	–	4, 18
P. bombayensis	♀: No report ♂: No report	26–27	–	20	Above ground, wet leaves	–	–	Sakleshpur, Karnataka	12°59′N, 75°43′E, ~ 850 m asl	29 July 1996	12
P. bobingeri	♀: 23.5–26 ♂: 21.3–24.8	24	18	20	Acacia tree, 4 m from ground	–	3.9 ± 0.4 (24)	Ponmudi hills, Kerala	8°45′N, 77°08′E, 1000 m asl	July 1999	7
P. graminirupes	♀: 27.3–29.4 ♂: 21.4–22.6	30–38	24	17	On ground, grass clump, rocky crevice	–	4.9 ± 0.5 (38)	Ponmudi hills, Kerala	8°45′N, 77°08′E, 1000 m asl	7 July 2000	8

*Based on Duellman and Trueb[2].

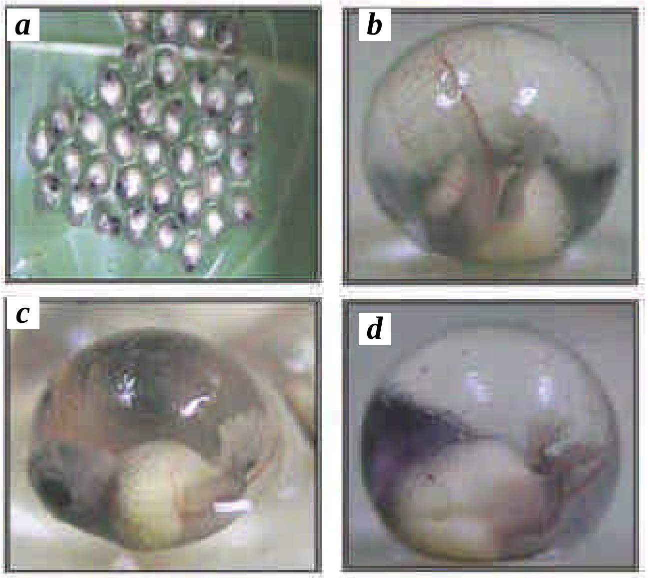


Figure 3. Developmental stages of *P.* cf. *leucorhinus* till day 13. ***a***, Mouth differentiation at 264 h; ***b***, Toe demarcation, translucent tail at 264 h; ***c***, Toe digit differentiation at 288 h and ***d***, Elongation of toe at 312 h.

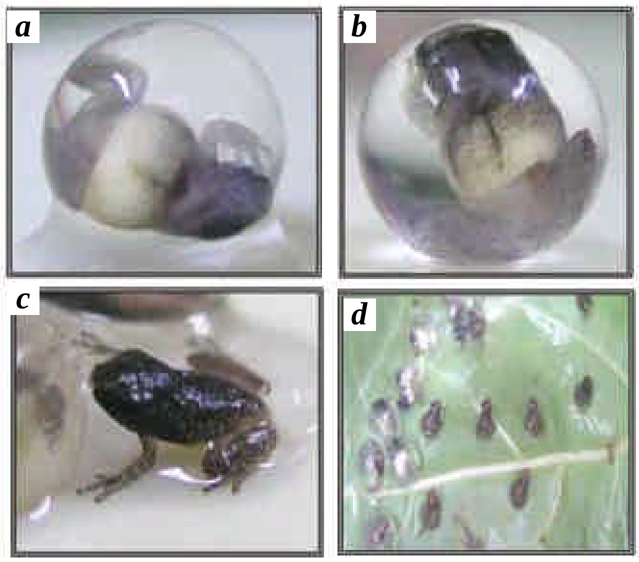


Figure 4. Developmental stages of *P.* cf. *leucorhinus* till day 19. ***a***, Finger differentiation, limb bends at 384 h; ***b***, Tiny froglet, with reduced tail at 408 h; ***c***, Hatched froglet at 432 h and ***d***, Froglets at 432 h.

parts were observed, but prominently into upper and lower lips during 336–384 h. Forelimb buds elongated during this period. Intermediate developmental stages are illustrated in Figures 3 and 4. Considerable reduction in yolk and proportional enlargement of head and elongation of hindlimb was observed. Toes emerged at 312 h, and differentiated by 336 h. By 384 h, fingers clearly differentiated and movements inside the jelly were observed. Tail and yolk got remarkably reduced during 432 h and tiny froglets measuring 4.54 ± 0.07 mm emerged out after 19 days (Figure 4 *c* and *d*).

Analysis of the intra group developmental stages of *P.* cf. *leucorhinus* with *P. glandulosus* and *P. variabilis* from the Western Ghats, shows that within 144 h, major developmental stages like demarcation of head, mouth, eye, fore limbs and hind limbs take place and the remaining period (that varies from species to species) is utilized for differentiation of fingers, toes, mouth parts, eyes and overall morphology of the body with utilization of yolk and regression of tail, which supposedly has a respiratory function[17]. Except for the variation in hatching periods, developmental pattern remains the same. However, the significant differences observed between these three species in female sizes, number of eggs and hatching periods might be attributed to the influence of environmental factors associated with their microhabitats. Table 1 compares the pattern of direct development in various *Philautus* species available in the Western Ghats. It was observed that the number of eggs in a clutch depends on the size of the female ($r = 0.85$, $P < 0.05$). Size of female, egg diameter and period of hatching are negatively influenced by each other; however, they are not statistically significant. All these observations were made during June to August (the period of the southwest monsoon in this region) highlighting the breeding period of the species.

There is an urgent need to look into the molecular, developmental and evolutionary aspects in detail to understand the phylogeography of the species from the Western Ghats, considering frequent reporting of new species in *Philautus* genus (since 2001, six species out of eight anurans were discovered from the Western Ghats).

1. Shi, Y.-B., *Amphibian Metamorphosis: From Morphology to Molecular Biology*, John Wiley, New York, 2000, p. 288.
2. Duellman, W. E. and Trueb, L., *The Biology of Amphibians*, McGraw-Hill, New York, 1994, p. 696.
3. Patil, N. S. and Kanamadi, R. D., Direct development in the rhacophorid frog, *Philautus variabilis* (Günther). *Curr. Sci.*, 1997, **73**, 697–701.
4. Bossuyt, F. and Dubois, A., A review of the frog genus *Philautus* Gistel, 1848 (Amphibia, Anura, Ranidae, Rhacophorinae). *Zeylanica*, 2001, **6**, 1–122.
5. Kuramoto, M. and Joshy, S. H., Two new species of the genus *Philautus* (Anura: Rhacophoridae) from the Western Ghats, southwestern India. *Curr. Herpetol.*, 2003, **22**, 51–60.
6. Biju, S. D. and Bossuyt, F., A new species of frog (Ranidae, Rhacophoridae, *Philautus*) from the rainforest canopy in the Western Ghats, India. *Curr. Sci.*, 2005, **88**, 175–178.
7. Biju, S. D. and Bossuyt, F., Two new *Philautus* (Anura: Ranidae: Rhacophorinae) from Ponmudi Hill in the Western Ghats of India. *Copeia*, 2005, **1**, 29–37.
8. Daniels, R. J. R., *Amphibians of Peninsular India*, Universities Press (India) Pvt Ltd, Hyderabad, 2005, p. 267.
9. Rao, C. R. N., On some new forms of *Batrachia* from S. India. *Proc. Indian Acad. Sci.*, *Sect. B*, 1937, **VI**, 387–427.
10. Krishnamurthy, S. V., Gururaja, K. V. and Manjunatha Reddy, A. H., Direct development in *Philautus glandulosus* (Anura: Rhacophoridae). *Herpetol. Nat. Hist.*, 2002, **9**, 97–102.

11. Biju, S. D., Reproductive mode in the shrub frog *Philautus glandulosus* (Jerdon, 1853) (Anura: Rhacophoridae). *Curr. Sci.*, 2003, **84**, 283–284.
12. Bossuyt, F., Roelants, K., Spithoven, L. and Daro, M. R., *Philautus bombayensis* (Bombay Oriental shrub-frog) reproduction. *Herpetol. Rev.*, 2001, **32**, 34–35.
13. Bossuyt, F., A new species of *Philautus* (Anura: Ranidae) from the Western Ghats of India. *J. Herpetol.*, 2002, **36**, 656–661.
14. Boulenger, R. A., *The Fauna of British India including Ceylon and Burma* (ed. Blanford, W. T.), Taylor and Francis, London, 1890, p. 541.
15. Thurstan, E., *Catalogue of the Batrachia*, *Salientia and Apoda* (*Frogs*, *Toads and Caecilians*) *of south India*, Superintendent, Government Press, Madras, 1988, p. 54.
16. Dutta, S. K. and Arachchi, K. M., *The Amphibian Fauna of Sri Lanka*, Wildlife Heritage Trust of Sri Lanka, Colombo. 1996, p. 230.
17. Townsend, D. S. and Stewart, M. M., Direct development in *Eleutherodactylus coqui* (Anura: Leptodactylidae): a staging table. *Copiea*, 1985, **2**, 423–436.
18. Dubois, A., Diagnose préliminaire d'un nouveau genre de Ranoidea (Amphibiens, Anoures) du sud de l'Inde. *Alytes*, 1986, **4**, 113–118.

ACKNOWLEDGEMENTS. We are grateful to the ISRO–IISc-Space Technology Cell; the Ministry of Environment and Forests, GOI; Indian Institute of Science, Bangalore for sustained financial as well as infrastructure support. We thank Karnataka State Forest Department for granting necessary permission. We thank Prof. S. K. Dutta for invaluable suggestions on the manuscript and species identification. We thank Sameer Ali, Karthick, Vishnu and Lakshminarayan for their assistance during fieldwork, and Sreekantha and Sudhira for suggestions on the manuscript.

Received 2 May 2005; revised accepted 10 October 2005

ZOOLOGICAL SCIENCE **24**: 525–534 (2007)

A New Frog Species from the Central Western Ghats of India, and Its Phylogenetic Position

Kotambylu Vasudeva Gururaja[1], Nilavara Anantharama Aravind[2], Sameer Ali[1], T.V. Ramachandra[1], Thirumalaisamy Palanichamy Velavan[3], Vaithilingam Krishnakumar[3] and Ramesh Kumar Aggarwal[3*]

[1]*Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560012, India*
[2]*Ashoka Trust for Research in Ecology and Environment, 659, 5th A Main Road, Hebbal, Bangalore 560024, India*
[3]*Molecular Markers Lab, Centre for Cellular and Molecular Biology, Uppal Road, Tarnaka, Hyderabad 500007, India*

Tropical evergreen forests of Indian subcontinent, especially of the Western Ghats, are known hot spots of amphibian diversity, where many new anuran species await to be identified. Here we describe from the Sharavathi River basin of central Western Ghats a new shrub-frog taxon related to the anuran family Rhacophoridae. The new frog possesses the characteristic features of rhacophorids (dilated digit tips with differentiated pads circumscribed by a complete groove, intercalary cartilages on digits, T-shaped terminal phalanges and granular belly, the adaptive characters for arboreal life forms), but also a suite of unique features that distinguish it from all known congeners in the region. Morphogenetic analysis based on morphological characteristics and diversity in the mitochondrial 12S and 16S rRNA genes revealed it to be a new *Philautus* species that we named *Philautus neelanethrus* sp. nov. The phylogenetic analysis suggests the new frog to represent a relatively early *Philautus* species lineage recorded from the region. The distribution pattern of the species suggests its importance as a bioindicator of habitat health. In general, this relatively widespread species was found distributed only in non-overlapping small stretches, which indirectly indicates the fragmentation of the evergreen to moist deciduous forests that characterize the Western Ghats. Thus the discovery of the new rhacophorid species described here not only further reinforces the significance of the Western Ghats as a major hotspot of amphibian biodiversity, but also brings into focus the deterioration of forest habitats in the region and the need for prioritization of their conservation.

Key words: amphibian biodiversity, conservation, shrub frog, Western Ghats, habitat, rDNA diversity

INTRODUCTION

The Western Ghats, a chain of hills of varied width and height running parallel to the western coast of India, is a hotspot of biological diversity (Myers *et al.,* 2000). This region harbors a high proportion of endemic species, especially in lower-vertebrate group such as amphibians, reptiles and fishes (Daniels, 2001; Dahanukar *et al.,* 2004); this endemism has been attributed to the prevailing geographical, climatic and phenological conditions providing the necessary humid environment and habitat (Roelants *et al.,* 2004). Amphibians form an important faunal group of this region, but are incompletely documented (Bossuyt, 2002); some represent disjunct populations that necessitate the integrated morphological and molecular analyses to resolve their phylogeography (Karanth, 2003).

It is quite evident that the Western Ghats, as a part of the Old World region, represent a Cenozoic refugium for old lineages and a unique reservoir of ancient endemic anurans (Duellman, 1999; Roelants *et al.,* 2004). In recent years, there has been increasing interest worldwide in understanding the biogeography and evolutionary lineages of amphibians of the Western Ghats, especially in relation to their links with Madagascar's fauna and to patterns of amphibian dispersal in the Indian Ocean region (Vences *et al*., 2003). With the discovery of a new primitive frog, it was established that India had an ancient biogeographical link with the Seychelles, and that amphibian endemism in the region dates back to 150–195 Mya (Biju and Bossuyt, 2003; Dutta *et al.,* 2004). Several lineages may have originated on the Indian subcontinent during the trans-Tethys drift (Bossuyt and Milinkovitch, 2001).

Approximately 500 species of ranids have been recorded in the Oriental realm. To date about 135 species have been recorded from the Western Ghats (Gururaja,

* Corresponding author. Phone: +91-40-27192635;
Fax : +91-40-27160591;
E-mail: rameshka@ccmb.res.in
doi:10.2108/zsj.24.525

2004), of which over 100 (nearly 75%) are endemic to the region. The order Anura is represented by 109 species, including members of the Rhacophoridae. Species of the genus *Philautus* in the family Rhacophoridae form a unique group because they undergo direct development, wherein the tadpole stage is avoided (Marmayou *et al.,* 2000). Since the recent revision of the genus *Philautus* (Bossuyt and Dubois, 2001), several new *Philautus* species have been described from the Western Ghats (Kuramoto and Joshy, 2003; Bossuyt, 2002; Biju and Bossuyt, 2005a, b), which strongly reinforces that this region is a center of amphibian diversity, where many more new species await description (Aravind *et al.,* 2004; Gower *et al.,* 2004). However, this pristine biogeographic reservoir of evolutionary history in the Western Ghats is now threatened by heavy human demographic pressure and interference (Aggarwal, 2004; Dutta *et al.,* 2004), warranting urgent protective measures and a preemptive conservation strategy. We here describe a new species of *Philautus* and analyze its phylogenetic relationships. Our results further highlight the significance of the Western Ghats as hotspot of amphibian diversity and the need for prioritization of its conservation.

MATERIALS AND METHODS

Study area

The Sharavathi River basin is situated in the central part of the Western Ghats (Fig. 1). The Sharavathi River originates at Ambuthirtha and flows towards west for about 132 km before joining the Arabian Sea at Honnavar. The type specimens of the new frog species described in this study were collected during stratified systematic sampling (Heyer *et al.,* 1994) with time-constrained and search-all methods (Vasudevan *et al.,* 2001). The type locality is Arodi, Sagar Taluk, Shimoga District, Karnataka state (14°08'25"N, 74°47'44"E), 534 m asl (meters above sea level), a moist deciduous forest patch. The region has an undulating terrain, with forests of evergreen and moist-deciduous types. Relatively flat areas within this terrain form a freshwater habitat known as *Myristica* swamps, dominated by members of plant family Myristicaceae. Localities across the study area where the new species was found are listed in Table 1.

Sampling

The new frog species was recorded in the study area (Fig. 1) over a period of 4 years since 2001. Although more than 150 specimens were enumerated during multiple field explorations, only nine individuals of the new species (including holotype and paratypes)

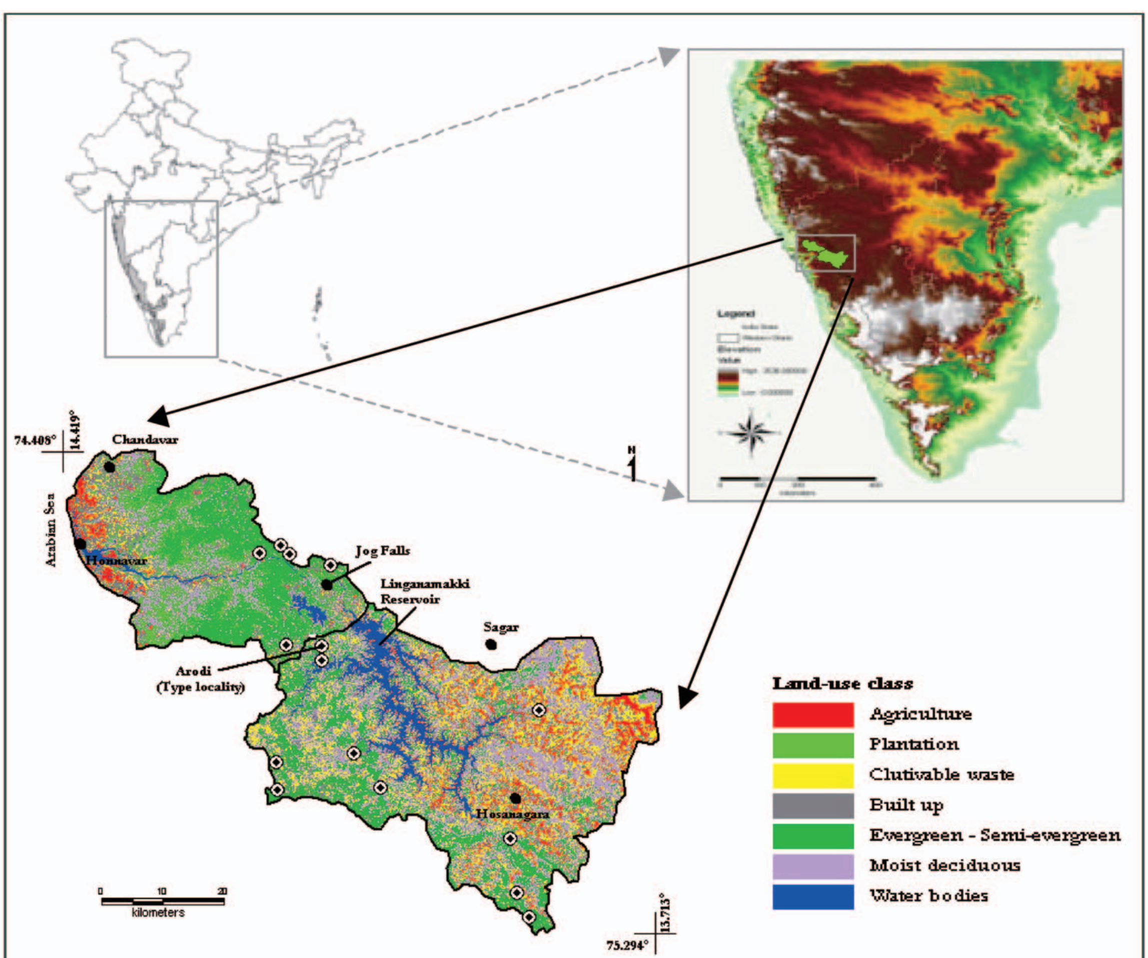


Fig. 1. Sharavathi River basin and the type localities of the new *Philautus* species.

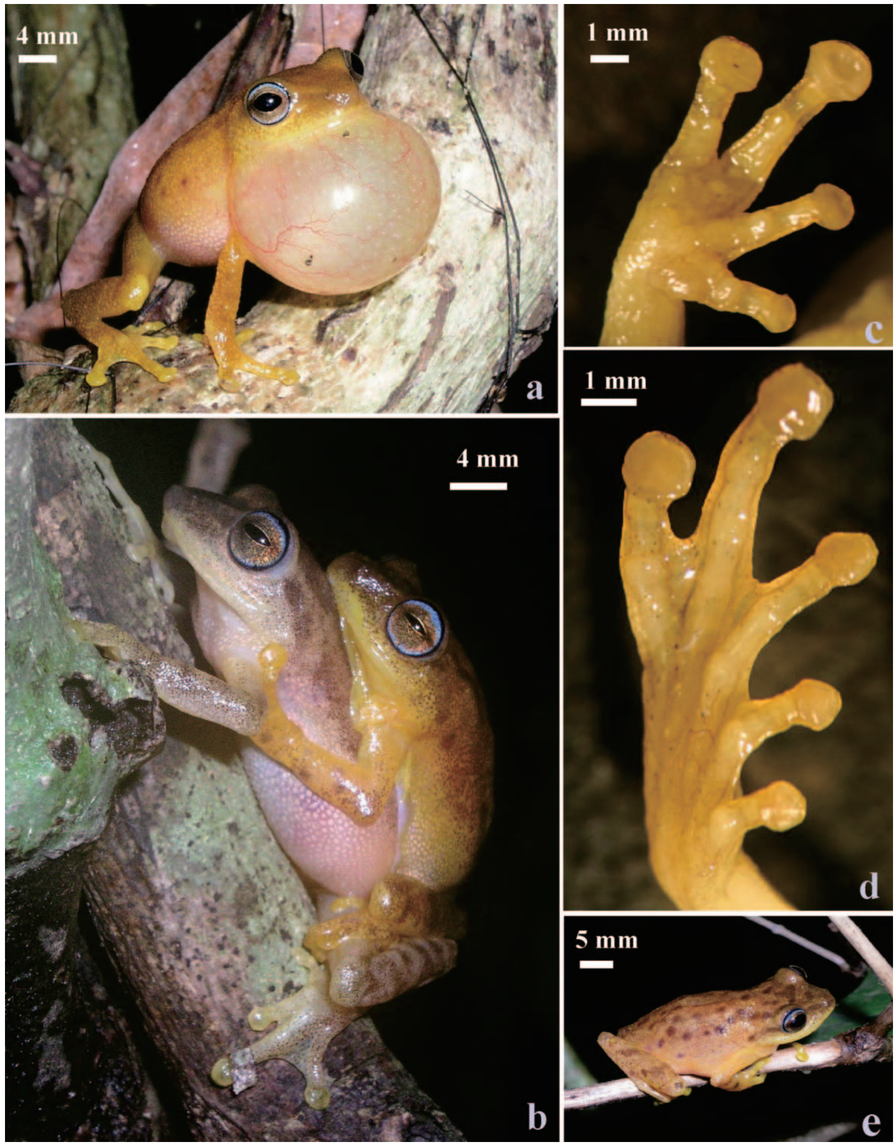


Fig. 2. Characteristic features of *P. neelanethrus* sp.nov. **(a)** Male while calling (SVL 29.8 mm, collected from the Nandiholé locality); **(b)** amplected pair (specimens not collected); **(c)** ventral view of forelimb; **(d)** ventral view of hindlimb; **(e)** dorsolateral view of an adult male.

Table 1. Localities across the central Western Ghats, India, where *Philautus neelanethrus* sp. nov. was recorded.

Area	Altitude (m asl)	Habitat
Kathalekan	619	*Myristica* swamp
Niluvase	692	Evergreen
Malemane1	603	Evergreen
Malemane2	615	Evergreen
Hilkunjiholé	599	Evergreen
Karni	598	Evergreen
Mavingundi	583	Evergreen
Nagodiholé	580	Evergreen
Dabbefall	566	Evergreen
Yenneholé	563	Evergreen
Hurliholé	598	Moist deciduous
Sharavathi	586	Moist deciduous
Muppane	571	Moist deciduous
Nandiholé	557	Moist deciduous
Arodi	534	Moist deciduous

were collected, on different dates by KVG, NAA and SA. The specimens were used for detailed morphometric description, as well as for molecular analysis to resolve its taxonomic status. Adult specimens of the new frog species were deposited in the Bombay Natural History Museum (BNHS), Mumbai (Holotype, BNHS-4510; Paratype, BNHS-4511) and in the museum of the Zoological Survey of India (ZSI), Kolkata, India (Paratype ZSI-A9866). Specimens were collected from the type locality, photographed, euthanized, and preserved in salt saturated 20% DMSO (dimethyl sulfoxide) solution and/or 80% ethanol. The preserved specimens were used for morphometric studies, and soft tissues taken from the same specimens were used to extract genomic DNA for molecular analysis.

Type specimens

Holotype (BNHS-4510): adult male, SVL 29.9 mm, collected at Arodi in the Sharavathi River basin on 7 July 2005 by KVG. Paratypes, two adult males: SVL 23.4 mm (ZSI-A9866) collected at Niluvase (13°44’18”N, 75°06’30”E; 692 m asl) on 6 November 2003 by KVG; SVL 28.7 mm (BNHS-4511) collected at Arodi (14°08’25”N,

Table 2. Morphometric measurements of *Philautus neelanethrus* sp. nov. (values are in millimeters, n=9, all males).

Parameter*	Mean±SD (n=9)	Range	Holotype (BNHS–4510)	Paratype (BNHS–4511)
SVL**	25.41±3.403	21.4–29.9	29.9	28.7
EL**	3.90±0.301	3.5– 4.4	4.1	4.1
EN**	2.66±0.205	2.5– 3.1	2.8	2.5
HL**	8.00±0.948	6.8– 9.1	9.0	9.1
HW**	9.54±1.334	7.8–10.8	10.8	10.7
IBE	8.81±1.108	7.6–10.2	10.0	10.2
IFE	4.94±0.777	4.0– 6.1	6.1	6.0
IN**	2.29±0.393	1.6– 2.7	2.4	2.7
IUE**	3.43±0.285	2.9– 3.8	3.8	3.6
MBE	1.78±0.285	1.3– 2.2	2.1	1.7
MFE	4.78±0.591	4.2– 5.7	5.7	5.5
MN	6.88±1.003	5.0– 8.2	8.2	8.0
NS**	1.30±0.247	1.0– 1.7	1.4	1.5
SL	3.66±0.403	3.1– 4.2	4.1	3.7
TYD**	No value	–	Absent	Absent
TYE	No value	–	Absent	Absent
UEW**	1.83±0.389	1.2– 2.8	2.2	2.4
fd_3	1.78±0.140	1.6– 1.9	1.8	1.9
FLL	6.35±0.833	4.8– 7.2	7.1	6.8
fw_3	0.77±0.163	0.7– 1.0	0.7	1.0
HAL**	7.91±0.442	7.4– 8.2	8.2	8.2
TFL**	5.65±0.980	4.6– 7.4	4.7	4.9
FFTF	4.97±0.203	4.8– 5.2	5.2	4.8
FL**	12.93±1.509	11.0–15.1	15.1	14.4
FOL**	9.80±1.581	7.7–12.0	12.0	11.4
FTL**	7.45±0.627	6.6– 8.1	7.0	6.7
IMT**	1.01±0.089	0.9– 1.1	0.9	1.1
ITL**	2.34±0.364	2.0– 3.1	2.0	2.3
MTFF	6.46±0.476	5.9– 6.7	6.7	6.7
MTTF	6.03±0.421	5.6– 6.4	6.4	6.1
td_4	1.61±0.110	1.5– 1.7	1.7	1.6
TFOL**	16.74±2.420	13.5–19.8	19.8	19.6
TFTF	5.14±0.104	5.1– 5.3	5.3	5.1
TL**	12.87±1.491	10.6–15.3	14.3	13.5
TW	2.24±0.566	1.4– 3.1	3.1	3.1
tw_4	0.92±0.185	0.7– 1.0	1.0	1.0

* See Supplemental Table 1 for explanation of abbreviations for various parameters.

** Parameters used for morphometric comparisons with congeners; for morphometric and meristic data on congeners, see Supplemental Tables 2 and 4.

74°47'44"E; 534 m asl) on 7 July 2005 by KVG.

Morphometric analysis

Nine individuals of new species were used for morphometric measurements. Thirty-five morphometric measurements were taken to the nearest 0.1 mm with digital slide calipers (Mitutoyo Corporation, Japan, CD-6BS) for each of the specimens (Table 2). Terminology (Supplemental Table 1) used in the description is based on Bossuyt and Dubois (2001).

A cluster analysis based on unweighted pair-group averages (UPGA) was used to understand the relationship of the new species to other, known congeners (Supplemental Tables 2, 3), and included data on 19 morphometric and three meristic characters (Table 2, Supplemental Table 4). The analysis was carried out using the software package STATISTICA (StatSoft Inc.).

Advertisement call analysis

Advertisement calls of the new species were recorded with a digital voice recorder (W-10, Olympus, Japan). A total of 16 calls from seven individuals were recorded at five different localities in the study area. Spectral features of the advertisement calls were analyzed using Sigview (version 1.91) acoustical software (SignalLab, Goran Obradovic).

Call-pattern characteristics of *P. neelanethrus* sp. nov. (n=16) were also compared with those of one of its closest congeners, *P. luteolus*, using Bartlett's test for homogeneity and significance of variances (Snedecor and Cochran, 1989). The data for *P. luteolus*, comprising six acoustic parameters based on 51 call samples, were taken from Kuramoto and Joshy (2001), where *P. luteolus* was referred to as *P.* cf. *travancoricus*. Parameters considered were total call duration, call duration in the fast and slow phases, number of pulses in the fast and slow phases, and frequency range.

DNA extraction and rDNA sequencing

Ribosomal typing was carried out to establish the species status of the new frog taxon. Total genomic DNA was extracted from muscle tissues, taken from preserved specimens collected from different localities, by the proteinase K, phenol-chloroform-isoamyl alcohol method (Shanker *et al.,* 2004). The DNA samples were used to determine molecular diversity across the 12S and 16S mitochondrial rRNA genes, in order to ascertain the species uniqueness and phylogenetic position of the new taxon. Parts of the 16S (~575 bp) and 12S rDNA (~435 bp) genes were amplified and sequenced as described by Dutta *et al.* (2004). Each sample was sequenced three times for both strands to confirm the sequence data. Sequences have been deposited in GenBank under accession numbers AY763797 (12S rDNA, 415 bp) and AY753560 (16S rDNA, 546 bp).

Phylogenetic analysis

The 12S and 16S rDNA sequences of the new frog taxon were used in similarity-based BLAST searches of the NCBI-GenBank database (National Center for Biotechnology Information, USA; http://www.ncbi.nlm.nih.gov) to identify related reference anuran species. Initially, corresponding sequences of >100 different reference anuran species were retrieved from the database. The final phylogenetic analysis included reference sequences for only 35 taxa, mainly of different *Philautus* species (Table 3), to ascertain the phylogenetic position of the new species, and also for possible molecular dating.

All sequences were aligned using the CLUSTAL-X program and then checked for large gaps. The aligned sequences were terminated flush at the ends to avoid missing data for any of the compared reference entries. Three aligned sequence sets, one each for 12S and 16S rDNA and one for combined 12S+16S, were used separately to derive corrected Kimura two-parameter distance estimates (Kimura, 1980) and to infer the phylogenetic position of the new taxon. Neighbor-joining trees were constructed with analytical routines available in the software packages PHYLIP 3.6 (http://evolution.genetics.washington.edu/phylip.html) and MEGA 2.1 (http://www.megasoftware.net). Character state-based maximum likelihood (ML) and maximum parsimony (MP) phylogenetic trees were also constructed using PhyloWin (http://pbil.univ-lyon1.fr/software/phylowin.html). In order to test for earliest branching patterns, all substitutions were considered, and separate analyses were conducted for assumed transition/transversion rate ratios (k) of 2 and 4. Support for nodes on the shortest tree and estimates of divergence time were derived using 1,000 bootstrap pseudoreplicates. The relative-rate test was performed to test the molecular clock hypothesis with MEGA 2 using Tajima's algorithm for clock hypotheses. In the final analysis, the phylogenetic trees were rooted using a representative species from each of the families, Dicroglossidae, Nyctibatrachidae, and Ranidae (Table 3).

Table 3. Details of the 12S and 16S rDNA sequences of the reference anuran taxa used in the final phylogenetic analysis (all sequences were retrieved from the NCBI-GenBank database).

Family	Sub-family	Genus	Species	16S rDNA	12S rDNA	Distribution
New frog species sequenced in the present study						
Rhacophoridae	Rhacophorinae	*Philautus*	*neelanethrus* sp. nov.	AY753560	AY763797	India
Ingroup Reference sequences						
Rhacophoridae	Rhacophorinae	*Philautus*	*luteolus*	AB167932	AB167904	India
Rhacophoridae	Rhacophorinae	*Philautus*	*wynaadensis*	AF249059	AF141796	India
Rhacophoridae	Rhacophorinae	*Philautus*	*microtympanum*	AF249046	AF249030	Sri Lanka
Rhacophoridae	Rhacophorinae	*Philautus*	*femoralis*	AY141833	AY141787	Sri Lanka
Rhacophoridae	Rhacophorinae	*Philautus*	*signatus*	AY141841	AY141795	India
Rhacophoridae	Rhacophorinae	*Philautus*	*charius*	AF249062	AY141794	India
Rhacophoridae	Rhacophorinae	*Philautus*	*aurifasciatus*	AY141851	AY141805	Java
Rhacophoridae	Rhacophorinae	*Philautus*	*petersi*	AF026366	AF026349	Malaya
Rhacophoridae	Rhacophorinae	*Philautus*	Sp. TBGRI*A*	AY880510	AY880596	India
Rhacophoridae	Rhacophorinae	*Philautus*	Sp. TBGRI*B*	AY880506	AY880592	India
Rhacophoridae	Rhacophorinae	*Philautus*	*griet*	AF536203	AY706108	India
Rhacophoridae	Rhacophorinae	*Philautus*	*schmarda*	AY880530	AY880617	Sri Lanka
Rhacophoridae	Rhacophorinae	*Philautus*	Sp. WHT3420	AY880515	AY880601	Sri Lanka
Rhacophoridae	Rhacophorinae	*Philautus*	*ingeri*	AY880496	AY880581	Malaya
Rhacophoridae	Rhacophorinae	*Philautus*	Sp. Java	AY880509	AY880595	Java
Rhacophoridae	Rhacophorinae	*Philautus*	*mjobergi*	AF026365	AF026348	Malaya
Rhacophoridae	Rhacophorinae	*Philautus*	*acutirostris*	AY326059	AY326059	Philippines
Rhacophoridae	Rhacophorinae	*Rhacophorus*	*pardalis*	AF215363	AF215189	Malaya
Rhacophoridae	Rhacophorinae	*Rhacophorus*	*malabaricus*	AF249050	AF249029	India
Rhacophoridae	Rhacophorinae	*Rhacophorus*	*arboreus*	AF458142	AF118476	Japan
Rhacophoridae	Rhacophorinae	*Polypedates*	*maculatus*	AF215358	AF215184	India
Rhacophoridae	Rhacophorinae	*Polypedates*	*cruciger*	AF215357	AY141799	Sri Lanka.
Rhacophoridae	Rhacophorinae	*Polypedates*	*leucomystax*	AF215343	AF161037	India
Rhacophoridae	Rhacophorinae	*Aglyptodactylus*	*madagascariensis*	AF458119	AF026341	Madagascar
Rhacophoridae	Rhacophorinae	*Boophis*	*erythrodactylus*	AF215339	AF026343	Madagascar
Rhacophoridae	Rhacophorinae	*Chirixalus*	*eiffingeri*	AF026363	AF026346	China
Rhacophoridae	Rhacophorinae	*Chirixalus*	*idiootocus*	AY141852	AY141806	China
Rhacophoridae	Rhacophorinae	*Chirixalus*	*palpebralis*	AF458130	AF458130	China
Rhacophoridae	Rhacophorinae	*Chirixalus*	*vittatus*	AF458131	AF161042	Myanmar
Rhacophoridae	Rhacophorinae	*Theloderma*	*corticale*	AF268256	AF268254	Vietnam
Rhacophoridae	Rhacophorinae	*Mantella*	*betsileo*	AF215282	AF215174	Madagascar
Rhacophoridae	Rhacophorinae	*Mantidactylus*	*boulengeri*	AF215318	AF215152	Madagascar
Reference sequences used as outgroup in the final analysis						
Ranidae		*Rana*	*temporalis*	AF249054	AF249022	India
Dicroglossidae		*Euphlyctis*	*cyanophlyctis*	AY014366	AF249015	India
Nyctibatrachidae		*Nyctibatrachus*	*major*	AF249052	AF249017	India

RESULTS

Taxonomy

Philautus neelanethrus sp. nov.

Diagnosis. A small sized frog, described as *Philautus* (Male: 23.2–29.9 mm SVL) based on small size, all digits with well-differentiated disks, predominantly inhabiting in shrubs, and presumably having direct development, is distinguished from all known congeners in the Western Ghats by the combination of absence of tympanum and supratympanic fold, both dorsal and ventral surfaces granular, unpigmented vocal sac (Fig. 2a, e), yellow to cream body coloration with minute brown dots and larger brown patches on the back, and a complete blue ring on the outer margins of the golden pupil.

Etymology. The species name *neelanethrus* is derived from Sanskrit meaning 'blue eye', and is a nominative singular noun standing in apposition to the generic name.

Description of the holotype (Male, BNHS-4510). A small-sized bush frog (SVL=29.9 mm), width of head broader than head length (HW=10.8 mm; HL=9.0 mm), flat dorsally, snout pointed in total profile, protruded slightly beyond mouth. Snout length is equal or subequal to diameter of eye (SL=4.1 mm; EL=4.1 mm). Canthus rostralis angular, loreal region slightly concave. Inter orbital distance (IUE=3.8 mm) flat and broader than upper eyelid (UEW=2.2 mm), wider than internarial distance (IN=2.4 mm). Internal distance between posterior margins of the eyes 1.64 times that of anterior margins (IFE=6.1 mm, IBE=10.0 mm). Nostrils oval, nearer tip of snout (NS=1.4 mm) than eye (EN=2.8 mm). Pineal ocellus absent. Vomerine ridge absent. Eyes protruding, prominent, pupil rounded, horizontal, with blue ring on the outer margin. Tympanum indistinct. Tongue bifid, without papilla, Supratympanic fold obscure/absent (intense brown dots indicate the fold), unpigmented single vocal sac present. In alcohol-preserved specimens, the blue ring on the eye turns dark blue in color.

Forearm (FLL=7.1 mm) less than hand (HAL=8.2 mm). Relative length of fingers I<II<IV<III. Finger tips with well-developed disks (fd_1=1.0 mm; fd_2=1.3 mm; fd_3=1.8 mm; fd_4=1.7 mm; fw_1=0.7 mm; fw_2=0.7 mm; fw_3=0.7 mm; fw_4=0.8 mm), with distinct circum-marginal grooves, fingers with dermal fringes on both edges. Webbing in hand absent, subarticular tubercles prominent, rounded and single, pre-pollex tubercle oval, distinct (Fig. 2c).

Hindlimbs long, heels do not overlap when folded at right angles to the body, tibia 4.6 times longer than wide (TL=14.3 mm, TW=3.1 mm). Tibia shorter than femur (FL=15.2 mm). Tibia longer than foot (FOL=12.0 mm). Heel to tip of fourth toe (TFOL=19.8 mm) 2.8 times length of fourth toe (LT_4=7.0 mm). Relative toe lengths I<II<III<V<IV. Toe disk width and toe width are: td_1=1.0 mm, td_2=1.0 mm, td_3=1.1 mm, td_4=1.7 mm, td_5=1.5 mm, tw_1=0.7 mm, tw_2=0.7 mm, tw_3=0.9 mm, tw_4=1.0 mm, tw_5=1.0 mm. Webbing distinct and medium (MTTF=6.4 mm, MTFF=6.7 mm, TFTF=5.3 mm, FFTF=5.2 mm). Tibiotarsal articulation reaches anterior border of eye. Inner metatarsal tubercle present (IMT=0.9 mm), nearly 2.6 times length of first toe (ITL=2.0 mm) (Fig. 2d).

Overall coloration of the male of *P. neelanethrus* sp. nov. (live specimen) yellowish (during breeding season) to creamish white (non-breeding season). Abdominal region turned pink during and after advertisement-call bouts. Dorsum with varied intensity of brown granulation. Skin on dorsal as well as on ventral surface granular. Granulation on ventral surface round and white, on dorsum brownish. Feeble cross bars present on forelimbs and hindlimbs. Circular brown patches (region with more brown granules) on head (4–5 in a line) and nearer to vent (1–2). In alcohol-preserved specimens, the overall yellow coloration turned to cream and the blue-colored ring around the eye turned to dark blue/black, but there were no changes in the brown pigmentation. The morphological measurements were based on nine specimens, with ranges, means, and standard deviations detailed in Table 2.

During one of the field surveys, an amplected pair was spotted wherein the female was larger than the male (Fig. 2b). The female was cream colored with brownish black granulation on the body. We observed this pair for more than 9 hours (from 21:30 to 6:30 h), during which time the amplected pair descended from a shrub and entered a leaf-litter heap, making their way into a cavity inside the wet foliar litter.

Advertisement calls. The mating call of *P. neelanethrus* sp. nov. starts with a shrill 'treeek' note followed by repeated 'tink' notes (treeek – tink-tink-tink-tink-……………….-tink). Variation was observed in the duration and pattern of calling, even though call notes and peak frequencies remained same. Calls were in the region of 2.35–2.41 kHz, and peak frequency was 2.35 kHz. The spectrogram of a call lasting for 6.6 sec, generated from a single call of a 29 mm *P. neelanethrus* sp. nov. male at 20:30 h on 18 June 2004, at 26.8°C (97% relative humidity), within 50 cm from the species and approximately 2 m above the ground, is shown in Fig. 3. Calling patterns analyzed using 16 calls (total duration of each call [mean±SD] 3.86±0.312 sec, range 1.93–

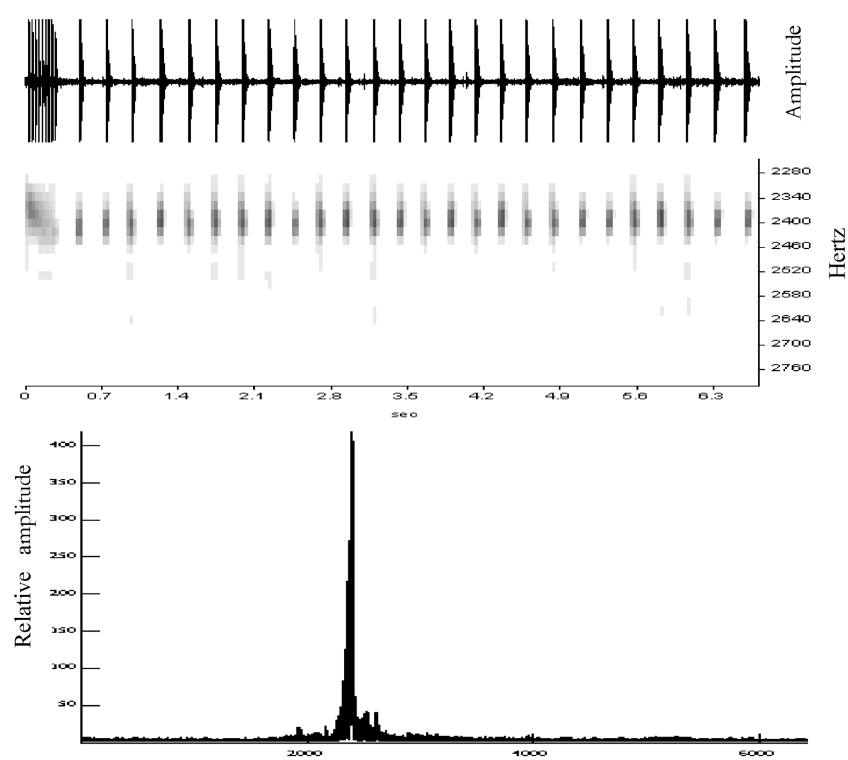


Fig. 3. Advertisement call spectrogram of *P. neelanethrus* sp.nov.

14.35 sec) revealed two types of calls, one with repeated short-duration calls (call duration 0.33±0.04 sec, range 0.27–0.42; number of pulses 10.88±1.654, range 9–15) and another with long-duration calls (call duration 3.34±3.029 sec, range 1.42–13.84; number of pulses 13.6±13.3, range 6–60). Two exceptionally long-duration calls examined (not included in the analysis) were 39.77 sec and 71.92 sec in duration, with 101–191 tinking notes.

The Bartlett test of homogeneity of variances revealed significant differences in many call characteristics of *P. neelanethrus* sp. nov. from *P. luteolus*, as evident from the χ^2 values for peak frequency, total duration, slow-phase duration, and number of pulses.

Comparison with congeners. As many as 118 valid species names are recognized in *Philautus* (Manamendra-Arachchi and Pethiyagoda, 2005), and we examined the nomenclature of all of them. For morphometric comparisons, data from 14 congeners (Supplemental Table 2) among the 20 available names (Supplemental Table 3) endemic to the Western Ghats, and *P. longicrus* (a species described from Borneo and Philippines, but included in the Indian frog fauna by some workers; Rao, 1937), were included in an unweighted pair-group average cluster analysis. The data on 19 morphometric and three meristic characters for the 15 reference taxa used for the cluster analysis are shown in Supplemental Table 4. As systematic morphometric information was not available for six congeneric species (Supplemental Table 3), these were not included in the cluster analysis; nonetheless, their known morphological features such as pointed snout, supratympanic fold, tympanum, granulation on dorsum and belly, and dorsum coloration, were used for comparisons to distinguish *Philautus neelanethrus* sp. nov. from each of them. *Philautus* taxa from Sri Lanka were not used for comparisons, as advocated by Manamendra-Arachchi and Pethiyagoda (2005).

With relatively small size (21.4–29.9 mm), yellow to cream coloration on the body, lack of tympanum, indistinct supratympanic fold, granular dorsum and ventral region, blue-colored outer margins of the eye, and distinct calling pattern, the new species clearly differs from all congeners. *Philautus neelanethrus* sp. nov is distinct from *P. beddomi, P. bombayensis, P. chalazodes, P. femoralis,* and *P. travancoricus* in having a pointed snout. It is distinct from *P. temporalis* in the absence of a tympanum and a distinct supratympanic fold. Apart from these, the dorsal coloration in *P. beddomi*, *P. chalazodes, P. femoralis*, and *P. temporalis* varies from green to brown, whereas in *P. neelanethrus* sp. nov. it is yellowish. Moreover, while the dorsum is smooth in *P. beddomi, P. chalazodes, P. femoralis, P. travancoricus*, and *P. temporalis*, whereas it is distinctly granular in *P. neelanethrus* sp. nov.

The UPGMA cluster analysis, based on 19 morphometric and three meristic characters for the other 15 congeners and reference species, revealed *P. neelanethrus* sp. nov. as a distinct species and closest to *P. luteolus* (Fig. 4). The distinction of *P. neelanethrus* sp. nov. from *P. luteolus* was even clearer when the clustering was done using only morphometric characters and excluding meristic characters, which are constrained by being subjective in their comparative weighting (data not shown). The relationship observed between *P. neelanethrus* sp. nov. and *P. luteolus* is also apparent in morphological features, many of which distinguish between them, though many others are similar between them. Distinctive features of *P. neelanethrus* sp. nov. include lack (indistinct) of tympanum and supratympanic fold, snout length equal/subequal to eye diameter, and a distinct blue ring on the outer margin of the eye. In contrast, *P. luteolus* has a distinct supratympanic fold seen as

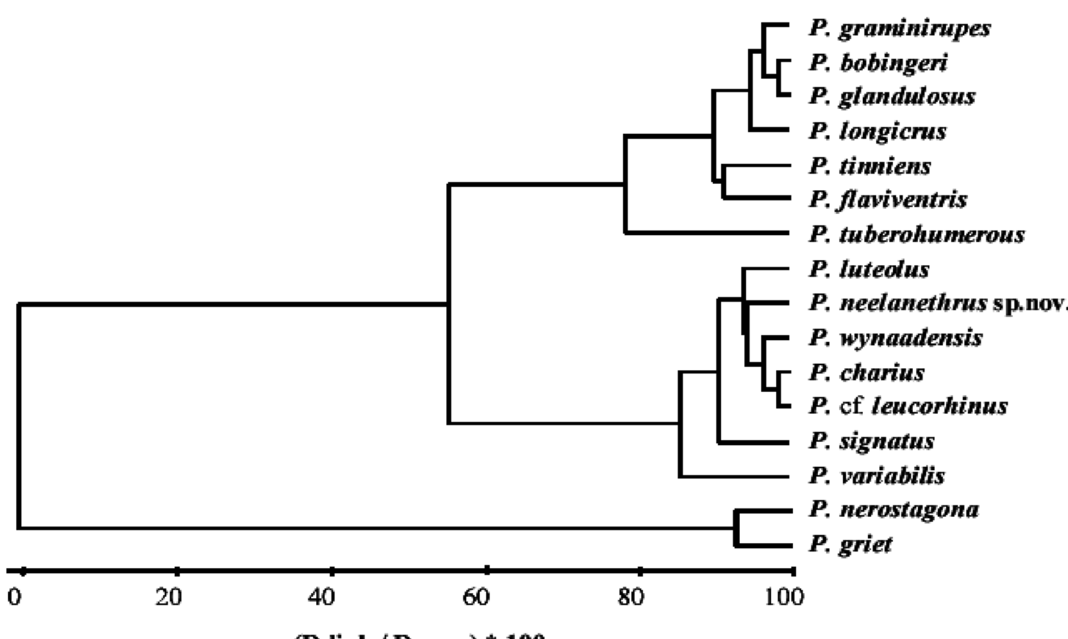


Fig. 4. UPGA cluster analysis of 16 *Philautus* species based on 19 morphometric and three meristic characters (see Table 2, and for reference data, Supplemental Table 4).

a strong, arch-shaped skin fold extending from behind eyes to the shoulder, and a longer snout compared to eye diameter (Kuramoto and Joshy, 2003). In their description of *P. luteolus*, Kuramoto and Joshy (2003) did not mention a distinct blue ring around the iris, which is also not visible in the preserved type specimen. The two species also differ in advertisement call pattern, and emerged as distinct in the phylogentic analysis. Advertisement call characteristics differed significantly, with a peak frequency of 2.39 kHz (range 2.35–2.41 kHz) in *P. neelanethrus* sp. nov. compared to 2.70 kHz (range 2.45–2.87 kHz) in *P. luteolus*. There were significant differences in peak frequency, total call duration, slow-phase duration, and number of pulses.

rDNA phylogenetic analysis

The sequenced rDNA fragments were identical for individuals of the new taxon collected from different localities. Phylogenetic analysis of the 12S and 16S sequences with a large number (>100) of reference amphibian taxa representing families Nyctibatrachidae, Dicroglossidae, and Ranidae revealed the new taxon to be a member of the family Rhacophoridae of Rhacophoroidea, and closest to the *Philautus* species (data not shown). A subsequent analysis done to resolve the exact taxonomic status of the new taxon, using a reduced number of reference taxa belonging mainly to the Rhacophoridae and including three taxa from the related families Ranidae and Nyctibatrachidae (Table 2) as outgroup species, revealed *P. neelanethrus* to be a new, distinct *Philautus* species most closely related to *P. luteolus* (Fig. 5). Moreover, *P. neelanethrus* sp. nov. was revealed to be a distinct and relatively early member of the sub-clade/ lineage including other *Philautus* species described from the Western Ghats, and overall as a member of a broader clade distributed in the Western Ghats and Sri Lanka.

Distribution

Philautus neelanethrus sp. nov. was widespread across the study area (Fig. 1, Table 1), though its abundance varied. There were 6–8 individuals/mhs (man-hours of search) in the *Myristica* swamps, where densities were relatively

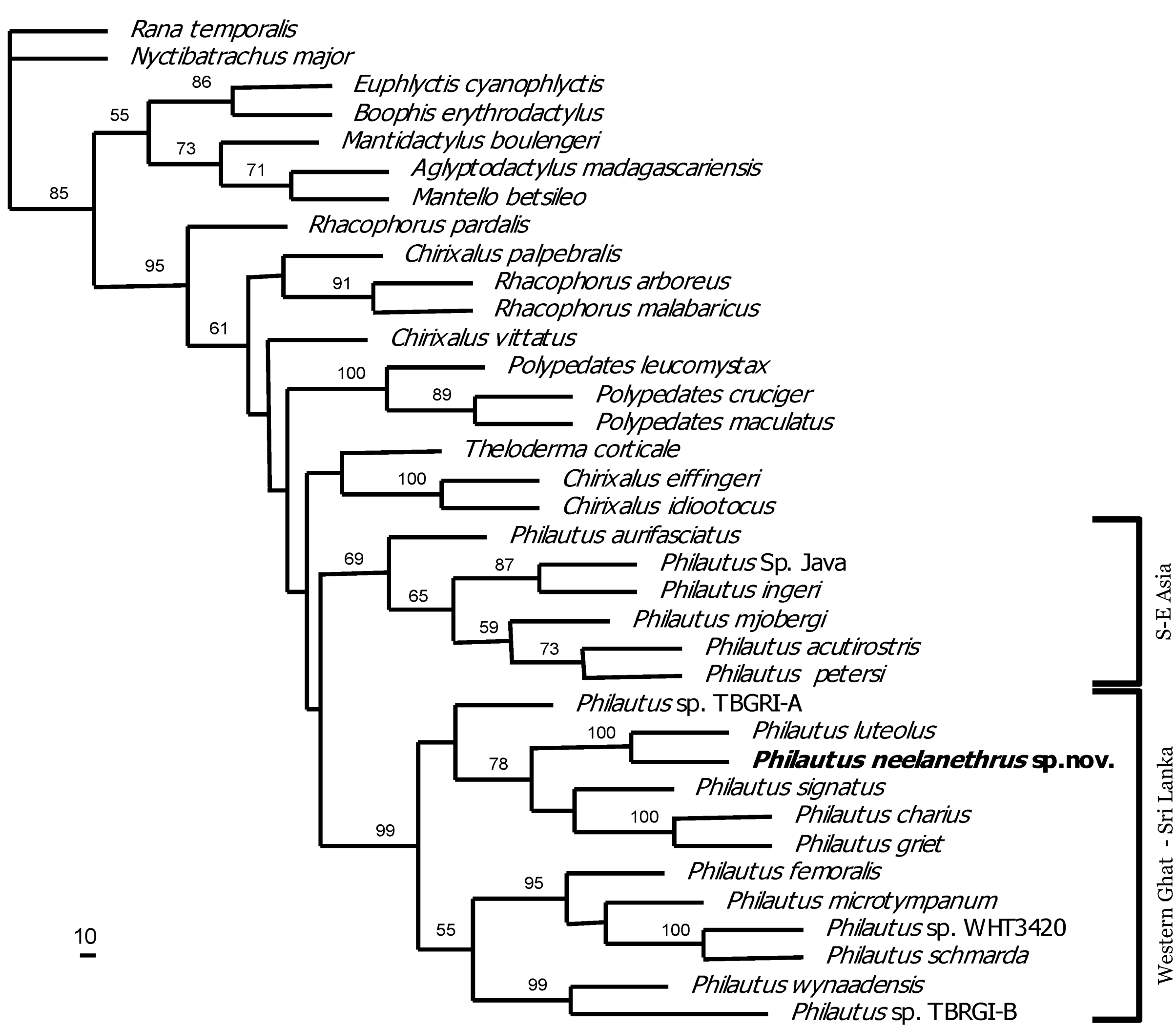


Fig. 5. NJ phylogram (gamma-corrected Kimura two-parameter consensus tree with Tr/Tv=4) based on the combined 12S+16S rDNA data set (alignment 788 bp long, of which 575 sites were complete (without any gaps) and 256 were phylogenetically informative) showing the phylogenetic position of the new frog taxon, *P. neelanethrus* sp. nov. Values at the nodes are bootstrap values.

high compared to the densities of 2–4 individuals/mhs observed in other locations in the Western Ghats (Table 1). Moreover, different localities where the frog was spotted were far from each other, with long stretches of the Ghats without any sign of the frog. Importantly, these stretches were characterized by various ecological (*e.g*., rock outcrops, forest fires) and/or anthropogenic disturbances (*e.g*., open/barren lands, agricultural fields, plantations, and built-up areas).

DISCUSSION

In recent years a number of reports on new descriptions and ancient lineages have suggested that the Western Ghats represent a major hotspot of amphibian diversity and probably a relict habitat (Dutta *et al.,* 2004). In the last five years, 13 new species of amphibians have been discovered from the Western Ghats. Of these, nine are anurans (Dubois *et al.,* 2001; Krishnamurthy *et al.,* 2001; Bossuyt, 2002; Biju and Bossuyt, 2003; Kuramoto and Joshy, 2003; Biju and Bossuyt, 2005a, b; Das and Kunte, 2005) and four are caecilians (Ravichandran *et al.,* 2003; Giri *et al.,* 2003; Bhatta and Prashath, 2004; Bhatta and Srinivas, 2004). Our description of a new species based on morphogenetic analysis from the same biodiversity hotspot adds to the growing list of amphibians from the region, clearly indicates the hotspot status of the region, and reinforces the current notion that there are several new species yet to be discovered (Aravind *et al.,* 2004) requiring proper methods for describing new species.

We described the new species based on morphometry, molecular analysis, and acoustics, which complemented the taxonomic description of the species. Also, the observation that the amplected pair of *P. neelanethrus* sp. nov. descended to the ground without any water body nearby was probably indicative of ground nesting and direct development to a froglet, which are characteristic of the genus (Marmayou *et al.,* 2000).

The study also revealed that although traditional approaches based on morphometric comparisons and acoustics provided an initial indication that *P. neelanethrus* was a new species, its identity and overall taxonomic relationships could most reliably be inferred based on molecular analysis. Furthermore, it is important to note that the specimens of the putative new species from different localities carried identical rDNA sequences, which strongly suggests that the isolated, disjunct small populations spread over a considerable part of the central Western Ghats were indeed *P. neelanethrus* sp. nov.*,* which is expected to be a very poor disperser.

Philautus neelanethrus sp. nov. was found mainly in the mid-altitudinal range (500–700 m asl) characterized by evergreen/semi-evergreen/moist deciduous forest patches in the central Western Ghats, and most importantly in *Myristica* swamps, which are considered to be living fossils among the vegetation types prevailing in the region (Chandran and Divakar, 2001). The phylogenetic and molecular-dating analysis suggests that *P. neelanethrus* sp nov. is a relatively old taxon among other species of *Philautus* endemic to the Western Ghats. Systematic sampling carried out in the Sharavathi River basin shows that forest patches (as mentioned above) are a prerequisite for this species to survive; these patches are not found in many parts of the study area due to multiple anthropogenic disturbances. These unique features, the relatively older origin of the taxon but presence of its extant population in restricted, non-overlapping and non-contiguous patches, suggests that there had been significant habitat fragmentation in the Western Ghats leading to the present day disjunct populations. The species thus appears to be a useful, indirect bioindicator of the ecological health of the Western Ghats, where the remaining evergreen/semi-evergreen/moist deciduous forests are becoming patchy and insularized.

A number of recent studies have documented habitat fragmentation in the Western Ghats due to various anthropogenic activities, *viz*, construction of dams for hydropower, extension of agricultural fields into forested areas, and urbanization (Vasudevan *et al.,* 2001; Gururaja *et al.,* 2003; Aggarwal, 2004). We emphasize here that such fragmentation of natural forest habitats has led to the formation of ecological barriers. These barriers have curtailed poor dispersers like *P. neelanethrus* sp. nov. from dispersing into adjoining similar habitats, leading to the formation of metapopulations. Such metapopulations are always at high risk of extinction due to progressively decreasing native habitats, inbreeding stress, invasion by introduced species, etc. Thus the new species is clearly an indicator of forest fragmentation, at the same time warning of the consequences of fragmentation of the remaining biodiversity in the region and calling for immediate conservation measures to be initiated.

The supplementary data for this article can be found online at http://dx.doi.org/10.2108/zsj.24.525.

ACKNOWLEDGMENTS

We thank Vishnu D Mukri, B Karthick, and Lakshminarayan of CES, IISc, Bangalore for assistance in the field; the Department of Forest, Government of Karnataka, for the necessary permission to carry out the work; Varad Giri for specimen verification at the BNHS museum; and the Director, CCMB, Hyderabad for permission to undertake the work at CCMB. RKA thanks the Department of Biotechnology and the Central Zoo Authority, India, for establishing the LACONES lab facilities used in the study.

REFERENCES

Aggarwal RK (2004) Ancient frog could spearhead conservation efforts. Nature 428: 467

Aravind NA, Shaanker RU, Ganeshaiah KN (2004) Croak, croak, croak; are there more frogs to be discovered in the Western Ghats? Curr Sci 86: 1471–1472

Bhatta G, Prashanth P (2004) *Gegeneophis nadkarnii* – a caecilian (Amphibia: Gymnophiona: Caeciliidae) from Bondla Wildlife Sanctuary, Western Ghats. Curr Sci 87: 388–392

Bhatta G, Srinivasa R (2004) A new species of *Gegeneophis* Peters (Amphibia: Gymnophiona: Caeciliidae) from the surroundings of Mookambika Wildlife Sanctuary, Karnataka, India. Zootaxa 644: 1–8

Biju SD, Bossuyt F (2003) New frog family from India reveals an ancient biogeographical link with Seychelles. Nature 425: 711–714

Biju SD, Bossuyt F (2005a) A new species of frog (Ranidae, Rhacophoridae, *Philautus*) from the rainforest canopy in the Western Ghats, India. Curr Sci 88: 175–178

Biju SD, Bossuyt F (2005b) Two new *Philautus* (Anura: Ranidae: Rhacophorinae) from Ponmudi Hill in the Western Ghats of India. Copeia 1: 29–37

Bossuyt F (2002) A new species of *Philautus* (Anura: Ranidae) from the Western Ghats of India. J Herpetol 36: 656–661

Bossuyt F, Dubois A (2001) A review of the frog genus *Philautus* Gistel, 1848 (Amphibia, Anura, Ranidae, Rhacophorinae). Zeylanica 6: 1–112

Bossuyt F, Milinkovitch MC (2001) Amphibians as indicators of early tertiary 'out-of-India' dispersal of vertebrates. Science 292: 93–95

Chandran MDS (1997) On the ecological history of the Western Ghats. Curr Sci 73: 146–155

Chandran MDS, Mesta DK (2001) On the conservation of the *Myristica* swamps of the Western Ghats. In "Forest Genetic Resources: Status, Threats, and Conservation Strategies" Ed by R Umashanker, KN Ganeshaiah, KS Bawa, Oxford & Indian Book House, New Delhi, pp 1–19

Dahanukar N, Raut R, Bhat A (2004) Distribution, endemism and threat status of freshwater fishes in the Western Ghats of India. J Biogeogr 31: 123–136

Daniels RJR (2001) Endemic species of Western Ghats and Satpura hypothesis. Curr Sci 81: 240–244

Das I, Kunte K (2005) New Species of *Nyctibatrachus* (Anura: Ranidae) from Castle Rock, Karnataka State, Southwest India. J Herpetol 39: 465–470

Dubois A, Ohler A, Biju SD (2001) A new genus and species of Ranidae (Amphibia, Anura) from south-western India. Alytes 19: 53–79

Duellman WE (1999) Patterns of Distributions of Amphibians: A Global Perspective. Johns Hopkins University Press, Baltimore, USA

Dutta SK, Vasudevan K, Chaitra MS, Shanker K, Aggarwal RK (2004) Jurassic frogs and the evolution of amphibian endemism in the Western Ghats. Curr Sci 86: 211–216

Giri V, Wilkinson M, Gower DJ (2003) A new species of *Gegeneophis* Peters (Amphibia: Gymnophiona: Caeciliidae) from southern Maharashtra, India, with a key to the species of the genus. Zootaxa 351: 1–10

Gower DJ, Bhatta G, Giri V, Oommen OV, Ravichandran MS, Wilkinson M (2004) Biodiversity in the Western Ghats: the discovery of new species of caecilian amphibians. Curr Sci 87: 739–740

Gururaja KV (2004) Sahyadri mandooka – amphibians of Western Ghats. Sahyadri e-news, http://wgbis.ces.iisc.ernet.in/biodiversity/newsletter/issue6/index.htm

Gururaja KV, Reddy AHM, Keshavayya J, Krishnamurthy SV (2003) Habitat occupancy and influence of abiotic factors on the occurrence of *Nyctibatrachus major* (Boulenger) in central Western Ghats, India. Rus J Herpetol 10: 87–92

Heyer WR, Donnelly MA, McDiarmid RW, Hayek C, Foster MS (1994) (Eds) Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Biological Diversity Handbook Series, Smithsonian Institution Press, Washington, DC

Karanth P (2003) Evolution of disjunct distribution among wet-zone species of the Indian subcontinent: testing various hypotheses using a phylogenetic approach. Curr Sci 85: 1276–1283

Kimura M (1980) A simple method for estimating evolutionary rate of base substitutions through comparative studies of nucleotide sequences. J Mol Ecol 16: 111–120

Krishnamurthy SV, Reddy AHM, Gururaja KV (2001) A new species of frog in the genus *Nyctibatrachus* (Anura: Ranidae) from Western Ghats, India. Curr Sci 80: 887–891

Kuramoto M, Joshy SH (2003) Two new species of the genus *Philautus* (Anura: Rhacophoridae) from the Western Ghats, Southwestern India. Curr Herpetol 22: 51–60

Manamendra-Arachchi K, Pethiyagoda R (2005) The Sri Lankan shrub-frogs of the genus *Philautus* Gistel, 1848 (Ranidae: Rhacophorinae), with description of 27 new species. Raff Bull Zool Suppl 12: 163–303

Marmayou J, Dubois A, Ohler A, Pasquet E, Tillier A (2000) Phylogenetic relationships in the Ranidae. Independent origin of direct development in the genera *Philautus* and *Taylorana*. CR Acad Sci Paris, Life Sci 323: 287–297

Myers N, Mittermeier RA, Mittermeier CG, daFonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853–858

Ravichandran MS, Gower DJ, Wilkinson M (2003) A new species of *Gegeneophis* Peters (Amphibia: Gymnophiona: Caeciliidae) from Maharashtra, India. Zootaxa 350: 1–8

Rao CRN (1937) On some new forms of batrachia from S. India. Proc Ind Acad Sci B 6: 387–427

Roelants K, Jiang J, Bossuyt F (2004) Endemic ranid (Amphibia: Anura) genera in southern mountain ranges of the Indian subcontinent represent ancient frog lineages: evidence from molecular data. Mol Phylogenet Evol 31: 730–740

Shanker K, Ramadevi J, Chaudhury BC, Singh L, Aggarwal RK (2004) Phylogeography of olive ridley turtles *(Lepidochelys olivacea*) on the east coast of India: implications for conservation theory. Mol Ecol 13: 1899–1909

Snedecor GW, Cochran WG (1989) Statistical Methods. 8th ed, Iowa State University Press, Ames

Vasudevan K, Kumar A, Chellam R (2001) Structure and composition of rainforest floor amphibian communities in Kalakad-Mundanthurai Tiger Reserve. Curr Sci 80: 406–412

Vences M, Vieites DR, Glaw F, Brinkmann H, Kosuch J, Veith M, Meyer A (2003) Multiple overseas dispersal in amphibians. Proc R Soc Lond B 270: 2435–2442

(Received August 9, 2006 / Accepted December 1, 2006)

TWO NEW FISH SPECIES OF THE GENUS *SCHISTURA* MCCLELLAND (CYPRINIFORMES: BALITORIDAE) FROM WESTERN GHATS, INDIA

Sreekantha [1], K.V. Gururaja [2], K. Remadevi [3], T.J. Indra [4] and T.V. Ramachandra [5,*]

[1,2,5] Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, Karnataka 560012, India
[3,4] Zoological Survey of India, 130, Santhome High Road, Chennai, Tamil Nadu 600028, India
E Mail: [1]sreekantha@ces.iisc.ernet.in; [3]remadevi_zsi@yahoo.com; [5,*]cestvr@ces.iisc.ernet.in (* Coressponding author)

web supplement

ABSTRACT

Schistura nagodiensis *and* S. sharavathiensis *are the new fish species described from Sharavathi river, central Western Ghats. These species are distinct from their closest congeners in* Schistura*, which are evident from variations in the combination of characters such as processus dentiformis, barbels, bars on body, extent of lateral line with pores, marks on lower lip, ray counts, shape of caudal fin, caudal bar, adipose crest, etc. Distinct clusters of Principal Components based on morphometric variables (PCA) further substantiate that these are significantly different from their closest congeners.*

KEYWORDS

Nemacheiline fishes, new descriptions, Principal Component Analysis (PCA), Schistura nagodiensis*,* S. sharavathiensis *Sharavathi river, Western Ghats*

ABBREVIATIONS

CES - Centre for Ecological Sciences; IISc - Indian Institute of Science; ZSI - Zoological Survey of India; SRS - Southern Regional Station; WGBIS - Western Ghats Biodiversity Information System; SL - Standard length.

The freshwater fish family, Balitoridae has been divided into two sub-families; Balitorinae and Nemacheilinae. Balitorinae consists of genera *Bhavania*, *Homaloptera*, *Travancoria* and *Balitora*, whereas *Aborichthys*, *Triplophysa*, *Acanthocobitis*, *Yunnanilis*, *Neonemacheilus*, *Nemacheilichthys*, *Oreonectes*, *Longischistura*, *Physoschistura*, *Schistura*, *Mesonemacheilus* and *Nemacheilus* belong to the Nemacheilinae. Of these, *Schistura* McClelland, 1838 has the largest assemblage of Nemacheiline species (Jayaram, 1999), which inhabits mainly hill streams, waterfalls and also penetrates into sub-terranean region (Vidthayanon, 2003), having wide distribution throughout South, Southwest and Southeast Asia. Western Ghats of India with a distinct biogeographical regime, has six taxa, namely *S. semiarmatus, S. denisoni denisoni, S. nilgiriensis, S. kodaguensis, S. denisoni mukambbikaensis* and *S. denisoni pambaensis* (Jayaram, 1999). Recent discoveries of fish species in Western Ghats conforms Dahanukar *et al*. (2005) highlight that there are many more unexplored species in the region, which requires detailed field investigations.

Ichthyodiversity and species distribution studies carried out in Sharavathi river basin, Western Ghats (Fig. 1) covering all seasons and microhabitats over a period of 36 months has led to the discovery of two new species of *Schistura* in ecologically sensitive habitats as well as provided insight into habitat preference of many endemic and rare species.

MATERIALS AND METHODS

Specimens were collected using a 1m × 2m net, dragging at the bottom of the streams and preserved in 6% formaldehyde, and were deposited at the Southern Regional Station, ZSI and CES, IISc. These specimens were classified as per Jayaram (1999) and compared using Menon (1987); Kottelat (1990); Talwar and Jhingran (1991); Kottelat (2004); Vishwanath and Shanta (2004); Vishwanath and Nebeshwar (2004); Vishwanath and Sharma (2005). Menon (1987); Kottelat (1990); and Jayaram (2002) were referred for terminologies and Kottelat (1990) for counts and measurements. Morphological measurements were done with a slide caliper (0.1mm precision). Thirty-one (26 nophometric and 5 meristic) characters of new species and congeners were analysed using Principal Component Analysis (STATISTICA, 1999).

Schistura nagodiensis sp. nov.

Material examined

Holotype: 26.xii.2003, Sharavathi river (13^{0}54'40"N-74^{0}53'49"E), Algod, Shimoga, Karnataka, coll. Sreekantha and Vishnu D, F-7595 ZSI/SRS, 28.0mm SL.

Paratypes: 12 exs., Sharavathi river (13^{0}54'40"N-74^{0}53'49"E), Algod, Shimoga, Karnataka, coll. Sreekantha and Vishnu D, 28.0mm SL and 25.0mm SL, F-7596 ZSI/SRS, 26.xii.2003; 25.0mm SL, 25.0mm SL, 26.0mm SL, 25.0mm SL, 26.0mm SL, 26.0mm SL, 25.0mm SL, 26.0mm SL, 25.0mm SL and 23.0mm SL IISc/CES/WGBIS: 3-5-3-5-007.

Etymology

Named after its type locality, Nagodi tributary of Sharavathi river, central Western Ghats.

Diagnosis

A species of *Schistura* depicted in Image 1[w], distinguishable from other members by the following combination of characters; processus dentiformis present; 6-9 broad dark brown bars on body, the anterior bars not reaching ventral side; males without a suborbital flap; posterior extremity of anterior nostril prolonged in a filament; incomplete lateral line extending to half length of pectoral with 8-10 pores; lower lip with a black mark on each side of median interruption (Image 2[w]); 8 ½ dorsal rays, 7-9 pectoral, 6 pelvic and 9+9 caudal rays; deeply emarginate or slightly forked caudal fin; black basal caudal bar, sometimes interrupted; caudal fin with two rows of spots; no axillary pelvic lobe; anus much nearer to anal fin; weakly

[w] See Images in the websupplement at www.zoosprint.org

Manuscript 1386; Received 29 June 2005; Revised received 04 January 2006; Finally accepted 07 March 2006; Date of publication 21 March 2006

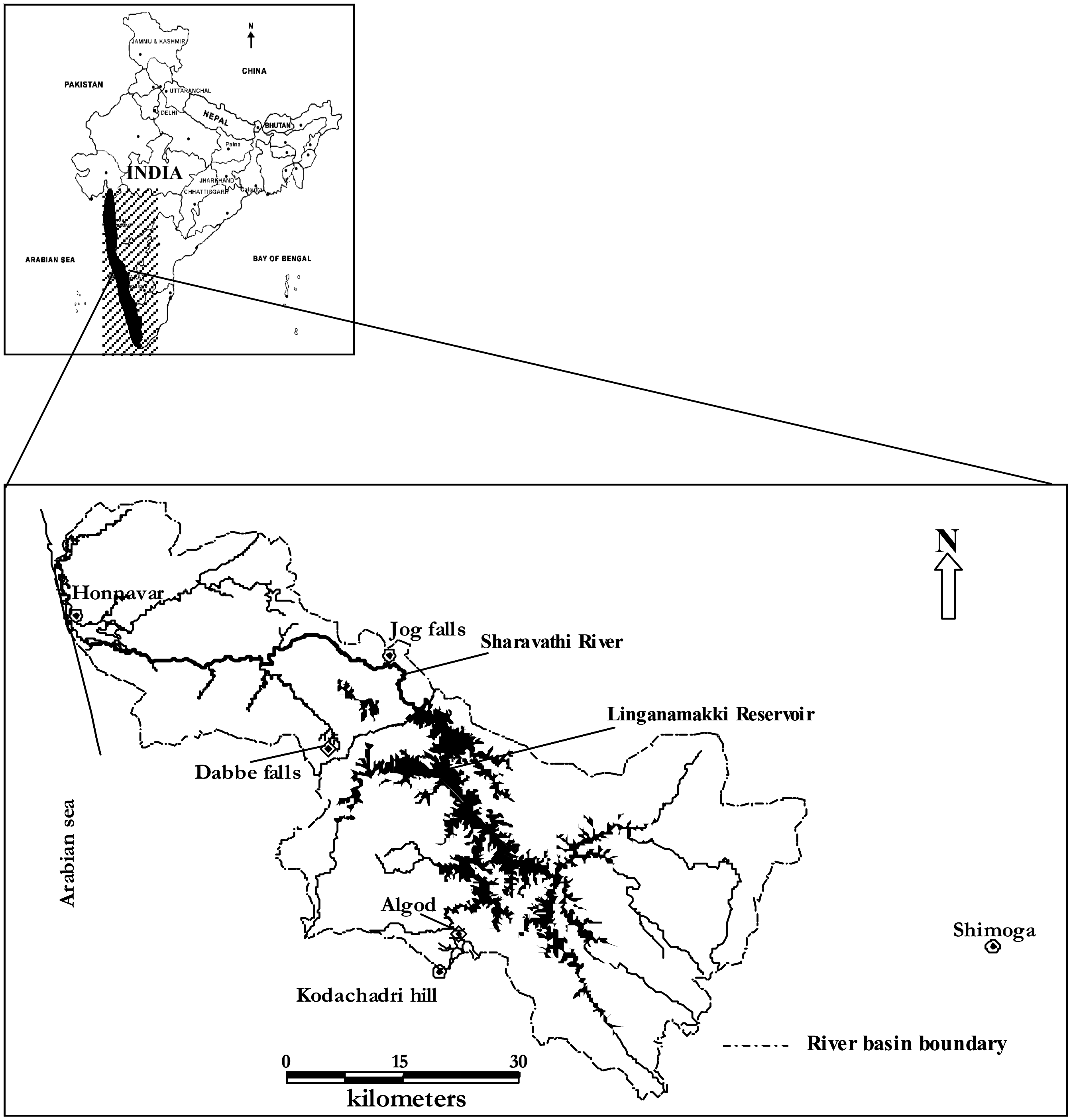


Figure 1. Sharavathi river basin with type localities of Schistura nagodiensis (◈) and Schistura sharavathiensis (◈).

developed adipose crest on peduncle.

Description

Morphological data and their proportionate values are listed in Tables 1 and 2 respectively. A relatively small species (largest 28mm in SL) compared to other species of *Schistura* with moderately elongated body, rounded anteriorly to origin of dorsal fin, slightly compressed thereafter; head depressed; snout obtuse; mouth semi-circular; lips thin, upper lip with a small incision in the middle, lower lip with a black mark on either side of median interruption; anterior nostril pierced in the front, posterior extremity prolonged in a filament; eyes large, diameter equals inter orbital width; barbels-inner maxillary shorter than outer, outer maxillary shorter than nasal, not extending to margin of eye; processus dentiformis present; incomplete lateral line with 8–10 pores, extending to half length of pectoral fin; cephalic lateral line system with 6 supraorbital, 4+10 infraorbital, 9 preoperculomandibular and 3 supratemporal pores; fin ray counts, dorsal 2/8½, pectoral 7–9, pelvic 1/6, anal 2/5 and caudal 9+9; dorsal fin equidistant from tip of snout to caudal fin base; distal margin of dorsal fin slightly convex; pelvic fin inserted slightly behind the origin of dorsal fin; anal fin at three quarters of SL, not reaching base of caudal fin; pectoral fin reaches half the distance to pelvic origin, pelvic fin extends beyond anus; caudal fin without axillary lobes, varies from deeply emarginate to slightly forked; weakly developed adipose crest on caudal peduncle.

Colour

Live specimens (in natural condition) light yellowish-brown with 6–9 dark brown cross bars, broader than interspaces; preserved specimens creamy white with black cross bars; bars broader along the lateral line, without reaching ventral surface and restricted to upper two-third of body except near caudal peduncle; near caudal peduncle extend to ventral surface; head and snout mottled with dark black spots; a shade of wine red on entire body surface, intense on dorsal fin in live specimens; two rows of spots at one quarter and three quarters of the height of dorsal fin; band on caudal fin base varies from dot to dissociate to complete; a prominent dark black spot on each side of median interruption.

Habitat

Specimen was collected from the Nagodi tributary, a perennial tributary of river Sharavathi with annual rainfall of over 5500mm. The catchment of this tributary is endowed with numerous torrential hill streams and vegetation cover (nearly 88%) (Figure 5a). Vegetation cover comprises of evergreen to semi-evergreen (36.54%), moist deciduous forests (20.04%), plantations (26.28%) and agricultural area (1.03%). The species is aptly named after the tributary to signify its occurrence as well as habitat preference.

Distribution

Sharavathi river basin, Central Western Ghats, Karnataka, India

Discussion

Characters such as elongated body with almost uniform depth, blunt snout, inferior mouth, dorsal fin inserted opposite to pelvic fin, with eight branched rays, emarginate caudal fin, pelvic fins not extending up to anal fin, body with scales, a dark band on the base of caudal fin, presence of characteristic colour pattern on the body in terms of cross bands and a band at the base of caudal fin indicates that this species is a member of *Schistura* genus.

Diagnostic features highlight that the new taxon has unique combination of characters compared to any other species of *Schistura* reported so far in Menon (1987), Kottelat (1990), Talwar and Jhingran (1991), Kottelat (2004), Vishwanath and Shanta (2004), Vishwanath and Nebeshwar (2004), and Vishwanath and Sharma (2005). Comparison with the species of Western Ghats is provided in Table 3. *Schistura nagodiensis* is comparable only to *S. kodaguensis* Menon. However, it differs from *S. kodaguensis*, which has 11–14 bands, tapering below, caudal fin slightly emarginate, dorsal with a light margin

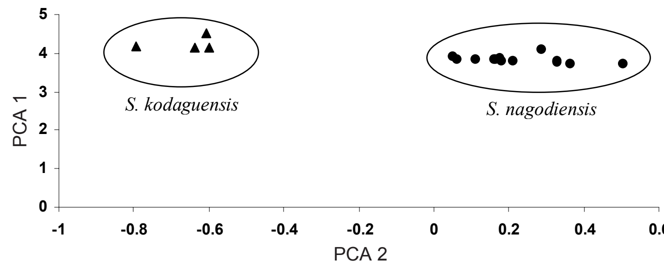


***Figure 2. Plot of principal components of 31 morphological parameters* – Schistura nagodiensis *and* S. kodaguensis**

bounded below by an arched black band and a dark base. It resembles to *S. robertsi* in the presence of black mark on the median part of lower lip, prolonged nasal filament, and banding pattern on the body, while differing in caudal fin (emarginate and with one row of dark pigments on the proximal area in *S. robertsi*), dorsal branched rays (7½), caudal rays (8–9+8 in *S. robertsi*). Plot of principal components (of PCA) gives distinct clusters indicating variations between *S. nagodiensis* and *S. kodaguensis* (Fig. 2). Eigen value of PC 1 is 264.2 (accounts for 98.85% variability) and PC 2 is 2.63. Appendix-I provides identification keys to new species.

Comparative Material

Schistura kodaguensis: 06.x.2004, Kootu Holé (12⁰26'59"N-75⁰42'46"E), about 8km northwest of Mercara, Coorg, Karnataka, 2 exs. 23.0mm SL and 29.0mm SL, coll. Sreekantha, Vishnu D. and Gururaja K.V., IISc/CES/WGBIS: 3-5-3-5-005.

Schistura nilgiriensis: 06.xi.2003, Sharavathi river, Niluvase (13⁰44'18"N-75⁰06'30"E), Shimoga, Karnataka, 2 exs. 39.0mm SL. and 43.0mm SL, coll. Sameer Ali, Gururaja KV and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-004.

Schistura denisoni denisoni: 21.xi.2003, Sharavathi river (13⁰52'44"N-75⁰03'64"E), Jayanagar, Shimoga, Karnataka, 2 exs. 31.0mm SL and 39.0mm SL, coll. Sreekantha and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-001.

Schistura semiarmatus: 23.xi.2003, Sharavathi river (75⁰03'52"N-13⁰52'45"E) Suttha, Shimoga, Karnataka, 2 exs. 32.0mm SL and 34.0mm SL. Coll. Sreekantha and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-006.

***Schistura sharavathiensis* sp. nov.**

Material examined

Holotype: 26.iii.2004, Sharavathi river (14⁰8'15"N-74⁰44'30"E), Kalkatte tributary, 1km upper to Dabbe falls, Shimoga, Karnataka, 29.0mm SL, coll. Sreekantha and Vishnu D. F–7597 ZSI/SRS.

Paratypes: 26.iii.2004, 3 exs., 26.0mm SL and 24.0mm SL, ZSI/SRS F–7598, 28.vii.2004; 26.0mm SL, IISc/CES/WGBIS: 3-5-3-5-008, locality and collectors as in Holotype.

Etymology

Named after its type locality, Sharavathi river, Central Western

Ghats.

Diagnosis

A species of *Schistura* depicted in Image 3^w, distinguishable from other members by the following combination of characters: processus dentiformis well developed; 16–18 almost regular brown bars on body, narrower than interspaces; males without suborbital flap; nasal tube with a prolonged barbel, long with unculi; lateral line with 5–6 pores, reaching one third of pectoral fin; lower lip with a median interruption, each side with 4–5 deep furrows; 8½ dorsal, 9 pectoral, 7 pelvic and 7–8+8 caudal rays, slightly emarginate caudal fin; black basal caudal bar with a darker central spot; caudal fin plain; no axillary pelvic lobe; pelvic origin below dorsal or slightly behind; anus much nearer to anal fin; a long and high adipose crest from just behind dorsal fin, a shorter ventral crest.

Description

Morphological and proportionate values of *Schistura sharavathiensis* are listed in Tables 1 and 2 respectively. Body moderately elongate, depth increasing to dorsal fin and thereafter tapering posteriorly; mouth semi-circular; both lips fleshy, median incision in upper lip and lower lip interrupted in the middle with 4–5 deep furrows on each side (Image 4^w); processus dentiformis well-developed; nasal tube with a prolonged barbel; head length slightly greater than depth; barbels well-developed, long with unculi; nasal barbel prolonged as in members of the genus *Oreonectes* of the same family; lateral line incomplete, ending at mid level of mid region of pectoral fin, with 5–6 pores, cephalic lateral line system with 6 supraorbital, 4+8 infraorbital, 9 preoperculomandibular and 3 supratemporal pores; fin ray counts include, dorsal $8^1/_2$, pectoral 9, pelvic 1/7, anal 2/5 and caudal 7–8+8; dorsal fin equidistant from tip of snout to caudal fin base; dorsal fin with convex distal margin; pelvic fin does not reach vent and separated by a wide distance; no axillary pelvic lobe; anal fin not reaching caudal fin base; pectoral fin reaches half the distance to pelvic origin; pelvic fin reaches half the distance to anal fin without reaching anus; caudal fin slightly emarginate with rounded lobes and upper lobe longer than lower; long ventral and dorsal adipose crest present.

Colour

Body light yellowish-brown with 16–18 almost regular thin cross bars, narrower than interspaces, dark brown in live specimens and dull white in preserved specimens, the bars reach ventral surface behind dorsal fin; dorsal fin with a row of spots at three quarters height; caudal fin plain with dissociated band at base with a central spot; other fins without any prominent colour pattern.

Distribution

Sharavathi river basin, Central Western Ghats, Karnataka, India.

Discussion

Schistura sharavathiensis resembles the species of the genus *Longischistura* Banarescu and Nalbant, only in the presence of a long adipose crest extending from a short distance behind dorsal fin to caudal base; but differs with respect to 10 dorsal rays, deeply forked caudal fin, complete to almost complete lateral line in *Longischistura* genus. It also resembles genus *Indoreonectes* in long nasal barbel (*Oreonectes* genus, Kottelat, 1990) and adipose crest on the caudal peduncle. However, it differs from *I. keralensis* and *I. evezardi* in the presence of rounded and banded caudal fin, broad and incomplete, irregular vertical bands or mottled all over the body. The identity of the species is confirmed based on the available literatures of *Schistura* in South-Asian region (Menon, 1987; Kottelat, 1990; Talwar and Jhingran, 1991; Jayaram, 1999; Kottelat, 2004; Vishwanath and Nebeshwar, 2004; Vishwanath and Shanta, 2004; Vishwanath and Sharma, 2005). Table 3 shows the comparison between the six recorded taxa of Western Ghats, which reveals that *S. sharavathiensis* differs significantly from the congeners, except for *S. nilgiriensis*. It differs in the presence of 5–14 vertical bands and a black spot at anterior base of dorsal fin in *S. nilgiriensis*. Appendix-I gives the identification keys for species. Plot of principal components (of PCA) shows different clusters indicating variations between *S. sharavathiensis* and *S. nilgiriensis* (Fig. 3) with eigen values of 159.29 for PC 1 (accounts for 96.48% variability) and 5.42 for PC 2.

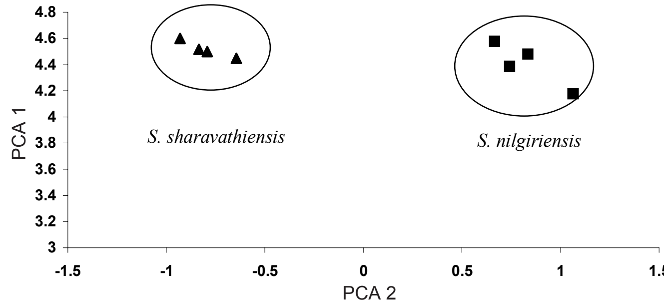


Figure 3. Plot of principal components of 31 morphological parameters – Schistura sharavathiensis and S. nilgiriensis

Comparative Material

Schistura kodaguensis: 06.x.2004, Kootu Holé (12^{0}26'59"N-75^{0}42^{0}46"E), about 8 km northwest of Mercara, Coorg, Karnataka, 2 exs. 23.0mm SL and 29.0mm SL, coll. Sreekantha, Vishnu D. and Gururaja K.V., IISc/CES/WGBIS: 3-5-3-5-005.

Schistura nilgiriensis: 06.xi.2003, Sharavathi river, Niluvase (13^{0}44'18"N-75^{0}06'30"E), Shimoga, Karnataka, 2 exs. 39.0mm SL. and 43.0mm SL, coll. Sameer Ali, Gururaja KV and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-004.

Schistura denisoni denisoni: 21.xi.2003, Sharavathi river (13^{0}52'44"N-75^{0}03'64"E), Jayanagar, Shimoga, Karnataka, 2 exs. 31.0mm SL and 39.0mm SL, coll. Sreekantha and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-001.

Schistura semiarmatus: 23.xi.2003, Sharavathi river (75^{0}03'52"N-13^{0}52'45"E) Suttha, Shimoga, Karnataka, 2 exs. 32.0mm SL and 34.0mm SL. Coll. Sreekantha and Vishnu D, IISc/CES/WGBIS: 3-5-3-5-006.

Table 1. Nophometric characteristics of **Schistura nagodiensis** ***sp. nov. and*** **Schistura sharavathiensis** ***sp. nov. (dimensions in mm)***

Parameters	*Schistura nagodiensis*				*Schistura sharavathiensis*			
	Holotype	Range (n=13)	Mean	SD	Holotype	Range (n=4)	Mean	SD
Total length	34.0	28.0–34.0	30.9	1.2	35.0	31.0–35.0	32.5	1.7
Standard length	28.0	23.0–28.0	25.6	1.1	29.0	24.0–29.0	26.2	1.7
Body depth	3.7	3.0–5.0	3.9	0.6	4.4	3.7–4.4	4.0	2.1
Head length	6.0	5.0–6.0	5.4	0.5	5.4	5.3–5.9	5.6	0.3
Head width	3.8	2.7–3.8	3.2	0.3	3.5	3.2–4.3	3.7	0.3
Eye diameter	1.3	0.9–1.5	1.3	0.2	1.5	1.2–1.5	1.4	0.5
Inter orbital width	1.5	0.9–1.7	1.3	0.2	1.6	1.2–1.8	1.5	0.2
Width of mouth	1.8	1.4–1.9	1.6	0.2	1.9	1.9–2.4	2.1	0.2
Snout length	2.0	1.5–2.5	1.9	0.3	2.6	2.1–2.6	2.3	0.2
Height of head at occiput	2.8	1.9–3.1	2.6	0.3	3.3	3.0–3.4	3.2	0.2
Pre-dorsal length	14	11.7–14	12.7	0.6	14.0	12.0–14.0	13.2	0.2
Post dorsal length	13.5	12.0–13.5	12.6	0.5	13.7	12.0–13.7	12.9	0.9
Inter-nostril distance	1.4	0.6–1.5	1.2	0.3	1.1	0.9–1.5	1.2	0.7
Pre-pelvic distance	14.5	11.3–14.5	12.5	1.1	13.8	10.8–13.8	12.1	0.3
Height of dorsal fin	3.8	3.2–4.4	3.9	0.3	5.8	5.1–5.8	5.4	1.3
Length of base of dorsal fin	4.7	3.1–4.7	3.9	0.5	4.2	4.2–5.0	4.4	0.3
LCPD	4.3	3.3–4.5	3.7	0.4	3.6	3.6–4.3	4.0	0.4
HCPD	3.5	2.8–3.9	3.2	0.3	4.2	3.1–4.7	3.8	0.3
Length of base of anal fin	2.2	1.9–3.5	2.4	0.4	2.7	1.6–2.7	2.1	0.7
Length of pectoral fin	4.2	3.8–4.7	4.3	0.2	5.1	3.4–5.2	4.6	0.6
Length of pelvic fin	4.1	3.3–4.3	3.9	0.3	4.7	3.7–4.7	4.2	0.8
Pre-anal length	19.0	15.0–19.0	17.1	1.0	21.0	18.2–21.0	19.1	0.4
Pre-anus length	20.0	17.0–21.0	18.7	1.2	18.0	14.3–18.0	16.6	1.3

HCPD - Height of caudal peduncle; LCPD - Length of caudal peduncle

Table 2. Proportional values of morphometry of **Schistura nagodiensis** ***sp. nov. and*** **Schistura sharavathiensis** ***sp. nov.***

Parameters	***S. nagodiensis*** **(N = 13)**		***S. sharavathiensis*****(N = 4)**	
	Range	Mean ± S.D.	Range	Mean ± S.D.
Standard length (mm)	23.0–28.0	28.0 (max)	24.0–29.0	29.0 (max)
Total length (mm)	28.0–34.0	34.0 (max)	31.0–35.0	35.0 (max)
%Standard length				
Body depth	12.0–20.0	15.2 ± 2.3	14.2–16.2	15.3 ± 0.9
Head length	19.2–26.1	21.3 ± 2.0	18.6–22.7	21.3 ± 1.8
Snout length	6.4–10.0	7.5 ± 1.1	8.1–9.6	8.8 ± 0.6
Pre-dorsal length	47.6–52.0	49.8 ± 1.4	48.3–53.1	50.3 ± 1.9
Pre-pelvic length	45.2–56.0	48.9 ± 3.0	43.5–47.7	45.9 ± 2.0
Height of dorsal fin	12.8–18.7	15.3 ± 1.6	19.6–22.9	20.8 ± 1.5
Base of dorsal fin	11.9–17.2	15.4 ± 1.7	14.5–19.2	16.9 ± 2.1
Pectoral fin length	15.0–20.4	16.8 ± 1.5	13.1–20.0	17.7 ± 3.3
Pelvic fin length	13.2–16.5	15.1 ± 0.9	14.2–18.3	16.0 ± 1.7
Base of anal fin	7.6–12.6	9.3 ± 1.4	6.5–9.6	8.0 ± 1.6
Length of caudal fin	16.2–24.0	20.9 ± 2.2	20.7–29.1	24.0 ± 3.6
Length of caudal peduncle	13.2–17.3	14.7 ± 1.2	12.4–17.1	15.4 ± 2.1
Pectoral fin to pelvic fin distance	22.8–36.0	27.6 ± 3.6	21.5–28.9	24.6 ± 3.2
Pre-anal length	68.0–80.0	73.2 ± 3.4	70.0–75.8	72.8 ± 2.4
Other proportions (%)				
VA in PA	14.3–40.0	26.7 ± 8.9	15.5–52.7	33.9 ± 16.5
HCPD in LCPD	62.2–97.1	86.1 ± 9.3	75.6–116.7	96.1 ± 19.9
Eye diameter in Snout length	52.4–88.2	67.7 ± 11.3	52.2–71.4	62.4 ± 8.9
Snout length in Head length	28.3–50.0	35.4 ± 6.5	36.8–48.1	41.4 ± 5.4
IOW in Eye diameter	80.0–115.4	98.1 ± 9.5	100.0–120.0	106.6 ± 9.4
Eye diameter in Head length	15.0–30.0	23.7 ± 4.2	22.6–27.8	25.5 ± 2.2

VA in PA - Vent to anal fin origin in pelvic fin to anal fin; HCPD in LCPD - Height of caudal peduncle in length of caudal peduncle; IOW - Interorbital width

Table 3. Comparison of morphological characters of* Schistura *of Western Ghats.

Species	SL (mm)	Pectoral fin rays	Black spot on Dorsal fin	Rows of spots on caudal fin	Lateral line	Caudal fin shape	Bars on body
***Schistura nagodiensis* sp. nov.**	28	7–9	Absent	Feeble	Incomplete	Deeply emarginated	7–9
***Schistura sharavathiensis* sp. nov.**	29	9	1/4th the height	Absent	Incomplete	Slightly emarginated	16–18 thin bands
Schistura denisoni denisoni	51.1	11	At the base	Present	Incomplete	Deeply emarginated	Variable
Schistura denisoni pambaensis	40	11	At the base	Present	Incomplete	Deeply emarginated	10–14
Schistura denisoni mukambbikaensis	36	10	At the base	Present	Incomplete	Deeply emarginated	5–6
Schistura kodaguensis	36	10	Absent	Present	Incomplete	Slightly emarginated	11–14
Schistura semiarmatus	56.5	11	At the base	Present	Complete	Slightly forked	9–10
Schistura nilgiriensis	51	10	At the base	Absent	Incomplete	Emarginated	11–13

Key to the Schistura *species of the Western Ghats (modified after Jayaram, 1999).*

1. Lateral line complete; body with bands and conspicuous black spots. .... *S. semiarmatus*
- Lateral line incomplete; body with only bands. 2

2. Black spot at anterior base or slightly above on dorsal fin 4
- No black spot at anterior base or slightly above on dorsal fin 3

3. 11–14 black bars on body, black markings on lower lip absent, feeble if present, caudal fin emarginate .... *S. kodaguensis*
- 6–9 black bars on body, two black markings on lower lip, caudal fin deeply emarginate or slightly forked .... ***S. nagodiensis* sp.nov**

4. Caudal fin slightly emarginate, without rows of spots 5
- Caudal fin deeply emarginate or slightly forked, with 3 or 4 rows of spots 6

5. 11–12 brown bars, broader than interspaces; black spot at base of dorsal fin; moderately long nasal barbels .... *S. nilgiriensis*
- 16–18 brown bars, narrower than interspaces; black spot at 1/4th height of dorsal fin; very elongated nasal barbel .... ***S. sharavathiensis* sp.nov**.

6. Body slender, about 6.5 times in SL; pelvic fin separated from anal opening by a considerable distance ...... *S. denisoni pambaensis*
- Body deeper, about 5 to 5.5 times in SL; pelvic fin reaching or almost reaching anal opening 7

7. Pelvic fin reach anal opening; caudal fin deeply emarginate with several rows of spots; dorsal with rows of spots .... *S. denisoni denisoni*
- Pelvic fin falling short of anal opening; caudal fin slightly emarginate without conspicuous spots; dorsal with a dark base and a dark band at distal end .... *S. denisoni mukambbikaensis*

References

Dahanukar, N., R. Raut and A. Bhat (2004). Distribution, endemism and threat status of freshwater fishes in the Western Ghats of India. *Journal of Biogeography* 31: 123-136.

Jayaram, K.C. (1999). *The Freshwater Fishes of the Indian Region.* Narendra Publishing House, New Delhi, 551pp.

Jayaram, K.C. (2002). *Fundamentals of Fish Taxonomy*. Narendra Publishing House, New Delhi, 174pp.

Kottelat, M. (1990). *Indochinese nemacheilines: A revision of nemacheiline loaches (Pisces: Cypriniformes) of Thailand, Burma, Laos, Cambodia and southern Viet Nam*. Verlag Dr. Friedrich Pfeil. Munchen, FRG, 262pp.

Kottelat, M. (2004). *Schistura spekuli,* a new species of cave fishes from northern Vietnam (Teleostei: Balitoridae). *Ichthyological Exploration of Freshwaters* 15(2): 187-191.

Menon, A.G.K. (1987). *Fauna of India and the Adjacent Countries: Pisces, Vol. IV, Teleostei - Cobitoidae, Part 1, Homalopteridae,* Zoological Survey of India, 259pp.

STATISTICA (1999). STATISTICA for Windows. StatSoft, Inc.

Talwar, P. K. and A.G. Jhingran, (1991). *Inland Fishes of India and Adjacent Countries - Vol. 1*, Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi, 541 pp.

Vidthayanon, C. (2003). *Schistura pridii*, a new nemacheiline loach (Teleostei: Balitoridae) from Upper Chao Phraya drainage, northern Thailand. *Ichthyological Exploration of Freshwaters* 14(4): 307-310.

Vishwanath, W. and K. Nebeshwar (2004). *Schistura reticulata*, a new species of balitorid loach from Manipur, India, with redescription of *S. chindwinica*. *Ichthyological Exploration of Freshwaters* 15(4): 323-330.

Vishwanath, W. and K. Shanta (2004). A new Nemacheiline fish of the genus *Schistura* McClelland (Cypriniformes: Balitoridae) from Manipur, India. *Journal of the Bombay Natural History Society* 101(1): 138–140.

Vishwanath, W. and K.N. Sharma (2005). A new Nemacheiline fish of the genus *Schistura* McClelland (Cypriniformes: Balitoridae) from Manipur, India. *Journal of the Bombay Natural History Society* 102(1): 79–82.

Acknowledgements

We are grateful to Dr. K.C. Jayaram, Chennai for invaluable suggestions during discussions. We acknowledge the financial assistance from the Ministry of Environment and Forests, Government of India. We thank the officials of Karnataka Forest Department and Karnataka Power Corporation Limited, Government of Karnataka for co-operation during the field investigation. We thank the Director and colleagues at ZSI, Southern Regional Station, Chennai for the support in identification of specimens. Suresh S., Vishnu D.M., Karthick B. and Ravindra assisted in specimens collection and Saveer Ahmed in digitizing mouth portion of specimens.

Fish diversity in relation to landscape and vegetation in central Western Ghats, India

Sreekantha, M. D. Subash Chandran, D. K. Mesta, G. R. Rao, K. V. Gururaja and T. V. Ramachandra*

Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

The Western Ghats, one of the well-known biodiversity hotspots of the world, harbours 289 species of freshwater fish of which 119 are endemic. The ecosystems in this region have been, over the past 150 years or so, experiencing tumultuous changes due to the ever-increasing human impacts. In this regard, a study was conducted in Sharavathi River, central Western Ghats to understand fish species composition with respect to landscape dynamics. The study, using a combination of remote-sensing data as well as field investigations shows that the streams having their catchments with high levels of evergreenness and endemic tree species of the Western Ghats were also richer in fish diversity and endemism, compared to those catchments with other kinds of vegetation. This illustrates that the composition and distribution of fish species have a strong association with the kind of terrestrial landscape elements and the importance of landscape approach to conservation and management of aquatic ecosystems. Occurrence of endangered, endemic species and the discovery of two new species of genus *Schistura* reaffirm the 'hottest hotspot' status of the Western Ghats, a repository of biological wealth of a rare kind, both in its aquatic and terrestrial ecosystems.

Keywords: Endemism, fish fauna, land-use, landscape elements, Sharavathi River basin, vegetation, Western Ghats.

LANDSCAPE changes such as habitat alterations, fragmentation and loss are causing a decline of many species of flora and fauna at an alarming rate throughout the world[1–3]. Hence, the emergence of a landscape-based approach for biodiversity assessment and management has assumed significance in recent years as it considers a species as part of a landscape consisting of diverse elements. For instance, deer in a pastureland makes use of several elements, such as heterogeneous vegetation patches in search of variation in fodder, temperature regimes (both warm and cold) and a waterbody for drinking[4]. The need for integrated management of various landscape elements constituting an ecosystem to maintain its characteristic biodiversity has also been stressed[5–7]. Various researchers[8–11], highlighted the role of terrestrial ecosystem in the study of freshwater fishes, emphasizing the need to adopt landscape approach, integrating both terrestrial and aquatic ecosystems. Despite the presence of two of the world's biodiversity hotspots in the vast terrain of India, a landscape approach is yet to gain attention in the conservation or management of the rich biodiversity in general and freshwater fishes in particular.

The Western Ghats, one among the 25 biodiversity hotspots of the world[12], is a chain of mountains, stretching north-south along western peninsular India for about 1600 km, harbouring rich flora and fauna. Various forest types such as tropical evergreen, semi-evergreen, moist and dry deciduous and high altitude *sholas* mingle with natural and man-made grasslands, savannas and scrub, in addition to agriculture, plantation crops, tree monocultures, river-valley projects, mining areas and many other land-uses. Over 4000 species of flowering plants (38% endemic), 330 butterflies (11% endemic), 289 fishes (41% endemic), 135 amphibians (75% endemic), 156 reptiles (62% endemic), 508 birds (4% endemic) and 120 mammals (12% endemic)[13–16] are among the known biodiversity wealth of the Western Ghats. This rich biodiversity coupled with higher endemism could be attributed to the humid tropical climate, topographical and geological characteristics, and geographical isolation (Arabian Sea to the west and the semiarid Deccan Plateau to the east).

The Western Ghats forms an important watershed for the entire peninsular India, being the source of 37 west-flowing rivers and three major east-flowing rivers and their numerous tributaries. The 289 freshwater fish species (41% endemic) reported from the Western Ghats belong to 12 orders, 41 families and 109 genera[14,15]. Notable among these are 33 species from Aralam Wildlife Sanctuary[17], 35 from Periyar River[18], 98 from Chalakudy River[19], 33 from the Kalakad–Mundanthurai Tiger Reserve[20], 92 from Nilgiri Biosphere Reserve[21] and 102 from Pune District[22]. Yadav[23] reported 135 species of fish from the part of the Western Ghats covering southern Gujarat, Maharashtra and Karnataka. The four major rivers (Kali, Bedthi, Aghanashini and Sharavathi) in Uttara Kannada District, Karnataka altogether account for 92 fish species[24]. Arunachalam[25] and Bhat[24] showed that fish species diversity and abundance are linked to diversity of aquatic habitats. The studies carried out so far, however, lack landscape ecological approach and have practically little

*For correspondence. (e-mail: cestvr@ces.iisc.ernet.in)

information about the nature of terrestrial landscape elements in the watershed.

The present study conducted in the upper catchment area of Sharavathi River in central Western Ghats, India, brings out the diversity of fish species in the selected tributary streams of the river, and their correlation with the predominant vegetation in the catchments of these streams. It also deals with the effects on the fish diversity due to the Linganamakki hydel reservoir. The study indicates that freshwater ecosystems are to be considered as parts of the general landscape (watershed/basin/catchment) and significant modifications in the natural vegetation of their catchments can have detrimental impacts on the native fish fauna.

Materials and methods

Study area

Sharavathi River in central Western Ghats, Karnataka, is a west-flowing river that originates in the hilltops at Ambuthirtha, Thirthahalli taluk, Shimoga District and flows northwest for about 132 km before joining the Arabian Sea near Honnavar town, Uttara Kannada District (Figure 1). The Jog, one of the magnificent waterfalls of India, is situated in the course of this river. We have chosen the upper catchment area (1991.43 sq. km) of Sharavathi River (situated at 74°67′11″–75°30′63″E and 14°7′27″–13°77′08″N, at an average altitude of 512 m) for this study. The water-spread area of Linganamakki reservoir is about 326 sq. km (at full reservoir level), which is sometimes attained during the peak of the rainy season. Several streams (Figure 2) in the western and southern regions of the catchment receiving more rainfall are perennial. Some of the streams drain directly into the reservoir, while others coalesce to form larger streams or tributaries such as Yenneholé, Huruliholé, Nagodiholé, Sharavathi, Hilkunji, Mavinaholé, Haridravathi and Nandiholé. The western and southern streams run through rugged terrain clad in evergreen to semi-evergreen forests, and through narrow valleys lush with areca (betel nut) gardens and paddy fields. The eastern streams flow through gentler topography, presently with moist deciduous forests, agriculture and plantations of forest trees. Rainfall in the east (about 1800 mm), though lesser than the western and southern catchments, nevertheless, is sufficient to support evergreen to semi-evergreen forests, according to the old historical records, and existing patches of relic vegetation. Throughout the catchment, the stream waters are heavily used for cultivation of various crops such as areca nut, spices, paddy, sugarcane, banana and vegetables. This river became a hub of developmental activities ever since the construction of hydroelectric dams. In 1932, a small dam was built at Hirebhaskara (in Sagar taluk). In 1964, a major dam at Linganamakki (74°50′54″E, 14°14′24″N, 512 m asl), having a total water-spread area of 326 sq. km was constructed, which submerged the Hirebhaskara dam and the lands belonging to 32 villages. Later, in the 1990s, another dam was built at Gerusoppa, Uttara Kannada, in the downstream of Sharavathi River, affecting 705 ha of primary forests. Earlier studies assessing cumulative impacts in this region have substantiated the human-induced changes and their implications on regional ecology and biodiversity[26–28].

Implementation of river-valley projects and the consequent immigration of people into the region and resettlement of the dam evacuees (from 32 villages) elsewhere, mainly in the catchment itself, impacted the natural ecosystems[26]. In addition, this region witnessed intensified selection felling of industrial timbers in the catchment-area forests, during the 1950s. Conversions of several patches, totalling 188.7 sq. km of natural forests into monocultures of teak (*Tectona grandis*) and various exotic tree species like *Casuarina*, *Eucalyptus* spp., *Acacia auriculiformis* and *Pinus* spp. (particularly during the post-independence era), were major ecological changes in the region. Opening up of more areas of forests due to creation of roads and power lines, expansion of agriculture, mining and quarrying would also have had an impact on the waterbodies[26,28]. Introduction of exotic fishes into the reservoir to boost commercial fish production is also expected to impact the local fish fauna. Apart from these, in the Linganamakki reservoir, several fish species were introduced to boost commercial fish production[29].

Land-use analysis of the catchment area

Land-use dynamics was analysed for the catchments of the streams studied for fish using temporal remote sensing data along with collateral data. Integration of remote-sensing data with collateral data has been done using Geographic Information System (GIS). Survey of India toposheet of scale 1 : 50,000 (48 J, K, N and O), which covers the Sharavathi River basin were used for digitization of base layers such as region's boundary, vegetation types, forest types and drainage networks. Multispectral data of IRS 1C (Indian Remote Sensing Satellite 1C) with spatial resolution of 23.5 m corresponding to green, red and NIR bands in 0.5–0.6, 0.6–0.7, 0.7–0.9 μm were used for land-use analyses. Satellite imageries of Path 97–Row 63, provide the entire image of the Sharavathi catchment region. The temporal data (of two seasons corresponding to the study period) were geometrically corrected taking the location (latitude and longitude) values of known points from the image as well as their corresponding ground values with the help of Survey of India toposheet and ground control points (GCPs) using Global Positioning Systems (GPS). Supervised classification technique based on Gaussian maximum likelihood algorithm was used for land-use analysis. The land-use categories considered were ever-

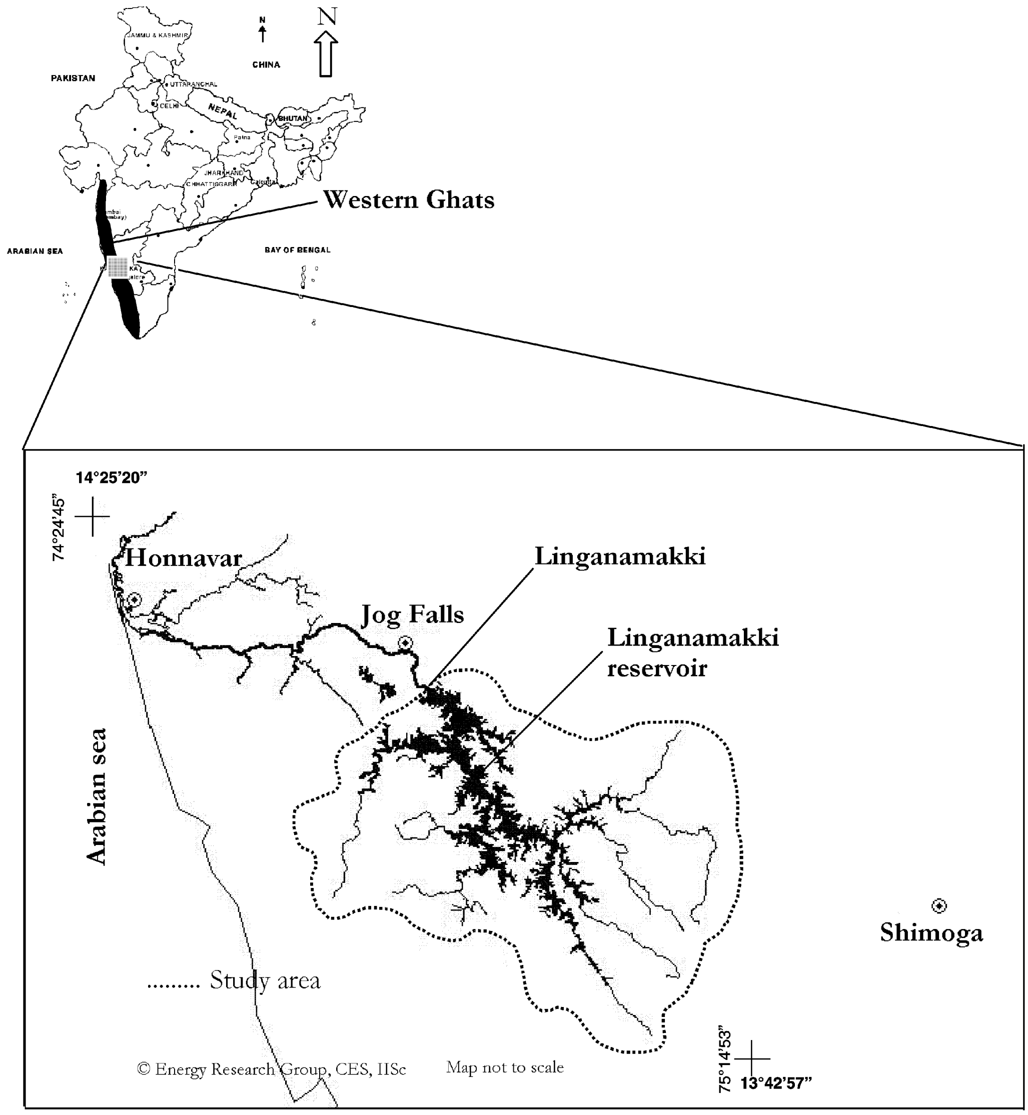


Figure 1. Map showing location of Sharavathi River basin and study area in the Western Ghats of India.

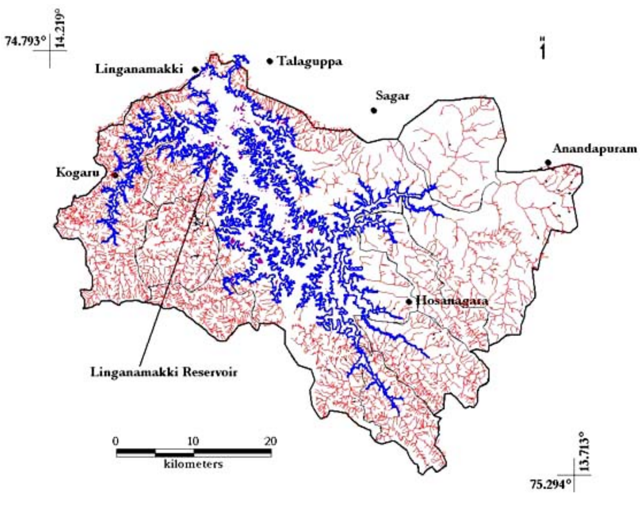


Figure 2. Drainage map of upper catchment of Sharavathi River basin.

green to semi-evergreen forests, moist deciduous forests, plantations, agricultural land and open land.

Fish sampling

Fish sampling was carried out from January 2002 to August 2004 in 41 localities (Figure 3) representing the eastern and western streams and the Linganamakki reservoir. Stratified random sampling method was adopted to locate the sampling sites considering the stream densities. Overall, 261 samplings were made with approximately 40 samplings per season (summer, winter and monsoon) in all the important aquatic microhabitats (riffles, pools, cascade, falls, embayment, run, backwater, etc.) using gill nets, cast nets, dragnets, and hooks and lines of varying dimensions. Standard keys[30–33] were followed for species identification.

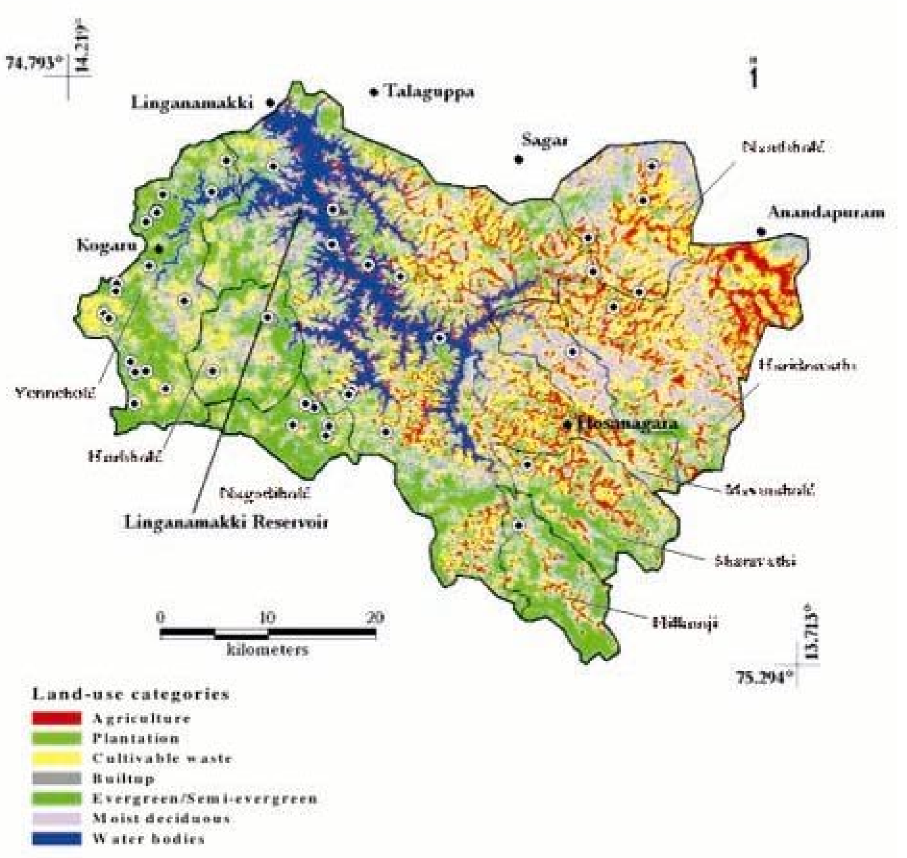


Figure 3. Classified image of the study area with major sub-basins and sampling points.

Unidentified fish specimens were preserved and subsequently identified at the Zoological Survey of India, Southern Regional Station, Chennai.

Fish species and terrestrial habitats

In order to understand the linkages between terrestrial vegetation and stream-fish distribution, eight stream localities were selected among the 41 sampling localities in which sampling was carried out using cast net, drag net and gill net to maximize fish diversity. Vegetation sampling was carried out in the catchment of these streams.

A combination of transects and quadrat method was used for tree sampling within the stream catchments. Five quadrats, each of 400 sq. m, were laid alternatively along the sides of the transect, keeping an inter-quadrat distance of 20 m. In each quadrat, trees (≥30 cm girth at 130 cm above ground) were recorded species-wise. Thereby we could gather data on the actual number of trees in each quadrat, the species to which they belong, and their girth. The transect data were used to estimate the number of trees per ha in a given patch of vegetation. Trees were categorized as 'evergreen' and 'deciduous' (palms excluded). The percentage of evergreen trees in the sample has been expressed as 'evergreenness'. The total endemic tree population in each sample was estimated and the same has been expressed as the 'percentage of endemism'.

Analysis of variance (ANOVA) was carried out to test the significance of variance among rainfall zones. As data pertaining to fish species richness and ecological status measures (i.e. endemic, endangered, vulnerable, lower risk and data deficient status)[15] and landscape variables were not normally distributed, they were transformed into $\log_e$ and those values with 'zero' into $\log_e + 1$. These data were first analysed for Pearson's correlation coefficient (r) to find the linear relationship between them. In order to reduce the number of landscape variables, Principal Component Analysis (PCA) of the transformed data was performed. Partial correlation coefficients were calculated between principal components with fish species richness and ecological status, to understand the influence of landscape variables on them.

Results and discussion

Rainfall and stream hydrology

The drainage pattern of the study area (Figure 2) indicates higher drainage density (3.82 km of stream per sq. km) towards the western and southern catchments with rugged hills and deep valleys, while the eastern flatter terrain has lower drainage density (1.54 km/sq. km). Analysis of rainfall data for 20 years (1981–2001) indicates that it varies from 4980 ± 1104 mm (west); 4092 ± 1167 mm (south) to 1883 ± 452 mm (east), and the variation is significant (ANOVA, $F = 94.24$, $P = 0.0001$). Streams range from perennial (on the western side), to intermittent (south and parts of west) to ephemeral (east).

Land-use analysis

Land-use analysis of the study area using remote-sensing data (Figure 3), supported by ground studies reveals that about 25% of the area is under moist deciduous forest and 16% under evergreen to semi-evergreen forest. Plantations (*Acacia auriculiformis*, *Casuarina equisetifolia*, *Pinus* spp., *Eucalyptus* spp. and areca nut orchards) cover 9.7% of the total landscape. About 21% of the land comes under the combination of grassland, scrub and cultivable waste. Agriculture (excluding areca nut orchards) covers 8.5%. The total water-spread area was 7.1% and the dry reservoir bed was 5.4% (both subject to seasonal changes). Barren lands, which include built-up area, roads and rocky areas, constitute 7.14% of the landscape. Vegetation analysis shows that natural vegetation is poor towards the eastern side, due to intense anthropogenic activities. This region has more of agriculture, monoculture plantations of exotic tree species, scrub and savanna, and built-up area. The forest is predominantly of moist deciduous type, with small isolated bits of semi-evergreen vegetation. In contrast, the western region with rugged hilly terrain and heavier rainfall (~5000 mm) has characteristic evergreen to semi-evergreen forests as the natural cover. These are interspersed with grassy blanks, scrub and savanna, areca nut gardens and paddy fields.

Ichthyodiversity: richness, endemism, threat status and distribution

We have recorded 64 species of fishes belonging to 38 genera and 17 families from the upper catchment of Sharavathi River. The maximum number of species that is likely to occur in the upper catchment of Sharavathi River is 67 according to Michaelis–Menten equation[15], requiring a sampling effort of 334 (Table 1). Similarly, maximum number of species in the reservoir is 41, requiring sampling effort of 98 and in the streams it is 37, requiring a sampling effort of 236. Cyprinidae with 31 species was the dominant family, followed by Balitoridae and Bagridae with 8 and 6 species respectively. Among the genera, *Puntius* was more diverse with seven species, followed by *Schistura* with six species. Annexure I details the species recorded from the region with their ecological status. Of the 64 species, 18 are endemic to the Western Ghats and 28 are confined to peninsular India. Varied ecological status of the twenty-two species indicates the uniqueness of the region and the need for its urgent conservation. The study area accounts for 6.88% of Indian freshwater fish (930 species) and 22.2% of the Western Ghats species (289), while constituting only 0.006% of the geographical area of the latter. Figure 4 depicts the percentage of endemism, threatened and data-deficient fish species in India, the Western Ghats and upper catchment of the Sharavathi River.

The discovery of two new species of genus, *Schistura* namely *S. nagodiensis* and *S. sharavathiensis*, in the perennial streams of the western side with evergreen to semi-evergreen clad landscape[34] highlights the ecological significance of the region. A critically endangered species, *Tor mussullah*, and the recently described *Batasio sharavathiensis*[35], a rare species restricted only to the Sharavathi River basin, are also candidates for the 'Critically endangered' status, and were recorded in the western part of the reservoir. *S. nilgiriensis* has been reported for the first time in Karnataka from this river basin[36].

Table 1. Probable relationship between cumulative species richness and number of samplings

Samplings	Collected species	$Y = a + b \ln(X)$ *a*	*b*	*r*	*P*	Estimated species
Total	64	–9.044	12.544	0.971	<0.001	67
Reservoir	39	10.011	6.765	0.938	<0.001	41
Stream	33	–7.036	8.127	0.953	<0.001	37

Y, Cumulative species richness, *X*, Number of samplings.

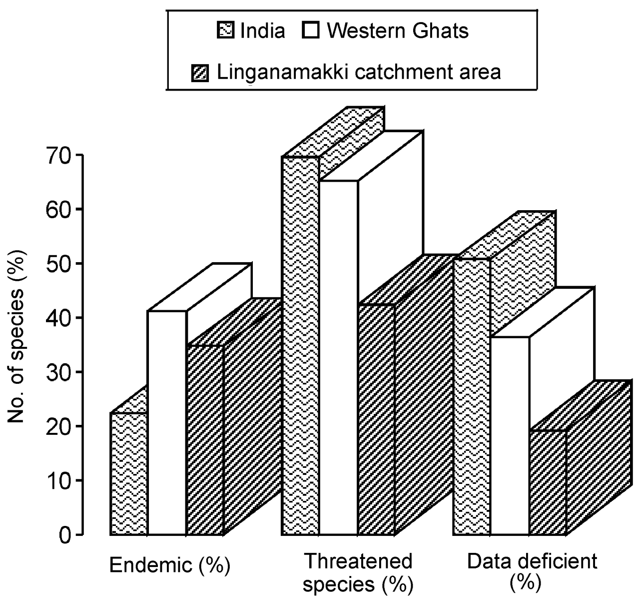


Figure 4. Percentage endemism, threatened and data-deficient freshwater fish species of India, the Western Ghats and the Linganamakki catchment area.

The reservoir had 39 species (Annexure I) of fish (ten endemic to the Western Ghats, three restricted to peninsular India, seven introduced and 18 non-endemics having distribution all over India). The streams studied had 33 species of which 12 were endemic to the Western Ghats, seven to peninsular India and 11 had all-India distribution (three with unknown status). Ecological status of reservoir and stream fish species is given in Table 2, indicating species richness is more in reservoir compared to stream habitats, due to generalist species (having wider distribution) and species introduced since 1969 for commercial production. On the contrary, endemics having narrow range of distribution were more associated with the western streams. This emphasizes the importance and high conservation values of stream habitats of the Western Ghats.

Fish richness, ecological status and vegetation variables: Table 3 details parameters such as fish species richness, endemism, ecological status, forest types and quality in the catchment areas as well as rainfall. There is significant positive correlation between tree evergreenness and tree endemism ($r = 0.859$, $P = 0.003$). Evergreen to semi-evergreen forests have more endemic tree species than deciduous forests. In fact, such forests should have been the natural climax vegetation all over the upper catchment of the Sharavathi River, because of the higher rainfall. A forest-working plan by Rao[37] for the Belandur State Forest of Anandapuram (Ananthapur) Range, Shimoga District (in the eastern catchment of Sharavathi River) stated that this region, receiving rainfall of 1130–1700 mm, had 15% of the forest area under evergreen *kans*. Nevertheless, during the 19th century and even during the early 20th century, there were substantial patches of evergreen to semi-evergreen *kan* forests in the central Western Ghats. Investigations by Chandran and Gadgil[38], indicate that the *kans* were sacred forests during the pre-colonial period, when the forest management was decentralized and was under the local community control. Agriculture, fuel-wood collection and cattle grazing through the last many centuries have altered the forests of the eastern catchment[26].

Stream fishes and catchment vegetation

Western streams: The western streams, running through rugged terrain, have more of their catchment area under evergreen to semi-evergreen forests. Notable among the evergreen trees (many of them endemics) were *Actinodaphne hookeri*, *Aglaia* spp., *Beilschmedia fagifolia*, *Cinnamomum* spp., *Diospyros* spp., *Dipterocarpus indicus*, *Euonymus indicus*, *Garcinia* spp., *Holigarna* spp., *Hopea ponga*, *Knema attenuata*, *Litsea* spp., *Myristica malabarica*, *Nothopegia colebrookeana*, *Olea dioica*, *Palaquium ellipticum*, *Persea macrantha*, *Poeciloneuron indicum*, *Symplocos beddomei* and *Syzygium* spp. These stream catchments have higher evergreenness and higher endemism among the trees.

The catchments of western streams in Yenneholé and Nagodi sub-basins with patches of evergreen forests are rich in endemic tree population (Table 3). Fish diversity and endemism are also highest in these streams. In addition to the evergreens, both these sub-basins have some relic patches of primaeval forests with characteristic endemic trees *P. indicum*, *P. ellipticum* and *D. indicus*. Though the catchment area of the Algod stream is covered more with secondary evergreen to semi-evergreen forests, it has 16 fish species of which six are endemic. Similarly, Huruli stream has 12 fish species of which five are endemic. Endemic fishes like *Barilius bakeri*, *B. canarensis* and *Schistura* spp. are exclusive to the western parts.

The commonly occurring deciduous tree species amidst the evergreen vegetation are *Terminalia paniculata*, *Lagerstroemia microcarpa*, *Careya arborea*, *Dillenia pentagyna*, *Vitex altissima* and *Ervatamia heyneana*. Older individuals represent most of these trees. Except the latter two, which are usually gap-finders, other deciduous species probably appeared in this high-rainfall zone because these forests have had a history of slash-and-burn cultivation until the late 19th century[39]. Banning of shifting cultivation led to the return of the evergreen species. These evergreen species with closed canopy prevented the regeneration of the more light-loving (heliophilous) deciduous trees.

Eastern streams: Catchments of the eastern streams were dominated by deciduous forests. The eastern landscape is much more fragmented with several tree monoculture industrial plantations. Annual rainfall of 1500–2000 mm here is sufficient to support evergreen to semi-evergreen forests, as described in the historical documents of the Forest Department, dating back to late 19th century and early 20th century. Brandis and Grant[40] reported the presence of 171 evergreen to semi-evergreen *kan* forests covering a total area of over 130 sq. km in the Sorab taluk, Shimoga District, immediate north of our study area, where the annual rainfall is around 1500 mm only. A forest-working plan of 1919 reported the presence of 11.6 sq. km of evergreen *kans* amidst the otherwise drier forests of the eastern catchment. These *kans* were reported to be the source of several perennial streams. The *kan* forests had several en-

Table 2. Ecological status of fish species in two major habitats of the catchment

Ecological status	Reservoir	Stream
Species richness	39	33
Endemic species (%)	25.0	42.4
Restricted to peninsular India (%)	7.5	21.2
Distributed throughout India (%)	47.5	36.3
Introduced species (%)	17.5	3.0

Table 3. Fish species richness, ecological status, rainfall and vegetation in streams and reservoir of the study area

Zone	Stream	Fish species richness	Total species richness	Endemic	Total endemic	Endangered	Vulnerable	Rainfall (mm)	Evergreenness (%) (trees)	Endemism (%) (trees)
Western	Yenneholé	18	22	8	10	3	6	4410.1–5597.5	86–100	46–58
	Huruli	12		5					88–94	52–57
	Algod	16		6					60–88	25–58
	Nagodi	19		8					68–99	36–71
Eastern	Nandiholé	14	14	2	2	0	2	1715.2–1156.7	0–16	0–11
	Hunsavalli	6		1					2–31	8–14
	Hosur	3		1					0–15	0–6
	Hebbailu	3		0					0–15	0–4
Reservoir		39	39	8	8	4	1	3423.2		

Table 4. Principal components derived from PCA of fish species richness and their ecological status in eight streams of Sharavathi River basin

Principal component analysis	PC1	PC2
Eigenvalues	4.484	0.31
Proportion of variance (%)	89.68	6.20
Loading score		
Species richness	0.443	–0.204
Endemism	0.421	0.792
Endangered	0.469	0.017
Lower risk	–0.432	0.575
Data-deficient	0.47	–0.005

demic and evergreen tree species such as *Vateria indica*, *Artocarpus hirsuta*, *Cinnamomum* spp. and *Litsea* spp.[37]. Even today, enmeshed in the landscape of deciduous forests, agriculture and scrub, occasional small, relic semi-evergreen forest patches are observable.

Hunsavalli stream catchment in the east is dominated by deciduous forests, with low percentage of endemism (8–14). However, one of the patches sampled in this catchment, perhaps the remains of an ancient *kan*, at Gentinakoppa village had 84% evergreenness and 50% tree endemism. The stream had six fish species, of which one was endemic. In Hosur stream catchment, also dominated by deciduous forests, tree endemism varies from 0 to 6%. However, a semi-evergreen forest patch at Aduru had 79% evergreenness and 58% tree endemism. Hosur stream had only three fish species, out of which one was endemic to the Western Ghats. Hebbailu stream catchment had moist deciduous forests, which do not exceed 15% in evergreenness. However, a forest sample at Kallukoppa village had 70% evergreenness with 30% tree endemism, while Hebbailu had only three fish species and no endemic species. We presume from these facts that the eastern streams also could have had more number of endemic fish species in the olden days than the present (only two species). Due to the spread of agriculture and intensified forest removal in their catchments, the forests became drier and the streams turned seasonal[26,28], with understandable adverse consequences on fish diversity and endemism.

Relationship between fish species richness and their ecological status

Pearson's correlation coefficient shows that fish species richness was positively related to the number of endemic (r = 0.752, P = 0.016), endangered (r = 0.935, P = 0.001) and data-deficient (r = 0.924, P = 0.001) species. Similarly, endangered fish species increased with an increase in endemic (r = 0.873, P = 0.002) and data-deficient (r = 0.984, P = 0.001) species. Lower risk category had negative influence on richness, endemism, endangered, vulnerable and data-deficient species (r = –0.802, P = 0.008; r = –0.732, P = 0.02; r = –0.889, P = 0.002; r = –0.657, P = 0.039 and r = –0.915, P = 0.001 respectively). Considering ecological status, vulnerability did not show significant relationship, except for lower risk category. Hence, it was removed from further analysis. Since fish parameters were correlated with each other, PCA provided reduced components out of them (Table 4). Principal component 1 (PC1) explained for 89.68% variance comprising species richness, endemism and ecological status, and PC2 for 6.2% contributed by endemism and lower risk category. Biplot of this analysis given in Figure 5, shows distinct clusters of streams from the eastern side versus western side, which conform the results indicating that the streams on the western side have higher species richness, dominated by endemic and endangered species[41].

Influence of landscape variables on fish species richness and their ecological status

Table 5 lists correlation coefficients highlighting the influence of land-use and vegetation in eight selected stream catchments. Results of PCA are detailed in Table 6, wherein PC1 explains for 77.27% variance from all land-

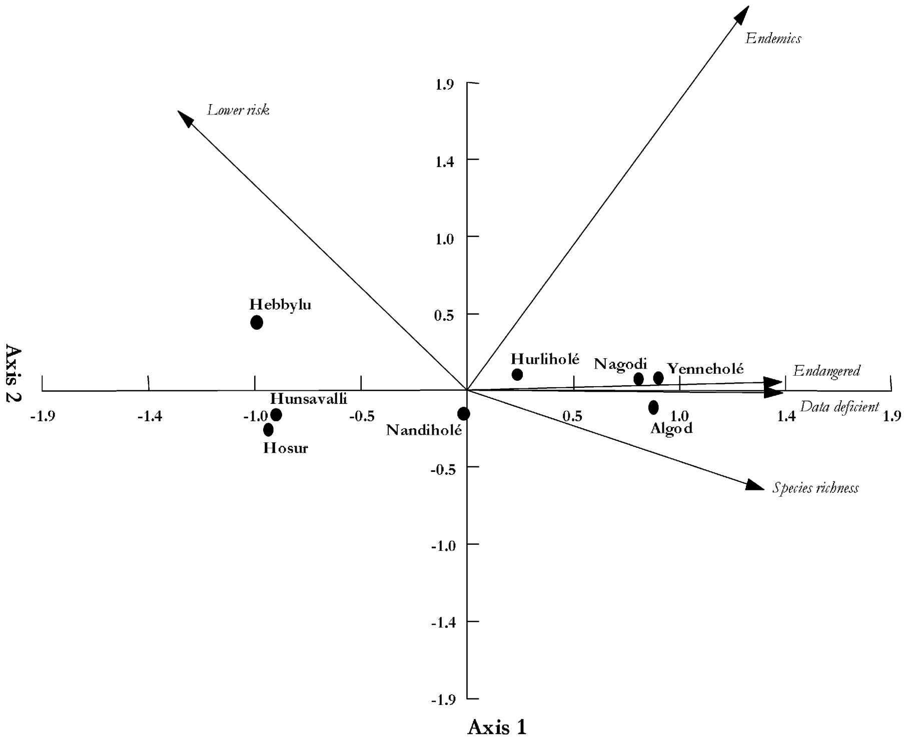


Figure 5. Biplot of principal components derived from eight studied streams of Sharavathi River basin on fish species richness, endemism and their ecological status. Vector scaled at 3.

Table 5. Correlation coefficient (*r*) for rainfall, land-use and vegetation variables among the eight stream localities in Sharavathi River basin ($N = 8$). Values in parenthesis denote level of significance (*P*)

Parameter	Rainfall	Evergreen–semi-evergreen	Moist deciduous	Agriculture	Open land	Tree endemics
Evergreen–semi-evergreen	0.977					
	(0.001)					
Moist deciduous	–0.701	–0.670				
	(0.026)	(0.035)				
Agriculture	–0.846	–0.775	0.355			
	(0.004)	(0.012)	(0.194)			
Open land	–0.875	–0.887	0.497	0.805		
	(0.002)	(0.002)	(0.105)	(0.008)		
Tree endemics	0.799	0.681	–0.756	–0.617	–0.558	
	(0.009)	(0.031)	(0.015)	(0.050)	(0.075)	
Tree evergreenness	0.854	0.766	–0.503	–0.774	–0.731	0.859
	(0.003)	(0.013)	(0.102)	(0.012)	(0.020)	(0.003)

Table 6. Eigenvalues and loading scores of rainfall, land-use and vegetation variables derived from PCA of eight streams from Sharavathi River

Principal component analysis	PC1	PC2
Eigenvalues	5.409	0.813
Proportion of variance (%)	77.27	11.61
Loading score		
Rainfall	0.425	0.039
Evergreen–semi-evergreen	0.405	0.083
Moist deciduous	–0.308	0.705
Agriculture	–0.366	–0.454
Open land	–0.378	–0.34
Tree endemics	0.367	–0.412
Tree evergreenness	0.386	0.06

scape variables, while PC2 accounts for 11.61% variance, mainly by moist deciduous forest, agriculture and tree endemism. Figure 6 depicts the biplot generated in PCA with score-loading and vectors, and highlights the influence of evergreen to semi-evergreen-type forests, rainfall, tree endemics, and evergreenness on streams on the western side compared to the influence of human-induced land-uses (agriculture and open land) and remnants of moist deciduous-type forests on streams located on the eastern side. Partial correlation coefficient (r_{xyz}) was calculated between PC1 and PC2 with fish species richness and their ecological status. Table 7 details the partial correlation coefficient values. It is evident that PC1 (derived from

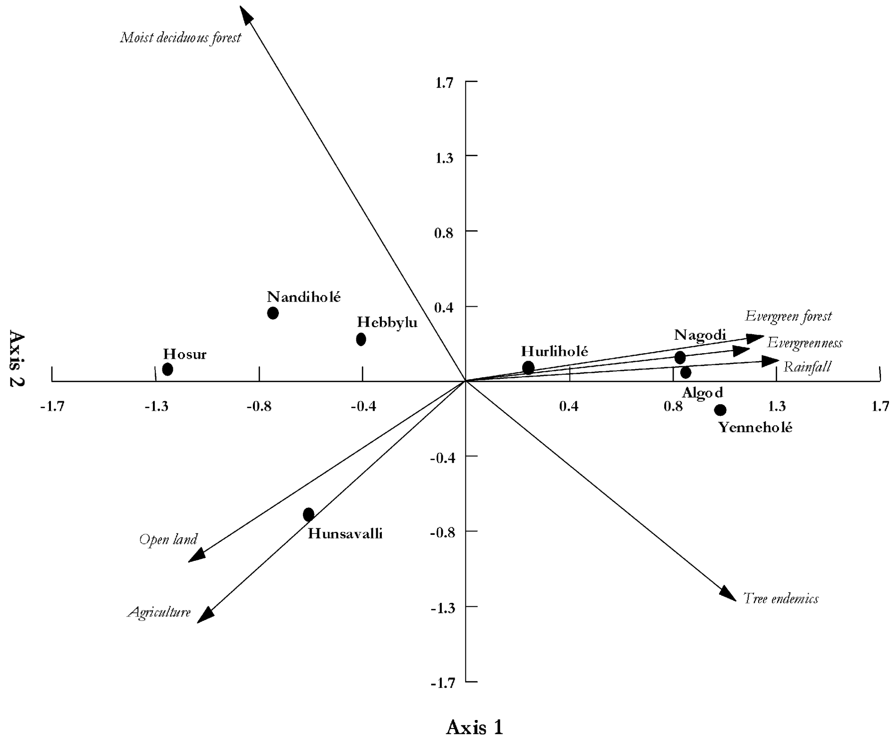


Figure 6. Biplot of principal components derived from eight studied streams of Sharavathi River basin based on landscape variables. Vector scaled at 3.

Table 7. Partial correlation coefficients between fish species richness, and their ecological status and principal components of landscape variables of the eight streams of Sharavathi River. Values in parenthesis denote level of significance (*P*)

Species variable	PC1*	PC2*
Species richness	0.764	–0.193
	(0.014)	(0.323)
Endemic species	0.971	–0.734
	(0.001)	(0.019)
Endangered	0.914	–0.504
	(0.001)	(0.101)
Vulnerability	0.222	0.202
	(0.299)	(0.316)
Lower risk	–0.852	0.095
	(0.004)	(0.412)
Data-deficient	0.931	–0.496
	(0.001)	(0.106)

*PC2 and PC1 were kept as control variables in the respective analysis.

rainfall and landscape variables from dominant land-use with vegetation of evergreen to semi-evergreen-type forests, tree endemics, and evergreenness) has positive influence on fish species richness, endemism, endangered and data-deficient species and has negative influence on the lower risk category. In contrast, PC2 (derived by moist deciduous-type forests) has negative influence on endemic fish species. These analyses substantiate that the perennial streams with their catchments clad in evergreen to semi-evergreen forests and higher levels of plant endemism are the habitats for rich and endemic fish fauna. Linkages of perennial streams, higher rainfall and vegetation type with the regional biodiversity highlight the need for decision makers to adopt landscape approach in the management of natural resources to conserve the hotspots of biodiversity.

Conclusion

Analysis of fish species composition, distribution and ecological status with reference to the terrestrial ecosystem in the catchment, revealed preference of the endemic fish fauna to perennial streams with their catchments having evergreen to semi-evergreen forests, which also have higher levels of plant endemism. On the contrary, streams whose catchments have moist deciduous forest or its degraded stages with low degree of endemism, have fishes with wider distribution ranges and few endemic species. PCA and partial correlation coefficient have revealed the influence of landscape variables on fish species richness, endemism and their ecological status. The fact that the eastern catchment, having relatively lesser rainfall and deciduous forest as the dominant type, had evergreen forests once, indicates that the stream of the eastern catchment also would have had high species richness and higher endemism among the fishes. Due to the spread of agriculture, large areas under forest monoculture and deciduous forests – resultant of fire, there is a decline in

Annexure I. Freshwater fishes in the upper catchment area of Sharavathi River with their distribution and ecological status

Species name	Global distribution	Ecological status*	Reservoir	Eastern sub-basins 1	2	3	4	Western sub-basins 5	6	7	8
Family: Cyprinidae											
Amblypharyngodon mellettinus	India	LR	–	–	–	–	–	+	–	–	+
Barilius bakeri	The Western Ghats	VU	–	–	–	–	–	–	+	–	+
Barilius bendelisis	India	LR	+	–	–	–	–	–	–	–	–
Barilius canarensis	The Western Ghats	DD	–	–	–	–	–	–	–	–	+
Barilius gatensis	The Western Ghats	DD	–	–	–	–	–	–	–	–	+
Brachydanio rerio	India	LR		+	+	+	+	+	+	+	+
Catla catla	Translocated		+	–	–	–	–	–	–	–	–
Cirrhinus mrigala	Translocated		+	–	–	–	–	–	–	–	–
Cirrhinus fulungee	India	LR	+	–	–	–	–	–	–	–	–
Cyprinus carpio communis	Translocated		+	–	–	–	–	–	–	–	–
Cyprinus carpio sp.	Translocated		+	–	–	–	–	–	–	–	–
Cyprinus carpio specularis	Translocated		+	–	–	–	–	–	–	–	–
Danio aequipinnatus	India	LR	–	+	+	+	+	+	+	+	+
Garra gotyla stenorhynchus	The Western Ghats	EN	+	–	+	+	+	+	+	+	+
Gonoproktopterus dubius?	The Western Ghats	EN	–	–	–	–	–	–	+	–	–
Gonoproktopterus kolus	The Western Ghats	EN	+	–	–	–	–	–	–	–	–
Labeo kontius	The Western Ghats	LR	+	–	–	–	–	–	–	–	–
Labeo rohita	Translocated		+	–	–	–	–	–	–	–	–
Oreichthys cosuatis	India	DD	–	+	–	–	–	–	–	–	+
Osteocheilichthys nashii	The Western Ghats	VU	+	–	–	–	–	–	+	–	+
Puntius arulius	The Western Ghats	EN	+	–	–	–	–	–	–	–	+
Puntius chola	India	VU	+	–	–	–	–	–	+	+	+
Puntius fasciatus	India	EN	–	–	–	–	–	–	+	+	+
Puntius filamentosus	India	DD	+	–	+	+	+	+	+	+	+
Puntius sahyadriensis	The Western Ghats	DD	–	–	–	–	–	–	+	+	+
Puntius sophore	India	LR	–	+	+	+	+	+	+	+	+
Puntius ticto	India	LR	–	–	+	+	+	+	+	+	+
Rasbora daniconius	India	LR	–	+	+	+	+	+	+	+	+
Salmostoma boopis	The Western Ghats	LR	+	+	–	–	+	+	+	+	+
Tor khudree	India	VU	+	–	–	–	–	–	–	–	–
Tor mussullah	The Western Ghats	CR	+	–	–	–	–	–	–	–	–
Family: Balitoridae			–								
Acanthocobitis botia	India	LR	–	–	+	–	+	–	+	+	+
Nemacheilus anguilla	The Western Ghats	LR	–	–	–	–	+	–	+	+	+
Schistura denisonii denisonii	India	VU	–	+	+	–	+	–	+	+	+
Schistura nilgiriensis	The Western Ghats	EN	–	–	–	–	–	+	–	–	–
Schistura semiarmatus	The Western Ghats	VU	–	–	+	–	+	–	+	–	+
Schistura nagodiensis	Unknown	DD	–	–	–	–	–	–	+	–	+
Schistura sharavathiensis	Unknown	DD	–	–	–	–	–	–	+	–	–
Schistura sp.?	Unknown	DD		–	–	–	–	–	–	–	+
Family: Cobitidae											
Lepidocephalus thermalis	India	LR	–	+	+	+	+	+	+	–	+
Family: Aplocheilidae											
Aplocheilus lineatus	India	LR	–	+	+	+	+	+	+	+	+
Family: Belonidae											
Xenentodon cancilla	India	LR	+	–	–	–	–	–	–	–	–
Family: Belontidae											
Pseudophromenus cupanus	India	DD	–	–	–	–	–	–	–	–	+
Family: Chandidae											
Chanda nama	India	VU	+	+	+	+	+	+	+	+	+
Parambassis ranga	India	DD	+	+	+	+	+	+	+	+	+
Family: Channidae											
Channa marulius	India	LR	+	–	–	–	–	–	–	–	–
Channa orientalis	India	VU	–	–	–	–	–	–	–	–	+
Family: Cichlidae											
Oreochromis mossambica	Translocated		+	+	–	–	+	–	–	–	–
Family: Gobiidae											
Glossogobius giuris	India	LR	+	–	–	–	+	+	+	–	+

(*Contd…*)

Annexure I. (*Contd..*)

Species name	Global distribution	Ecological status*	Reservoir	Eastern sub-basins 1	2	3	4	Western sub-basins 5	6	7	8
Family: Mastacembelidae											
Mastacembelus armatus	India	LR	+	–	–	–	–	–	–	–	–
Family: Bagridae											
Aorichthys sp.	Unknown		+	–	–	–	–	–	–	–	–
Batasio sharavatiensis	The Western Ghats	DD	+	–	–	–	–	–	–	–	–
Mystus bleekeri	India	VU	+	–	–	–	–	–	–	–	–
Mystus cavesius	India	LR	+	–	–	–	–	–	–	–	–
Mystus keletius	India	DD	+	–	–	–	–	–	–	–	–
Mystus malabaricus	The Western Ghats	EN	+	–	–	–	–	–	–	–	–
Family: Claridae											
Clarias batrachus	India	VU	+	–	–	–	–	–	–	–	–
Clarias dussumieri dussumieri	India	VU	+	–	–	–	–	–	–	–	–
Family: Heteropneustidae											
Heteropneustis fossilis	India	VU	+	–	–	–	–	–	–	–	–
Family: Schilbeidae											
Pseudeutropius atherinoides	India	EN	+	–	–	–	–	–	–	–	–
Family: Siluridae											
Ompok bimaculatus	India	EN	+	–	–	–	–	–	–	–	–
Ompok pabo	India	DD	+	–	–	–	–	–	–	–	–
Wallago attu	India	LR	+	–	–	–	–	–	–	–	–
Family: Sisoridae											
Glyptothorax lonah	The Western Ghats	LR	+	–	–	–	–	–	–	–	–

*Dahanukar *et al.*[15]; CR, Critically endangered; EN, Endangered; VU, Vulnerable; LR, Lower risk; DD, Data-deficient; ?, Identification incomplete due to lack of multiple specimens; +, Present; –, Absent.
1, Nandiholé; 2, Haridravathi; 3, Mavinaholé; 4, Sharavathi; 5, Hilkunji; 6, Nagodi; 7, Huruli; 8, Yenneholé.

fish species richness, particularly pushing the endemic fish fauna of the streams to the verge of extinction.

While conceding the need for adopting more sophisticated experimental designs in future, this study indicates the need for adoption of a holistic ecosystem management for conservation of particularly the rare and endemic fish fauna of the Western Ghats. The premium should be on conservation of the remaining evergreen and semi-evergreen forests, which are vital for the perenniality of streams. Through appropriate management there still exists a chance to restore the lost natural evergreen to semi-evergreen forests in those catchments where the annual rainfall is down to 1800 mm. Historical records and relic patches provide ample evidence that such vegetation existed in the past. Natural forests in the lower rainfall areas of the Western Ghats are more fragile and are therefore prone to lose their evergreenness faster than those in high-rainfall areas.

This study highlights that endangered and endemic fish species are precariously clinging onto the stream habitats where patches of primaeval forests, though degraded substantially, still persist.

1. Imhoff, J. G., Fitzgibbon, J. and Annable, W. K., A hierarchical evaluation system for characterizing watershed ecosystems for fish habitat. *Can. J. Fish. Aquat. Sci.*, 1996, **53**, 312–326.
2. Dale, V. H., King, A. W., Mann, L. K., Washington-Allen, R. A. and Mccord, R. A., Assessing land-use impacts on natural resources. *Environ. Manage.*, 1998, **22**, 203–211.
3. Lecis, R. and Norris, K., Habitat correlates of distribution and local population decline of the endemic Sardinian newt *Euproctus platycephalus*. *Biol. Conserv.*, 2003, **115**, 303–317.
4. Forman, R. T. T., *Land Mosaics: The Ecology of Landscapes and Regions*, Cambridge University Press, Cambridge, 1997, p. 632.
5. Melinchuk, R., Ducks unlimited's landscape approach to habitat conservation. *Lands. Urban Plann.*, 1995, **32**, 211–217.
6. Knight, R. L., Ecosystem management and conservation biology. *Lands. Urban Plann.*, 1998, **40**, 41–45.
7. Ward, J. V., Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biol. Conserv.*, 1998, **83**, 269–278.
8. Richard, C., Johnson, L. B. and Host, G. E., Landscape-scale influences on stream habitats and biota. *Can. J. Fish. Aquat. Sci.*, 1996, **53**, 295–311.
9. Wilson, M. F., Gende, S. M. and Marston, B. H., Fishes and the forests – Expanding perspectives on fish–wildlife interactions. *Bioscience*, 1998, **48**, 455–462.
10. Mcdowall, R. M. and Taylor, M. J., Environmental indicators of habitat quality in a migratory freshwater fish fauna. *Environ. Manage.*, 2000, **25**, 357–374.
11. Jackson, D. A., Peres-Neto, P. R. and Olden, J. D., What controls who is where in freshwater fish communities – The roles of biotic, abiotic, and spatial factors. *Can. J. Fish. Aquat. Sci.*, 2001, **58**, 157–170.
12. Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. and Kent, J., Biodiversity hotspots for conservation priorities. *Nature*, 2000, **403**, 853–858.
13. Daniels, R. J. R., Biodiversity of the Western Ghats: An overview. In *Wildlife and Protected Areas, Conservation of Rainforests in India* (eds Gupta, A. K., Ajith Kumar and Ramakantha, V.), ENVIS Bulletin, 2003, vol. 4, pp. 25–40.
14. Babu, K. K. S. and Nayar, C. K. G., A new species of the blind fish *Horaglanis* Menon (Siluroifea: Claridae) from Parappukara

(Trichur district) and a new report of *Horaglanis krishnai* Menon from Ettumanur (Kottayam district), Kerala. *J. Bombay Nat. Hist. Soc.*, 2004, **101**, 296–299.
15. Dahanukar, N., Raut, R. and Bhat, A., Distribution, endemism and threat status of freshwater fishes in the Western Ghats of India. *J. Biogeogr.*, 2004, **31**, 123–136.
16. Gururaja, K. V., Sahyadri Mandooka: Western Ghats amphibians. *Sahyadri e-news*, 2004, **6**; http://wgbis.ces.iisc.ernet.in/biodiversity/newsletter/issue6/index.htm.
17. Shaji, C. P., Easa, P. S. and Basha, S. C., Freshwater fish diversity in Aralam Wildlife Sanctuary, Kerala, South India. *J. Bombay Nat. Hist. Soc.*, 1995, **92**, 360–363.
18. Zacharias, V. J., Bharadwaj, A. K. and Jacob, P. C., Fish fauna of Periyar Tiger Reserve. *J. Bombay Nat. Hist. Soc.*, 1996, **93**, 35–43.
19. Ajithkumar, C. R., Devi, K. R., Thomas, K. R. and Biju, C. R., Fish fauna, abundance and distribution in Chalakudy River system, Kerala. *J. Bombay Nat. Hist. Soc.*, 1999, **96**, 244–254.
20. Johnsingh, A. J. T., The Kalakad–Mundanthurai Tiger Reserve: A global heritage of biological diversity. *Curr. Sci.*, 2001, **80**, 378–388.
21. Easa, P. S. and Shaji, C. P., Freshwater fish diversity in Kerala part of Nilgiri Biosphere Reserve. *Curr. Sci.*, 1997, **73**, 180–182.
22. Kharat, S., Dahanukar, N., Raut, R. and Mahabaleshwarkar, M., Long-term changes in freshwater fish species composition in North Western Ghats, Pune District. *Curr. Sci.*, 2003, **84**, 816–820.
23. Yadav, B. E., Ichthyofauna of northern part of Western Ghats. *Rec. Zool. Surv. India*, 2003, **215**, 1–40.
24. Bhat, A., Diversity and composition of freshwater fishes in four river systems of Central Western Ghats, India. *Environ. Biol. Fishes*, 2003, **68**, 25–38.
25. Arunachalam, M., Assemblage structure of stream fishes in the Western Ghats (India). *Hydrobiologia*, 2000, **430**, 1–30.
26. Ramachandra, T. V., Chandran, M. D. S., Sreekantha, Mesta, D. K., Rao, G. R. and Ali, S., Cumulative impact assessment in the Sharavathi River basin. *Int. J. Environ. Dev.*, 2004, **1**, 113–135.
27. Ali, S. *et al.*, Ecological status of Sharavathi Valley Wildlife Sanctuary. ENVIS Technical Report 19 (Sahyadri Conservation Series – 1), Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 2006.
28. Karthick, B. and Ramachandra, T. V., Water quality status of Sharavathi River basin, Western Ghats. ENVIS Technical Report 23 (Sahyadri Conservation Series – 5), Centre for Ecological Sciences, Indian Institute of Science, Bangalore, 2006.
29. Sreekantha and Ramachandra, T. V., Fish diversity in Linganamakki Reservoir, Sharavathi River. *Ecol. Environ. Conserv.*, 2005, **11**, 337–348.
30. Day, F., In *The Fauna of British India, including Ceylon and Burma*, Secretary of State for India in Council, 1889, vols 1 and 2, p. 547; 509.
31. Jayaram, K. C., In *The Freshwater Fishes of India, Pakistan, Bangladesh, Burma and Sri Lanka – A Handbook*, Zoological Survey of India, Kolkata, 1999, p. 551.
32. Menon, A. G. K., In *Fauna of India and the Adjacent Countries: Pisces Vol. IV, Teleostei – Cobitoidae, Part 1, Homalopteridae*, Zoological Survey of India, Kolkata, 1987, p. 259.
33. Talwar, P. K. and Jhingran, A. G., In *Inland Fishes of India and Adjacent Countries*, Oxford & IBH, New Delhi, 1991, vols 1 and 2, p. 1158.
34. Sreekantha, Gururaja, K. V., Remadevi, K., Indra, T. J. and Ramachandra, T. V., Two new fish species of the genus *Schistura* McClelland (Cypriniformes: Balitoridae) from Western Ghats, India. *Zoos' Print J.*, 2006, **21**, 2211–2216.
35. Bhat, A. and Jayaram, K. C., A new species of the genus *Batasio* Blyth (Siluriformes: Bagridae) from Sharavathi River, Uttara Kannada, Karnataka. *Zoos' Print J.*, 2004, **19**, 1339–1342.
36. Ali, S., Gururaja, K. V. and Ramachandra, T. V., *Schistura nilgiriensis* (Menon) in Sharavathi River basin, Western Ghats, Karnataka. *Zoos' Print J.*, 2005, **20**, 1784–1785.
37. Rao, M. S. N., Working plan report of Belandur State Forest, Ananthapur Range, Shimoga District, Forest Department, Shimoga, 1919.
38. Chandran, M. D. S. and Gadgil, M., *Kans* – Safety forests of Uttara Kannada. In Proceeding of the IUFRO Forest History Group Meeting on Peasant Forestry (ed. Brandl, M.), 2–5 September 1991, Forstliche Versuchs-und Forschungsanstalt, Freiburg, 1993, pp. 49–57.
39. Rao, V. P. M., Memo dated 17 September 1891, on revival of *Kumri* cultivation, Forest Department, Shimoga, 1891.
40. Brandis, D. and Grant, I. P., Joint report no. 33 dated 11 May 1868 on the *kans* in the Sorab taluk. Forest Department, Shimoga, 1868.
41. Gururaja, K. V. and Ramachandra, T. V., Developmental mode in white-nosed shrub frog *Philatus* cf. *leucorhinus*. *Curr. Sci.*, 2006, **90**, 450–454.

ACKNOWLEDGEMENTS. We thank the scientists and staff, Zoological Survey of India, Southern Regional Station, Chennai for help during the course of this investigation. We express our gratitude to Dr K. C. Jayaram, Chennai for timely help and valuable suggestions. We also thank the Ministry of Environment and Forests, Government of India and Karnataka Power Corporation Limited, Government of Karnataka for the financial support. Remote sensing data required for the analysis were provided by National Remote Sensing Agency, Hyderabad. We thank our colleagues Vishnu D. Mukri, Shridhar Patgar, S. Ali, Lakshminarayana, Pankaj Kumar Mohanta and Susanto Sen and also the fishermen of Linganamakki reservoir for assistance during field investigations.

Received 16 March 2006; revised accepted 23 January 2007

Nestedness pattern in freshwater fishes of the Western Ghats: an indication of stream islands along riverscapes

Sreekantha, K. V. Gururaja and T. V. Ramachandra*

Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

Fragmented habitats exhibit distinctive patterns of species richness and species composition. They often exhibit patterns of pronounced nestedness, wherein the species present in comparatively depauperate locations represent statistically proper subsets of those present in locations that are richer in species. The current study has been conducted on the freshwater fishes of Sharavathi River, considering 41 stream and reservoir sites with 261 sampling events to understand the nestedness pattern in fish communities. Of the 64 fish species collected, 39 are from the reservoir and 33 from the stream islands. For the species of the stream islands, including the reservoir fishes in the stream, the nestedness index, *T* was 8.27°C, while species exclusive to stream islands had *T* = 10.5°C. In contrast, in species that are common to both stream islands and the reservoir, *T* was 0.37°C. Relatively higher *T* in the exclusive stream species composition implies that they are highly depauperated due to fragmentation in the streams and its negative influence on the stream fish communities.

Keywords: Community structure, freshwater fish, habitat fragmentation, island biogeography, nestedness pattern, riverscape, stream island, Western Ghats.

HUMAN activities have changed about one-third to one-half of the earth's land surface and are leading to substantial and growing modification of the earth's biological resources. Worldwide, 34 areas have been identified as biodiversity hotspots that have exceptional concentrations of endemic species and are experiencing exceptional loss of habitat[1,2]. It is estimated that in 1995 more than 1.1 billion people, nearly 20% of the world's population, were living within these hotspots that cover about 12% of the earth's terrestrial surface, with a population growth rate of 1.8% yr^{-1}, which is substantially higher than that of the world as a whole (1.3% yr^{-1}) as well as above that of the developing countries (1.6% yr^{-1})[3]. Humans derive many utilitarian benefits from ecosystem services and goods, and the resulting impact on the global biosphere now controls many major facets of ecosystem functions[4,5], especially in the tropical regions. The most important impact is the massive degradation of habitat and extinction of species, taking place on a catastrophically short timescale[6], resulting in the modification of both the identities and numbers of species in ecosystems[7]. The decline of many biological populations worldwide is attributed to habitat fragmentation of the terrestrial and aquatic ecosystems[8].

In aquatic systems, fragmentation can have deleterious effects on ecosystem integrity. A continuous (non-fragmented) riverine ecosystem is dominated by flow seasonality imposed by monsoonal rains[9], with floods and droughts as important features of these rivers. The aquatic environments are known for their dynamic nature, especially stream landscapes, which are highly variable in space and time. Dynesius and Nilsson[10] determined that 77% of the total discharge of the 139 largest river systems in the northern third of the world is affected by river fragmentation caused by dams, reservoirs, inter-catchment diversions, and irrigation. Thus construction of dams has resulted in the disruption of natural dispersal pathways and subsequent changes in the structure and function of aquatic and wetland communities[11], and is regarded as the biggest conservation threat to aquatic communities in many river basins throughout the world[12] due to the biased extinctions of rare species[7]. Thus understanding how populations persist in fragmented environments is a central problem in basic and applied ecology.

Among fishes inhabiting running waters, three modes of adaptation (life history, behavioural and morphological) exist for surviving floods and droughts[13]. Many species have clear adaptation to life in rapidly flowing streams, few other typical of upstream regions, large and predators are exclusive to the deep pools. Overall life-history stages of the stream fishes must be adapted to changes that occur at different spatial and temporal scales. Morphological, physiological and behavioural characteristics accompanied by climatic factors result in migration of fish species that is reflected by local extinction during unfavourable conditions and recolonization during favourable conditions[14].

Fragmented habitats, both terrestrial and aquatic, tend to exhibit distinctive patterns of species richness and species composition. As fragmentation of natural, continuous habitats continues, the areas of the fragments become

*For correspondence. (e-mail: cestvr@ces.iisc.ernet.in)

smaller, and distances between them increase. The taxa occurring in fragments become isolated, as the surrounding habitat is often unsuitable, hampering successful immigration[15]. In such conditions, species distribution patterns within these fragmented habitats have often exhibited patterns of pronounced nestedness[16], which are common among many communities[17].

A nested biota is one in which the species present in comparatively depauperate locations represent statistically proper subsets of those present in locations that are richer in species. An area of suitable habitats, initially inhabited by a common ancestral biota, is fragmented into an archipelago of islands. On each island of the archipelago, there will be one species which is nearest its minimum sustainable population size, and thus at greatest risk of local extinction. As the area continues to shrink, populations of the archipelago's constituent species will tend to become extinct in the order of their specific extinction risks[18]. This orderly extinction pattern is the key factor in the nestedness pattern. The nestedness phenomenon has been recognized for quite some time, but only recently have statistical tests been developed for the analysis of orderliness in species assemblages[19]. Patterns of community structure in many naturally and anthropogenically fragmented environments can be analysed[20]. The best way to quantify nestedness is to use the Atmar and Patterson method, which utilizes a combination of a thermodynamic measure of order and a Monte-Carlo simulation[21]. The nestedness pattern has been revealed for several archipelagos and communities associated with them, e.g. plants, mussels, butterflies, caddisflies, orthopterans, fish parasites, fish, amphibians, reptiles, birds and mammals[15,17,19–21].

Fish assemblages in tropical rivers are characterized by high taxonomic diversity[22]. Recent compilation of freshwater and secondary freshwater fishes of the Western Ghats shows that there are 318 species, of which 27 are critically endangered and 55 endangered, while 128 are data-deficient species. Of the 27 critically endangered species, 24 are endemic to the region. Similarly, of the 55 endangered species, 37 are endemic. Yet, 49 endemic species are data-deficient[23]. Analysis of fish species composition, distribution and ecological status with reference to the terrestrial ecosystem in the catchment, revealed the preference of the endemic fish fauna to perennial streams with their catchments having evergreen to semi-evergreen forests, which also have higher levels of plant endemism[24]. Many of the species in the Western Ghats are characterized by their localized distribution (to a river basin or part of a river basin) and specific adaptation to lotic environments. Although damming the rivers at small scales is being practised widely in the region for centuries, with large-scale planning, massive projects have been initiated and implemented over the past century. The necessity to understand the implications of aquatic habitat fragmentation and its influence on the fish species composition and structure resulting due to such massive transformation has led the present study. This is the first attempt to provide the nestedness pattern in the fish community in the Western Ghats, something that is unique for fish survey. As most of the rivers of the Western Ghats are now altered, understanding the implications is vital for the effective management and restoration of running water ecosystems of the region.

Materials and methods

Study area

Sharavathi river (catchment area of 2784 km^2), one of the west-flowing rivers of Central Western Ghats, traverses over a distance of 132 km before joining the Arabian Sea (Figure 1). The region spans between 74°50′54″–75°30′63″E and 13°77′08″–14°7′27″N. It receives high annual rainfall (1715–5598 mm) that occurs mainly during June to October. The river has been exploited to generate hydroelectric power, which resulted in the construction of two major dams across it. The Linganamakki dam (74°50′54″E, 14°14′24″N, 512 m amsl), constructed in 1964 has a water-spread area of 326.34 km^2.

Eight major tributaries with numerous stream networks of this river are considered as sub-basins. These sub-basins with undulating terrains have tropical evergreen, semi-evergreen and moist deciduous forests in their catchments[24]. Formation of lacustrine ecosystem in the form of the Linganamakki reservoir has isolated these eight sub-basins into discrete flowing reaches, disrupted the flow connectivity and converted them into stream islands. We used the terms 'stream island' and 'sub-basin' interchangeably, according to the context.

Sampling

Fish sampling was carried out in 41 selected stream and reservoir sites with 261 samplings from January 2002 to August 2004. Collections were made using gill nets, cast nets, dragnets and hooks and lines of varying sizes[24]. Within each site all microhabitats like riffle zone, pools, cascade, falls, embayment, run and plunge were considered for sampling. Based on the standard literature available, the collected specimen were identified[24]. Species richness of a stream island is the sum total of the individual sampling species richness that falls within the catchment of a sub-basin. Similarly, species richness from the sampling sites of the reservoir was pooled and used as a reference list.

Data analysis

Presence–absence (1 = present, 0 = absent) matrices were assembled representing stream islands as rows in order of decreasing species richness and species as columns in

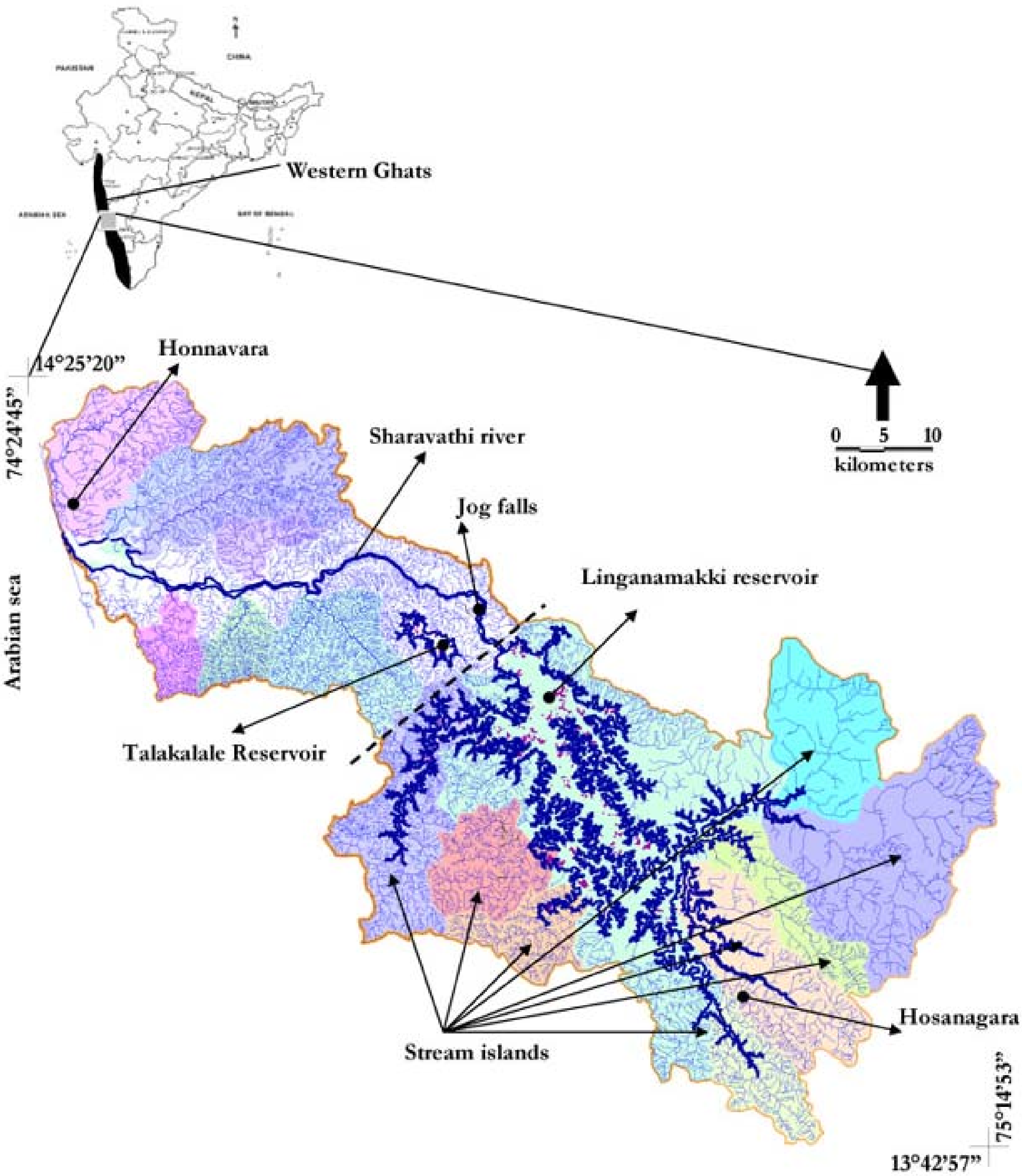


Figure 1. Sharavathi river basin drainage network. South of dashed line constitutes study area.

order of decreasing ubiquity. Nestedness analyses for different groups of species were carried out in stream islands, viz. (i) all species from the stream islands, (ii) species common to stream islands and reservoirs (derived from reference list) and (iii) species that are exclusive to stream islands.

The basis for this classification was purely on the species occurrence during sampling. Nestedness of species assemblages was determined using nested temperature calculator[25]. Nested patterns can be related to thermodynamics[26] with an index T on scale of 0–100°C, with 0°C representing complete nestedness and 100°C representing complete randomness[25]. Indication of unmarked heterogeneity in the original dataset is given by the mixed presence and absence of species or sites along the boundary line. The stability of individual populations was determined by calculating the state occupancy of the individual species[18]. Monte-Carlo randomizations of the data matrix

Table 1. Stream island-wise data on fish attributes and corresponding land-use values

Data type	Parameter	Eastern stream islands			Southern stream islands		Western stream islands		
		Nandi Holé	Haridravathi	Mavina Holé	Sharavathi	Hilkunji	Huruli Holé	Nagodi	Yenne Holé
Fish	Species richness	22	25	22	28	25	32	41	49
	Western Ghats endemics (%)	8.3	14.3	9.1	22.2	20.0	40	23.5	35.5
	Endangered (%)	0.0	7.1	9.1	5.5	13.3	12.0	11.8	9.7
	Vulnerable (%)	16.7	21.4	9.1	16.7	6.7	24.0	17.6	0.0
	Lower risk (%)	58.3	57.1	63.6	61.1	66.7	44.0	52.9	38.7
	Data deficient (%)	16.7	14.3	18.2	11.1	13.3	12.0	17.7	22.6
Land-use	Semi-evergreen (%)	3.31	2.3	4.4	19.2	43.3	32.8	52.1	37.9
	Moist-deciduous (%)	38.1	28.2	41.6	22.9	22.5	27.9	16.6	19.8
	Plantation (%)	5.5	5.6	7.9	14.7	11.6	10.7	13.7	15.9
	Water (%)	0.01	0.1	0.03	0.0	0.0	0.9	0.0	0.1
	Agricultural (%)	11.3	18.2	9.8	10.3	4.2	1.9	1.1	1.4
	Non-vegetated (%)	11.1	13.9	11.6	12.5	5.6	7.6	7.5	10.1
	Open field (%)	30.6	31.9	24.7	20.4	12.9	18.2	9.1	14.9

Note: Non-vegetated: Habitation, roads, rocky area; Open field: uncultivated agricultural land, barren land, dry river bed.

(500 runs) were used to compare with the observed matrix. If the obtained value was lower than that of the randomly generated assemblage, the assemblage can be declared as nested[27].

Results and discussions

The present investigation reports 64 fish species from the study area. Among these, 39 species are found in reservoir sampling sites (lacustrine region) and 33 in the stream islands. Stream island-wise data on species richness, endemism, IUCN (World Conservation Union) status, existing land-use pattern and fragmentation details are given in Table 1. Species richness, endemism and extent of threatened species are relatively high in the western stream islands than the southern and eastern stream islands. Similar pattern follows in case of forest cover, wherein extent of semi-evergreen to evergreen forests is relatively more in the western stream islands than the southern and eastern stream islands.

Nestedness pattern

The species assemblages in eight stream islands were nested significantly as indicated by the *T* value (Tables 2–5). Nestedness index considering all the species from the stream islands was 8.27°C, the probability of which is similar to a randomly generated nesting pattern is almost zero ($P < 6.15 \times 10^{-10}$). The species such as *Schistura denisonii denisonii*, *Oreichthys cosuatis* and *Schistura semiarmatus* with both unexpected presence and unexpected absence along with stream island Nandi Holé are responsible for idiosyncrasy. Presence of *Amblypharyngodon melettina* in the Hilkunji stream island and *Barilius gatensis* in the Haridravathi stream island represents unexpected presence (Table 2). These are the species with high risk of local extinction from those stream islands. Similarly, the ideal candidates for reintroduction are *O. cosuatis* to Huruli, Sharavathi and Haridravathi stream islands, *S. semiarmatus* to Huruli stream island and *Schistura* sp. to Yenne Holé stream island, where their probability of survival is high.

Aplocheilus lineatus, *Barilius bendelisis*, *Brachydanio rerio*, *Chanda nama*, *Cirhina fulungee*, *Danio aequipinnatus*, *Garra gotyla stenorhynchus*, *Lepidocephalus thermalis*, *Mystus cavacius*, *Mystus malabaricus*, *Parambassis ranga*, *Puntius sophore*, *P. ticto*, *Rasbora daniconius*, *Glossogobius giuris*, *Ompok bimaculatus*, *P. chola*, *Gonoproktopterus kolus*, *Acanthocobitis botia*, and *P. filamentosus* are the most ubiquitous species. Whereas species like *A. mellettina*, *Barilius canarensis*, *Clarias dussumieri dussumieri*, *Glyptothorax lonah*, *Pseudophromenus cupanus*, *Puntius arulius*, *Schistura sharavathiensis*, and *Schistura* sp.1 are the most marginal species.

T for species that are common to stream islands and reservoirs was 0.37°C. This is almost completely nested without many idiosyncratic species (Table 3). Reservoirs and streams provide hospitable habitats, resulting in structured immigration and emigration of these fish species.

For species that are exclusive to stream islands, *T* was 10.5°C, with more number of idiosyncrasy in species as well as in stream islands (Table 4). Species such as *O. cosuatis*, *B. gatensis*, *A. melettina*, *S. denisoni denisoni*, *Nemacheilus anguilla*, *Salmostoma boopis*, etc. are responsible for idiosyncrasy in the system.

Table 5 provides *T* and Monte Carlo run results for various species groups. Most of the hospitable species have wider distribution in general and are less susceptible to fragmentation, while marginal species with narrower distribution are more susceptible to fragmentation. The processes for such nestedness are selective immigration,

Table 2. Nestedness pattern of all the species found in the stream islands

Species	YNH	NGH	HRH	SVH	HDH	HKH	MVH	NDH
Aplocheilus lineatus	1	1	1	1	1	1	1	1
Barilius bendelisis	1	1	1	1	1	1	1	1
Brachydanio rerio	1	1	1	1	1	1	1	1
Chanda nama	1	1	1	1	1	1	1	1
Cirhina fulungee	1	1	1	1	1	1	1	1
Danio aequipinnatus	1	1	1	1	1	1	1	1
Garra gotyla stenorhynchus	1	1	1	1	1	1	1	1
Lepidocephalus thermalis	1	1	1	1	1	1	1	1
Mystus cavacius	1	1	1	1	1	1	1	1
Mystus malabaricus	1	1	1	1	1	1	1	1
Parambassis ranga	1	1	1	1	1	1	1	1
Puntius sophore	1	1	1	1	1	1	1	1
Puntius ticto	1	1	1	1	1	1	1	1
Rasbora daniconius	1	1	1	1	1	1	1	1
Glossogobius giuris	1	1	1	1	1	1	1	1
Ompok bimaculatus	1	1	1	1	1	1	1	1
Puntius chola	1	1	1	1	1	1	1	1
Gonoproktopterus kolus	1	1	1	1	1	1	1	1
Acanthocobitis botia	1	1	1	1	1	1	1	1
Puntius filamentosus	1	1	1	1	1	1	1	1
Mastacembelus armatus	1	1	1	1	1	1	1	0
Puntius sahyadriensis	1	1	1	1	1	1	1	0
Salmostoma boopis	1	1	1	1	1	1	0	0
Schistura denisonii denisonii	1	1	1	1	1	0	0	1
Nemacheilus anguilla	1	1	1	1	0	0	0	0
Osteocheilichthys nashii	1	1	1	1	0	0	0	0
Oreichthys cosuatis	1	0	0	0	1	1	0	1
Barilius bakeri	1	1	1	0	0	0	0	0
Channa marulius	1	1	1	0	0	0	0	0
Ompok pabo	1	1	1	0	0	0	0	0
Schistura semiarmatus	1	1	0	1	0	0	0	0
Puntius fasciatus	1	1	1	0	0	0	0	0
Schistura nagodiensis	1	1	1	0	0	0	0	0
Tor khudree	1	1	1	0	0	0	0	0
Batasio sharavatiensis	1	1	0	0	0	0	0	0
Clarias batrachus	1	1	0	0	0	0	0	0
Labeo kontius	1	1	0	0	0	0	0	0
Pseudeutropius atherinoides	1	1	0	0	0	0	0	0
Tor mussullah	1	1	0	0	0	0	0	0
Channa orientalis	1	1	0	0	0	0	0	0
Wallago attu	1	1	0	0	0	0	0	0
Barilius gatensis	1	0	0	1	0	0	0	0
Amblypharyngodon mellettina	1	0	0	0	0	1	0	0
Barilius canarensis	1	0	0	0	0	0	0	0
Clarias dussumieri dussumieri	1	0	0	0	0	0	0	0
Glyptothorax lonah	1	0	0	0	0	0	0	0
Pseudophromenus cupanus	1	0	0	0	0	0	0	0
Puntius arulius	1	0	0	0	0	0	0	0
Schistura sharavathiensis	1	0	0	0	0	0	0	0
Schistura sp.1	0	1	0	0	0	0	0	0

YNH, Yenne Holé; NGH, Nagodi Holé; HRH, Huruli Holé; SVH, Sharavathi Holé; HDH, Haridravathi Holé; HKH, Hilkunji Holé; MVH, Mavina Holé, and NDH, Nandi Holé.

selective extinction, selective levels of stress tolerance, nested habitats and passive sampling[28]. Superior dispersers generally exhibit a greater degree of nestedness than poor dispersers, and the weakest nested patterns may be expected among species with naturally poor dispersal abilities[15]. This is evident in the present analyses, wherein the species common to both reservoir and stream island show greater degree of nestedness compared to those of

Table 3. Nestedness pattern of the species common to both stream islands and reservoirs

Species	YNH	NGH	HRH	SVH	HKH	HDH	MVH	NDH
Barilius bendelisis	1	1	1	1	1	1	1	1
Brachydanio rerio	1	1	1	1	1	1	1	1
Chanda nama	1	1	1	1	1	1	1	1
Cirrhinus fulungee	1	1	1	1	1	1	1	1
Garra gotyla stenorhynchus	1	1	1	1	1	1	1	1
Mystus cavesius	1	1	1	1	1	1	1	1
Mystus malabaricus	1	1	1	1	1	1	1	1
Parambassis ranga	1	1	1	1	1	1	1	1
Glossogobius giuris	1	1	1	1	1	1	1	1
Ompok bimaculatus	1	1	1	1	1	1	1	1
Puntius chola	1	1	1	1	1	1	1	1
Gonoproktopterus kolus	1	1	1	1	1	1	1	1
Mastacembelus armatus	1	1	1	1	1	1	1	0
Puntius filamentosus	1	1	1	1	1	1	1	0
Salmostoma boopis	1	1	1	1	1	1	0	0
Osteocheilichthys nashii	1	1	1	1	0	0	0	0
Channa marulius	1	1	1	0	0	0	0	0
Ompok pabo?	1	1	1	0	0	0	0	0
Tor khudree	1	1	1	0	0	0	0	0
Batasio sharavatiensis	1	1	0	0	0	0	0	0
Clarias batrachus	1	1	0	0	0	0	0	0
Labeo kontius	1	1	0	0	0	0	0	0
Pseudeutropius atherinoides	1	1	0	0	0	0	0	0
Tor mussullah	1	1	0	0	0	0	0	0
Wallago attu	1	1	0	0	0	0	0	0
Clarias dussumieri dussumieri	1	0	0	0	0	0	0	0
Glyptothorax lonah	1	0	0	0	0	0	0	0
Puntius arulius	1	0	0	0	0	0	0	0

Table 4. Nestedness pattern of exclusively stream-dwelling species in the stream islands

Species	YNH	NGH	SVH	HDH	HRH	HKH	MVH	NDH
Aplocheilus lineatus	1	1	1	1	1	1	1	1
Brachydanio rerio	1	1	1	1	1	1	1	1
Chanda nama	1	1	1	1	1	1	1	1
Danio aequipinnatus	1	1	1	1	1	1	1	1
Garra gotyla stenorhynchus	1	1	1	1	1	1	1	1
Lepidocephalus thermalis	1	1	1	1	1	1	1	1
Parambassis ranga	1	1	1	1	1	1	1	1
Puntius sophore	1	1	1	1	1	1	1	1
Puntius ticto	1	1	1	1	1	1	1	1
Rasbora daniconius	1	1	1	1	1	1	1	1
Glossogobius giuris	1	1	1	1	1	1	1	1
Acanthocobitis botia	1	1	1	1	1	1	1	1
Puntius chola	1	1	1	1	1	1	1	0
Puntius filamentosus	1	1	1	1	1	1	1	0
Salmostoma boopis	1	1	1	1	1	1	0	0
Puntius sahyadriensis	1	1	1	1	1	0	1	0
Schistura denisonii denisonii	1	1	1	1	0	0	0	1
Nemacheilus anguilla	1	1	1	0	1	1	0	0
Osteocheilichthys nashii	1	1	1	0	1	0	0	0
Barilius bakeri	1	1	0	0	1	0	0	0
Puntius fasciatus	1	1	0	0	1	0	0	0
Schistura nagodiensis	1	1	0	0	1	0	0	0
Schistura semiarmatus	1	1	1	0	0	0	0	0
Channa orientalis	1	1	0	0	0	0	0	0
Oreichthys cosuatis	1	0	0	1	0	1	0	1
Amblypharyngodon mellettina	1	0	0	0	0	1	0	0
Barilius canarensis	1	0	0	0	0	0	0	0
Pseudophromenus cupanus	1	0	0	0	0	0	0	0
Puntius arulius	1	0	0	0	0	0	0	0
Schistura sharavathiensis	1	0	0	0	0	0	0	0
Schistura sp.1	0	1	0	0	0	0	0	0
Barilius gatensis	0	0	1	0	0	0	0	0

Table 5. Nestedness parameters for three species groups

Case	Matrix results		System temperature (°C)	
	T (°C)	Fill (%)	Average ± SD	Statistical significance (*P*)
All species in stream islands	8.27	36.6	50.3 ± 6.91	6.15×10^{-10}
Species common to stream islands and reservoirs	0.37	41.1	46.6 ± 8.35	1.1×10^{-8}
Species exclusive to streams	10.5	44.0	48.8 ± 7.39	1.39×10^{-7}

stream islands alone (Table 5). The fish species common to both reservoirs and stream islands showed almost packed matrix with very low *T*. This leads to the inference that the anthropogenic activities in the catchment area of Sharavathi river over the last century in the form of construction of dams have resulted in homogenization of pool-loving fish fauna. Large reservoir area provided them an ideal habitat to flourish and to migrate from one stream island to another in accordance with the changing habitat conditions favoured by changes in climate. Whereas the species restricted to stream islands are responsible for the overall increase in *T*, for the very reason that more randomness, many idiosyncratic species and sites with unexpected absence and presence occur here. This indicates that the construction of the dam might have led to the randomization of fish fauna in the lotic systems (stream-island fishes) due to submergence of lotic habitats, in addition to complete isolation of stream islands.

Analysis of the land-use data revealed that the study area is experiencing rapid changes over the last 50 years[29]. Submersion of about 326.34 km^2 area by the dam and the corresponding impacts in the form of human migrations and immigrations resulted in unequal distribution of human population over the study area. Human habitations in the stream islands of the western and southern part are less compared to the eastern stream islands due to remoteness and isolation. Consequently, large forests areas were cleared and converted to agriculture and monoculture plantations in the eastern stream islands, resulting in higher sedimentation and conversion of perennial streams into ephimeral and seasonal ones, which had further implications on the microhabitat characteristics of the streams[29]. Specific levels of stress tolerance among the species resulted in selective extinction, while species capable of migrating over a long distance and withstand lacustrine ecosystem migrated to other regions. It is apparent from the present study that selective extinction, selective migrations and selective levels of stress tolerance of the fish species determine the nestedness in a fragmented riverscape.

Conclusions

Major streams and tributaries of a riverscape become isolated stream islands due to a reservoir that choked the stream network and continuity due to habitat fragmentation as a consequence of anthropogenic activities. Fish assemblages in these isolated streams often exhibit strong nestedness pattern driven by selective extinction, levels of stress tolerance and immigration in species. The present study indicates the randomization of fish fauna in the lotic systems (stream-island fishes) and at the same time homogenization of species in the lacustrine habitats due to construction of dams.

1. Aravind, N. A., Tambat, B., Ravikanth, G., Ganeshaiah, K. N. and Umashaanker, R., Patterns of species discovery in the Western Ghats, a megadiversity hot spot in India. *J. Biosci.*, 2007, **32**, 781–790.
2. Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. and Kent, J., Biodiversity hotspots for conservation priorities. *Nature*, 2000, **403**, 853–858.
3. Cincotta, R. P., Wisnewski, J. and Engelman, R., Human population in the biodiversity hotspots. *Nature*, 2000, **404**, 990–992.
4. Myers, N., Environmental services of biodiversity. *Proc. Natl. Acad. Sci. USA*, 1996, **93**, 2764–2769.
5. Palumbi, S. R., Humans as the world's greatest evolutionary force. *Science*, 2001, **293**, 1786–1790.
6. Novacek, M. J. and Cleland, E. E., The current biodiversity extinction event: scenarios for mitigation and recovery. *Proc. Natl. Acad. Sci. USA*, 2001, **98**, 5466–5470.
7. Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M. and Siemann, E., The influence of functional diversity and composition on ecosystem processes. *Science*, 1997, **277**, 1300–1302.
8. Fahrig, L., Effects of habitat fragmentation on biodiversity. *Annu. Rev. Ecol. Evol. Syst.*, 2003, **34**, 487–515.
9. Dudgeon, D., The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annu. Rev. Ecol. Syst.*, 2000, **31**, 239–263.
10. Dynesius, M. and Nilsson, C., Fragmentation and flow regulation of river systems in the northern third of the world. *Science*, 1994, **266**, 753–762.
11. Zampella, R. A. and Bunnell, J. F., Use of reference-site fish assemblages to assess aquatic degradation in pinelands streams. *Ecol. Appl.*, 1998, **8**, 645–658.
12. Wu, J., Huang, J. and Han, X., Three-gorges dam: risk to ancient fish. *Science*, 2003, **302**, 1149–1150.
13. Lytle, D. A. and Poff, N. L., Adaptation to natural flow regimes. *Trends Ecol. Evol.*, 2004, **19**, 94–100.
14. Magoulick, D. D. and Kobza, R. M., The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biol.*, 2003, **48**, 1186–1198.
15. Yiming, L., Niemelia, J. and Dianmo, L., Nested distribution of amphibians in the Zhoushan archipelago, China: can selective extinction cause nested subsets of species? *Oecologica*, 1998, **113**, 557–564.
16. Atmar, W. and Patterson, B. D., The measure of order and disorder in the distribution of species in fragmented habitat. *Oecologia*, 1993, **96**, 373–382.

17. Poulin, R. and Valtonen, E. T., Nested assemblages resulting from host size variation: the case of endoparasite communities in fish hosts. *Int. J. Parasitol.*, 2001, **31**, 1194–1204.
18. Patterson, B. D. and Atmar, W., Nested subsets and the structure of insular mammalian faunas and archipelagos. *Island Biogeography of Mammals* (eds Heaney, L. R. and Patterson, B. D.), Academic Press, London, 1986, pp. 65–82.
19. Jonsson, B. G., A null model for randomization tests of nestedness in species assemblages. *Oecologia*, 2001, **127**, 309–313.
20. Hecnar, S. J. and M'Closkey, T. M., Patterns of nestedness and species association in a pond dwelling amphibian fauna. *Oikos*, 1997, **80**, 371–381.
21. Olivier, H. and Martin, H., Nested subset analysis as a tool for characterizing plant community composition in Flemish woodlands. In Proceedings IAVS Symposium, Nagano, Japan, 2000, pp. 357–360.
22. Jepsen, D. B. and Winemiller, K. O., Structure of tropical river food webs revealed by stable isotope ratios. *Oikos*, 2000, **96**, 46–55.
23. Sreekantha, Sahyadri mathsya. *Sahyadri e-news*, 2006, **XVII**, http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue17/main_index.htm, last accessed on 6 September 2007.
24. Sreekantha, Subash Chandran, M. D., Mesta, D. K., Rao, G. R., Gururaja, K. V. and Ramachandra, T. V., Fish diversity in relation to landscape and vegetation in central Western Ghats, India. *Curr. Sci.*, 2007, **92**, 1592–1603.
25. Atmar, W. and Patterson, B. D., The nestedness temperature calculator. AICS Research Inc, http://aics-research.com/nestedness/tempcalc.html, last accessed on 6 September 2007.
26. Ibanez, J. J., Caniego, J. and Garcia-Alvarez, A., Nested subset analysis and taxa-range size distributions of pedological assemblages: implications for biodiversity studies. *Ecol. Model.*, 2005, **182**, 239–256.
27. Schmera, D., Nested assemblage structure of caddisflies (Insecta: Trichoptera) inhabiting in North-Hungarian streams. *Folia Hist. Nat. Mus. Matraensis*, 2004, **28**, 195–198.
28. Fischer, J. and Lindenmayer, D. B., Treating the nestedness temperature calculator as a 'black box' can lead to false conclusions. *Oikos*, 2002, **99**, 193–199.
29. Ramachandra, T. V., Subhash Chandran, M. D., Gururaja, K. V. and Sreekantha, *Cumulative Environmental Impact Assessment*, Nova Science Publishers, New York, 2007.

ACKNOWLEDGEMENTS. We thank the Ministry of Environment and Forests, Government of India and Karnataka Power Corporation Limited, Government of Karnataka for financial support. We thank our colleagues Vishnu D. Mukri, Shridhar Patgar, Sameer Ali and Lakshminarayana for help in field data collection and Avinash for GIS layers of Sharavathi river basin.

Received 9 March 2008; revised accepted 23 October 2008

MEETINGS/SYMPOSIA/SEMINARS

International Congress of Global Warming on Biodiversity of Insects: Management and Conservation (GWBIMC, 2009)

Date: 9–12 February 2009
Place: Coimbatore, India

Themes: Impact of global warming on insect migration and behaviour; Impact of global warming on biodiversity/management of agricultural insects; Impact of global warming on conservation/management of forestry insects; Impact of global warming on management of medical and veterinary insects; Impact of global warming on mosquito and its transmitted diseases; Global warming on biotechnological advancement in insects; Global information system (GIS) and remote sensing (RS) on insects.

Contact: Dr K. Murugan
Organizing Secretary, GWBIMC, 2009
Department of Zoology
School of Life Sciences
Bharathiar University
Coimbatore 641 046, India
Ph (O): +91-422-2422 222, ext 492
Fax: +91-422-2422 387, 2425 706
Mobile: +91-989483849
E-mail: kmvvk@yahoo.com
Congress website:
http://www.b-u.ac.in/Seminarfiles/webi.pdf

3rd National Conference on Recent Trends in Instrumentation Applications (RETINA '09)

Date: 19–20 March 2009
Place: Kovilpatti

Topics include: Process measurement and instrumentation; Biomedical engineering; Industrial automation; Instrumentation RAG–BAG.

Contact: Prof. A. Abudhahir
Coordinator, RETINA '09
Department of Electronics and Instrumentation Engineering
National Engineering College
K. R. Nagar
Kovilpatti 628 503
Tel: 04632 222502
Mobile: 9842520419
E-mail: eieretina09@yahoo.com
Website: http://www.nec.edu.in/retina09.htm

BIOENERGY STATUS OF SHARAVATHI RIVER BASIN, WESTERN GHATS, INDIA

Ramachandra T. V.♣*, Sreekantha* and Purnima G. B.*

**Centre for Ecological Sciences, Indian Institute of Science; ♣Centre for Sustainable Technologies, Indian Institute of Science, Bangalore 560012, India.*

ABSTRACT

Most of the developing countries including India depend heavily on bioenergy and it accounts for about 15% of the global energy usage. Its role in meeting a region's requirement has increased the interest of assessing the status of biomass availability in a region. The present work deals with the bioenergy status in the Linganamakki reservoir catchment of the Sharavathi river basin, Western Ghats, India, by assessing the energy supply and sector wise energy consumption. The study reveals that majority of the households (92.17%) depend on fuelwood for their domestic energy needs with the per capita fuelwood consumption of 1.2 tonnes/year, which is higher than the national average (0.7 tonnes/year). This higher dependence on fuelwood has contributed to the degradation of forests, resulting in scarcity of bioresources necessitating exploration of viable energy alternatives to meet the growing energy demand.

Keywords: Bioenergy, Biostatus, Energy alternatives, Biogas, Sustainable Energy.

1.INTRODUCTION

Energy is considered as the prime mover of a region's development. In India, more than 70% of the total population inhabits rural areas and 85–90% of energy requirement is being met by bioresources. In the context of energy crisis due to dwindling of fossil fuel based energy resources, the importance of biomass as a renewable energy resource has increased in recent years. Although biomass energy is

Address for Correspondence:

Dr. T.V. Ramachandra

Energy Research Group,CES R.NO. 215, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

E Mail: cestvr@ces.iisc.ernet.in; cestvr@hamsadvani.serc.iisc.ernet.in; energy@ces.iisc.ernet.in

Telephone: 91-080-23600985 / 2293 3099/ 2293 2506

Telefax: 91-080-23601428 / 23600085 / 23600683 [CES TVR]

URL: http://ces.iisc.ernet.in/energy/Welcome.html

predominantly used in rural areas, it also provides an important fuel source for the urban poor, and many rural, small and medium scale industries. Field investigations reveal that most of the rural population still depends on the traditional devices (which are energy inefficient) for cooking and water heating, etc. leading to excess consumption of local resources. Lack of information about the resources and technologies may be cited as the reason for this situation.

Bioresources are diverse solid carbonaceous material ranging from fuelwood collected from farmlands and natural woodland, to plantation crops grown specifically for energy purposes, agricultural and forestry residues, food and timber processing residues, animal residues and aquatic flora. The energy released from the reaction of these materials with oxygen is known as bioenergy and it is being used in various ways to meet daily energy needs of the society. Bioenergy is the most developed renewable energy, providing 38% of the primary energy needs of developing countries. In the developing world as a whole, about 2 billion people rely solely on fuelwood as their energy source for water heating and cooking. In order to achieve sustainable, self-reliant and equitable development of a region, it is imperative to focus on efficient production and use of bioenergy to meet both traditional and modern fuel requirements.

The rural energy scenario in India is dominated by the domestic sector, which accounts for 75% of the total energy consumed. The fuel consumption pattern of the domestic sector in rural areas is characterized by higher dependence on bioresource-based fuels such as fuelwood, agricultural residues, etc. Cooking and water heating (for bathing and washing) are the prime end-uses in domestic sector accounting for over 90% of the energy. Rural population still depends on the traditional devices for cooking and water heating, etc., which are energy inefficient leading to excess consumption of local resources. This is mainly due to the lack of knowledge of energy efficient devices and renewable energy technologies. According to the recent National Sample Survey (NSS) data, about 36.5% of fuel needs in urban and 17.2% fuel needs in rural area is met by sources like kerosene and electricity. All other cooking is done either with fuelwood or dung cakes. This reveals the higher dependence on bioresource to meet the energy requirement that is mainly due to availability of bio-fuels at zero private cost and also non-availability of other sources of energy (high costs and unreliable supply network).

The estimate done at regional level for Karnataka (a federal State in India) shows that 8.5 million tonnes of fuelwood is required annually for cooking purpose in Karnataka. Inclusion of additional domestic demands such as water heating, space heating, etc., pushes it to 11.2 million tonnes annually. The demand for fuelwood is continuously rising along with increase in population. The State has only 16.9% of the area under forests (38,724 km^2 of the total area of 191,791 km^2).

The burgeoning population coupled with unplanned developmental activities based on ad-hoc decisions has led to bioresource scarcity in many parts of Karnataka. Present fossil fuel potential is unable to meet the growing demands of the society. There is a need to look for viable alternatives to meet the scarcity. Thus, there is a requirement for interventions particularly in rural development and in general, the energy system to boost the energy potential at disaggregated levels to balance demand

and availability. This necessitates the understanding of the present energy consumption pattern and exploring locally available alternative energy sources in order to ensure resource sustainability.

Alternatives like biogas technology has made inroads in rural economy in some districts like Uttara Kannada,Udupi, Shimoga, etc. in Karnataka State (with higher literacy among women) during the last two decades due to economic viability, ecological soundness, technical feasibility and social acceptance. Biogas from biomass and animal wastes is an excellent technology that provides an alternate source of fuel in rural areas with an output of both energy and manure by using locally available resources like animal dung and other organic material.India is a pioneer in the field of developing technology for biogas production from animal dung (Srinivaran, 1979). Animal dung is a potentially large biomass resource and dried dung has the same energy content as wood. When burned for heat, the efficiency is only about 10%. About 150 million tonnes of cow dung (dry) is used for fuel each year across the globe, 40% of which is in India (UNEP, 1980). Biogas is produced by biological decomposition of organic material in the absence of air. The efficiency of conversion of animal residues could be raised to 60% by digesting anaerobically (to produce biogas). Biogas production will also resolve the conflict between energy recovery and nutrient utilisation as the effluent from the digester could be returned to the fields.

For 2002–03, a target of setting up of 0.12 million family type biogas plants had been allocated to States and agencies. About 70,440 plants have been completed during the period April to December 2002, which is almost 117% over the target of 60,000 plants planned for the corresponding period (MNES, 2003).

Current study was carried out in the Linganamakki reservoir catchment of Sharavathi river basin, Western Ghats, India to assess the impacts due to developmental work (in the form of hydroelectric power stations with reservoir) on local energy resources and demand. This region is considered to be one of the biodiversity hotspots as it harbours rich flora and fauna. The people residing in this area are largely dependent on these forests for daily energy needs (fuelwood) and sustenance. It is observed that the boundary of the energy flow extends beyond the sub-basin limit of the Sharavathi River. Hence a river basin-hydrological unit is considered for this investigation as energy movement is related to geographical features and shows similar trends in relatively homogenous features.

Karnataka State mainly depends on hydroelectricity (67%) of which Sharavathi river basin's share is about 48%. It is one of the west flowing rivers of India, which traverses over a length of 132 km through undulating terrain in the Western Ghats with rich biodiversity and joins the Arabian Sea. The study area is situated at latitude 74°67'11" to 75°30'63" east and longitude 14°7'27" to 13°77'08" north with an area of 1992 sq. km. This river is extensively utilized for hydroelectric power generation (1450 MW). The Karnataka Power Transmission Corporation Limited (KPTCL) has constructed a dam at Linganamakki towards meeting the electricity requirement of the State.

The Linganamakki reservoir is about 105 km west of the district headquarter, Shimoga. Figure 1 provides the location of the study area while; Figure 2 is the remote sensing composite image that was used to assess the bioresource availability in various

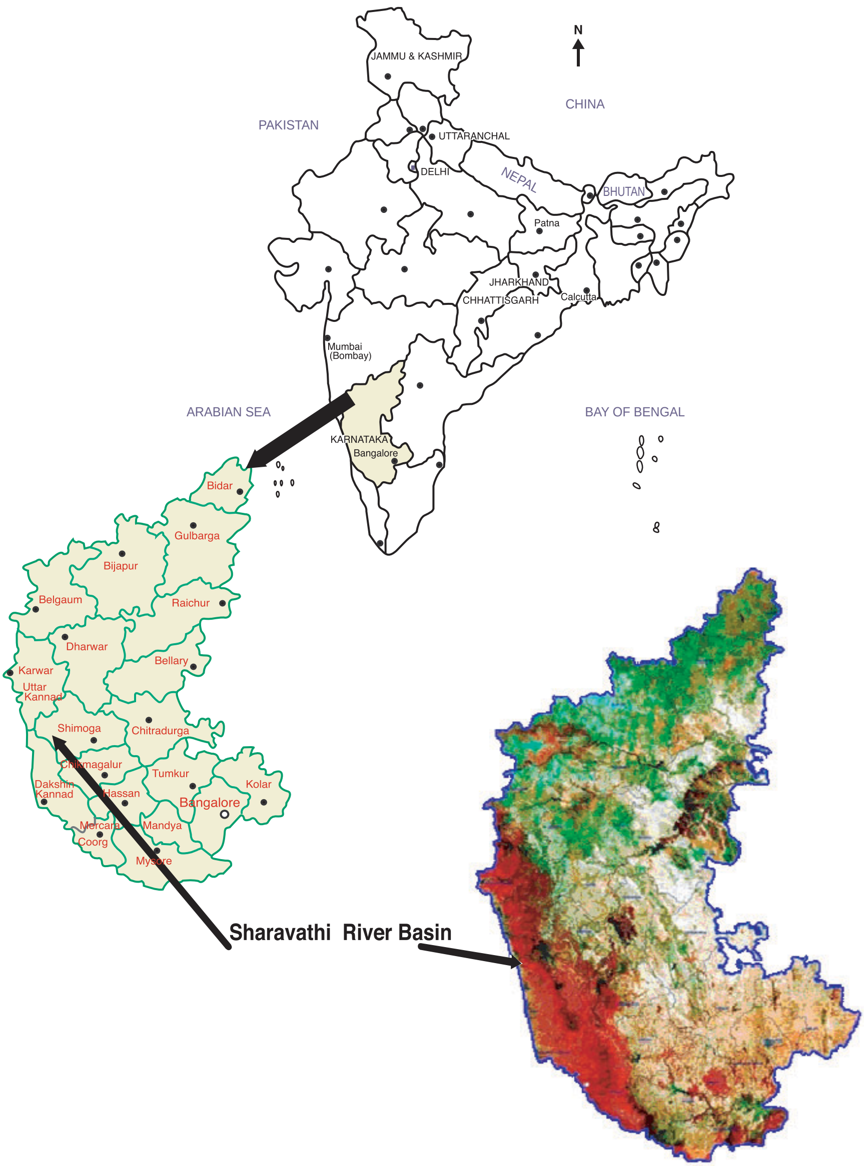


Figure1: Location of the study area.

land use categories. The mountainous terrain of Western Ghats binds the western part of the study area, which has rich vegetation cover of evergreen to semi-evergreen type. The vegetation richness gradually recedes towards east. The hills slope towards east and transition between Maidan and Malnad can be seen on eastern part of the study area. It is further divided in to sub-basins based on major tributaries and associated streams as given in Figure 3.

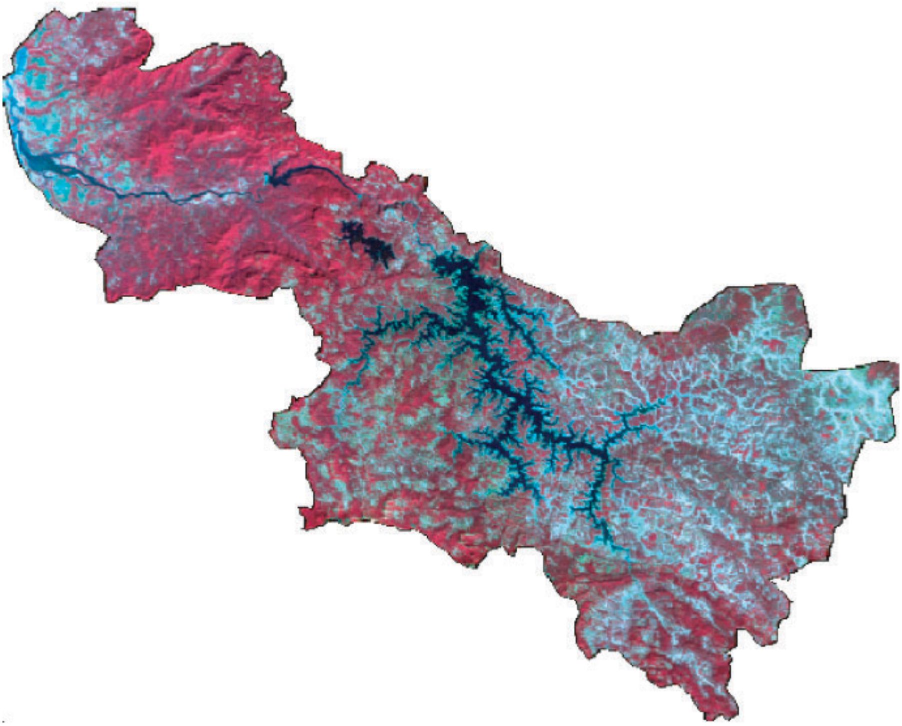
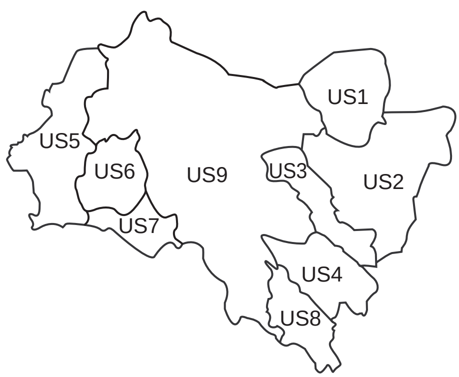


Figure 2: Remote sensing composite image of the study area.



US1	Nandiholé	US2	Haridravathiholé	US3	Mavinaholé
US4	Sharavathi	US5	Yenneholé	US6	Hurliholé
US7	Nagodiholé	US8	Hilkunjiholé	US9	Linganmakki (Central Zone)

Figure 3: Sub-basins in the study area.

Assessment of the energy consumption pattern and bioresources availability was done in order to quantify the energy demand and to understand the present status of energy supply and prospects for alternate policies and technologies along with management strategies to ensure the sustainability of the ecosystem. The Ministry of Environment and Forests, Government of India through the forest departments in each State has implemented the JFPM (Joint Forest Participatory Management) programme through a participatory approach involving village communities and voluntary agencies in the conservation and regeneration of forests. The performance of this programme in the river basin has been explored to assess the efficacy in resource management. Presently under JFPM, about 23 Village Forest Committees (VFCs) are active.

The National Commission on Agriculture (NAC) in 1976 projected the fuelwood demand up to the year 2000 (Kumar, 1999). The net per capita fuelwood consumption was estimated at about 194 kg/year. The demand projections estimated on that basis for fuelwood was 157.5 million tonnes in 2000. The Commission did not project an appreciable shift away from non-commercial fuels.

Comparative analysis of village level domestic energy consumption patterns across coastal, interior, hilly and plain zones considering regional and seasonal variations was done for Uttara Kannada District in 1999. Average consumption (kg/capita/day) of fuel wood for cooking ranges from 2.01 ± 1.49 (coastal) to 2.32 ± 2.09 (hilly). Season wise cooking fuel wood requirement for coast and hilly zones, ranges from 1.98 and 2.22 (summer) to 2.11 and 2.51 (monsoon) respectively, while for water heating (for bathing and washing), it ranges from 1.17 ± 0.02 (coast) to 1.63 ± 0.05 (hilly). Examination of present role of biomass in the energy supply of Uttara Kannada district, Karnataka and the potential for future biomass provision and scope for conversion to both modern and traditional fuels reveals that fuel wood was mainly used for cooking, and horticultural residues from coconut and areca nut trees were used for water heating purposes. Most of the households in this region still use traditional stoves whose efficiency is less than 10%. Energy from various crop residues was calculated: paddy husk-170.12 million kWh, bagasse-136.3 million kWh, groundnut-11.64 million kWh and maize-1.66 million kWh. The total residues available for the district were calculated to be 42020.37 tonnes. The total energy available from horticultural residues is: areca-540.58 million kWh, coconut-247.04 million kWh and cashew–38.365 million kWh. The total biogas available was calculated to be 46.29 million m^3, which could meet 30% of the population's energy demand. The fodder requirement was estimated to be 1.09 million tonnes of which 0.21million tonnes could be met by agro-residues. The improved cook stoves (ASTRA stoves-designed at ASTRA, Indian Institute of Science) were distributed under an eco-development programme, which was done through local people's active participation and after consultations with the villagers and local NGOs (Non-Governmental Organizations). These stoves are characterized by complete fuel combustion with as little excess air as practicable to generate the highest temperature of flue gases. The efficiencies of these stoves are in the range of 32–41%.The study also reveals that grazing in forests as well as removal of fuelwood (for domestic and small scale industries) has affected the sustainability of the forests, as there is large-scale degradation in many localities (Ramachandra et al, 2000).

Centre for Sustainable Technologies (formerly known as ASTRA), Indian Institute of Science conducted a detailed survey in six villages in a dry arid zone that revealed: (a) fuelwood is a dominant energy source (81.6%) used mainly for household activities, (b) cooking is a major activity consuming human and fuelwood energy and efficiency of improved stoves are in the range of 5.08%, (c) human energy in h/day/household (especially women and children) was inefficiently used in fuelwood gathering (2.6), cooking (3.68), carrying food to farms (1.82), fetching water (1.53), taking cattle for grazing (5.54) etc., (d) kerosene consumption for lighting is about 4.3l% non-electrified house (78% of the houses being non-electrified) and (e) industrial consumption is very small. Essential factors determining biomass availability for energy are: (i) The future demand for food, determined by the population growth and the future diet; (ii) The type of food production systems that can be adopted world-wide over the next 50 years; (iii) Productivity of forest and energy crops; (iv) The (increased) use of bio-materials; (v) Availability of degraded land; (vi) Competing land use types, e.g. surplus agricultural land used for reforestation. The focus has been put on the factors that influence the potential biomass availability for energy purposes.

Six biomass resource categories for energy are (i) energy crops on surplus cropland, (ii) energy crops on degraded land, (iii) agricultural residues, (iv) forest residues, (v) animal manure and (vi) organic wastes. The amount of re-circulating biomass is the key variable for controlling nutrient availability within an ecosystem. In this regard, recycling of biomass, rotation of crops, and biomass-producing strips inter-cultured with crop areas maintain the nutrition balance in agricultural lands. Part of the biomass is locally consumed in providing fodder to the draught animals. It can be used as a layer to suppress evaporation and as organic input for crop production, satisfying part of the nutrient requirements enhancing soil fertility and improving its moisture holding and permeability characteristics (Datye, 1997).

Even though forests cater most of the daily energy needs in rural areas, there is a need to focus on viable energy alternatives to cater to the growing demand of the burgeoning population. In this context, biogas generators lessen the dependence on forest and increases green areas leading to improved environment. More than 2 million biogas plants have been built in India so far. With a potential market for 30 plants attached to households with 3 cattle or more, the social and environmental advantages of biogas are just beginning to be explored. In rural areas, where there is generally no electricity supply, the introduction of biogas has given women a sense of self-worth and time to engage in more activities outside the home (Rene and Gunnar, 1997). Important sociological issues that have prevented widespread adoption of Biogas generators in India (during the evolution of biogas) are scarcity of animal residues, asphyxiation, fire explosion, kitchen fire, digester bursting or cracking and hazardous developments with respect to human safety (Goswami and Sutar, 1993).

Stall-feeding instead of field grazing is one of the best ways to circumvent the scarcity of animal residues and it facilitates increased production of biogas. Also, it would aid the regeneration of forests as the damages to saplings are minimised. However, stall-feeding is a labour-intensive activity demanding high labour inputs during the growing season. Cutting and carrying grass and carrying water to the cattle absorb 60–75% of the total labour. Slurry of biogas plant serves as manure and supply humus to soils, thereby helps in soil conditioning (John, 1986).

However, certain barriers hinder the overall potential of community biogas plants for cooking. Compared to biogas, fuel wood is available at zero cash cost and the cost of a stove is still high and acts as a deterrent, especially for the poor. Scarcity of large funds hinders the installation process of biogas plants. NGOs are suffering with improper incentive facilities for construction and maintenance, and also with unavailability of technology packages and adequate demonstration units. No organization at village level is willing to take leadership and accept responsibility of biogas plants. Inadequate funding and scarcity of skilled personnel for construction and maintenance affect the full potential use of biogas plants. Maintenance of biogas plants in some areas is affected by scarcity of water. Women and children play a dominant role in most of the household activities (like gathering of fuelwood, cooking etc.), but lack of representation of women in decision-making has also contributed to the problem.

The barriers for improved cooking technologies could be grouped as financial, technical and institutional from both supply and demand perspective. The improved stove cost varies with the design and is expensive compared to the traditional stoves. The government provides subsidy for improved stoves, which the households claim after the installation. Some households still consider the cost as high due to lack of knowledge of certain direct and indirect benefits, and also availability of fuel wood, dung cakes and crop residues with no cash expenditure. Inaccessibility of the improved stove accessories along with the scarcity of the trained builders and service facilities in rural areas hinder the diffusion of devices. The distance from the nearest urban centre and availability of transportation facilities also plays a dominant role in adopting the alternate energy technologies (Ravindranath and Hall, 1995).

The entire study area falls under two taluks namely, Sagar and Hosanagara of Shimoga District. Talukwise bioenergy available in the study area from agricultural residues, forests, horticultural residues, plantation and livestock is tabulated in Table 1.This shows that despite good resource potential in the region, growing demand for fuelwood would threaten the sustainability of the resources. In order to understand the impacts at local scale, the entire upper river basin is divided into eight sub-basins based on the major tributaries and their respective watershed areas. The central part does not fall under any of the major tributaries and was considered separately (central zone). The western part of the river basin has three sub-basins, southern part has two sub-basins and the eastern part has three sub-basins.

Bioresource availability and energy demand assessments were done through primary and secondary data collections. The primary data collection mainly aimed at quantifying the energy needs, identifying the technological options, selection of the best options and integrating the optimal mix of technologies. Secondary data collected from government departments at district and taluk head quarters included villagewise demography and occupational and infrastructural facilities data, land holding particulars of the individual households (agriculture, horticulture, landless, etc.), household list of each village, village level data on livestock population, landuse data, cropping pattern, productivity and the daily rainfall data for the last 50 years.

Table 1: Talukwise bioenergy availability in the study area

			Total bioenergy availability (million kcal)							
Taluk	Total area (ha)	Total Population	Agricultural Residues	Horticultural Residues	Forests	Plantation	Livestock	Total Availability (million kcal)	Demand (million kcal)	Status
Sagar	194009	200211	36367.10	2404076	1807114.0	41607.49	45072.44	4334237.03	816860.9	5.30
Hosanagara	142279	115019	29818.66	1387760	956524.2	15185.86	59453.78	2448742.50	469277.5	5.22

Table 2: Category wise adult equivalents (AE) for computation of PCFC

Category	AE
Men (between 18–59 years)	1.00
Women (between 18–59 years)	0.80
Men (>59 years)	0.80
Women (>59 years)	0.80
Boys (between 6–18 years)	0.50
Girls (between 6–18 years)	0.50
Kids (between 1–5 years)	0.35
Child (1 year)	0.25

In this regard, questionnaire based stratified random sampling of households was done in a cluster of selected villages to collect the data of energy consumption pattern, resources available, and social, economical and cultural aspects. Forty-two villages were selected which are distributed over the entire study area and based on factors such as per capita forest area, per capita agricultural area, etc., which have a role in the energy consumption pattern in a village.

Land holding by a family is considered as the primary criterion for selection of households for energy survey. Households were selected covering all communities from all land holding (small/medium/large) and land less categories. Totally 447 households in 42 villages were covered, which comprises households of 90 landless labourers. Affordability to advanced technologies is determined by the household income and agriculture is the main income source in the rural area. The social and cultural aspects of the households lead to their own fuel preferences. Thus, community-wise variation in the fuel type and quantity in use can be expected.

Representation of energy consumption data in terms of per capita consumption and standard adult equivalents are useful to visualize the consumption pattern and for easier comparison. Hence the analysis was done through the computation of per capita fuel consumption (PCFC) and is given by 'eqn (1)'.

$$PCFC = FC/P \tag{1}$$

Where, FC (fuel consumed in kg/day, P = number of adult equivalents.

The adult equivalents for computation of PCFC are listed in Table 2, depending on the age and sex. The total demand for a sub-basin was computed based on the total population and the annual per capita fuelwood requirement.

Quantification of the source-wise bioresources potential (sub-basin wise) was done through land cover and land use analysis using remote sensing data-IRS 1C MSS (Multi Spectral Sensor) data of 1999 and 2003. The land cover analysis shows that 70% of river basin is under vegetation indicating the predominance of bioresources. The bioresource availability under each category was obtained by multiplying the spatial extent of each land use type with the annual productivity. The annual

Table 3: Demographic features of the study area

Sub-basin	Total area (sq. km)	Population density (persons/sq. km)
Yenneholé	189.00	35.87
Nagodiholé	65.17	48.41
Hilkunjiholé	85.08	72.87
\Hurliholé	97.88	76.63
Sharavathi	119.40	94.19
Central zone	540.55	100.48
Nandiholé	143.60	101.27
Mavinaholé	95.08	106.84
Haridravathiholé	278.90	112.49

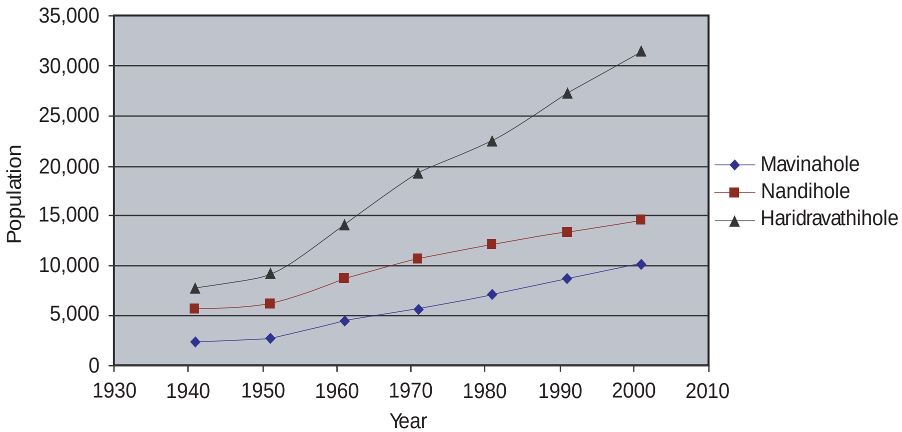


Figure 4: Population trend for the eastern clusters.

availability is based on aggregation of biomass productivity for each type of forest patches. In the present case, the productivity of evergreen to semi-evergreen forests was considered as 3.6–6.5 tonnes/ha/year. The deciduous forests have biomass productivity of 3.9–13.5 tonnes/ha/year. The homogenous plantations were considered as 3.6–6.5 tonnes/ha/year in terms of annual biomass productivity.

2. RESULTS AND DISCUSSIONS

2.1. Demography

The population density computed for each sub-basin is listed in Table 3. Yenneholé sub-basin, which is a part of Sharavathi Wildlife Sanctuary, has low population density. Among all sub-basins, Haridravathiholé sub-basin on the eastern part has high population density (112.49 persons/sq. km). Trends in population change over six decades were analysed for eastern, central and western sub-basins and is depicted in Figures 4, 5 and 6 respectively. In the eastern part of the study area, apart from

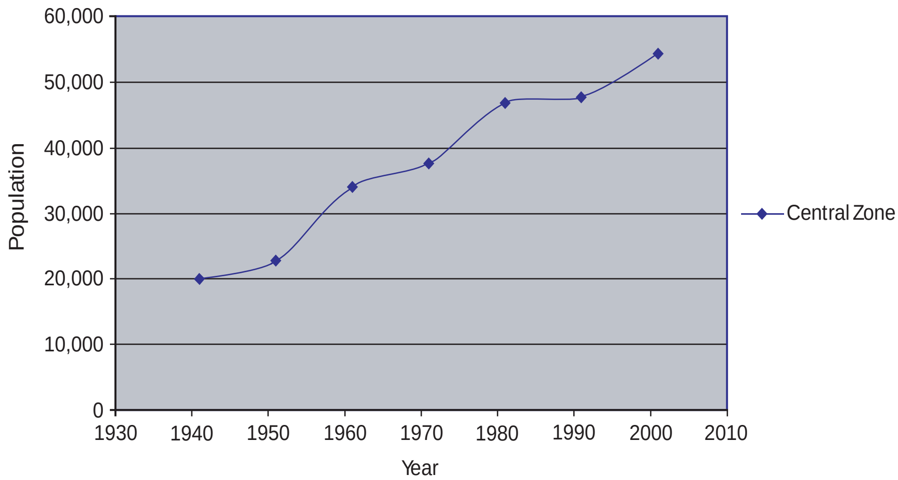


Figure 5: Population trend for the Central zone.

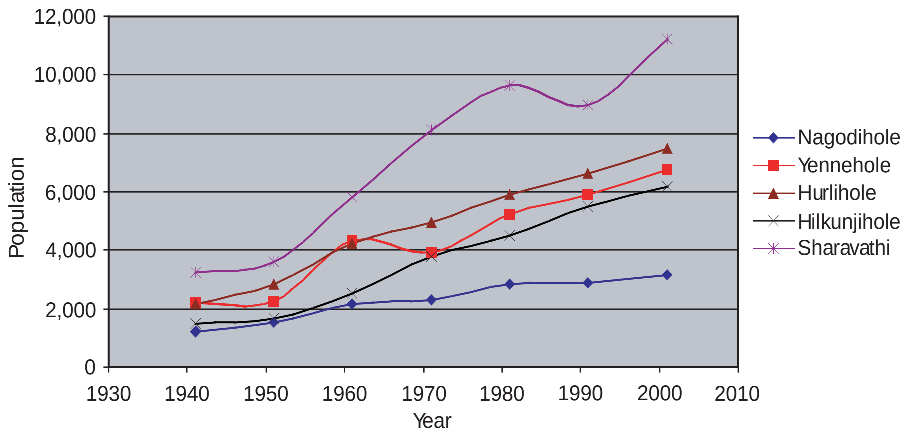


Figure 6: Population trends for the western and southern clusters.

Haridravathiholé sub-basin, Nandiholé and Mavinaholé sub-basins have low rates of population increase. The Sharavathi sub-basin and central zone recorded rapid increase compared to the neighbouring Hilkunjiholé sub-basin. Similarly, population increase is comparatively higher in Hurliholé and Yenneholé (western part) than the Nagodiholé sub-basin.

2.2. Energy Scenario

From Table 4, it is evident that the majority of the households (92.17%) still depend on fuelwood for their cooking energy needs followed by biogas plants (10.06%) and LPG (3.80%). This higher dependence on fuelwood is due to the availability of the

Table 4: Individual share of energy sources in cooking

Energy Source	Number of Households	% Households
Fuelwood	412	92.17
Biogas	45	10.06
LPG	17	3.80

forest resources in the immediate vicinity at zero cost. Two types of fuelwood collection are observed in the region namely, daily collection and seasonal collection. The daily fuelwood collection is the task performed by women who normally spend about 1–5 hours to collect dry and fallen trees from forest areas during non-rainy seasons. The seasonal fuelwood collection is usually performed by men (from nearby households in a group) during summer for usage in monsoon. It involves mainly lopping of trees and some times it is more harmful to the forests as full tree is removed. It was seen that the fuelwood extraction is not uniform over the entire forest patch. The forest areas nearer to human settlements tend to be more deteriorated. Also, normally people cut tree branches or trees, as collecting dead and fallen tree parts are a tedious and time-consuming task. Less dependence on LPG may be due to the lack in availability of resources, infrastructure and higher costs.

The study shows that there is enormous potential for the biogas technology over the study area to replace the usage of fuelwood in domestic energy for cooking. Biogas has a higher heating value than producer gas and coal gas, which implies increased services. As a cooking fuel, it is cheap and extremely convenient. Based on the effective heat produced, a 2m^3 biogas plants could replace, in a month, fuel equivalent of 26 kg of LPGor 37 litres of kerosene or 88 kg of charcoal or 210 kg of fuelwood or 740 kg of animal dung cake. It is a clean fuel without any health hazards or offensive odour and burns with soot less, clean bluish flame thereby making cleaning of cooking utensils easier. Biogas technology has enhanced energy supply decentralization, thus enabling rural areas to meet their energy requirements especially when the commercial fuels are inaccessible. In terms of cost, biogas is cheaper than conventional biomass fuels (dung cakes, fuelwood, crop wastes, etc.) as well as LPG, and is only fractionally more expensive than kerosene. Biogas systems have attracted considerable attention for the potential of waste recycling, pollution control and improvement of sanitary conditions, in addition to providing fuel and manure free of pathogens.

All surveyed houses use twigs and horticultural residues (coconut wastes, etc.) for water heating. In Sagar taluk alone, out of 230 sampled houses, 141 areca land owners use green manure for the plantations. Green leaves required for this purpose, are obtained from the forestland. Each areca plantation owner is permitted by the government to use forests (in the ratio 1:9) for collection of leaves. Farmers lop trees in one-third of the allocated forest area and use green leaves for mulching, while twigs and branches are used for energy production. This method of collection results in canopy opening and degradation of forest patches. This necessitates the exploration of viable energy alternatives to conserve forests while meeting the growing energy demand.

Cooking and water heating are the major domestic end-uses of wood energy. Space heating during winter is met either along with water heating or in paddy fields while

Table 5: Fuelwood consumption among landholding category for cooking and water heating

Type of activity	Season	kg/person/day
Cooking	All	1.82
Water heating	Summer	1.41
	Winter	1.43
	Monsoon	1.56

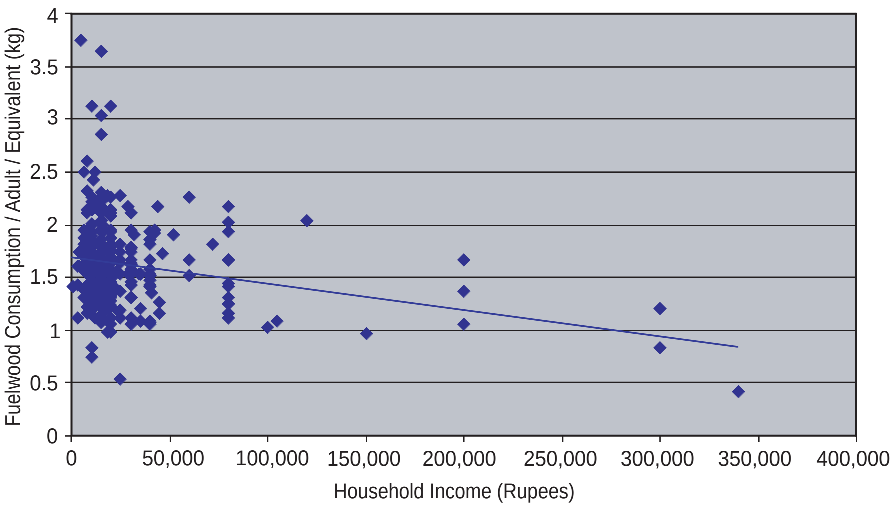


Figure 7: Variation in Fuelwood Consumption for cooking with respect to Household Income.

guarding the crops from wild animals. Quantification of fuelwood requirement specifically for this activity is difficult. The per capita fuelwood consumption for cooking and water heating among landholding category is given in Table 5. Seasonal variation can be clearly seen for water heating as the region experiences extremes in temperature throughout the year. There is no significant variation in cooking fuelwood consumption. Average annual fuelwood consumption by an individual including all activities amounts to 1.2 tonnes. This value is double the national average of 0.7 tonnes/capita/year (Ramchandra et al., 2000a; Sinha et al, 1997). A similar trend of fuelwood consumption was observed in the neighbouring Uttara Kannada district, which showed a yearly per capita fuelwood consumption of 1.44 tonnes (Ramachandra et al, 2000b).

Analyses of fuelwood requirement with respect to income show a linear declining trend as shown in Figure 7. The low-income groups depend on fuelwood as a source of cooking energy. Increase in income promotes the people to afford alternative energy sources like biogas, etc. This transition in the energy ladder has considerably reduced the dependence on fuelwood. The household survey shows that out of 43 biogas

Table 6: Fuelwood consumption among landless category for cooking and water heating

Season	Cooking (kg/person/day)	Water heating (kg/person/day)
Summer	1.62	1.29
Winter	1.88	1.33
Monsoon	1.90	1.52
Average	1.80	1.38

Table 7: Details of the small-scale industries of the region

Industry type	Number of Industries	%Share of wood	Average employment
Agriculture based	21	18.75	5.00
Brick making	5	4.46	—
Food processing	11	9.82	6.14
Wood based	72	64.29	2.78
Miscellaneous	3	2.68	—

owners in the sampled households, 33 households have an annual income of Rs. 30,000. Further, out of the 17 LPG owning households, 16 households have an annual income above Rs. 30,000. However, most of the households in this region belong to low-income category and cannot afford LPG, etc.; there is a scope for energy interventions in the form of improved energy-efficient fuelwood cook stoves or biogas with appropriate financial incentives, service back up, etc.

Due to the changes in socio-cultural practices, livelihood aspects and accessibility to resources, the energy consumption pattern in landless category shown in Table 6, seems to vary from that of landholding category. This category is solely dependent on fuelwood for cooking and water heating activities. Based on this, the annual consumption of fuelwood works out to be 1.16 tonnes/capita. Seasonal variation is seen in fuelwood consumption for cooking as well as water heating. During field survey, it was observed that all households depend on traditional devices for cooking, which are energy inefficient. Use of biogas, LPG and kerosene is absent for cooking.

To assess energy in industry sector, sample survey was conducted for 32 industries out of 112 industries, which depend on biomass. Totally about 112 natural resource based industries were surveyed for analysing the composition and employment abilities of the small-scale industries of the region and results are given in Table 7. These industries being situated in the sub-urban areas of the region, serve as the source of employment to many local people. Wood based industries such as carpentry, manufacture of cane products, etc., constitute 64.29% of the total due to the cheap and easily available wood in the region. This is followed by agriculture-based industries like rice and flourmills with 18.75%.

Sub-basin wise bioenergy status was computed to evolve specific management strategies based on the local conditions, which is given in Table 8. This shows that the

Table 8: Sub-basin wise annual fuelwood availability and demand

Sub-basin	Availability (tonne/year)	Demand (tonne/year)	% Utilization
Central zone	213484.86	65175.6	30.53
Yenneholé	112386.10	8136.0	7.24
Hurliholé	50281.10	9001.2	17.90
Nagodiholé	36978.70	3786.0	10.24
Hilkunjiholé	13788.70	7440.0	53.96
Sharavathi	33564.50	13496.0	40.21
Mavinaholé	34886.90	12189.6	34.94
Haridravathiholé	77481.70	37645.2	48.59
Nandiholé	48416.00	17923.2	37.02

Table 9: Biomass availability from areca residues

Sub-basin	Areca (ha)	Production (tonnes)	Leaves (tonnes)	Inflorescence (tonnes)	Nuts and Husk (tonnes)	Leaf sheath (tonnes)
Mavinaholé	146.48	183.10	1799.47	1384.21	545.77	593.23
Haridravathiholé	282.98	353.72	3476.38	2674.13	1054.37	1146.06
Hilkunjiholé	64.23	80.28	789.02	606.94	239.31	260.11
Hurliholé	260.24	325.30	3197.05	2459.27	969.65	1053.97
Nagodiholé	142.66	178.32	1752.55	1348.11	531.54	577.76
Nandiholé	341.81	427.26	4199.13	3230.10	1273.58	1384.32
Sharavathi	220.97	276.21	2714.66	2088.20	823.34	894.94
Yenneholé	180.39	225.49	2216.08	1704.68	672.13	730.58
Central zone	1160.50	1450.61	14256.59	10966.61	4323.98	4699.97
Total	2800.20	3500.30	34400.92	26462.25	10433.69	11340.96

eastern and southern sub-basins have percentage utilisation greater than 30. The sub-basin wise area and bioresidues available for areca (*Areca catechu*) and coconut (*Cocos nucifera*) are given in Tables 9 and 10 respectively. These residues (and bagasse during seasons) are most commonly used as a source of fuel for water heating. Bagasse is the fibrous residue left after extracting the juice from sugarcane (*Saccharum officinarum*). The quantity of bagasse depends on the fibrous content of the sugarcane and is in the range of 30–32%, which is a rich energy source. The area under sugarcane in the river basin is 281.82 ha with a production of 17,094 tonnes. The bagasse available is about 5470.08 tonnes, which has an energy equivalent of 19145.28 million kcal/year. One tonne of bagasse can generate 2.5 tonne of steam in steam generators. Bagasse is used as a fuel in improved jaggery making stoves in Baniga village of Hosanagara Taluk. With this, the plant has attained self-sufficiency in terms of fuel requirement. This technology has not reached all places in the river basin, which is evident from the survey that most households still use, huge wooden logs in traditional stoves (with efficiency of 5–8%).

Table 10: Biomass availability from coconut residues

Sub-basin	Coconut (ha)	Nuts (tonnes)	Leaves (tonnes)	Inflorescence (tonnes)	Husk (tonnes)	Nut/shells (tonnes)	Leaf sheath (tonnes)
Nagodiholé	9.05	10858	53.26	9.86	16.29	42.80	5.61
Haridravathiholé	127.87	153439	752.62	139.37	230.16	604.80	79.28
Hilkunjiholé	13.51	16210	79.51	14.72	24.31	63.89	8.37
Central zone	211.20	253447	1243.10	230.21	380.17	999.00	130.94
Mavinaholé	21.43	25713	126.12	23.36	38.57	101.35	13.28
Nandiholé	62.43	74920	367.48	68.05	112.38	295.31	38.71
Sharavathi	64.19	77028	377.82	69.97	115.54	303.61	39.80
Yenneholé	11.33	13597	66.69	12.35	20.39	53.59	7.03
Total	521.01	625213	3066.67	567.90	937.81	2464.38	323.03

Table 11: Sub-basin wise livestock population and dung yield

		Dungyield			Dung yield	
Sub-basin	Buffalo population	High (kg/day)	Low (kg/day	Cattle population	High (kg/day)	Low (kg/day)
Nagodiholé	1008	15120.0	12096	3106	23295.0	9318
Central zone	12510	187650.0	150120	29218	219135.0	87654
Nandiholé	818	12270.0	9816	1761	13207.5	5283
Haridravathiholé	6011	90165.0	72132	20471	153532.5	61413
Yenneholé	1850	27750.0	22200	7913	59347.5	23739
Hurliholé	2285	34275.0	27420	3350	25125.0	10050
Sharavathi	2168	32520.0	26016	6303	47272.5	18909
Hilkunjiholé	2416	36240.0	28992	3708	27810.0	11124
Mavinaholé	67533	640702.5	363645	6490	48675.0	19470

Agricultural households own 5–6 animals (considerably high number) for manure, tilling and transportation purposes. Free fodder availability due to vast grazing areas in the region has contributed to higher number of livestock per household. Table 11 show sub-basin wise livestock population and dung yield, while Table 12 gives the biogas availability with potential for cooking energy. The dung yield by livestock depends on various factors and differs from place to place. Usually the effective dung available from stall-fed animals is more than that of grazing animals. Similarly, dung available during monsoon and winter is more due to the availability of sufficient green fodder compared to summer. It is estimated from the survey that, the average dung yield by various livestock is 7.82 kg/cattle/day, 12.64 kg/buffalo/day, 10.3 kg/bullock/day, 1.95 kg/sheep/day and 1.95 kg/goat/day. Table 13 shows the extent of stall-feeding and open grazing by different livestock. Grazing in forests reduces the effective dung available and also harms forest regeneration.

Table 12: Sub-basin wise biogas availability with potential for cooking energy

		With maximum efficiency			With minimum efficiency		
Sub-basin	Human population	Biogas (m^3/day)	Usage	% Potential	Biogas (m^3/day)	Usage	% Potential
Nagodiholé	3155	1613.43	548.56	17.38	770.90	262.11	8.30
Central zone	54313	17084.97	5808.88	10.69	8559.86	2910.35	5.35
Nandiholé	14542	3758.89	1278.02	8.78	1835.67	624.13	4.29
Haridravathiholé	31371	10235.29	3480.00	11.09	4807.62	1634.59	5.21
Yenneholé	6780	3658.09	1243.75	18.34	1653.80	562.29	8.29
Hurliholé	7501	2494.80	848.23	11.30	1348.92	458.63	6.11
Sharavathi	11247	3351.28	1139.43	10.13	1617.30	549.88	4.88
Hilkunjiholé	6200	2690.10	914.63	14.75	1444.17	491.01	7.91
Mavinaholé	10158	3409.87	1159.35	11.41	1675.83	569.78	5.61
Total	145267	48296.74	16420.89	11.30	23714.09	8062.79	5.55

Table 13: Extent of stall feeding and open grazing by different livestock

Type of livestock	% Householdswith livestock	% Households with open grazing livestock	% Households with stall feeding livestock
Buffalo	74.94	66.9	33.13
Bullock	34.90	9.0	91.00
Cattle	73.10	95.1	4.89

Table 14 illustrates the role of family income in energy transition as biogas plants are found more in high-income households. However, there are several non-operational biogas plants due to technical snags. This necessitates proper training and awareness among the villagers as well as local service units with trained technicians to handle energy efficient devices. Among the 91 surveyed landless, low-income category households, none of them had biogas plants mainly due to high installation cost, space limitation and lack of service support in post installation period.

Table 15 shows the relative share of various fuel types in the river basin. In all the sub-basins, nearly 90% of energy potential is of forest resources. This also accounts for energy used in the commercial sectors such as hotels, and fuelwood used during festivals, etc., which is about 30% of the total energy consumption. To understand the sub-basin wise bioenergy status, percentage share of energy demand to the availability is computed and is listed in Table 16. This reveals that Hilkunjiholé (61.8%) and Haridravathiholé (57.2%) sub-basins need immediate intervention to prevent further degradation of natural resources. Central zone, Nandiholé, Sharavathi and Mavinaholé sub-basins are having moderate availability of resources.

Table 14: Income-wise biogas distribution in the river basin

Income range (Rupees/year)	Number of households having biogas plants among sampled households	Category-wise percentage of biogas plant holders
00000–15000	1	0.58
15000–25000	7	5.22
25000–50000	10	13.33
50000–100000	6	28.57
>100000	19	76.00

Table 15: Percentage share of energy from various sources

Sub-basin	% Share of Forest resource	% Share of Biogas	% Share of Coconut	% Share of Areca
Nagodiholé	93.73	1.31	0.19	4.76
Central zone	90.41	2.35	0.77	6.47
Nandiholé	89.99	0.65	0.99	8.37
Haridravathiholé	90.56	3.81	1.28	4.36
Yenneholé	96.88	0.99	0.08	2.05
Hurliholé	92.19	1.53	0.00	6.28
Sharavathi	88.10	2.82	1.40	7.64
Hilkunjiholé	88.13	5.72	0.74	5.41
Mavinaholé	91.57	2.89	0.48	5.06
Total	91.72	2.18	0.66	5.44

2.3. Role of JFPM in Energy Development

The participatory approach in forest management with 23VFCs was initiated in the study area in 1996. The data of 10VFCs illustrates that about 286 ha of land was brought under plantations, within which, 215 ha was of Non-Timber Forest Produce (NTFP) type and remaining 71 ha was of Acacia plantation to cater the fuelwood requirement.

The data collected on the plantation activities in sampledVFCs show that the scheme formulated from ecological and energy point of view has lost its significance due to the improper selection of species and plantation area. The vital objective of the JFPM scheme to fulfil the daily fuel, fodder and food requirement of the local population is deprived due to monoculture plantations. Apart from this, VFCs failure in protecting the degraded land and forest patches is leading to considerable decrease in regeneration.

Land use analysis (Table 17) shows that Haridravathiholé has about 34.7% barren area. Similarly, in all the sub-basins, the percentage barren lands available ranges between 10 and 35%. Thus, there is greater scope for initiating energy plantations in

Table 16: Sub-basin wise energy demand and availability

	Energy availability (million kcal)					Energy demand	
Sub-basin	Forest	Biogas	Coconut	Areca	Total	(million kcal)	% Usage
Nagodiholé	166404.15	2323.65	348.28	8453.05	177529.13	22148.10	12.47
Central zone	960681.87	24992.17	8129.38	68763.75	1062567.17	381277.26	35.88
Nandiholé	217872.00	1572.55	2403.09	20253.66	242101.30	104850.70	43.31
Haridravathiholé	348667.65	14660.07	4921.61	16767.59	385016.92	220224.42	57.20
Yenneholé	505737.45	5176.71	436.13	10688.80	522039.09	47595.60	9.12
Hurliholé	226264.95	3745.89	———	15420.31	245431.15	52657.02	21.45
Sharavathi	151040.25	4842.13	2470.70	13093.58	171446.66	78951.60	46.05
Hilkunjiholé	62049.15	4029.05	519.93	3805.68	70403.81	43524.00	61.82
Mavinaholé	156991.05	4956.28	824.76	8679.39	171451.48	71309.16	41.59
Total	2795708.52	66298.50	20053.88	165925.81	3047986.71	1022537.90	33.55

Table 17: Details of barren area in the river basin

Sub-basin	Total area (sq. km)	Barren area (sq. km)	% Barren area
Haridravathiholé	278.9	96.78	34.70
Hilkunjiholé	85.1	10.10	11.86
Hurliholé	97.8	19.80	20.22
Mavinaholé	95.1	21.27	22.37
Nagodiholé	65.1	8.31	12.74
Nandiholé	143.6	42.34	29.48
Sharavathi	119.4	20.61	17.26
Yenneholé	189.0	37.47	19.82
Central zone	540.5	131.95	24.41

the eastern clusters where there is urgent requirement for energy planning. The selection of the species considering the local needs in terms of fuel, food and fodder, through active public participation will ensure the success of the programme.

2.4. Integrated Energy Planning

Analysis at the sub-basin level illustrated that the energy situation varies within various sub-basins and correspondingly the management strategies need to be designed. Decentralized approach can be considered for planning the energy interventions. By introducing the improved fuelwood cook stoves, fuelwood consumption can be reduced considerably. Because, the most commonly used traditional cook stoves have very less efficiency of 10%. Fuel efficiency studies (Ramchandra et al, 2000) conducted in 82 households showed that for cooking, there is a fuel saving of 42% in improved stoves compared to traditional stoves, whereas, for water heating, the fuel saving is 19–24% with improved stoves. Use of improved stoves for cooking activity and water heating can save annually about 38,600 tonnes and 16,507 tonnes of fuel wood respectively.

Along with this, restriction on open grazing in the forestlands and promotion of stall-feeding allows regeneration and increases the effective dung availability. Thus, appropriate livestock rearing with the introduction of improved varieties along with natives would enhance the dung yield for biogas as well as manure. According to the data, about 88% of the total households have the potential to install biogas plants. At least 60% utilization of this resource can lead to fuelwood saving of 8839.8 tonnes annually. The estimation shows that about 119 villages have the potential to supplement the cooking energy for more than 60% of the total population.

Monsoon paddy cultivation is practiced in the study area. After the crop is harvested, the fields are kept unused until the next season. In this regard, farmers need to be properly guided to suitably select the cropping system depending on water availability such as cultivating horse gram in areas where moisture content is less. Fodder cultivation can supplement fodder requirement for the livestock, which can be stall-fed considerably, there by increasing the dung yield.

The Gram Panchayath (at village level), Revenue and Forest Departments should take active participation in energy planning and development. With proper training to the village people as well as departmental staffs, it is possible to manage their own ecosystem with effective scientific guidance. JFPMoffers an opportunity to increase the forest wealth of the region. If sufficient protection is provided, the forests in the study area, though under extensive population pressure, can retain self-regenerating capacity due to highly favourable environmental conditions. If this protection is extended to other degraded areas of the river basin with complete protection from destructive wood collection, grazing by animals, etc., there is tremendous scope for re-establishing the healthy forests in most of the study area.

3. CONCLUSIONS

Based on the survey, it was found that the per capita fuelwood consumption for cooking and water heating, which are the major end-uses of the energy consumption, is 1.2 tonnes/year. As per the data, some of the eastern and southern sub-basins are facing scarcity of resources and there is a large scope for energy plantations in the degraded forestlands. Viable alternatives like biogas will help in meeting the energy demand efficiently for the river basin. The analysis shows that about 88% of the total households have the potential to install biogas plants. At least 60% utilization of this resource can lead to fuelwood saving of 8840 tonnes annually. The estimation shows that in 119 villages, biogas has the potential to supplement the cooking energy of more than 60% of the total population.

ACKNOWLEDGEMENTS

We are grateful to Prof. M.D. Subhash Chandran and Prof. Niranjan V. Joshi for suggestions during discussions. We acknowledge the Karnataka Power Transmission Corporation Limited, Government of Karnataka and the Ministry of Environment and Forests, Government of India for the financial assistance and necessary infrastructure support. We thank Shruthi for the assistance in literature review and Joshua D. David for proof reading the manuscript.

REFERENCES

Srinivasan, H.R.,*Gobar gas-Retrospect and Prospects,* Director of Gobar Gas Scheme, Khadi and Village Industries Commission, Bombay, 1979.

United Nations Environment Programme,*Guidebook on Biogas Development,* United Nation Publication, 1980.

Ministry of Non-conventional Energy Sources Annual Report, MNES, New Delhi, India, 2003.

Kumar, S.S.,*Carrying Capacity Based Regional Development Planning-Towards Evolving a General Framework,*Regional Environmental Management Plan-Issues and Approaches, Tata Energy Research Institute, Bombay, 1999.

Ramachandra, T.V., Subramanian, D.K., Joshi, N.V., Gunaga, S.V. and Harikanthra, R.B., End Use Efficiencies in the Domestic Sector of Uttara Kannada District,*Energy Conversion and Management,* 2000, 41, 833–845.

Datye, K.R.,*Banking on Biomass,* Centre for Environmental Education, Ahmedabad, India, 1997, 25–29.

Rene Karottki and Gunnar Boye Olesen,*Biogas in India: A Sustainable Energy Success Story,* Implementing Sustainable Development, 1997. http://www.ecouncil.ac.cr/rio/ focus/report/ english/inforse.htm.

Goswami K. P. and Sutar, R.F., *Human Safety Consideration in Evolving Biogas Technology,* Changing Villages, 1993, Oct-Dec, 190–197.

John S. Holtzman,*Stall Feeding of Cattle in the Mandara Mountains of Northern Cameroon,* Overseas Development Institute, Regent's park London, 1986. http://www.odi.org.uk/ pdn/ papers/24a.pdf.

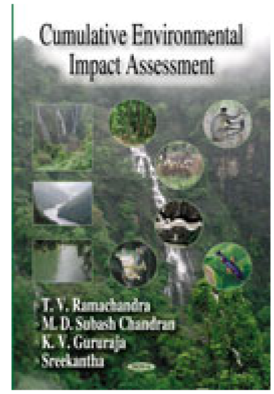
Ravindranath, N. H. and Hall, D.O., *Biomass, Energy, and Environment,* Oxford University Press, Oxford, 1995.

Ramachandra, T.V., Subramanian, D.K., Joshi, N.V., Gunaga, S.V. and Haritantra R.B., Domestic Energy Consumption Patterns in Uttara Kannada District, Karnataka State, India,*Energy Conservation and Management,* 2000a, 41, 775–831.

Sinha, C.H., Ramana, P. V. and Joshi, V.,*Rural Energy Planning in India: Designing Effective Intervention Strategies in Rural and Renewable Energy: Perspectives from Developing Countries,* Tata Energy Research Institute, India, 1997, 5–16.

Ramachandra, T.V., Joshi, N.V. and Subramanian, D.K., Present and Perspective Role of Bioenergy in Regional Energy System,*Renewable and Sustainable Energy Reviews,* 2000b, 4, 375–430.

Cumulative Environmental Impact Assessment



Authors: T. V. Ramachandra (Indian Institute of Science, India)

Book Description:
An ecosystem is a complex of interconnected living organisms inhabiting a particular area or unit of space, together with their environment and all their interrelationships and relationships with the environment having a well-maintained ecological processes and interactions. It is characterized by the abundance of individual species populations; interspecies relationships; activity of organisms; physical and chemical characteristics of environment; flows of matter, energy, and information; and description of changes of these parameters with time. Hence, its surroundings can be categorised into physical and biological environment, which are self-defined, self-maintained and self-sustained dynamic natural systems. The physical environment comprises of lithosphere, hydrosphere and atmosphere, while the living beings in the biosphere constitute biological environment. The biosphere contains many delicate biological processes that have taken billions of years to evolve and there is a natural equilibrium for life sustaining processes dependent on relatively slow rates of recycling. These natural processes as well as resources are being over driven by human activities to meet the growing demands of the population. These developmental activities by humans ignoring the ecosystems and functional aspects are instrumental in bringing about irreversible changes in the ecosystem and their environment.
The concern now is on the rise for the changes due to human induced activities that are proving detrimental, as it has exceeded the recycling rates of natural processes, which are altering the very nature of the environment. These changes are drastic, both to the environment and its inhabitants alike. Under such circumstances, it is necessary to do a retrospective analysis of the present situation to identify the degree of seriousness of different kinds of anthropogenic activities on the environment, plausible measures to curb further damaging to environment and better ways to live in harmony with the environment.

Table of Contents: