

DEVELOPING THE PROCEDURES FOR ASSESSMENT OF ECOLOGICAL VALUE AND CONDITION OF INDIAN RIVERS IN THE CONTEXT OF ENVIRONMENTAL WATER DEMAND

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INTRODUCTION

Environmental water demand (also often referred to as “Environmental Flows”) is a compromise between water resources development and maintenance of a river in some ecologically acceptable or agreed condition. The issue of environmental water demand is relatively new in the world. Existing assessment methods reflect the diversity of opinions on this subject and range from comprehensive expert panel approach to arbitrary selected hydrological indices. In many developing countries, like India, the issues of environmental water demand have not yet received the required attention. Smakhtin and Anputhas (2006), attempted to stimulate the debate about environmental water demand in India by suggesting a simple desktop assessment method and using it in several major river basins. The method however was designed in the conditions of very limited hydrological and no ecological data. One of the major problems with developing environmental flow work in countries like India is that despite a significant general knowledge on some aquatic ecosystem components (e.g. fish), it is not tailor-made for environmental flow assessments. This means that it is not, as a rule, known how different ecosystem components in different geographical settings react to changes of flow caused by water resources or land developments. The impacts of reducing / increasing high, medium or low flows on fish, invertebrates, riparian vegetation, or sediment regime (which is one determinant of aquatic habitat), are not quantified. In some countries, the lack of such relationships and quantitative knowledge is addressed by expert panels and/or by certain scoring systems which rank a condition of an ecosystem and/or its sensitivity to flow changes (DWAF, 1997; www.rpdc.tas.gov.au/soer/indicator/). Such scores are then fed into the determination of an environmental category or ecological management class (EMC). EMC, in turn, is used (together with measures of flow variability or analysis of hydrological time series) to determine the acceptable limits of flow reduction / increase in a river, i.e. actual environmental flows. The higher the EMC, the more water will need to be allocated for ecosystem maintenance or

conservation and more flow variability will need to be preserved. The existing scoring systems reflect the level of available expertise and ecological data. This report attempts, for the first time, to introduce a prototype ecological scoring system in India and illustrate it through the applications in several major river basins.

METHODOLOGY

Ideally, the ecological management classes should be based on empirical relationships between flow and ecological status/conditions associated with clearly identifiable thresholds. However, so far there is no sufficient evidence, or knowledge for such thresholds (e.g. Beecher 1990; Puckridge *et al.* 1998). Therefore EMC is a management concept, which has been developed and used in the world because of a need to make decisions with limited lucid hydro-ecological knowledge. In the conditions of uncertainty with regard to which EMC is required for a particular river, the EMCs may be used as default ‘scenarios’ of environmental protection and associated environmental flows - as ‘scenarios’ of environmental water demand (Smakhtin and Anputhas, 2006). It is possible to estimate environmental demand corresponding to all or any of such default EMCs and then consider which one is the most feasible for a river in question, given the existing and future basin developments. Alternatively, it is also possible to use expert judgment in order to place a river into the most ‘achievable’ EMC. One can think of an “ecological water passport” for a basin. Such “passport” could include answers to the following three broad questions:

- What is the ecological sensitivity and importance of a river basin? The rationale for this is that the higher the ecological sensitivity and importance of aquatic ecosystems in a river basin, the higher the EMC should ideally be
- What is the current condition of aquatic ecosystems in a river basin? The more pristine the current condition of the basin is, the more incentive should ideally be to keep it at that
- What is the trend of change? This question aims to identify whether a river is still changing, how fast and due to what impacts. The rationale is that if deterioration of aquatic environment still continues it will be more difficult to achieve a higher EMC even if it is necessary due to its high importance and sensitivity.

As this is the first time that such approach is introduced in India, the focus should be on highlighting the main aquatic features and problems of each basin. This means that *aggregate environmental indicators*, which reflect different features or conditions of a river basin, could be used for scoring. The literature on environmental indicators is fairly extensive and its comprehensive review is beyond the scope of this report. Some of the relevant recent works include, for example, Galbraith (2001), who developed a set of indicators that could be used to assess the condition and coping capacity of freshwater ecosystems at the basin scale. They include % of the basin under natural vegetation, % of the floodplain under agricultural and urban land use, % of the lakes in eutrophic state, and several others. Similar indicator approach has been widely used in large-scale international water assessment programs such as Global International Waters Assessment (GIWA, <http://www.giwa.net>), Watersheds of the World (Revenga *et al.* 1998) or Land-Ocean Interactions in the Coastal Zone (LOICZ,

<http://www.loicz.org>). However, the aggregate environmental indicators have never been used in the context of environmental flow assessment before.

The first question above may be seen as an attempt to design a condensed measure of ecological value of the basin, albeit in non-monetary terms. Examples of semi-quantitative and quantitative indicators include:

- *Presence of rare and endangered aquatic biota*
- *Presence of unique aquatic biota*
- *Diversity of aquatic habitats*
- *Presence of protected areas, areas of natural heritage and pristine areas which are crossed by the main water course in the basin*
- *Sensitivity of aquatic ecosystems to flow reduction*

Indicators from this group are calculated using national ecological surveys and databases. Considering that most of ‘ecological’ attention in countries like India has so far been given to fish, such indicators as *rare and endangered biota and unique biota* are calculated here using available fish data. Rare and endangered fish species are first identified using IUCN (1994) categories such as CR (critically endangered) and EN (endangered). Their cumulative number is then expressed as the proportion of the total number of species found in a river basin. Assessment of *diversity of aquatic habitats* and *sensitivity of aquatic ecosystems to flow reduction* requires expert judgment and knowledge of a particular river. *Presence of protected or pristine areas* can be assessed against existing guidelines for protected area management – i.e. IUCN (1980), which sets the aim of 10% of the basin to be protected.

The second question above relates to how the river system looks like at present, compared to some reference condition in the past (e.g. prior to major dams’ construction), or compared to some similar and relatively undisturbed sub-basins in the same physiographic settings. The indicators used in this study include:

- *% of the watershed remaining under natural vegetation cover types*
- *% of the floodplain areas remaining under natural cover types*
- *% of aquatic biota that are exotics*
- *overall richness of aquatic species*
- *the degree of flow regulation*
- *the degree of river fragmentation*
- *human population density in a river basin (% of population density in the main floodplains)*
- *overall water quality in the basin*

The first two indicators are normally estimated from the GIS maps, remote sensing data, or already published literature sources. In some cases, percentage of the floodplain areas actually remaining in a basin compared to some past reference condition may be used as an alternative to the second indicator. A *proportion of exotic species* (e.g. fish), can be calculated as a percent of the number of total fish species recorded in the basin. *Overall species richness* may be assessed as a proportion of the total number of species in a country, or in a larger geographical region, whichever is more appropriate, or by an expert score on a scale from low to high. The most straightforward way of calculating the *degree of flow regulation* is as a ratio of total storage of all dams to the long-term mean annual natural flow volume of the basin. A *degree of river*

fragmentation can be represented by some simple indicator of changes to habitat - longitudinal and latitudinal (river-floodplain) connectivity of rivers). *Human population density in a river basin as percentage of population density in the main floodplains* (which could be seen as an aggregate indicator of human pressure on aquatic ecosystems) may be calculated using Census data and GIS, where the floodplains are arbitrary defined as areas within 2.5 km of either side of the main channel and the channels of the main tributaries (e.g. Revenga et al. 1998). An approximation of the overall water quality in a river is indexed using Indian national water quality categorization, which has several classes, from A to E – depending on the level of pollution.- expressed by ranges of several constituents.

With regard to the *third question above*, no specific indicators are used and ‘trend assessment’ is left primarily to professional judgment. It may be seen as an attempt to foresee how the river will look like in the short-term (e.g. 5 years) and in the long-term (e.g. 20 years) in case of a “do-nothing-to-protect-aquatic-environment” scenario.

Regardless of the original units and ways of estimation of every individual indicator, all indicator values in this study are then converted to a standard scoring system, which includes ratings: 1 (none), 2 (minor), 3 (moderate), 4 (high) and 5 (very high). Table 1 summarizes the indicators which have been used in this study, explains why an indicator has been considered and how it is relevant in the context of the estimation of environmental water demand. The scores for individual indicators are then summed up and the sum of indicator scores is expressed as a percentage of the maximum achievable score. The actual percentage shows the degree of the deviation of a basin from its natural condition and therefore – the most probable environmental management class. The later, in turn, may be related to the amount of water which needs to be allocated for environmental purposes in this basin.

THE STUDY BASINS

The river basins which have been selected for this study include Krishna, Cauvery, Narmada, Periyar and part of Ganga. The selection has been based primarily on availability of expertise and data for each basin. The attempt, however, has been made to ensure the geographical spread of basins throughout the country, the range of catchment sizes, degrees of development and environmental issues. Most of selected basins are earmarked for interbasin water transfers under the National River Linking Project (NRLP).

The methods of estimation of individual indicators have varied slightly between the basins, due to varying data availability, specifics of the basin and professional judgment. In some cases, attempts have been made to evaluate additional indicators, such as *aquatic plant species or phytoplankton richness* (e.g. Narmada). In some river basins, certain indicators could not be estimated (e.g. *degree of river fragmentation* in Krishna and Cauvery). These specifics are reflected in individual basin sections. However, every attempt was made to maintain the full spectrum of indicators for each river basin. In the light of many data uncertainties, the scoring system used here should be regarded as tentative and the entire approach - developing. In most of the cases, the indicators have been assessed at the basin-scale, which is obviously very coarse.

But the same principles can be applied at smaller scales (sub-basins or reaches), which has actually been done to a possible degree in Krishna and Cauvery rivers basins.

Krishna River Basin

The Krishna River originates in the Western Ghats at an altitude of 1337 m and flows to the Bay of Bengal through the peninsular states of Maharashtra, Karnataka and Andhra Pradesh. The total length of the river is approximately 1400 km and the total catchment area is 258948 km². The interior of the basin is a plateau at altitudes of 300 – 600 m. The river basin receives the major portion of its rainfall (up to 80% of annual total) during southwest monsoon period from June to September.

Additional primary ecological data (Arunachalam 1999, 2004) exist for the Thungabhadra sub-basin - one of the main tributaries of Krishna - and this sub-basin has been evaluated separately. Each sub-basin (Thungabhadra and the remaining part of Krishna without Thungabhadra) has been additionally separated into three parts: the headwater areas with a number of streams smaller than 10 km² (Arunachalam et al. 2005), the middle reaches affected by reservoirs and the lower reaches (including delta) where development impacts are the most pronounced (Figure 1). Several experimental sub-basins have been studied from each of these areas. The presence of rare, endangered and unique aquatic biota have been rated on the basis of fish catch data summarized in the assessment of 327 species of freshwater fishes in India (CAMP 1997) using the IUCN (1994) categories. Diversity of aquatic habitats has been studied in the field by Armantrout (1990) and Arunachalam (1999, 2000 and 2004) using selected 100-m reaches of Krishna, Bhima, Thunga, Bhadra and other rivers in the basin. Proportional abundance of habitat types in three areas (headwaters, middle and lower) have been estimated using the mean value of available habitats in streams studied from headwater areas (40 streams), middle reaches (20 sites) and lower reaches (Jayaram 1995). The scoring system for habitat diversity is based on Arunachalam (2000) who has studied aquatic habitats for peninsular rivers in India and identified their main types. Degree of regulation was not possible to estimate at the accepted separation of the basin due to uncertainties with flow estimates at required river points. Estimation of other indicators is explained in Tables 1 - 3.

Cauvery River Basin

The Cauvery River, with a total basin area of 87,900 km² originates from the Western Ghats in Karnataka state and extends over parts of Tamil Nadu and Kerala. Cauvery River has 29 major tributaries and 'distributaries' – man-made canals that are comparatively ancient and have become *de facto* rivers (Johal *et al* 2005). The river flows through small patches of upstream jungle and gorges, followed by predominantly vast monotonous plain – into a diverse delta with the Pichavaram mangroves.

Similarly to the Krishna River, for this study, Cauvery river basin is broadly categorized into headwater, middle and lower (delta) areas and several experimental sub-basins have been studied from each of these areas (Figure 2) to determine the representative scores for each of the three areas. Headwater sub-basins are dominated by streams of the 1-3 order. The middle reaches

extend up to the Grand Anicut (a dam constructed in 11-th century) and the lower areas - from the Grand anicut to the outlet, including the delta.

The studies of the Cauvery river ecology mainly focused on fish (Hora 1942, Rajan 1963, Easa and Shaji 1995) with more recent reports on the invertebrates (Jayaram 2000, Sivaramakrishnan *et al* 1995). Similarly to Krishna basin, CAMP (1997) data have been used, CR and EN and unique fish species (IUCN, 1994) in different experimental sub-basins have been identified and their proportion of the total number of species has been calculated. A number of fish species in more than 50 sites in the headwater sub-basins and 30 sites in middle and lower reaches have been used to evaluate the overall fish richness (Arunachalam 1999, 2004; Jayaram 2000) as a proportion of overall species reported in India. The averages of these proportions have then been calculated for headwater, middle and lower areas to produce the representative indicator values. The diversity of aquatic habitats has been evaluated by estimating the number of different habitat types present in the same reaches from all three areas, based on the scoring system proposed by Arunachalam (2000). Percentage of watershed and floodplain remaining in natural cover types has been calculated as the mean value of this percentage in experimental sub-basins of headwaters and middle areas based on field surveys by Arunachalam (1994, 2004). For lower area these indicators are assessed from the literature (Jayaram 2000). Percentage of exotic fish species is calculated (similarly to rare and endangered species) using the primary data by Arunachalam (2004) and the published literature (Sugunan, 1999; Sreenivasan, 1989). Six districts in Karnataka, three districts in Kerala, seven districts in Tamil Nadu and one district in Pondicherry have been used to approximate the human population density in the floodplains of the main river and tributaries (NSII 1991). Other indicators are estimated as explained in Tables 1 and 4.

Narmada River Basin

The Narmada River, with a catchment area of 94,235 km² and total length of 1312 km, is the largest west flowing river on the Indian peninsula (Figure 3), crossing three states - Madhya Pradesh (MP), Maharashtra (MS) and Gujarat (GS). Climate ranges from temperate at the source to subtropical at the outlet. The rainfall varies from between 1400 -1700 mm in the upstream parts to some 130 mm in the estuary. Narmada flows through the only rift valley of India. The alluvial tract between Jabalpur and Handia is over 320 km long and some 80 km wide and is the most intensely cultivated part of the otherwise relatively underdeveloped basin. In the estuarine part, the main river course divides into two branches before joining the sea. Although, the altitudes are generally under 1000 m amsl, Narmada is essentially a mountainous river tucked between the two ranges. The banks of Narmada are stable and the river lacks floodplains, which are extensive in other major Indian basins. Curvatures, pools and water falls are other characteristic features of Narmada.

Through most of its course, Narmada has prime quality forests maintaining its flow throughout the year. These forests are unique for India and are rich in biodiversity, hosting Panthers, Sloth bears, Sambars, Barking and Spotted deer, Black bucks, Wild boar, Porcupines, Foxes, Hyenas, Tigers, wild cats, including a highly threatened Caracals, Flying squirrels, Jackals, Blue bulls, the four-horned Chinkara (the Indian Gazelle) and many others. The prime forest area at

Khandwa – the Chandragharh forest supports endemic tree species of Anjan (*Hardwickia binata*), attaining large heights.

Narmada basin hosts some 20 million people, of which the majority is tribal people who depend entirely on the river and its forests for their livelihood. The population stress on the river is, however, low compared to other basins in India. Narmada has only three townships, two of which have population less than 70,000 as per 1991 census. The only major city of Jabalpur has a population of over 0.7 million.

This mean annual river flow of over 45.6 BCM remains largely untapped at present, although heavily committed for development. Over the next few decades, the construction of 29 large, 450 medium and some 3000 minor dams is planned (Alwares and Billorey, 1988). By now, Barna and Tawa dams (on tributaries) were constructed in 1970s and Bargi dam on the main stream was completed in 1991. The estimation of indicators for Narmada basin is explained in Tables 1 and 5.

Periyar River Basin

The Periyar River (Figure 4) with a total catchment area of 5243 km² and a length of under 300 km, originates at the altitude of 1830 m amsl in the Western Ghats. The annual rainfall ranges from 4000 mm in the upstream parts to 200 mm in the coastal areas. The basin is located primarily in Kerala State. Kerala has 41 west flowing rivers carrying a total annual discharge of 72.7 BCM - higher than the total flow of large rivers like Cauvery or Krishna (Sugunan, 1995). The Periyar mean annual flow volume of 12.3 BCM is the largest among the Western Ghats' river basins.

The characteristic feature of the basin is the Western Ghats' forests, where about 70% of the trees are endemic to the region due to geographic barriers and where streams are the home for a number of endemic fishes (Pascal 1996). The Periyar Lake in the upstream part of the basin is surrounded by such forests, renowned for the sanctuaries like the Tiger Reserve - one of the 18 biodiversity hotspots of India and a home for several endangered species. More downstream, the river meanders through Malayattoor, Kalady and Alwaye - holy places of worship, attracting up to 50 mill pilgrims annually. In its most downstream parts, the river flows through the Eloor industrial belt into Cochin estuary. The basin has 9 irrigation schemes and 16 hydroelectric projects. The total volume of all reservoirs in the basin is estimated to be 3.28 BCM (KSEB, 2005). Of these, the Idukki reservoir is the largest (around 2 BCM). Compared to other Western Ghat rivers, Periyar is relatively better studied ecologically. The estimation of indicators for Periyar is explained in Tables 1 and 6.

Ganga River Basin (Rishikesh to Narora reach)

Ganga is the longest (2525 km) river and the largest river basin in India. It supports over 300 million people across its 800,000 km² catchment area in India, and also extends into Bangladesh, China and Nepal. The mean long-term annual river flow is estimated to be 525.0 BCM. Live storage capacity in the basin has increased significantly over the last 50 years - from 4.2 to 37.8 BCM (<http://wrmin.nic.in>). In addition, a substantial storage capacity of over 17.0 BCM will be created on completion of current projects and yet additional storage of over 29.6 BCM is planned

(<http://wrmin.nic.in>). Therefore, after the construction of all currently proposed dams, about 30% of annual utilizable flow (i.e. 250 BCM) could be stored.

The above developments threaten the aquatic ecology of the basin, but very few ecological studies have been conducted in the basin to date. Due to the mere size of the basin and lack of ecological studies, it is not possible to consider the entire basin in this study. The study therefore attempted to describe the ecological value and condition of a 295 km stretch of the Ganga, between Rishikesh and Narora, where WWF-India has been co-ordinating the Dolphin Conservation Programme (Figure 5). The area covered under the study is about 16,780 km² in Uttar Pradesh and Uttaranchal States. Some ecological information can be derived or inferred from sources like Behera (1995), Payne et al. (2003), Rao (1995) and Zoological Survey of India (1991). These have been supplemented by other, more 'global' sources, like the World Resources Institutes's Earth Trends database and its publications as well as Dudgeon (2000), Menon (2004, 1999), Kottelat and Whitten (1996) and Nilsson et al. (2005). Also, the Census of India (1991, 2001) and maps from National Atlas and Thematic Mapping Organisation (NATMO) have been used. In the study reach itself, there is no major water storage dams, except for Tehri reservoir upstream.

INDICATORS AND TRENDS IN STUDY BASINS

Krishna River Basin

Tables 2 and 3 summarize the results for Thungabhadra sub-basin and the rest of Krishna river basin respectively. Both sub-basins are more pristine in the upstream areas, with diverse and relatively unfragmented habitat, limited or no exotics and high percentage of natural cover types. Both sub-basins are broadly similar in most of the indicator scores, which have a clear tendency to deteriorate downstream with the progressive increase of human pressure. The exception is the higher richness of fish in both sub-basins in their middle reaches, which is partially due to the tributary effects, creating more diverse and deeper habitats. In lower reaches species richness drops due to over fishing downstream of reservoirs and due to the impacts of urbanization. The practice of using trawl net with small mesh size (8 – 10 mm) almost wipes out the whole fish population (Arunachalam, pers. obs.). In the Krishna sub-basin also, the middle reaches support more species than the headwater and lower reaches, primarily due to increasing size of streams which still remain in a more natural condition compared to lower areas. Lower reach including delta (Jayaram 1995) has limited freshwater species but is represented by 40 species of brackish and coastal marine fish.

Myers et al. (2000) described the global hotspots of biodiversity, which include the upstreams of Krishna River and its tributaries originating from the Western Ghats. It is therefore important to ensure that these areas are conserved. The pressure in the upstream parts of the basin has overall been relatively limited compared to the lower reaches, where deteriorating trends are alarming. River discharge has been decreasing at the outlet from 1968. The conflicts of sharing Krishna river water already exists between the states of Karnataka and Andhra Pradesh. Major flow of water is obstructed by increasing number of large and medium sized dams, which has completely changed the sediment regime of the river and fragmented its habitats in middle and lower

reaches. Krishna delta with an area of some 200 km² with mangrove forest faces threats of deforestation, overgrazing, harvesting of juvenile fauna and expansion of agriculture and shrimp aquaculture.

Environmental flow provisions are deemed necessary and immediate downstream of most reservoirs in the basin and into delta to avoid its further degradation. The points of receptions or extraction of water under the planned NRLP links have to be considered in this regard. In addition, to conserve some of the unique and endangered species in the headwaters, these provision are also needed, although not immediate.

Cauvery River Basin

Streams in Cauvery river basin from headwater reaches to outlet, exhibit remarkable habitat heterogeneity which is exploited by guilds of fish species. Headwaters support more endangered fishes and these streams can be used as “reference sites” for the entire basin. These headwater streams have high gradients and predominantly bedrock substrates. Endangered fishes are confined to such rocky stream types. Similar sites are present in the middle areas, but to a lesser extent. In the lower reaches, fish diversity and abundance decline significantly due to reduced flows

Headwaters have most of the protected areas, middle reaches - less than 1 % and in the lower reaches, the mangrove swamps of Pichavaram and Muthupet lagoon are protected by the State Forest Department. Some pristine areas may still be declared protected in the upstream areas (e.g. in the catchments of Moyar, Bhavani and Amaravathi streams). In middle and lower reaches there are a few heritage sites including Vishnu temples at Srirangapatnam, Sivasamudram and Srirangam; Cauverypoompattinam, which was an ancient capital of the Cholas Kingdom in the 1st century AD. Most of the headwaters are still under natural vegetation cover, but the pressure from human settlements progressively increases downstream.

Perhaps the major basin-specific feature adversely affecting basin ecology is a trend for expansion of coffee, tea and, to a limited extent, cardamom plantations. The high elevation in the upstream parts of Cauvery creates ideal conditions for these cultures. These developments threaten with denudation due to the removal of riparian forests. Associated population growth may lead to abstraction of water from first and second order streams for domestic use, while the increased waste loads may eliminate the endemic fauna. Habitats in the headwaters are still up to 70% in undisturbed conditions. This is analogous to the habitat intactness and can be regarded as wilderness (Mittemeier et al 2003). These areas need protection, and extension of coffee and tea plantation should be curtailed to avoid further loss of wilderness area and potential drying up of small streams. Environmental flows have to be established to regulate further extension of coffee and tea plantations in the headwaters.

Cauvery River at present is highly fragmented by various impoundments (Kathiresan 2000). Mangrove vegetation tends to be more luxuriant at lower salinities (Kathiresan et al 1996) and some degraded areas in the delta are mainly due to high salinity, caused by reduced freshwater inflow (MSSRF 1998). Further reduction or a continuation of the current limited inflow will be detrimental to the coastal areas (Ittekkot et al. 2000).

Fishes upstream are affected directly by physical barriers (e.g. Lower Anicut, the Great Anicut and the Upper Anicut) to their migration, by the inundation or drying out of spawning grounds (upstream or downstream of dams), which is reflected by the poor species richness in the lower reaches. Some indigenous ichthyofauna (e.g. the anadromous fish, *Tenulosa ilisha*, or *Puntius* spp., which used to form 28% of the landings in 1943–44) have completely disappeared from Cauvery after the construction of Mettur dam (Shugunan 1995). Population density in Cauvery is among the highest in the world (350 people / km² compared to the world's average of 42 people/ km²). The population growth is also 2.5 times the rate of the world's population growth as a whole which is seen as the major threat to the vast native forests in the basin and their disappearance in the nearest decades (Cincotta and Engelman 2000).

Narmada River Basin

Earlier studies of CIFRI (1993), NPA (1987), RRSL (1987) and Dubey (1993) did not identify any endangered, rare or unique species of fish in the basin. The only *rare* organism reported was the water monitor lizard which lived in the estuary (Alwares and Billorey, 1988). There is some limited evidence however, that up to 10 species may be classified as endangered and 8 – as unique (Arunuchalam, pers.comm.). Narmada and its main tributaries is rich in habitat types, which include pools, gorges, water falls, deep waters etc. The river has a number of pristine and protected areas: it flows through Bandhavgarh National Park (430 km²), Kanha biosphere reserve (940 km²), Satpura National Park (524 km²) and three forest reserves of Mandla, Seoni and Hoshangabad with areas of 110, 416 and 449 km² respectively. A number of protected areas and forest reserves on one hand and the relatively low population density on the other mean that the basin remains largely under natural cover. At present, Narmada has only a few structures and flow fragmentation is relatively low. But the planned storage construction may turn the river network into small stagnant closed water storage systems. According to Rao et al. (1999), fishes of Narmada predominantly belong the local endemic carp group (Mahseer, Hilsa and Catla). Dubey (1993) reported that exotic fishes like grass or silver carp do not occur in the basin.

The attempt was made here to separate between fish, aquatic plants, phytoplankton and zooplankton species richness (Table 5). The richness of *aquatic plants* is related to the degree of nutrients. Narmada has a relatively moderate aquatic flora (Unni, 1996) reflected in a moderate score and range of 10 - 30 %. The later however is based on observations at three sites in headwaters while the data on other parts of the river is absent. The quantitative studies on *phytoplankton* (e.g. in Ganga) show high fluctuations and vary between thousands and millions of cells per liter, being correlated with the degree of pollution. The clear waters of Narmada have relatively lower numbers. The distribution and composition of *zooplankton* indicates the status of water quality and are available for many Indian rivers. Relative values for Narmada reflect good present condition. The diversity of naturally occurring periphytic algae and diatoms, as well as the diversity of naturally occurring zooplankton, is however quite high in Narmada waters. Despite the limited data on actual constituents, the overall water quality is good (Unni, 1996) mostly free from pollution throughout its course, except for a small estuarine part of over 20 km.

Neither significant changes nor rapid development are likely to be possible in the Basin, since even the basic infrastructure, like roads, is lacking. The hilly terrain of the basin is a major

disadvantage for development. Agriculture is the main source of livelihood for tribal people. Fast urbanization is unlikely and the negative impacts of already existing towns on the river (e.g. on water quality) would be limited even in the next 25 years. At the same time, a large number of mainstream dams, if constructed without provisions of fish ladders and environmental flow releases, will definitely have adverse impacts on river ecology. Lack of flow, decline in dominant fisheries, stagnant conditions in dams and resultant eutrophication and water born diseases are potential impacts in the long-term.

Periyar River Basin

For a relatively small basin, Periyar has a number of endemics and several threatened species (Kurup et al. 2001) as well as a range of various habitat types (Table 6). 30% of the basin area is covered with dense pristine forests, parts of which, crossed by the river, include wild sanctuaries. The river has no floodplains similarly to other west flowing rivers. Introduction of exotic fishes into reservoirs have reduced the abundance of endemic fishes. However, in the River itself, the exotics have not been reported so far. Various sources report variable number of fish species in different parts of the basin, varying from 27 in Periyar tributaries, to 150 in the downstream parts (Arun 1998; Arunachalam 2000). The basin is rich in fish species having some 70% of the species present in the Western Ghats and significant proportion of all species in India, CAMP (1997) identified a variety of endemic species in Periyar. It was proposed to declare the upper reaches of Periyar as potential fish sanctuary (Joseph 2004). No aquatic plants recorded in the basin.

A major negative trend in all Western Ghat rivers is the construction of dams. The existing hydroelectric projects (e.g. Idukki) and the four proposed projects in Periyar pose flooding threat to some of the primary forests and additional fragmentation in already significantly fragmented main river. Another major impact is sand mining fuelled by the construction boom in Kerala. Sand mining has affected the stability of river banks leading to loss of land and making large areas flood prone. The quantity of sand that could be extracted safely is 19178 tones annually, but the actual quantity removed is 30 times more (Pratapan, 1999). Indiscriminate sand mining deepens river channel which promotes saline intrusion in the coastal area.

Another major threat in the basin is water pollution. The physico-chemical analyses and reviews of the Periyar River water quality are available from 1976 onwards for a period of 25 years (Paul and Pillai 1976, 1981). These analyses show consistent decline in pH, oxygen levels, increase in water temperature, high radioactivity, pesticide pollution, elevated levels of heavy metals etc. A variety of shell fishes downstream such as crab, prawn etc have become extinct due to water pollution (Joseph 2004). GreenPeace (2003) describes Eloor industrial area in the downstream Periyar as one of the most vulnerable 'hotspots' of industrial pollution in the world. A parallel reduction in flow will further increase algal blooms and occasional fish kills as has already been experienced in the past.

Ganga River Basin (Rishikesh to Narora reach)

The indicators' values for this reach of the Ganga river are summarized in Table 7. Ganga is the top basin in India with regard to fish species richness, but estimates of total number of species vary significantly. The World Bank identified about 350 species (Kottelat and Whitten 1996),

while Talwar (1991) reported 375 species. Of these, the estimates of freshwater species are between 104 and 161 (Menon 1999, Payne *et al* 2003). In the study reach between Rishikesh and Narora, Behera (1995) recorded 82 species of fish. Of these 4 to 10 are threatened or endangered according to different sources (Menon, 1999, Behera 1995, Arunachalam, pers. obs.). These include the ‘endangered’ *Tor tor*, a Mahseer, *Bagarius bagarius*, *Pangasius pangasius*, and *Rita rita* (Behera 1995). In addition, 12 species of freshwater turtles are present, out of which 6 species are considered endangered in terms of the Schedule I of the Indian Wildlife Protection Act, 1972 (Rao 1995). In the same stretch, two species of crocodile *Crocodylus palustris* and the *Gavialis gangeticus*, locally known as Gharial, are found. Both are considered *endangered* (IUCN 1994). The Common Indian otter (*Lutra lutra*), and Smooth Indian otter (*Lutra perspicillata*), have also been sighted in this stretch of the river. Both species are designated as threatened (IUCN 1994). More than 100 species of birds, both migratory and residential have been sighted (Behera 1995), of which several are endangered. The area around Narora was proposed as a potential bird sanctuary in 1978 (Rao, 1995). 51 species of aquatic insects and 15 species of mollusks are also observed.

Comparing the list of fish species from the stretch (Behera, 1995) with the list of endemic fish species of India (Karmakar and Das, 2004), it is inferred that *no endemic freshwater species of fish* has been reported from the stretch. However, one species of Crocodile, *Crocodylus palustris*, twelve species of turtles and one aquatic mammal species, *Platanista gangetica* – the Gangetic dolphin have been recorded (Rao 1995). Though Gangetic Dolphin is also found in the Brahmaputra, it is considered *unique* to the entire Ganga-Brahmputra-Meghna (GBM) basin, and its characteristics separating it from the Irrawady and Indus dolphins have been well documented (Behera 1995). Though the crocodile is not unique to the Ganga system, it is ‘*endangered*’ animal as per IUCN classification (IUCN 1994) and protected under Schedule I of the Wildlife Act, 1972. Thus, although they are not unique in the strict sense, the presence of these animals makes this stretch important for conservation.

Ganga becomes a mature river after Haridwar flowing over hundreds of metres of alluvium. In the upper part of the reach, the *aquatic habitats* include riffle areas, rocky, sandy and muddy river banks, while the lower part is dominated by sandy and muddy banks and deep pools (Rao 1995). The shallow parts of the river turn into islands during low flows and thus - into good nesting grounds for turtles and island breeding birds.

Protected areas include the Hastinapur Wildlife Sanctuary (2073 km²) which hosts the two-toed Barasingha – swamp deer, Sambhar, Cheetal, blue-bull, wolf, leopard, hyena and wild cat. Birds on the Red List reported from the sanctuary area are Greater Spotted Eagle, Swamp Francolin, Sarus crane and Finn’s Weaver.. In 2005, the 85-km stretch of the Ganga between Narora and Brijghat has been declared a Ramsar Site due to the WWF’s on-going gangetic Dolphin Conservation Programme. Considering the river reach only (without its catchment) the protected area proportion is therefore around 30% of the length, which is well above the IUCN norm of 10%. This approach has been used here to raise the importance of the reach for conservation.

Sensitivity of aquatic ecosystem to flow reduction is very difficult if impossible to evaluate in the absence of direct relationships between ecosystem and flow changes. The diversion of the flow in the Ganga has been ongoing since the early 1850s and riverine ecosystems have gradually adjusted to such diversions with certain losses. However, there have been instances when parts of

the river in this reach went dry in the past. This cannot be explained by natural flow variability only, but is rather the cause of diversions. Such events lead to increased stress on the ecosystem, especially on species like Dolphin that need deep pools of water and high flow velocities (Behera 1995). Das *et al* (2005) has analyzed the impacts of irregular water flow from barrages on river Dolphin population and found that reduced dolphin numbers correlate with reduced downstream flow in the study stretch. Other scientists have identified reduced river flows as one of the primary threats to the populations of dolphins, Mahseer, crocodiles and turtles (Rao 1995), but no quantitative data on this exists.

Since the Gangetic plains have been inhabited for centuries, the dominant land-use has been agriculture and this certainly affected the proportion of the natural cover in the basin. According to some recent sources (Watersheds of the World, 1998), over 80% of the original forest cover in the entire Ganga basin has been lost. Some areas in the sub-basin of the study reach remain under grasslands (e.g. protected areas like the Hastinapur Sanctuary). Forests have recently started to show some trend of recovering (a marginal increase in forest area of 2-5% is reported in the past decade - Census of India 2001). However most of the basin is under agriculture. Similarly, almost the entire floodplain of the Ganga has been converted to agricultural land. The *floodplain areas remaining* range from 1.5 km (at both sides of the river in total) at Haridwar to some 20 km near Narora Barrage (estimated using images from www.earth.google.com). Less than approximately 10% of the original (i.e.10,000 years ago) floodplains still remain (R. Sinha - pers. comm.).

The degree of flow regulation in the basin is still relatively low. There have been no storage reservoirs along the stretch or upstream of it, until the completion of the Tehri dam in 2005. Nilsson *et al.* (2005) classify the entire basin, including the main channel and tributaries as 'moderately affected' by regulation. However, 4 major barrages have been constructed in the study reach from 1850s onwards. Some sources suggest that diversion and regulation in the reach remove some 50% of the discharge compared to 66% for the entire basin (Payne *et al* 2003). This however is likely to be significantly overestimated as the data on observed historical flows in the Ganga is not readily available. The barrages fragment the main river into 3 reaches, resulting in 0.0133 structures per km across the flow, which is used here as an estimate of the degree of river fragmentation (Table 1 and 7). Some of the barrages constructed more recently, like the refurbished lower Ganga barrage at Narora, have fish ladder arrangements that restore connectivity to a limited degree.. However, these structures are based on designs for rivers in the temperate zone (Kottelat and Whitten 1996) and effectiveness of the same designs in the tropical rivers is unknown.

Behera (1995) reports over 80 species of fish in the study stretch. A comparison with Menon's (1999) description of freshwater fish in the Ganga basin reveals that about 60 of these are native. Thus, slightly over than 20% of the fish species recorded in the stretch are *exotic fish*. Exotic species include carps and catfishes that may have been introduced for fisheries.

According to Census of India (2001), there is little difference in the human population density between areas adjacent to the river and those further away from it (Table 7). The water quality of the study reach is regularly monitored by CPCB (www.cpcb.nic.in) at Rishikesh, Haridwar, Grahmukteshwar and Narora and occasionally – during research projects (Behera (1995). It

varies in different parts of the reach from class B to D with most of it falling into class D due to contamination of the river by human wastes (high coli form) above permissible thresholds and high BOD values around Narora due to sugar industries.

In the short-term, the flow downstream of the Tehri dam is likely to decrease, while the increased use of groundwater for irrigation may reduce baseflow, especially during summer months. The increasing diversion of river water for irrigation is the single most important consumptive use in the study reach. In addition, the power generation facility of the Tehri Dam, will need the peaking power requirement to be satisfied and creates a pulse discharge into the river downstream that can be felt as far as Rishikesh or even Haridwar. These factors adversely affect the single most important ecological issue in the reach - the protection of the Gangetic dolphin. Although due to recent conservation efforts its population doubled (from 22 to 45) since 1995, the habitat for the dolphin in the Ganga is threatened by irrigation diversions and flow variability changes. The overall prospects for the dolphins in the country remain a concern with their annual dying out rate of nearing 10%. However, overall, the ecological status of the stretch is likely to improve in the next 5 years with the continuing conservation efforts.

DISCUSSION AND CONCLUSIONS

Once the scores for individual indicators have been estimated, it is possible to calculate the sum of them and express it as the percent of the total *maximum possible* sum of all indicators. This percentage may then be converted into the most likely Environmental Management Class (EMC), which, in turn, determines how much water (*environmental flows*) needs to be allocated for environmental purposes in this or that river basin (Smakhtin and Anputhas, 2006). Similarly to various number and type of ecological indicator used, various procedures and categories can be proposed on how to use the indicators to establish the EMC, or - directly - the environmental flows themselves. In this study, the scores have been divided into 6 unequal categories, each representing one of the six EMCs described in Table 8.

The rules of thumb have been that rivers/ basins in the most natural category (A) are rare and even if present may not always be assigned this category due to development needs and existing resilience of ecosystems. The other extremes - classes E and F - should generally not be considered as feasible management options. Classes from B, C and D together thus cover most of the available range of percentage values (Table 8). This system is clearly arbitrary at present and a much more research effort and expert discussions are required to justify how to convert the indicator scores into different EMCs.

The final summary of all indicators and the estimation of EMCs for each basin or sub-basin are given in Table 9. Most of the basins examined in this study fall into class C, three - into class B and two - into D. The basins/ reaches in the highest class B are primarily headwater or smallish basins located /originated in the Western Ghats, with high habitat diversity, species richness and relatively less developed compared to basins located further downstream. This combination of relatively natural condition on one hand, and higher sensitivity /importance due to more species diversity etc- on the other, places them into such high category. Two sub-basins in the lowest (in this study) class D are on the contrary located in the most downstream parts of the basins. It can

also be noted that lower Krishna, although in class C, is at the lowest boundary of this class (Tables 8 and 9). An interesting example is that of Narmada basin: it falls into class C primarily due to its two low scores on rare and unique species (Table 9). This reduces the importance of the basin and makes the otherwise relatively natural basin an 'attractive' candidate for development. But as Table 5 indicates, there are unpublished sources suggesting that rare and unique species in Narmada do exist, which may raise the scores of these indicators and increase the overall EMC of Narmada. At the same time, Periyar basin, which scores high on most of the sensitivity/importance indicators reaches high class B despite its low score due to multiple dams. In general, high indicators of sensitivity/importance together with high indicators of the current ecological conditions place the river into a high management class, while any 'loss' of indicator scores – either in terms of current condition, or importance/sensitivity – leads to lower EMC and hence – lower environmental allocation.

Smakhtin and Anputhas (2006) presented, amongst the others, relationships between EMCs and the amount of natural long-term mean flow at the outlets of major river basins on India. If their relationships are used together with the procedure suggested herein, the environmental water requirements at the outlet of Krishna, for example, would be in 18% of the long-term mean flow, Cauvery – around 11% of its long-term flow, Narmada – 14% and Periyar – 28%. It is important to understand though that this report introduces the approach rather than the final method for setting EMCs for Indian rivers. Even if the EMC setting approach is retained for future management of Indian rivers in principle, it is necessary to be aware of its multiple limitations, including, but not limited to the following:

- A set of indicators used here is very preliminary and the selection of indicators needs to be revisited
- The existing information base for determining any ecological indicator in India is very limited. The authors of this report used their own knowledge and judgment on specific rivers, but other specialists will need to be involved in estimating the scores to improve the level of confidence
- The scale of the analysis was very coarse and a similar or a different set of indicators needs to be used at much smaller scales, e.g. for a particular reach of any river, rather than for arbitrary selected big parts of already very large river basins (with Periyar being the only exception).
- There seems to be lack of agreement on such specifics as how many fish species are there in India overall – which determines the estimation of several indicators). There is little knowledge on other aquatic species' diversity
- It is a challenge to account coastal fish diversity into the picture of EMC estimation for a river basin, unless of course estuarine freshwater requirements are estimated using a protocol different from environmental flow assessment for inland rivers
- The procedures used in this report to convert the indicator scores into EMC are arbitrary and illustrative. They are given here primarily to stimulate the further development in this field

It should also be noted that although useful, the scoring approach may not only be used for estimation of just EMCs. It may also be applied to estimate the permissible levels of reduction / increase of various flows – directly, as suggested by Smakhtin and Anputhas (2006).

As an immediate follow-up to this preliminary study on ecological scoring, the authors of this Report propose to thoroughly prepare and hold a national workshop, which would engage some 10 aquatic ecologists and hydrologists and which would result in a more reliable assessment methodology of environmental importance and condition of Indian water bodies.

We also consider important to start the process of ecological status assessment of all Indian water resources – at the fine scale of spatial resolution. This large-scale new program should tap into already existing massive ecological expertise in the country and to redirect it from largely descriptive / inventory type work into the context of quantification of ecological water requirements of Indian rivers and wetlands.

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REFERENCES

- Alwares, C. and Billorey, R. 1988. Damming the Narmada - India's greatest planned environmental disaster. Natraj Publishers, Dehra Dun. 196 pp.
- Armantrout, N. B. 1990. Aquatic Habitat Inventory. Bureau of Land Management. Eugene district, USA. 32 pp.
- Armantrout, N. B. 1997. Glossary of Aquatic Habitat Inventory Terminology. Western division. American Fisheries Society, Bethesda, Maryland, USA. 159 pp
- Arun, L.K. 1998. Status and distribution of fishes in Periyar lake-stream systems of Southern -Western Ghats. Fish Genetics and Biodiversity Conservation: National Bureau of Fish Genetic Resources publications, Nature conservators, Muzaffarnagar 251001:492 pp
- Arunachalam, M. 1999. Biodiversity and ecological structure of fishes in streams of South India. Department of Biotechnology, Government of India, New Delhi 119 pp.
- Arunachalam, M. 2000. Stream fish habitat inventory methodology. In: Ponniah, A.G; and Gopalakrishnan, A. (eds.) Endemic Fish Diversity of Western Ghats. National Bureau of Fish Genetic Resources- National Agricultural Technology Project, Lucknow. 347 pp
- Arunachalam, M. 2000. Assemblage structure of stream fishes in the Western Ghats (India) *Hydrobiologica* 430: 1-31.
- Arunachalam, M.; Sankaranarayanan, A.; Manimekalan, A.; Soranam R.; and Johnson, J. A. 2002. Fish fauna of some streams and rivers in the Western Ghats of Maharashtra. *Journal of the Bombay Natural History Society* 99:337-341.
- Arunachalam, M. 2004. Germplasm inventory, evaluation and gene banking of freshwater fishes. National Agricultural Technology Project. Government of India. Project Report (unpublished), 204 pp.

- Arunachalam, M.; Sivakumar, P.; and Muralidharan, M. 2005. Habitat Evaluation of pristine headwater streams of Western Ghats mountain ranges, Peninsular India. In: Johal, M. S. (ed.) Proceedings of the National Seminar: New Trends in Fishery Development in India. Punjab University. Chandigarh. 286 pp
- Beecher HA. (1990). Standards for Instream Flows. *Rivers* 1(2) 97-109
- Behera, S. 1995. Studies on Population Dynamics, Habitat Utilisation, and Conservation aspects of *Platanista gangetica* between Bijnor and Narora, Ph.D. thesis, submitted to Jiwaji University, Gwalior
- Bilagrami, K.S. 1991. Biological Profile of the Ganga: Zooplankton, Fish, Birds and other minor fauna. In: The Ganga: a Scientific Study .The Ganga project Directorate, Ministry of Environment and Forests. Government. of India, New Delhi
- CAMP (Conservation Assessment and Management Plan) 1997. Report of the workshop Freshwater fishes of India 1997. Zoo Outreach Organization and National Bureau of Fish Genetic Resources, Lucknow. 137 pp
- Census of India 1991-2001 – Village Directory Data CD New Delhi
- Chatterji, S.N, K.S Rao and A.K. Singh, 1993. Recent advances in Freshwater Biology Anmol Publications Pvt. Ltd. New Delhi. 380 pp.
- CIFRI. (Central Inland Capture Fisheries Research Institute) 1993. Studies on the fish conservation in Narmada Sagar, Sardar Sarovar and its down stream. CIFRI, West Bengal, India.
- Cincotta, R. P.; and Engelman, R. 2000. Nature's place: Human population and the future of Biological Diversity, Washington, D. C., *Population Action International*, 80 pp.
- CPCB (Central Pollution Control Board) 1992. A system for surface water classification in India, Mimeo, 1– 16.
- Das, S.; Chatterjee, A.; Behera S.; Bhatia, S.; and Gautam, P. 2005 Concerns of environmental flows in rivers in the context of the proposed Interlinking of Rivers in India. Abstracts of the NIE/IWMI workshop on Environmental Flows, New Delhi, March 2005.
- Dave, J.H. 1957. Immortal India. Bhavan's Publication, Mumbai. 168 pp.
- Department of Environment 2000, Government of Maharashtra, Bombay, 8 pp.
- Dubey, G.P. 1984. Narmada Basin Water Development Plan: Part 1: Development of Fisheries. Narmada Planning Agency, Government of Madhya Pradesh.
- Dubey, G.P. 1993. Status prior to the year 1980 of Hydrobiology, Fisheries and Socioeconomic conditions of fishermen in Narmada Basin, in Rao, K.S. (Ed.), Recent Advances in Freshwater Biology. Anmol Publications Pvt. Ltd., New Delhi. 380 pp
- Dudgeon, D. 2000: Large-Scale hydrological changes in Tropical Asia: Prospects for Biodiversity, in *Bio Science*, 50 (9): 793-806
- DWAF – Department of Water Affairs and Forestry of South Africa - (1997) White paper on a National Water Policy for South Africa. Pretoria, South Africa
- Easa, P. S. and C. P. Shaji. 1995 Freshwater fish diversity in the Kerala part of the Nilgiri Biosphere Reserve. *Current Science*. 73: 180 – 182
- Galbraith H. (2001) Indicators of Ecosystem condition, sustainability and coping capacity. Unpublished Report to the United Nations World Assessment Programme Indicator Development Unit. Unpublished Report, Galbraith Environmental Sciences, Boulder, Colorado, USA

Green Peace. 2003 Status of human health at the Eloor Industrial Belt. Kerala, India. A cross sectional Epidermological study. Green Peace, India

Hora, S. L. 1942 A list of fishes of Mysore state and of the neighbouring hill ranges of the Nilgiris, Wynad and Coorg. Records of the Indian Museum . 44: 193 – 200

Ittekkot, V., C. Humberg and P. Schafer 2000 Hydrobiological alterations and marine biogeochemistry a silicate issue? *Bioscience* 50: 776 – 782.

IUCN (International Union for Conservation of Nature and Natural Resources.) 1980. World Conservation Strategy, IUCN, Gland, Switzerland, 1980.

IUCN (International Union for Conservation of Nature) 1994 Guidelines for applications of IUCN Redlist criteria at Regional levels: version 2.3. IUCN species survival commission. IUCN, Gland, Switzerland and Cambridge, UK 12 pp.

Jayaram, K.C. 1995. The Krishna River system Bioresources study. Records of the Zoological Survey of India, Occasional paper No. 160. Zoological Survey of India, Calcutta. 167 pp

Jayaram, K.C. 2000. Cauvery Riverine System: An Environmental study. The Madras Science Foundation. 257 pp.

Johal, M. S.; Armantrout, N. B.; and Arunachalam, M. 2005. Changing Indian Rivers M. S. Johal (ed.) Proceedings of the National Seminar 'New trends in fishery development in India'. Panjab University. Chandigarh, pp 286.

Joseph, K.J. Nambisan, P.N K. Shynamma and , P.T Lakshmanan. 1984. Studies on Phytoplankton of polluted waters *Journal of the Marine Biological Association, India* 26 (182) 42-46.

Joseph, M.L. 2004. Status Report on Periyar River. Kerala, India, 43 pp

Joy, C.M. and Balakrishnan, K. P. 1990. Physico chemical aspects of a tropical river receiving industrial effluents 17-236, R. K. Trivedy (Ed.) River pollution in India. Ashish Publishing House, New Delhi 294 pp

Karamchandani, S. J.; Desai, K.R.; Pisolkar, M.D.; Bhatnagar, G.K. 1967. Biological investigations on the fish and fisheries of Narmada River, 1958-1966. *Bulletin of Central Inland Fisheries Research Institute, Barrackpore*, 10: 40pp.

Karmakar, A. K.; and Das, A. 2004 Endemic Freshwater Fishes of India, Zoological Survey of India, Occasional Paper no. 230, Kolkata, 1-125pp

Kathiresan, K. 2000 A review of studies on pichavaram mangrove, southeast India. *Hydrobiologia* 430: 185 – 205.

Kathiresan, K. Moorthy, P.; and Ravikumar, S. 1996. A note on the influence of salinity and P^H on rooting of *Rhizopora mucronata* Lamk. seedlings. *Indian Forestry*. 122: 763 – 764.

Khatri, T. C. 1985. A note on the limnological characters of the Idukki reservoir. *Indian Journal of Fisheries* 32 (2): 267-269.

Kottelat, M. and Whitten, T. 1996 Freshwater Biodiversity in Asia With Special Reference to Fish, World Bank Technical Paper No. 343, World Bank, Washington DC, USA; 28 pp

KSEB (Kerala State Electricity Board) 2005. Fact file on dams. Government of Kerala. Thiruvananthapuram, India

Kurup, B M. Radhakrishnanan, K.V., Manoj Kumar .T.J. (2001) biodiversity status of fishes inhabiting Rivers of Kerala .India, with special reference to endemism – threats and conservation. Thirunanthapuram, 76 pp

Manjreker, N.2000. A walk on the wild side, Information guide to National Parks and Wildlife sanctuaries of Karnataka Forest Department Wildlife wing. 78 pp.

Menon, A.G.K. 1999 Checklist – Freshwater Fishes of India, Occasional paper no 175, Zoological Survey of India; Kolkata, India

Menon, A. G. K. 2004 Threatened fishes of India and their conservation, Zoological Survey of India, Kolkata, pp. 1-170

Mittemeier, R. A., C. G. Mittemeier, T. M. Brooks, J. D. Pilgrim, W. R. Konstant, G. A. B. da Fonseca and C. Kormes 2003 Wilderness and biodiversity conservation. Proceedings of the . National . Academy of Sciences 100: 10309 – 10313.

MoWR (Ministry of Water Resources, Government of India) www.wrmin.nic.in, Website information on Ganga Basin accessed on Jan 14th 2007.

MSSRF (M.S. Swaminathan Research Foundation), 1998 Coastal wetlands: mangrove conservation and management, MSSRF 12 pp.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. de Fonesca and J. Kent 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403: 853 – 858.

Nath, D.; Shrivastava, N.P. 1999. Decline of Carp fishery in Narmada in the context of construction of Dam on the River and its Tributaries. *Journal of Inland Fisheries Society*, India. 31(2). pp 25-27.

NIH (National Institute of Hydrology) 1988 Floodplain mapping of river Ganga between Raoli and Narora using multi temporal satellite data, TR – 56 National Institute of Hydrology, Jal Vigyan Bhavan, Roorkee

Nilsson, C., Reidy C A., Dynesius M., Revenga C.,l. 2005 Fragmentation and Flow Regulation of the World’s Large River Systems, *Science* 308, 405-408

NPA (Narmada Planning Agency) 1987. Narmada basin water development plan – Development of fisheries. Narmada Planning Agency, Government of Madhya Pradesh State.

NSII (National Statistical Institute of India)1991, Population statistics, India, Population data (New Delhi, NSII.

Pascal, J.P 1996. Wild and Fragile – Analysis 28-32. *Down to Earth* Aug 15.

Paul,, A.C. and K.C Pillai, 1976. Studies of pollution aspects in Periyar river. Unpublished project report.

Paul, A.C. and K.C.Pillai, 1981. Geochemical transport of trace metals in Periyar River. Proceedings of seminar on status of Environmental studies in India. Trivandrum, Kerala,357-362

Payne, A. I., R. Sinha, H. R. Singh, S. Huq 2003 A Review of the Ganges Basin: its Fish and Fisheries, in Proceedings of the Second International Symposium on the Management of Large Rivers for fisheries, Wellcome R. and T. Petr – Eds., Food and Agriculture Organization Regional Office for Asia and the Pacific, Bangkok, Thailand, RAP Publication 2004/17, pp. 229-251

Ponniah, A.G; and Gopalakrishnan, A. (eds.) (2000) Endemic Fish Diversity of Western Ghats. National Bureau of Fish Genetic Resources- National Agricultural Technology Project, Lucknow. 347 pp

Pratapan, S. 1999. Periyar- Under Severe Strain. The Hindu Survey of Environment

Puckridge, J.T., Sheldone, F. Wlaker, K.F and Boulton A. J (1998) Flow variability and ecology of large rivers. *Marine and Freshwater Research* 49, 55-72

- Rajan, S. 1963, Ecology of the fishes of the River Pykara and Moyar (Nilgiris), South India. Proceedings of the Indian Academy of Science 58: 291 – 323.
- Rao, K.S.; S.N Chatterjee and A.K Singh,. 1991. Studies on Pre-impoundment fishery potential of Narmada Basin. (Western Region) in the context of Indira Sagar, Maheswar, Omkareshwar and Sardar Sarovar Reservoirs. *Journal Inland Fishery Society*, 23(1): 34 - 41.
- Rao, K.S.; Shrivastava, S.; Choubey, U. 1999. Utility of Macro invertebrate in biological water quality in some Central Indian Rivers. In Durgaprasad and Pichia (Ed.), *Inland Water Resources of India*. Discovery Publishing House, New Delhi. 223-246.
- Rao, R. J. 1995 Studies on Biological Restoration of Ganga River in Uttar Pradesh: An indicator species approach, School of Studies in Zoology, Jiwaji University, Gwalior
- Revenga, C., S. Murray, J. Abramovitz and P. Hammond 1998 Watersheds of the world: Ecological value and vulnerability, Washington , D. C; World Resources Institute.
- RRSL (Rapid Reconnaissance Survey of Limnological aspects of Narmada) (1987). Bhopal, Vikram University and RD University,. Jabalpur for Govt. of Madhya Pradesh.
- Scott, P. A. (ed.) 1989 A directory of Asian wetlands, IUCN, Gland, Switzerland and Cambridge, U.K. 118 pp.
- Sharma, B.K.; Naik, L.P. 1995. Species composition distribution and abundance of Rotifers in river Narmada, M.P. (Central India). In Timotius, K. H. and Goltenboth, F (Ed.), *Tropical Limnology*, Vol.III. Satya Wacana Christian University, Salatiga, Indonesia, p 77 -87.
- Singh,R.K.; Anandh, H. 1996. Water quality index of some Indian Rivers. *Indian Journal of Environmental Health*, 38(1): 21-34.
- Sivaramakrishnan, K. G.; Venkataraman, K.; Sridhar, S.; and Marimuthu, S .; 1995. Spatial patterns of benthic macroinvertebrate distribution along river Kaveri and its tributaries *Internatinal Journal of Ecology and Environmental Science* 21:141 –161.
- Smakhtin V.U.and Anputhas, M. 2006 An assessment of environmental flow requirements of Indian river basins. IWMI Research Report N 107, Colombo, Sri Lanka.
- Sreenivasan, A.1989. Status of some exotic fish introductions in Tamil Nadu *In Exotic Aquatic species in India* (ed. M. Mohan Joseph), 59 – 62, special publication, Asian Fisheries Society, Indian Branch.
- Sugunan, V. V. 1995 Reservoir fisheries in India. FAO Fisheries Technical Report, 345, Food and Agricultural Organization of United Nations, Rome, 423 pp.
- Talwar, P. K. 1991 Pisces and Faunal Resources of Ganga, Part I, 1-11, Zoological Survey of India, Kolkata; 91 pp
- Unni, K.S. 1996. Ecology of the River Narmada. A.P.H. Publishing Corporation, New Delhi, India. 371pp
- Unni, K. S. 2003 Ecology of Indian Rivers, International Book Distributors, Dehradun, India. 310 pp
- Xenopoulos, M.A., Lodge, D.M., Alcamo, J. Märker, M.,Schulze, K. and van Vuuren, D.P. (2005). Scenarios of fish extinction from climate change and water withdrawal. *Global Change Biology* 11: 1–8

Table 1 A preliminary set of basin indicators, their scoring systems and justification

INDICATOR	RANGE	SCORE	JUSTIFICATION IN THE CONTEXT OF ENVIRONMENTA FLOW ASSESSMENT
INDICATORS RELATED TO ECOLOGICAL VALUE (IMPORTANCE AND SENSITIVITY)			
Rare and endangered aquatic biota	Very High High Moderate Minor None	5 4 3 2 1	The total number of rare and endangered species can be expressed as percentage of the total number of species in a country or in region, or in basin - depending on the scale of analysis. These percentages may be related to the range and to the score. The more rare and endangered aquatic biota is present in the basin, the more sensitive the rivers generally are to flow changes (e.g. to reduction). Consequently the more effort is needed to maintain the flow in a river at least at existing levels
Unique aquatic biota	Very High High Moderate Minor None	5 4 3 2 1	The number of unique (normally endemic) species can be expressed as percentage of the total number of species in a country or in region, or in basin - depending on the scale of analysis. These percentages may be related to the range and to the score. The more unique aquatic biota is present in the basin, the more important it is to ensure that they do not get affected by flow modifications. Therefore, more flow and more flow variability needs to be preserved in a river
Diversity of aquatic habitats	Very High High Moderate Minor None	5 4 3 2 1	Can be estimated either by professional judgment or by more quantitative approach, e.g. by identifying different habitat types in representative river reaches and then calculating the representative value for a basin. Example habitats include runs (rapidly flowing water with a gradient over 4 % with no surface turbulence), pools, glides (a shallow stream reach with a maximum depth of under 5 % of the average, and without surface turbulence), pocket water (one or a series of small pools in a section of flowing water containing numerous obstructions), backwater (abandoned channel that remains connected to the active main river or secondary channel in which the inlet is blocked with deposition at low water velocities but the outlet remains connected with the active main channel), floodplains and marshes (including mangroves), etc. The more habitat types are present, the more incentive should exist to preserve them to ensure the aquatic biodiversity as well.
Presence of protected areas, areas of natural heritage and pristine areas which are crossed by the main water course in the basin	>10% 5-10% 3-5% 1-3% <1%	5 4 3 2 1	Based on the IUCN aim of 10% of the basin area to be protected. The more area is protected, pristine or “a must to be preserved”, the more flow is likely to be necessary to be left in rivers, or to be released into them for maintenance of aquatic life.
Sensitivity of aquatic ecosystems to flow reduction	Very High High Moderate Minor None	5 4 3 2 1	Can be evaluated using professional judgment and knowledge of a river. A limited decrease in flow (and associated width and depth) may in some rivers result in particular habitat types (e.g. floodplains, riffles, brackish costal wetlands, estuaries) become unsuitable for biota, compared to other rivers, e.g. smaller rivers versus larger rivers, rivers in drier areas versus those in more humid ones, etc. Highly sensitive ecosystems need more water to maintain them in the current or desired condition.
INDICATORS RELATED TO ECOLOGICAL CONDITION OF AQUATIC ECOSYSTEMS IN THE BASIN			
% of watershed remaining under natural vegetation cover types	70-100% 50-70% 30-50% 10-30% <10%	5 4 3 2 1	Can be estimated using RS images, from literature sources or based on field surveys. These are measures of the extent to which natural vegetation communities have persisted in a watershed or a floodplain. An area that retains a high proportion of natural cover types may be expected to also have many essential ecosystem services, such as flood control, still intact. Because it still contains “natural capital” in the form of natural communities, the ecological structures and functions of such a watershed or floodplain would also be expected to be more sustainable, and their resilience to and ability to cope with anthropogenic and natural stress would be greater. The higher the values of both indicators, the more biodiversity is likely still be preserved and the more the basin is insured against the functional degradation. If the natural capital is important to maintain at existing condition, the higher EMC will be necessary and more environmental flows will be required.
% floodplain remaining under natural vegetation cover types	70-100% 50-70% 30-50% 10-30% <10%	5 4 3 2 1	

Degree of flow regulation	> 100% 50 - 100% 20 - 50% 10 - 20% 0 - 10%	1 2 3 4 5	The first indicator is the total dam storage in a basin as % of the mean flow, the second - the catchment area upstream of dams as % of the total catchment area. These are important determinants of the habitat condition and aquatic biodiversity. Many riverine species move large distances through channel network as part of their life history requirements. Dams and weirs disrupt longitudinal connectivity and fragment populations leading to decline in aquatic biodiversity. Migratory species often form the basis of productive fisheries and are typically the most affected by such barriers. A high density of impoundments prevents biota from migrating to preferred habitats such as upstream spawning beds. As these ecological processes are degraded, the sustainability and coping capacity of the system is reduced. Environmental flows should be allocated to cater for longitudinal and lateral connectivity. The more the river system is fragmented, the lower is the ecological status and lower environmental management class is achievable.
% of the watershed closed to movement of aquatic biota by anthropogenic structures	70-100% 50-70% 30-50% 10-30% <10%	1 2 3 4 5	
Degree of flow fragmentation	0 0.001-0.01 0.01-0.1 0.1-1 >1	5 4 3 2 1	This indicator is an alternative to the above one. The ranges are expressed in a number of structures per km of river length. Naturally flowing river without structures With/out upstream storage reservoirs and with possibilities of movement upstream – like fish ladders - for aquatic fauna With/out upstream storage reservoirs and with possibilities of movement upstream – like fish ladders - for aquatic fauna With/out storage reservoirs with/out possibility for movement upstream for aquatic fauna only during monsoon With/out storage reservoirs with/out possibility for movement upstream for aquatic fauna only during monsoon
% aquatic biota that are exotics	≥ 0% <5% <10% <20% >20%	5 4 3 2 1	Successful invasion by exotic species often incurs losses and disruptions in ecosystem structures and functions (e.g., loss of biodiversity due to competitive exclusion and predation, disruption and modification of food webs, loss of habitat for fish and wildlife). Thus, the % of exotic species in a reach or a basin provides information on its likely sustainability and coping capacity. The higher the proportion of exotic species the lower the achievable EMC is.
Fish species relative richness, aquatic plants species relative richness, etc	Very High High Moderate Minor None	5 4 3 2 1	These are measures of biodiversity remaining in a system and therefore – of its ecological capital and ability to self-organize and sustain itself and cope with stressors. It is important to address relative richness, rather than just species counts because the baseline biodiversity of an area is conditional on habitat types, geographical locations, etc. Thus, the number of species that inhabit a watershed should be expressed as percentage of the number that would be expected to occur there in the absence of human interventions. Xenopoulos <i>et al</i> (2005) have shown that fish species numbers are reducing with reducing discharge. The reference condition is however very often difficult to establish and consequently the quantification of ranges is also difficult. As a surrogate for the percent of some ‘natural’ reference condition, the species richness may be quantified as percent of overall species in the country or geographical zone, or established by professional judgment.
Human population density in the entire river basin as % of the population density in the main floodplains	< 10% 10- 20% 20-40% 40-60% >60%	1 2 3 4 5	Can be estimated using Census data. Districts located primarily in floodplain areas can be used to estimate population density in floodplains, other districts - to estimate population density in the rest of the basin. This measure may be seen as an aggregate indicator of human pressure on aquatic ecosystems and as an indicator of disruption of lateral connectivity in river basins.
Overall water quality in the basin	Class A Class B Class C Class D Class E	5 4 3 2 1	National Indian categorization of water quality is used, where each class is characterized by certain ranges of constituents such as pH, DO, BOD, MPN and some others. Water in Class A can be used for drinking after disinfection, Class B - only for swimming and bathing. Water in Class C requires conventional treatment and disinfection before drinking., water in Class D is suitable for propagation of wildlife and fisheries. Class E water is only suitable for such uses as irrigation and industry cooling

Table 2 Indicators for the Thungabhadra sub-basin of the Krishna River basin

Indicator	Value	Score	Justification and comments	Data sources
Rare and endangered aquatic biota	High	4	An arbitrary but quantitative scoring system is used based on % of endangered fish species of the total species in the basin (> 20% endangered species – very high, 10-20%- high, 5 -10% - moderate, 2-5 % - low and < 2% - minor or none). Of the total 118 species in the sub-basin, 12 are endangered and critically endangered in the headwaters (10.1%).	Arunachalam 2004 CAMP (1997); Arunachalam et al 2002
	Moderate	3	In the middle reaches, 5 endangered species are represented (4.2%).	
	Low	2	In the lower reaches only 3 such species are represented (2.5 %).	
Unique aquatic biota	Moderate Minor	3	A similar scoring system is used as for endangered species - based on % of unique fish of the total fish species in the basin (> 20% endangered species – very high, 10-20%- high, 5 -10% - moderate, 2-5 % - low and < 2% - minor or none). Out of 118 fish species, 9 endemics (7.6%) are present in the headwaters	Arunachalam 2004 CAMP (1997). Arunachalam <i>et al.</i> , 2005
		1	In the middle and lower reaches, 2 endemic species (1.7%) are present Headwater reaches support more unique fauna because the Western Ghats' streams are mostly bedrock valleys and streams are strongly confined. Out of 11 endemic species 5 species (<i>Barilius canarensis</i> , <i>Glyptothorax trewavasae</i> , <i>Botia straita</i> , <i>Longischistura bhimachari</i> and <i>Hypselobarbus dobsoni</i>) have narrow distribution	
Diversity of aquatic habitats	High	4	In the upstream reaches of Thunga and Bhadra, falls, cascades, pools, riffles, glides, runs and pocketwater are all present.	Arunachalam 2004; Jayaram 1995. Scott, 1989 Arunachalam <i>et al.</i> , 2005
	Moderate	3	In the middle reaches, reservoir habitat types are wetlands and deep-water, while downstream of reservoirs and the reaches in between- runs, deep pools and backwater habitats are present.	
	Minor	2	In the lower reaches, the only habitat types are runs with fine sand and occasional large pools.	
Presence of protected and pristine areas	1–3%	2	The sub-basin has 1.62 % as protected area with two wildlife sanctuaries (Bhadra and Ghataprabha) and Khudremukh National Park. More forests can be protected as buffer zones of Khudremukh National Park and sanctuaries.	Arunachalam 2004 Manjrekar 2000 Jayaram 1995
Percentage of watershed remaining under natural vegetation	70 –100%	5	In the headwaters almost all the streams are under natural cover type (90%).	Arunachalam 2004 Jayaram 1995. www.annauniv.edu.krishna (for middle and lower reaches)
	50 – 70%	3	In the reservoirs and the reaches 10 – 15 km downstream of them, the percentage of natural cover is under 65 %, but in most of the middle reach the percentage is under 50 %.	
	10 – 30%	2	In the lower reach in the Karnataka part up to the confluence of Thungabhadra with Krishna river: 28 – 30 %.	
Percentage of floodplain remaining under natural vegetation	30 -50 %	3	Floodplains are present in the middle and lower reaches only. Middle reaches before the Thungabhadra reservoir	
	10 – 30 %	2	From the Thungabhadra reservoir towards the AP boundary	
Percentage of aquatic biota that are exotics	0%	5	In the headwater reach there are no exotic fish species	Arunachalam 2004 Sugunan, 1995
	< 5 %	4	In the middle reaches, particularly - in the reservoir sector - introduced species of <i>Cirrhinus mrigala</i> , <i>Labeo rohita</i> are present. But the proportion in rivers upstream and downstream of the reservoir is still small since species' introduction 40 years ago	
Fish species relative richness	50 – 70 %	4	Upstream reach is represented by 68 species (57.6 %) of the total 118 recorded in sub-basin.	Arunachalam 2004 Jayaram 1995; Ponniah and Gopalakrishnan 2000
	70– 100%	5	Middle reach is represented by 78 species (66.1 %)	
	30 -50 %	3	Lower reaches are represented by 31 species (26.3 %). A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary	

			from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 20.4% of this total species.	
Human population density in the basin as % of that in the main floodplains	< 10 %	1	Score is based on mean values from middle and lower reaches, which have an indicator value 7%. Floodplains have been delineated using GIS.	District Planning Maps 2001, Karnataka. Census data (NSII 1991).
Overall water quality in the basin	A	5	Headwaters are under relatively natural conditions with high levels of dissolved oxygen, low levels of TDS, very low alkalinity and no enrichment of nitrates and phosphates.	Arunachalam 2004 Jayaram 1995; CPCB 1992.
	C	3	In the middle and lower reaches,, non-point and point sources of pollution and nutrient enrichment from paddy fields contribute to the pollution.	

Table 3 Indicators for the Krishna River sub-basin (excluding Tungabhadra sub-basin)

Indicator	Value	Score	Justification and comments	Data sources
Rare and endangered aquatic biota	Low	2	An arbitrary but quantitative scoring system is used based on % of endangered fish species of the total species in the basin (> 20% endangered species – very high, 10-20%- high, 5 -10% - moderate, 2-5 % - low and < 2% - minor or none). In the headwater reaches, based on surveys of 15 streams, 5 endangered species (3.6%) are identified (out of the total 140 species in the sub-basin)	Arunachalam 1999 Arunachalam et al .2002 Arunachalam 2004 Jayaram 1995 CAMP (1997).
	Moderate	3	In the middle reaches downstream of the reservoirs in Maharashtra and Karnataka 11 endangered species present (7.9%).	
	Moderate	3	In the lower reach below the Thungabhadra river confluence with Krishna river 10 endangered species (7.1%) are present	
Unique aquatic biota	High	4	A similar scoring system is used as for endangered species - based on % of unique fish of the total fish species in the basin (> 20% endangered species – very high, 10-20%- high, 5 -10% - moderate, 2-5 % - low and < 2% - minor or none). In the headwaters, 11 unique species out of the total 140 (7.9%) are present	Arunachalam 1999 Arunachalam et al .2002 Arunachalam 2004 Jayaram 1995 CAMP (1997).
	Low	2	Middle and most of the lower reaches are represented by 4 species (2,8 %)	
Diversity of aquatic habitats	Very high	5	In the headwaters a number of streams surveyed exhibit pools, riffles, glides, runs, alcoves/pocketwater, etc	Arunachalam 2004 Jayaram 1995 www.annauniv.edu/ceg/iom/omour/Andra
	High	4	Below the confluence with Thungabhadra, several streams were surveyed which have deep pools, falls cascades, riffles, rapids and glides	
	Low	2	In the lower reaches habitats are mostly riparian wetlands and wet hollows in delta.	
Presence of protected and pristine areas	<1 %	1	In the headwaters, 0.97% of the area is protected with 5 Wildlife sanctuaries (Koyna, Bhimsankar, Phansad, Radhnagiri and Chaprala)	Department of Environment 2004 Manjreker 2000 Revenga et al. 1998
	3-5 %	3	Nagarjunasagar reserve is 4.7 % of the area of the middle reaches	
	<1 %	1	Mangrove ecosystem in the delta which needs to be protected has an area of 200 km ² . It could be considered for maintenance by means of environmental flow releases	
Percentage of watershed remaining under natural vegetation	50 – 70%	4	Many headwater streams surveyed have the range of 55 – 68 % of natural cover types	Arunachalam 2004 Jayaram 1995 NSII 1991
	30 -50%	3	Middle reaches - below Dhom dam and Wai town have the range of 38 – 47 %.	
	10 – 30%	2	Two streams surveyed in lower reaches had a range of 18 –28 % of natural cover types.	

Percentage of floodplain remaining under natural vegetation	30 -50 %	3	Floodplains are rare in the headwaters of Krishna and Bhima In middle reaches in Maharashtra, most of the floodplains are flood hollows with natural cover types. In middle reaches in Karnataka below the impoundments, extensive cultivation of Bengal gram in the floodplain areas. Below the confluence of Thungabhadra and Krishna and up to the Nagarjunasagar reservoir. Overall, approximately 55% of the existing floodplains are under natural cover - mainly due to natural cover in protected areas and mangrove forests in the delta	Arunachalam 2004 www.annauniv.edu
	10 – 30 %	2		
Percentage of aquatic biota that are exotics	≥ 0%	5	In the headwaters there are no exotic fish species. In the middle reaches, including the reservoirs, the proportion of introduced species of <i>Catla catla</i> , <i>Cirrhinus mrigala</i> , <i>Labeo rohita</i> is small. The native fish dominate commercial fish catch. In the lower reach introduced species of Gangetic carps form 30% of the commercial catch. <i>Pangasius pangasius</i> a native pangasid catfish constitute the major catch. In the delta, native marine and estuarine species are the major faunal component.	Sugunan, 1995 Jayaram 1995
	< 5 %	4		
	< 10%	3		
Fish species relative richness	30 -50 %	3	The headwaters have some 41 % of the total species in the basin The middle reaches support 71.4 % of the total The lower reach has around -41% of the total species in the basin. In the delta no primary freshwater species are present, but 40 estuarine and coastal marine species are recorded A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 24.2% of total species.	Arunachalam et al. 2002 Arunachalam 1999 Arunachalam 2004; Ponniah and Gopalakrishnan 2000; NATP 2004
	70– 100%	5		
	30- 50%	3		
Human population density in the basin as % of that in the main floodplains	20 - 40 %	3	In the headwaters floodplains are rare In the middle reach this proportion is 25.9 %. In the lower reach this proportion is 43.6%.	NSII 1991, Government of Andhra Pradesh Department of Environment (2004).
	40 – 60 %	4		
Overall water quality in the basin.	A	5	In all the headwater streams, the water quality is close to natural conditions Upstream of impoundments at Yadgiri town (Bhima river), Haripur ghat (Krishna) and below the reservoirs, Krishna river at Wai are polluted by sewage. In the middle reaches point sources from industries and sewage from towns exist. In the lower reaches textile, sugar and manganese mixing industries are sources of pollution	Department of Environment, 2004 Andhra Pradesh CPCB, 1992 Jayaram 1995
	C	3		
	E	1		

Table 4 Indicators for the Cauvery River basin

Indicator	Value	Score	Justification and comments	Data sources
Rare and endangered aquatic biota	High	4	A similar scoring system as in Tables 2 and 3 above has been used.. Streams in headwaters have 16 endangered fish species (12%) out of total 135 species in the basin The reservoirs Hemavathy, Kabini, Krishnarajasagar, Markonahalli and Harangi, and streams below them in the middle reaches, support 8 endangered species (6%). In the lower reaches, only 3 endangered species are found (2%). Common tolerant species such as <i>Pseudophromanus cupanus</i> , <i>Puntius filamentosus</i> , etc., occur in lower reaches. Near delta, no rare and endangered freshwater fish species present	CAMP 1997. Arunachalam 1999, 2004
	Moderate	3		
	Low	2		
Unique aquatic biota	High	4	A similar scoring system as in Tables 2 and 3 above has been used.. Headwater reaches host all 22 species that are endemic native fish (16% of total basin species) Middle reaches have 6 endemic species (4.5%) Lower and coastal areas have no unique fauna.	CAMP 1997. Arunachalam 1999, 2004
	Low	2		
	None	1		
Diversity of aquatic habitats	Very high	5	In headwaters, habitats are diverse with falls, cascades, pools, riffles, glides, runs and pocketwater Bedrock and boulders and the leaf litter with woody debris contribute to fish habitat heterogeneity in headwaters (Western Ghats) In the reservoirs, the habitat types are wetlands (limnetic zones) and deep-water (euphotic zone). In the middle reaches of the river, run, deep pools and backwaters are prevalent. In lower reaches, most habitats are riparian wetlands and floodplains with runs, Mangrove swamps and lagoons contribute to habitat heterogeneity	Arunachalam 1999, 2000, 2004 Arunachalam et al 2005
	Moderate	3		
	Moderate	3		
Presence of protected and pristine areas	5-10%	4	Compared to the overall watershed area, the headwaters have some 7.8% of the area protected with 7 wildlife sanctuaries (Biligiri Rangasamy, Brahmagiri, Cauvery, Nugu, Thalacauvery, Mudumalai and Wynaad) and 4 National Parks (Bandipur, Rajiv Gandhi (Nagerhole), Mukurti and Silent Valley). Caveripoompattinam - the ancient capital of the Chola Kingdom in the estuary. Pichavaram mangroves and the lagoon in the Vedaranyam Wildlife Sanctuary are the major protected spots or heritage sites. Vedaranyam Swamps and the Muthupet Lagoon can be declared RAMSAR sites.	Manjrekar, 2000 Dave, 1957
	<1%	1		
Percentage of watershed remaining under natural vegetation	70– 100%	5	In the headwater reaches almost all streams surveyed are under natural cover in the range of 74 – 85 %. Only tea and coffee plantations reduce this proportion. In some streams surveyed in the middle reaches, this percentage is up to 53 %, but the lowest part of the middle reaches - 20 km from the reservoir towards coastal area is under 50% Estuarine area has a low natural cover proportion, only mangrove forest Pitchavaram and distributaries raise it up.	Arunachalam 2004 Jayaram 2000
	30 -50%	3		
	< 10 %	1		
Percentage of floodplain remaining under natural vegetation	30 -50 %	3	Floodplains are present only in middle and lower reaches From Mayanoor to upper anicut, the floodplains are less than 50% under natural vegetation.. This stretch forms about 30 – 40% of the overall floodplains in the basin. Below the Grand Anicut floodplains are impacted by rice and banana cultivation. In the delta region floodplains are mostly converted into shrimp farm	Arunachalam 2004 Jayaram 2000
	< 10 %	1		
Degree of flow regulation	10-20%	4	Taken from the cited source as is (19%). More detailed estimation was not possible due to uncertainties or absence of flow estimates at required points in the basin	Nilsson et al (2005)
Percentage of aquatic biota that are exotics	> 0%	5	In the headwaters there are no exotic fish species In the middle and lower reaches, all channels below impoundments and the entire river from Bhavani Town, proportion of exotic fishes are low (< 5 %)	Arunachalam 2004; Das, 1989 Sreenivasan, 1989
	< 5 %	4		

			(Almost all reservoirs are dominated by introduced exotics and gangetic carps. Of 58 species recorded in reservoirs, the introduced species form some 41 %. In the biomass of commercial catch the introduced species constitute 80 – 90 % and the native species - less than 5 %.)	
Fish species relative richness	50 – 70 % 50 – 70 % 10 – 30 %	4 4 2	Headwaters host 68 species (50 % of the total in a basin) The middle reaches host 72 species (53 % of the total) Approximately 18% in the lower reaches (but in the delta - less than 5 %) A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 23.62% of total species.	Arunachalam 1999, 2004; Jayaram 2000; CAMP 1997; Ponniah and Gopalakrishnan 2000;
Human population density in the basin as % of that in the main floodplains	40 – 60 %	4	Estimated for middle and lower reaches only In the lower reaches, the ratio is 42.4% and in middle - 51%.	NSII, 1991
Overall water quality in the basin	A C D	5 3 2	Most of the headwater streams surveyed have high levels of dissolved oxygen, low levels of total dissolved solids, very low alkalinity and hardness and no enrichment of nitrates and phosphates. In the middle reaches, non- point and point sources of pollution increase. High pollution from industries in the stretch of delta except the Pichavaram mangroves and the Muthupet lagoon regions	Arunachalam, 2004 Jayaram 2000 CPCB, 1992

Table 5 Indicators for the Narmada River basin

Indicator	Value	Score	Justification and comments	Data source
Rare and endangered aquatic biota	None	1	The CIFRI, 1994 studies suggested that there are no endangered or threatened fishes. Some unpublished sources suggest that up to 10 species may be considered endangered.	Karamchandani <i>et al.</i> , (1967).Dubey (1984). Rao <i>et al.</i> (1991)
Unique aquatic biota	None	1	There are no reports on unique aquatic fish biota in the Narmada basin, though studies have been conducted over 50 years' period on distribution of fish species.	Chatterji <i>et al.</i> (1993). Nath & Shrivastava (1999). Dubey (1993).
Diversity of aquatic habitats	High	4	Narmada has diverse of habitats, including pools, gorges, waterfalls and deep waters similar to other major river systems in India.	Rao et al, 1991, 1999 Unni (1996)
Presence of protected or pristine areas	>10%	5	Narmada basin includes many sanctuaries and 38 % of all forests are forest reserves.	Alwares & Billorey, 1981.
Sensitivity of aquatic ecosystem to flow reduction	Moderate	3	The construction of Tawa dam resulted in reduction of water depths and loss of carp breeding grounds, spawning and feeding in the central 240 km stretch of Narmada basin. Carp dominates Narmada fish and flow reduction is the reason for reduced carp fisheries.	Nath & Shrivastava (1999).
Percentage of watershed remaining under natural vegetation	10-30%	2	The National Remote Sensing Agency reported that 21% of the Narmada basin has natural forest cover types. Others quote 38%. The likely average is around 30%.	Forest Dept, Govt. of M.P. Reconnaissance survey. Alwares & Billorey, 1981.
The degree of flow regulation.	0-10%	5	Calculated as the ratio of total storage to long-term mean annual flow at the outlet. The actual live storage capacity at 2006 is 2.07 BCM. Annual mean outflow is 45.6 BCM, the ratio is around 4.5%	CWC (2006)
Percentage of watershed closed to movement of aquatic biota by structures	10-30%	4	At present, this indicator is low and the score is thus high, but if the reservoir construction goes as planned, the entire river basin will be fragmented and the percent of watershed closed could grow up to 100%	Alvares & Billorey, 1981
Percentage of aquatic biota that are exotic	None	5	No exotic fish species have been reported	Rao <i>et al.</i> (1991). Dubey (1993)
Species' relative richness, including fish, aquatic plants, phytoplankton and zooplankton	Moderate	3	Narmada has 76-84 fish species according to existing estimates, which is relatively low compared to the total number of species in India (< 14%). It supports 19 species of aquatic vegetation, relatively low compared to other rivers. The total number of Phytoplankton species is 174 in the upstream and declines towards the middle stretches. Greater water current reduced the phytoplankton numbers to 34 species downstream. Zooplankton: maximum number of 72 rotifer species is reported only from Narmada and nowhere else in India. Four new species of zooplankton have recently been identified. The likely overall score of aquatic species richness in the basin is moderate	Nath & Shrivastava (1999); Dubey (1984) Unni (1996); Sharma & Naik (1995); Dubey (1993)
Overall water quality in the basin	Class B	4	Class A is from the source to Mandla (200 km), Class C from Mandla to Jabalpur stretch (100 km), B – the stretch up to the confluence with Kunti river (540 km), class C from confluence with Kunti river up to Bharuch, D –downstream of Bharuch (8 km). Overall water quality is B (40% under Class C, 40% under Class B, and about 20% under Class A)	CPCB water quality atlas (1994)

Table 6 Indicators for the Periyar Basin

Indicator	Value	Score	Justification and comments	Data Sources
Rare and endangered aquatic biota	Very high	5	Periyar basin, has 5 critically endangered fishes and 14 threatened species. 14 species have become extinct. Some fish species disappeared over the past few years, including some cyprinids, Goby, cat fishes and eels.	Arun (1998); Kurup et al (2001)
Unique aquatic biota	Very high	5	56 % of the endemic fishes of Kerala are reported from Periyar (32 species) which makes it a unique ichthyfaunal basin of southern India.	Kurup et al (2001); Arun (1998)
Diversity of aquatic habitats	Very high	5	Many threatened fish species inhabit pools, streams, runs, cascades – a diverse aquatic habitat types' system.	Arunachalam (2000)
Presence of protected and pristine areas	Very high	5	The river flows through the famous Periyar Wild life Sanctuary. Latest satellite imagery shows that around 30% of the basin is covered by dense pristine forests	MoEF GoI, The Hindu survey of Environment 2001 Forest report (1999), KSPCB (1981)
Sensitivity of aquatic ecosystem to flow reduction	High	4	Multiple dams reduced flow which leads to decline in fish diversity, extinction of fish, prawns and shrimps – particularly in lower reaches. Large-scale fish mortality between Edamalayar and Eloor industrial sites are reported as well as algal bloom of <i>Oscillatoria sp.</i> . Given the number of impacts and that Periyar is a relatively small river, the sensitivity to further flow reduction is high	Kerala state water authority, Joseph (2004)
Percentage of the watershed under natural vegetation	30-50%	3	National Remote Sensing data shows 30% of the watershed is covered by dense natural forests	Joseph, 2004
Degree of flow regulation	20-50%	3	Calculated as the ratio of total storage capacity (3.27 BCM) to long-term mean annual flow volume at the outlet (12.3 BCM), which equals 25%	KSEB (2005)
Percentage of the basin closed to movement of aquatic biota by structures	70-100%	1	The construction of 15 dams and wiers have almost closed the river system to movement of the biota through the basin	
Percentage of aquatic biota that are exotic	<10%	3	Some species have been introduced in reservoirs (carp), which can be found in streams as well at present.	Sugunan 1995.
Fish species relative richness	Very High	5	The basin is very rich in fish species having 208 species out of the total of 287 species in the Western Ghats (70%) or out of estimated total 577 in India (36%).	Joseph, 2004
Overall water quality in the basin	Class B	4	Water quality of the upstream and middle reaches is, as a rule, in class B. The water quality was rated as class C in the most downstream parts	Singh and Anandh (1996) Joy and Balakrishnan (1990)

Table 7 .Indicators for the Rishikesh – Narora reach of the Ganga River Basin

Indicator	Value	Score	Justification and comments	Data Sources
Rare and endangered biota	High	4	There are at least 4 (and according to other estimates- up to 10) endangered freshwater fish in the reach. In addition in the study reach there are: endangered Gangetic Dolphin, 6 endangered turtle species,, 2 species of endangered crocodile, 2species of threatened otter, several endangered bird species	Menon (1999) Dudgeon (2000) Rao (1995) Behera (1995)
Unique Aquatic Biota	High	4	Gangetic Dolphin is unique and 60 fish species of the study stretch are endemic	Behera (1995) Menon (1999)
Diversity of aquatic habitats	Moderate	3	Presence of upstream reservoirs, muddy, sandy banks and fast flowing reaches as well as formation of islands during low flows offer relatively diverse habitats for wildlife.	Rao (1995)
Presence of protected and pristine areas	>10% of the reach	5	The Brijghat – Narora stretch is a Ramsar site and Hastinapur Wildlife Sanctuary is located close to Madhya Ganga barrage.	WWF (2005)
Sensitivity of aquatic ecosystems to flow reduction	Moderate	3	With diversions from the Ganga ongoing for over 100 years, the ecosystem would have 're-adjusted' to the reduced flows. Rapid increases of summer flows (associated with glaciers melting in Himalaya) have been recorded leading to submergence of small islands used by turtles. Overall, given the river size, the sensitivity is still moderate	
Percentage of watershed under natural vegetation	10-30%	2	The historical destruction of forests is estimated to be over 80%. The trend seems to be reversing due to focus on plantation in Uttar Pradesh. It may however be misleading since the plantations may create mono-cultures	Revenga et al (1998)
Percentage of floodplains remaining	<10%	1	The current width of the flood plain is of the order of 2-3 km compared to anecdotal evidence of several tens of km width of flooding in the past	R. Sinha pers. comm.
Degree of flow regulation	10- 20%	4	While there has been little storage in the basin before, the recent construction and commissioning of Tehri Dam has started filling up a large 3.54 BCB reservoir. Four barrages in the study stretch also contribute to flow regulation, which remains relatively low- with correspondingly high score	Behera (1995)
Number of dams or other significant barriers per km of river channel	~0.01333	3	This is an indicator of fragmentation. Some newer structures have fish ladders that could 'reduce' fragmentation but their effectiveness is unknown. Four barrages exist over a stretch of approximately 300 km. However, since the river is not heavily regulated, and in monsoon upstream movement by aquatic biota is possible, a lower score is given	
% of aquatic biota that are exotic	> 20%	1	Of the about 80 fish species recorded in the study area, 60 are considered native and the rest are alien	Behera (1995) Mennon (1999)
Aquatic species richness	Very high	5	Ganga has the highest fish species richness compared on any other river in India – 350-375 species (according to various estimates) out of estimated 577 total species (66%). This is partially determined by its mere size crossing many physiographic zones. The study stretch has some 82 fish species which is some 22% of the basin's total number of fish species and much lower in the national context (14%)	Kottelat and Whitten (1996) Talwar (1991) Behera (1995)
Human population density as % of that in the main floodplains	>60%	5	There is little difference between population density in 'floodplain' subdistricts compared to those further away from the river (532 persons/km ² versus 577)	Census of India (2001)
Overall water quality in the basin	Class D	2	The water cannot be used for drinking or bathing, but still suitable for propagation of wildlife and fisheries. Regular monitoring reveals substantial contamination by human waste as well mixing of discharges from industrial effluent, mainly from sugar mills.	CPCB (www.cpcb.nic.in) Behera (1995)

Table 8 Approximation of Environmental Management Classes (EMC) by total indicator scores

A sum of actual indicator scores as percentage of the maximum possible sum	EMC	Most likely ecological condition	Management perspective
91-100	A	Natural rivers with minor modification of in-stream and riparian habitat.	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions etc.) allowed.
75-90	B	Slightly modified and/or ecologically important rivers with largely intact biodiversity and habitats despite water resources development and/or basin modifications.	Water supply schemes or irrigation development present and / or allowed.
50-74	C	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present.	Multiple disturbances associated with the need for socio-economic development, e.g. dams, diversions, habitat modification and reduced water quality
30-49	D	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation
15-29	E	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem.	High human population density and extensive water resources exploitation. Generally this status should not be acceptable as a management goal. Management interventions are necessary to restore flow pattern and to “move” a river to a higher management category.
0-14	F	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern, river habitats etc (if still possible / feasible). – to “move” a river to a higher management category.

Table 9 Definition of probable Environmental Management Categories (EMC) for selected study basins based on their indicator scores

BASIN/REACH	ECOLOGICAL INDICATORS*													SUM OF INDICATOR SCORES	MAXIMUM POSSIBLE SUM OF SCORES	PERCENT OF THE MAXIMUM	PROBABLE EMC
	Rare and endangered aquatic biota	Unique aquatic biota	Diversity of aquatic habitats	Presence of protected or pristine areas	Sensitivity of aquatic ecosystem to flow reduction	Percentage of watershed remaining under natural vegetation	Percentage of floodplains remaining under natural vegetation (or % of floodplains remaining)	The degree of flow regulation.	Percentage of watershed closed to movement of aquatic biota by structures or degree of flow fragmentation	Percentage of aquatic biota that are exotic	Aquatic species' relative richness,	Human population density as % of that in the main floodplains	Overall water quality				
Thungabhadra –Headwaters	4	3	4	2		5				5	4		5	32	40	80	B
Thungabhadra- Middle	3	1	3	2		3	3			4	5	1	3	28	50	56	C
Thungabhadra- Lower	3	1	3	2		2	2			4	3	1	3	24	50	48	D
Krishna-Headwaters	2	4	5	1		4				5	3		5	24	40	60	C
Krishna –Middle	3	2	4	3		3	3			4	5	3	3	33	50	66	C
Krishna – Lower	3	2	2	1		2	2			3	3	4	1	25	50	50	C
Cauvery-Headwaters	4	4	5	4		5				5	4		5	36	40	90	B
Cauvery-Middle	3	2	3			3	3			4	4	4	3	28	45	62	C
Cauvery – Lower	2	1	3	1		1	1	4		4	2	4	2	25	55	45	D
Narmada	1	1	4	5	3	2		5	4	5	3		4	37	55	67	C
Periyar	5	5	5	5	4	3		3	1	3	5		4	43	55	78	B
Ganga (Rishikesh-Narora reach)	4	4	3	5	3	2	1	4	3	1	5	5	2	42	65	65	C

* Some indicator have not been calculated in individual river basins either because they were not applicable (e.g. there are no floodplains in most headwater areas and in Narmada basin) or due to data limitations

FIGURES

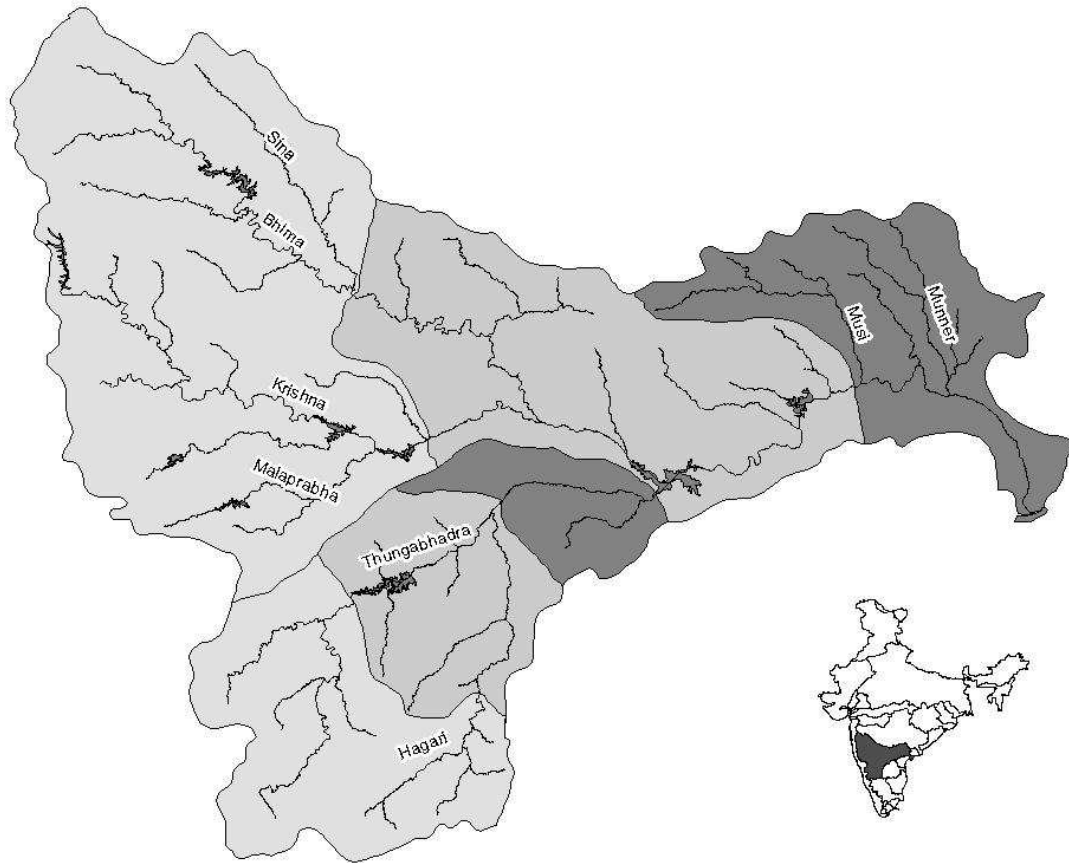


Figure 1 A schematic map of the Krishna River Basin, showing the boundaries of the two main sub-basins (Thungabhadra and the remainder of Krishna), separated into headwater, middle and lower areas for this study

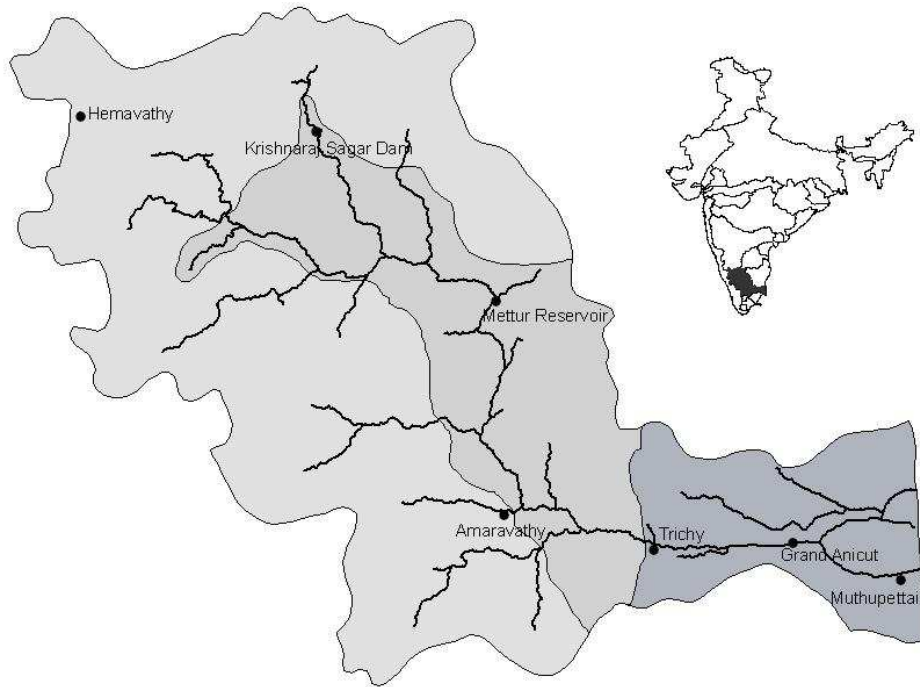


Figure 2 A schematic map of the Cauvery River Basin, showing the boundaries headwater, middle and lower areas



Figure 3 A schematic map of the Narmada River basin

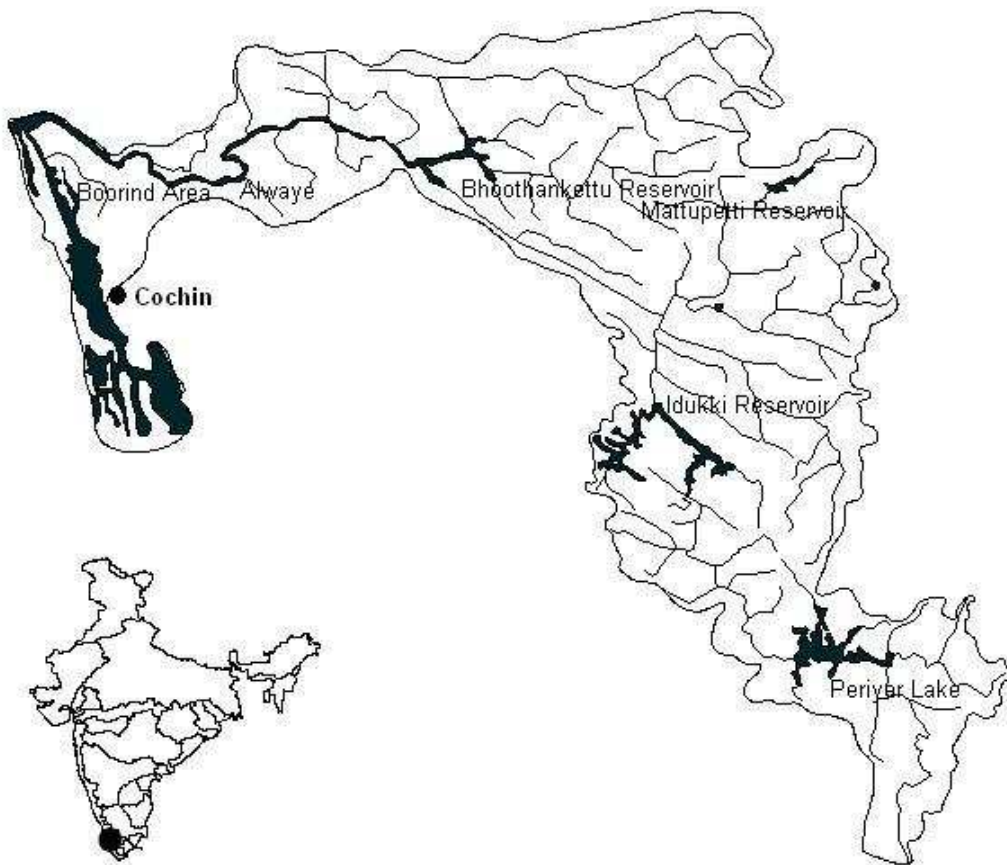


Figure 4 A schematic map of the Periyar River basin

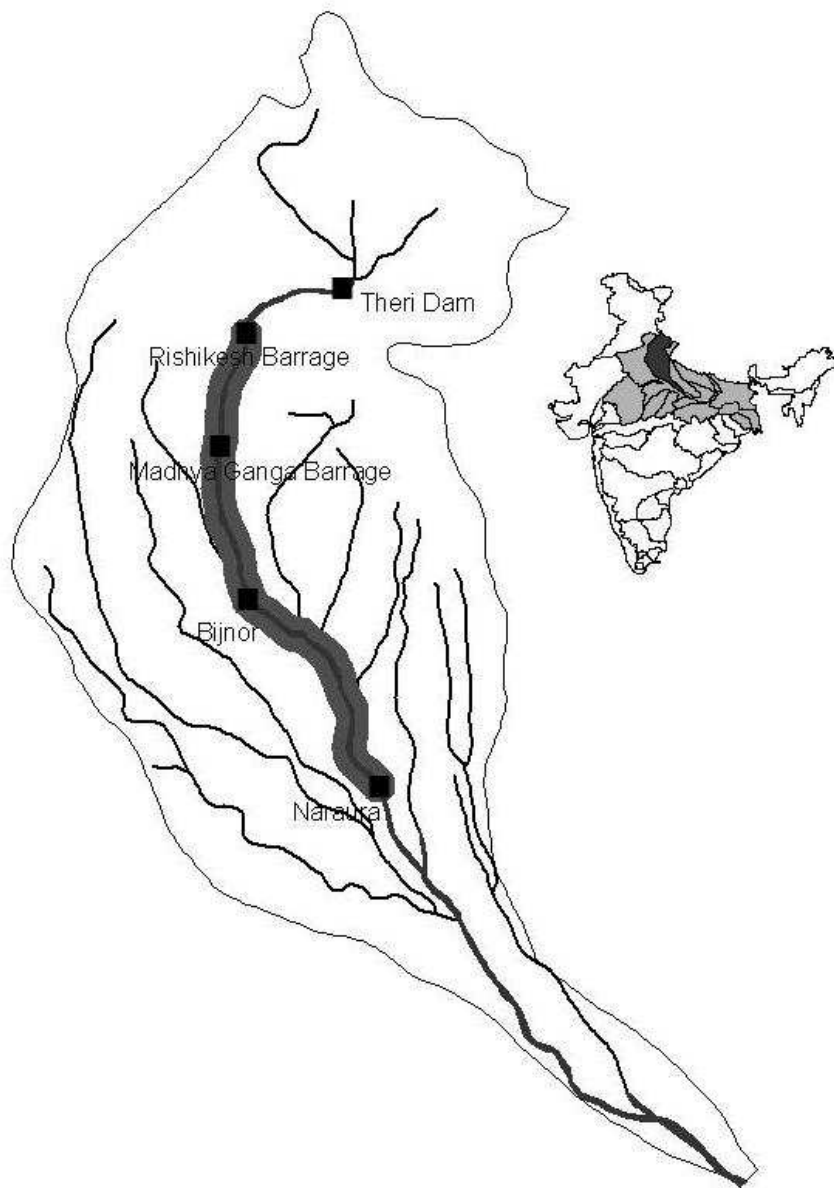


Figure 5 A schematic map of the Ganga River basin, showing the location and extent of the sub-basin upstream of Narora as well as the enlarged map of the Ganga reach between Rishikesh and Narora.