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REVIEWS

River inter linking in India: status, issues, prospects and implications on aquatic ecosystems and freshwater fish diversity

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Abstract India is a vast country in terms of natural resources and considered one of the mega- biodiversity countries in the world. The freshwater aquatic resources of the different river basins are unevenly distributed in space and time and the country is suffering from the increasing population and shortage of all kind of natural resources like water. To fulfill the water demand and mitigate flood and drought, Indian Government has been planning a huge scheme encompassing the Himalayas and most of India, by linking all major rivers through interlinking canals systems and building several dams. Though the concept of interlinking of rivers is novel and new in India, it had rather initiated long back in other countries of ancient civilization. This is considered as one of the options to remedy spatial mismatch in water availability and demand. To overcome those, National Water Development Agency (NWDA) has taken up massive project and nearly 30 links have been proposed to interlink the major rivers. The Government of India has approved the country's first river interlinking project on Ken–Betwa and a MOU has been signed among the states of Uttar Pradesh and Madhya Pradesh and the Union Government. The feasibility report of most of the links have been completed and detailed project reports of Ken–Betwa River link is expected to be finalized soon. Our study indicated presence of rich fish diversity and threatened fishes in river Betwa and improved aquatic environment in river Ken which makes it a high priority area in view of proposed interlinking. The current state of knowledge indicates that large dams, interbasin transfers and water withdrawal from rivers have many negative as well as positive impacts on freshwater aquatic ecosystem. As regards to the impact on fish and aquatic biodiversity, there could be positive as well as negative impacts. The present paper is aimed at explaining and synthesizing the long term plan and its implications, creating baseline database, requirement of appropriate technology, manpower and related issues especially with reference to riverine aquatic ecosystem and conservation of fish biodiversity.

Keywords River linking · River basins · Implication · Aquatic biodiversity · Fish · Conservation · India

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Introduction

In the global picture, India is identified as a country where water scarcity is expected to grow considerably in the coming decades (Bandyopadhyay et al.

2003). Further, drought conditions resulting from the climatic variability cause considerable human suffering in many parts of the country, as scarcity of water for both satisfaction of basic needs and crop protection. In view of the large variations in rainfall over space and time the country receives about 4,000 km^3 of water as precipitation annually, but due to different precipitation patterns and mismanagement, it often leads to wastage (Ali 2004). Large variation in the water availability in different river basins of India is presented in Fig. 1. Some parts of the country receives more rain leading to heavy floods, particularly in the Brahmaputra and Ganga rivers affecting some areas, like Assam, Bihar, West Bengal and Uttar Pradesh while large areas in Rajasthan, Gujarat, Andhra Pradesh, Karnataka and Tamil Nadu face recurring droughts. The rapid growth in the demand of freshwater has driven by growth in the population and of the economies, has lead to this natural resource becoming scarce in many parts of the India. As a result, the ratio between the number of people and the available water resource is worsening day by day. To fulfill the water demand and mitigate flood and draught the National Water Development Agency (NWDA) has proposed 30 river links throughout the country. While these proposed projects can potentially solve water supply issues in regions of water

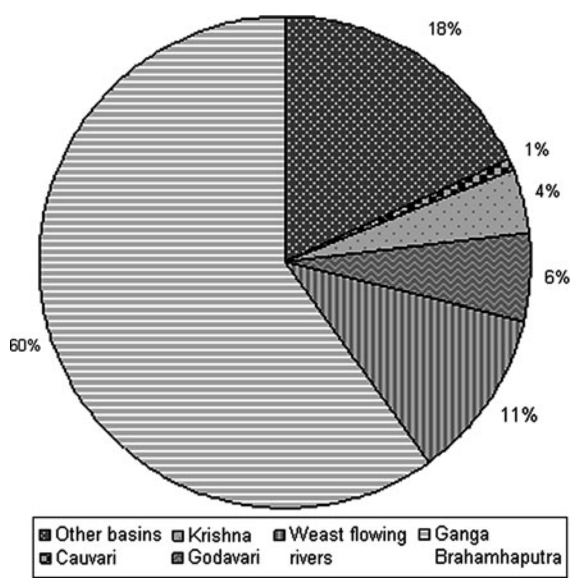


Fig. 1 Variation in the availability of water in Indian rivers (after Patel 2004)

shortage, may be come with significant costs in future. Large scale inter basin transfers are typically very high cost, and thus economically risky, and they usually also come with significant social and environmental costs, usually for both the river basin providing and the river basin receiving the water. In USA, the longest and best known schemes carried out so far is the California state water project, which envisages transfer of water from the Sacramento river in North California to Southwards through a 715 km long aqueduct with a lift of about 1,000 m to meet domestic, industrial, and irrigation demands (NWDA 1982). Similarly, in China, there are schemes existing from ancient time and recently, supplemented by modern construction techniques. Now, China is also planning for a transfer of 45 billion cubic metres (BCM) of water from the Yangtze river to the North China planes. In comparison, India is transferring 10 BCM through the existing schemes and has plans to add about 200 BCM. The number of large dams (more than 15 m high) has increased nearly seven fold since 1950, from about 5,750 to more than 41,000 (ICOLD 1998; Vőrősmarty et al. 1997), impounding 14% of world's annual runoff (L'vovich and White 1990). Cox (1999) suggested the following five criteria to justify or reject Inter Basin Water Transfer Projects (IBWT):

1. The area of delivery must face a substantial deficit in meeting present or projected future water demands after due consideration has given to alternative water-supply sources and reasonable measures for reducing water demands have been attempted.
2. The future development of the area of origin must not be substantially constrained by water scarcity; however consideration to transfer that constrains future development of an area of origin may be appropriate if the area of delivery compensates the area of origin for productivity losses.
3. A comprehensive environmental impact assessment must show that there is a reasonable degree of certainty that it will not substantially degrade environmental quality within the area of origin or area of delivery. However, water transfer may be justified where compensation to offset environmental injury is provided.
4. A comprehensive assessment of socio-culture impacts must indicate reasonable degree

certainties that water transfer will not cause substantial socio-cultural disruption in the area of origin or area of water delivery. However, transfer of water may be justified where compensation to offset potential socio-cultural losses is provided. The net benefits from transfer must be shared equitably between the transfer origin and the area of water delivery.

A background of the interlinking proposal in India

- 1972—Ganga Cauvery link proposed by Union Minister Dr. K.L. Rao.
- 1974—Garland Canal proposal by Captain Dinshaw J Dastur, a pilot. Both plans rejected due to technical infeasibility and huge costs.
- 1980—Ministry of Water Resources frames the National Perspective Plan (NPP) envisaging inter-basin transfer.
- 1982—The National Water Development Agency (NWDA) set up to carry out pre-feasibility studies. These form the basis of the ILR plan.
- 1999—A national commission (NCIWRDP) set up to review NWDA reports concluded that it saw 'no imperative necessity for massive water transfers in the peninsular component' and that the Himalayan Component would require more detailed study.
- August 15, 2002—President Abdul Kalam mentions the need for riverlinking in his Independence-day speech; based on which senior advocate Ranjit Kumar filed a PIL in Supreme Court.
- October 2002—Supreme Court recommends that the government formulate a plan to link the major Indian rivers by the year 2012.
- December 2002—Govt. appointed a Task Force (TF) on Interlinking of rivers (ILR) led by Mr. Suresh Prabhu. The deadline was revised to 2016.

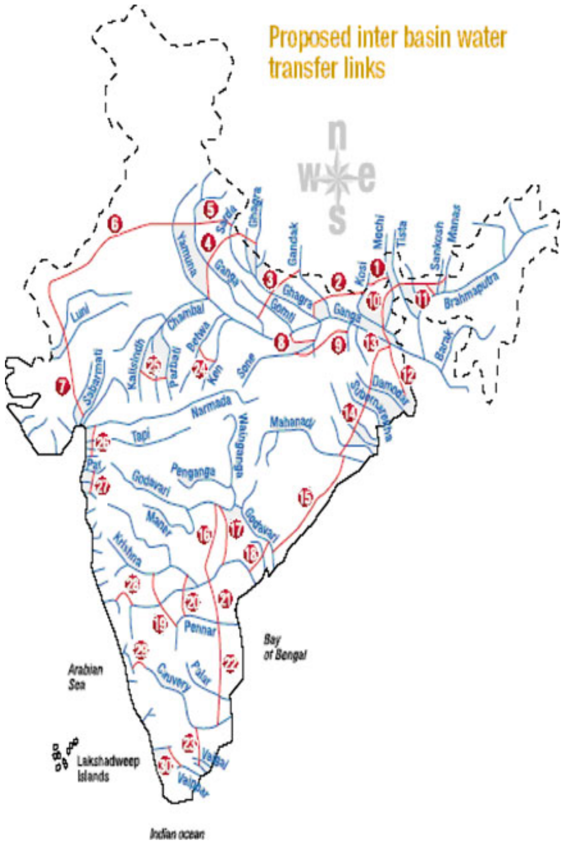
The transfer schemes in India at present consider 30 possible linking projects. Interlinking project has two components—the Himalayan and the Peninsular (Shiva and Jalees 2003). The Himalayan component includes construction of storage dams on the main tributaries of Ganga and Brahmaputra to transfer 'surplus' water to the west. The Peninsular component involves connecting rivers like Godavari and Mahanadi that have the surplus water with rivers like Krishna and Cauvery. Thirty link canals are envisaged, of which 14 will be in the Himalayan component and 16 in the peninsular component (Fig. 2). The logic behind the interlinking project is based on the view that there is 'surplus' water in some river basins or sub-basins, which, if transferred to the other 'deficit' river basins, would greatly reduce the regional imbalance in the availability of water in the different river basins.

Himalayan and peninsular links

The Himalayan component entails construction of reservoirs and canals on the main tributaries of the Ganga and the Brahmaputra to transfer excess water to the west covering the parts of southern Uttar Pradesh, Haryana, Punjab and Rajasthan and finally proceeding towards south meeting the peninsular component. It also proposed to link the main Bramhaputra and its tributaries with Ganga, and the Ganga with Mahanadi. This component would provide an additional irrigation of about 22 million hectares and would the ultimate irrigation potential from 133 million hectares to 148–150 million hectares facilitating the generation of about 30,000 MW hydropower, besides providing flood control in the Ganga–Brahmaputra basin (Das Gupta 2004).

The peninsular river interlinking has been divided into four major components: (1) Interlinking of the Mahanadi-Godavari-Krishna-Cauvery Rivers, where surpluses from the Mahanadi and the Godavari Rivers are intended to be transfer to the more interior parts of peninsula. (2) Interlinking of western flowing rivers, originating on the Western Ghats, North of Bombay and South of river Tapi. The scheme incorporates water supply by canal to the metropolitan area of Mumbai; and also provides irrigation of coastal area in Maharashtra. (3) Interlinking of Ken–Chambal provide water grid for Madhya Pradesh and Uttar Pradesh. (4) Diversion of the other west flowing rivers to the east. The plan includes the construction of an interlinking canal system backed up by adequate storage space to transfer water to meet the needs of draught affected areas. It is expected that this peninsular development would provide additional irrigation of about 13 million hectares and will be expected to generate about 4,000 MW of power. Details of the proposed Himalayan and Peninsular rivers link plans are tabulated in Table 1.

Fig. 2 Proposed inter basin water transfer links in India



1 Kosi - Mechi
2 Kosi - Ghagra
3 Gandak - Ganga
4 Ghagra - Yamuna
5 Sarda - Yamuna
6 Yamuna - Rajasthan
7 Rajasthan - Sabarmati
8 Chunar - Sone Barrage
9 Sone Dam - Southern Tributaries of Ganga
10 Manas - Sankosh - Tista - Ganga
11 Jogighopa - Tista - Farakka (alternative)
12 Farakka - Sunderbans
13 Ganga (Farakka) - Damodar - Subernarekha
14 Subernarakha - Mahanadi
15 Mahanadi (Manibhadra) - Godavari (Dowlaiswaram)
16 Godavari (Inchampalli) - Krishna (Nagarjunasagar)
17 Godavari (Inchampalli) - Krishna (Pulichintala)
18 Godavari (Polavaram) - Krishna (Vijayawada)
19 Krishna (Almatti) - Pennar
20 Krishna (Srisailam) - Pennar
21 Krishna (Nagarjunasagar) - Pennar (Somasila)
22 Pennar (Somasila) - Palar - Cauvery (Grand Anicut)
23 Cauvery (Kattalai) - Vaigai - Gundar
24 Ken - Betwa
25 Parbati - Kalisindh - Chambal
26 Par - Tapi - Narmada
27 Damanganga - Pinjal
28 Bedti - Varda
29 Netravati - Hemavati
30 Pamba - Achankovil - Vaippar

Ken–Betwa interlinking (KBI): First interlinking plan

Feasibility studies of most of the links have been completed and the Government of India has approved the country's first river interlinking project on Ken–Betwa and MoU has been signed among the state of Uttar Pradesh and Madhya Pradesh and Union Government. The Ken–Betwa interlink (KBI) involves building a dam at Daudhan 2.5 km upstream of existing Gangau weir on river Ken and diverting the water to Betwa through a link canal of 231.45 km. The KBI area is spread in the Panna and Chhatarpur district of Madhya Pradesh. Both the rivers are potential tributaries of river Yamuna. River Ken has its origin on the North West slope of the Kaimur hills in the Jabalpur district of Madhya Pradesh and total length of the river is 427 km, out of which 292 km lies in Madhya Pradesh, 84 km in Uttar Pradesh and 51 km in common boundary. Betwa River originates in the Raisen district of Madhya Pradesh and the total length of river is 590 km, out of which 232 km lies in Madhya Pradesh and 358 km in Uttar Pradesh. The detail progress report of Ken–Betwa link between Madhya Pradesh and Utter Pradesh is expected to ready by December 2008 (The Hindu 2008).

In a recent study made in river Betwa revealed the presence of exceedingly rich species spectrum of threatened, migratory and commercially important fishes with a wide distribution of species, families and genera (Lakra et al. 2010). Presence of threatened fishes of regional conservation concern in the river also makes it a high priority area for urgent conservation and management measures to save them from further endangerment. Presently, the fish fauna of the River is highly threatened due to presence of dams and water diversions resulting fragmentation of habitat and have been subjected to extensive anthropogenic alterations (Lakra et al. 2010). Studies on streamflow and drought severity studies of river

Table 1 The proposed Himalayan and Peninsular river links in India

Himalayan river links	Peninsular river links
Kosi–Mechi	Mahanadi (Manibhadra)–Godavari (Dowlaiswaram)
Kosi–Ghagra	Godavari (Inchampalli)–Krishna (Nagarjunasagar)
Gandak–Ganga	Godavari (Inchampalli)–Krishna (Pulichintala)
Ghagra–Yamuna	Godavari (Polavaram)–Krishna (Vijayawada)
Sarda–Yamuna	Krishna (Almatti)–Pennar
Yamuna–Rajasthan	Krishna (Srisailam)–Pennar
Rajasthan–Sabarmati	Krishna (Nagarjunasagar)–Pennar (Somasila)
Chunar–Sone Barrage	Pennar (Somasila)–Palar–Cauvery (Grand Anicut)
Sone Dam–Southern Tributaries of Ganga	Ken–Betwa
Manas–Sankosh–Tista–Ganga	Parbati–Kalisindh–Chambal
Jogighopa–Tista–Farakka (alternative)	Par–Tapi–Narmada
Farakka–Sunderbans	Damanganga–Pinjal
Ganga (Farakka)–Damodar–Subernarekha	Bedti–Varda
Subernarakha–Mahanadi	Netravati–Hemavati
	Pamba–Achankovil–Vaippar

Betwa were conducted by Pandey et al. 2007. They observed the upper reaches of river course were more prone to sever droughts than were the lower reaches. On the other hand, in river Ken the presence of protected area (Panna National Park) on the upper stretch and forest cover on the mid stretch of river tends to have positive impact on its aquatic habitat. Review of literatures shows that there is a complete lack of information on the pattern of abundance, distribution, fish habitat aspects and threats at different spatial scales, which are urgently required for management plans of this river. Recently, many authors have addressed the ambitious proposal of river interlinking and suggested potential issues (ecological, social, economic, biodiversity conservation etc.) for successful implementation in the context of Indian situation (Misra et al. 2007; Jain et al. 2005). However, the issues pertaining to fish and aquatic biodiversity have not been addressed in the earlier studies. We are discussing here several aspects of fish and aquatic habitat and their relationship between other components and to this project.

Aquatic resources and related issues

The Indian mainland is drained by 15 major, 45 medium and over 120 minor rivers, besides numerous ephemeral streams (Sharma and Mc-Cornick 2006). Table 2 represents the surface water resource potential in the river basins of India. There are several worries over the surplus basin identified for the river –linking project. The very facts regarding the issue is the amount of the surplus water, which occurred only during monsoon while the rest of the year they also suffer more evaporation than precipitation thereby receding the water budget. The adequate rainfall during monsoon month serves the need for the period of non precipitation and sustaining the growth of crops. It is important to mention that the Indian subcontinent is tilted towards east and most of the rivers in the northern part of the country as well as in peninsular part flow with general trends towards east and southeast, sinking their load in the Bay of Bengal. To supply water in the western part by linking these rivers will need the extra effort for working against the general slop. Besides these issues, one major threat is the serious contamination of river water bodies in many ways if they are connected with each other through canals and water grids. If it happens the resulting scenario will be beyond imagination. Most of the Indian rivers are seriously suffering from widespread fecal and organic matter contamination. If the rivers are linked with each other the condition will certainly worsen the rivers that are now less contaminated with organic matter may suffer more. Moreover, the fecal contamination seriously affects the use of water as a drinking water source or bathing, as well as the ecological health of the river. In case of major rivers like Ganga and Yamuna, highly polluted rivers that

Table 2 Surface water resource potential in the river basins of India (*Source*: MOWR 1999)

S. no.	Name of the river basin	Length	Catchment area	Average annual potential (Km^3)	Estimated utilizable surface water (Km^3)	Present use of surface water (Km^3)
1	Indus(up to border)	1,114	321,289	73.305	46.000	40.00
2	a. Ganga	2,525	861,452	522.803	250.000	–
	b. Brahmaputra at Jogigupta	961	194,413	537.322	250.000	–
	c. Barak and other rivers flowing into Meghna like Gomti, etc.	–	41,273	48.357	24.000	–
3	Godavari	1,465	312,812	111.348	76.300	38.00
4	Krishna	1,401	258,948	23.500	58.000	47.00
5	Cauvery	800	81,155	21.594	19.000	18.00
6	Pennar	597	55,213	6.741	6.741	5.00
7	East flowing rivers between Mahanadi and Pennar	–	–	22.520	13.110	–
8	East flowing rivers between Pennar and Kanyakumari	–	–	16.453	16.453	–
9	Mahanadi	851	141,589	66.879	49.990	17.00
10	Brahmani and Baitarni	799	30,033	30.044	18.297	N.A
11	Subernarekha	–	–	12.748	6.813	–
12	Sabarmati	371	21,674	3.355	1.925	1.80
13	Mahi	583	34,342	11.020	3.095	2.50
14	West flowing rivers of Kutch, Saurashtra including Luni	–	–	15.098	14.980	–
15	Narmada	1,312	98,145	46.039	–	–
16	Tapi	724	65,145	14.879	–	–
17	West flowing rivers from Tapi to Tadri	–	–	87.411	11.936	8.00
18	West flowing rivers from tadri to kanyakumari	–	–	113.532	24.273	–
19	Area of inland drainage in Rajasthan Desert	–	–	–	–	–
20	Minor river basins draining to Bangladesh and Burma	–	–	31.000	–	–
	Total			1,875.948	688.913	

pass through large towns and cities, are linked with the less polluted rivers, the entire country may suffer from sever river water pollution effects.

Fish ecology and biodiversity

Biodiversity conservation in general and fish germplasm resources in particular has become an issue of great concern throughout the world. India is endowed with a rich fish biodiversity (2,243 fish species) and ranks 9th in term of freshwater mega biodiversity countries and a significant portion of the freshwater fish production in India is based on the harvest from wild population (Lakra 2008). The riverine fisheries play promising role in socioeconomic development by providing nutritional security for the burgeoning Indian population and contribute to economic upliftment of farmers and fisher folks. The fisheries sector contributes 4.5% to the agricultural GDP and 1.4 per cent to the total GDP. The diverse river system in India harbor one of the richest fish germplasm resources in the world and as many as 272 species (Hora 1929) have so far been recorded from River Ganga basin. The freshwater fish biodiversity of the rivers/streams of the two hot spot areas viz, North East and Western Ghat includes 296 and 287 species (Vishwanath et al. 2007; Ponniah and Gopalakrishnan 2000) while the rivers of Central India harbors as many as 166 indigenous fish species (Sarkar and Lakra 2007).

In view of the significance and to achieve sustainable utilization of these resources, appropriate planning for conservation and management strategies are of utmost importance and the greatest challenge is to secure the IPRs related to fish germplasm so that the country is able to maintain its stake on its biological resource and their potential benefits. To respond to new challenges and developments, govt. of India has legislated the Biological Diversity Act (2002) and Biological Diversity Rules (2004). Any loss of genetic variation due to environmental alterations results in erosion of evolutionary flexibility in the adaptation to changing environment and risk of extinction. The threats are wide ranging including habitat alterations, reduction of natural habitat area, construction of dams, diversion or reclamation of river beds that reduce water discharge in rivers, and global climatic variations etc. At present most of the Indian rivers are highly regulated. Out of 30 world river basins marked as global level priorities for the protection of aquatic biodiversity includes nine river basins from India, and these are Cauvery, Ganges–Brahmaputra, Godavari, Indus, Krishna, Mahanadi, Narmada, Pennar and Tapi. The impact of various stresses leads to decline in effective population sizes over a period of time, depending on original population size and magnitude of the threat (Table 3). The current state of knowledge shows that inter basin transfer of the rivers have many negative as well as positive impacts on aquatic ecosystem (WCD 2000). As regards impact on fish and aquatic biodiversity resources, there could be advantageous as well as disadvantageous effects. There could be mixing of fish species resulting more gene flow, loss of certain amount of biodiversity as also entry of some invasive fish species between the river basins. Kottelat and Whitten (1996) considered the biological change that environmental degradation brings about, and enumerated pollution, increased sedimentation, flow alteration and water diversion, and introduced species as the main causes for decreased ichthyofaunal diversity in Asian countries. The impact of these stresses leads to decline in effective population sizes over a period of time, depending upon original population size and magnitude of the threat. The present paper highlights various core issues, knowledge gaps, strategies and research priorities and the role of scientific interventions for sustainable conservation and management of aquatic genetic resources.

To date the efforts to counter the ecosystem impacts of large dams have had only limited success, which is due to limited efforts to understand the ecosystem and the scope and nature of impacts. There are reports that, dams can enhance riverine fisheries, particularly tail water fisheries immediately below dams that benefit from discharge of nutrients from the upstream reservoir. The nature of cumulative impacts to river system may be significant, but a lack of research on the topic makes predictive assessment difficult (WCD Report 2000). Interlinking intend to alter the natural distribution and timing of stream flow. Ecological response to altered flow regimes in a specific river depends on how the components of flow have changed relative to the natural flow regime for the particular river or stream (Poff and Ward 1989). Without high flushing flows, species with life stages that are sensitive to sedimentation, such as the eggs and larvae of many invertebrates and fish, can suffer high mortality rate (Sear 1995). According to the WWF Living Planet Index (WWF 2004a), populations of freshwater species showed a decline of over 30 per cent from 1970 to 2003. This decline in freshwater species is attributed to factors related to infrastructure development (like dams, inter and intra basin water transfers, canalization, flood-control, river diversions and large-scale irrigation, deforestation, alien invasive species and urban and industrial pollution). These drivers change the characteristic of river basins and their ecosystems in many ways. Worldwide examples of habitat alteration and impact on biodiversity are presented in Table 4. Diversion of water, channelization and dam construction, disrupt natural biological cycles of aquatic species viz. seasonal migration of fish and various insects with aquatic larval stage and other aquatic species as well as ethnic fauna of various riparian plant species. In contrast to these local impacts, most of the benefits from dams such as low electricity costs, industrial development, and flood protection for people living in low-lying areas, are felt some distance away, especially in towns and cities (Dudgeon 2005).

Table 3 Summary of threats of river basin

Basin name	Countries within basin	Large dams	Types of risk
Yangtze	China	46	Large basin under stress from population pressures. Loss of habitat threatens bird species as well as endangered Yangtze River dolphin
La Plata	Argentina, Bolivia, Brazil, Paraguay, and Uruguay	27	River basin with high biodiversity; threats to Pantanal and other internationally important wetlands
Tigris-Euphrates	Turkey, Iraq, Syria, Iran and Jordan	26	Arid basin; potential for conflicts over water withdrawal between Turkey and downstream countries
Salween	China, Myanmar, Thailand	16	Relatively pristine river with high biodiversity values; Serious concerns about human rights abuses in Myanmar
Kizilirmak	Turkey	15	Small heavily fragmented basin; Ramsar site located in Delta
Ganges	India, Nepal, China, Bangladesh	14	Endangered Ganges River dolphin; Sundarbans mangroves in delta
Tocantins	Brazil	12	Relatively developed river basin; further dam development and improved navigation will exacerbate degradation for use of farmland
Amazon	Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, Guyana, Suriname, Paraguay and French Guyana	11	One of most important basins for biodiversity; lower dams may affect coastal areas
Mekong	Thailand, Laos, China, Cambodia, Vietnam and Myanmar	11	Basin with high biodiversity and very productive fisheries; droughts and low water levels are current threats
Brahmaputra	China, India, Bhutan, Bangladesh	11	High biodiversity in upstream areas; high population pressure in delta
Xun Jiang (Pearl River)	China, Vietnam	10	Highly developed basin; some important sites for amphibians
Danube	Germany, Austria, Slovakia, Hungary, Croatia, Serbia and Montenegro, Romania, Bulgaria, Moldova, Ukraine	8	68 Ramsar listed sites as well as UNESCO biosphere reserve in delta
Huang He (Yellow River)	China	8	River basin with severe water shortages; 4 endemic bird areas, 1 Ramsar site
Kura-Araks	Azerbaijan, Iran, Georgia, Armenia, Turkey	8	Biodiversity hotspot with 4 Ramsar sites, 1 Endemic Bird Area and 21 IBA's
Yesil-Kelkit	Turkey	8	Breeding populations of many birds in Delta
Büyük Menderes	Turkey	7	River delta protected as National Park, protected bird areas
Çoruh	Turkey	7	Fast flowing river with significant tourist industry based on rafting
Susurluk	Turkey	7	N/A
Ebro	Spain and Andorra	6	High economic importance of delta; important bird sites
Indus	Afghanistan, Pakistan, India, and China	6	Endangered Indus River Dolphin
Qezel Owzan	Iran	6	Endangered sturgeon species

Fish are good indicator of the functioning of freshwater ecosystem, of habitat structure, and ecological integrity of river system because of their diverse reproduction, trophic level and their complex habitat requirement (Schlosser 1985; Schiemer and Spindler 1989; Copp et al. 1991). Freshwater fishes

Table 4 Dams and their associated reservoir impact on freshwater biodiversity (After McAllister et al. 2001)

Blocking movement of migratory species up and down rivers, causing expiration or extinction of genetically distinct stock species
Changing turbidity/sediment level to which species/ecosystem are adapted in the rivers affects species adapted to natural levels. Trapping silt in reservoir deprives downstream deltas and estuaries of maintenances materials and nutrients that help them productive ecosystem
Filtering out of woody debris which provide habitat and sustain a food chain
Changing condition in river flooded by reservoirs running water becomes still, silt is deposited, deepwater zones, temperature and oxygen condition are created that are unsuitable for riverine species
Possibly fostering exotic species which tend to displace indigenous biodiversity
Flood plains provided vital habitat to diverse river biotas during highwater periods in many river basins. Dams management that diminishes or stops normal river flooding of these plains will impacts Diversity and fisheries
Changing the normal season estuarine discharge which can reduce the supply of entrained nutrients, impacting the food chain that sustains fisheries in inland and estuarine deltas
Modifying water quality and flow patterns downstream

are not only most diverse group of vertebrate they also feature the greatest proportion of threatened species (Bruton 1995; Leidy and Moyle 1998; Duncan and Lockwood 2001). The various impacts on fish biodiversity are discussed here under following points:

Effects on fish migration

The WCD cross check survey found that impeding the passage of the migratory fish species was the most significant ecosystem impact. Migratory fish require different environments for the main phases of their life cycle: reproduction, production of juveniles, growth and sexual maturation. As a physical barrier, the dam disrupts the movement of species leading to change in upstream and down stream species composition and even species loss. Blockage prevents migration by fragmenting rivers systems and restricting the passage of fauna and its use of various types of habitat (Rosenberg et al. 1997). As species are pushed in smaller habitats, increased inbreeding often leads to a decline in genetic variability. Habitat simplification includes the loss of habitat quality, diversity, and complexity (Reeves et al. 1997). Obstructions have been the reason for the extinction of entire stocks (salmon in the Rhine, Seine and Garonne rivers) or for the confinement of certain species to a very restricted part of the river basin (salmon in the Loire, shad in the Garonne or Rhône) as reported by Porcher and Travade (1992). Many anadromous fish population such as salmon and shad have died out as a result of altering their migratory routes. For example, a study of threatened fish of Oklahoma suggested that the loss of free flowing river habitat due to reservoirs had let to 55% of the human- induced species loss, while a further 19% was caused by dams acting as barrier to fish migration (Hubbs and Pigg 1976). On the East Coast of the USA, the building of dams has been identified as the main reason for the extinction or the depletion of migrating species such as salmon and shad on the Connecticut, Merrimack and Penobscott rivers (Baum 1994; Meyers 1994; Stolte 1994). Zhong and Power (1996) reported that the number of fish species decreased from 107 to 83 because the migration was interrupted by the Xinanjiang dam (China).

In India the construction of Farakka barrage on river Ganga, has grossly affected Hilsa (*Tenualosa ilisha*), major carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*), cat fishes, fresh water prawns and many more fishes (Tyagi et al. 1999). A series of barrages and dams have been commissioned in the upper segment of river Ganga from Rishikesh to Narora (Rao 2001) and the Tehri dam constructed in the hills of Uttarakhand has considerably reduced the water flow and have shown detrimental effects on physical attributes and destruction of feeding, spawning, and migration routes of mahseer (Sharma 2003). Recently, Lakra et al. (2010) reported the considerable loss of fish species in the downstream of Betwa River due to damming and resulting fragmented river channel. The dam in this river prevents migratory fishes such as *Tor tor*, *Bagarius bagarius*, *Pangasius pangasius*, *Silonia silondia* and *Sperata aor* from having access to portions of their native ranges

Table 5 Examples of world wide biodiversity impact from habitat alteration resulting from hydrological development (After Rosenberg et al. 1997)

Type of habitat alteration	Location	Effects
Blockage by dam/ habitat fragmentation	Tocuri Dam, tocantins river, Brazil	Interrupted upstream, reproductive migration of long distance migratory species; population of these species were negatively affected in lower Tocantins, downstream of dans (Ribeiro et al. 1995)
	Upper Volga river, Russian Federation	Change to fish fauna following construction of four major reservoir; 7 species (mainly anadromous rhcophils) disappeared, and more of these 9 are reproducing naturally and will probably disapared when stocking is discontinued (Poddubny and Galat 1995)
Habitat simplification	Upper Volga river, Russian Fedration	Limited bioproductivity in reservoirs because of considerable changes "typical riverine fish habitat remain only in the upper reaches of tributaries and in the forewater of dams and account for no more than 1% of the total water surface area" (Poddubny and Galat 1995)
	River Rhine, Lower Rhhone river, Europe	
Unnatural discharge regimes	Colorado River, USA	Elimination of 2 year classes of endemic Colorado squawfish from its most productive remaining nursery habitats in the Green River Catch, perhaps because extreme flow fluctuating and alteration of seasonal flow regimes (Jones and Tyus 1985 as cited in Carlson and Muth 1989)

upstream of the dam for spawning, thus resulting in genetic isolation and declining fish population.

Loss of habitat

River regulation in general has a detrimental effect on native fish populations while often enhancing condition for introduced species, especially those which are habitat generalists (Cadwallader 1990; Walker 1985; Gehrke et al. 1995). Examples of world wide biodiversity impact from habitat alteration resulting from hydrological development are given in Table 5. Dam construction can dramatically affect fish habitat. The consequence of river impoundment is the transformation of lotic environment to lentic habitats. From a study of the threatened fish of Oklahoma, Hubbs and Pigg (1976) suggested that 55% of the man-induced species depletions had been caused by the loss of free-flowing river habitat resulting from flooding by reservoirs, and a further 19% of the depletion was caused by the construction of dams, acting as barriers to fish migration. In India, the construction of Farakka barrage on river Ganga which has grossly affected Hilsa, major carps, catfishes, Freshwater prawns and many more fishes (Tyagi et al. 1999). The endangered Ganges river dolphins (*Platanista gangetica*), which inhabit major river systems such as the Ganga and the Brahmaputra in the Indian subcontinent (Vaholikar and Firoz Ahmed 2003). The type of habitat in which these dolphins tended to concentrate made them vulnerable to habitat disturbance from water development projects such as the Ganges-Kobadak Irrigation Project (Smith 1998). Correspondingly in river Ken, which is one of the least polluted rivers in India (http://panna.nic.in/tiger.htm), and proposed for interlinking are of concerned about how the construction of a dam and reservoir will impact the aquatic habitat and fish fauna of the river.

Alteration in spawning and breeding grounds

A decrease in fresh water flow and in nutrients due to diversion of water, channelization and dam construction affect the nursery areas several ways, including increasing salinity, allowing predatory fishes to invade and reducing the available food supply. When water of one basin diverted into another one, changes in volume and seasonality of flow result. New biota from the source basin may invade the recipient basin and compete with the native species. If all the water is diverted from the source basin this will clearly have serious impact on any unique species or genetically different stock (WWF). On the Columbia river and its main tributary the Snake river, most spawning habitat were flooded, due to the construction of dams creating an uninterrupted series of impoundments. On the Indus river, the construction of the Gulam Mahommed Dam has deprived the migratory *Hillsa ilisha* of 60% of their previous spawning areas (Welcomme 1985). Nath and Srivastava (1999) reported the Kosi and Gandak projects have put a serious threat to fisheries and the breeding ground in certain stretches have completely lost. Considerable reduction of flow in the residual various tailing below the dam may completely dry up the fish spawning/breeding grounds, shallow areas are formed which impede fish movements. About 40% of the spawning grounds in the Qiantang river above the Fuchunjiang dam were lost by flooding (Zhong and Power 1996). This can lead to changes in species composition with loss of obligate floodplain spawners.

Effect of changed temperature

Dams can modify thermal and chemical characteristics of river water. This can affect fish species and populations downstream. Water temperature changes have often been identified as a cause of reduction in native species. Cold-water release from high dams of the Colorado river has resulted in a decline in native fish abundance (Holden and Stalnker 1975). The fact that *Salmo spp.* had replaced some 20 native species has been attributed to the change from warm-water to cold-water. Water-chemistry changes can also be significant for fish. Release of anoxic water from the hypolimnion can cause fish mortality below dams (Bradka and Rehackova 1964). During high water periods, water which spills over the crest of the dam can become over-saturated with atmospheric gases (oxygen and nitrogen) to a level which can be lethal for fish. Mortality can result from prolonged exposure to such lethal concentrations downstream of the spillways. Substantial mortalities of both adult and juvenile salmonids caused by high spillway flows which produced high super saturation (120–145%) have been observed below the John Day dam on the Columbia river (Raymond 1979). The Yacyreta dam on the Parana river generates supersaturated levels of total dissolved gases that can affect the health condition of fish. In 1994, massive fish mortality was observed in a 100 km reach below the dam (Bechara et al. 1996). In India, analysis of time series data of 30 years from published literature and from current investigations on the River Ganga and water bodies in its plains, indicate increased minimum water temperatures; 1.5°C in colder stretches of the Ganga and 0.2–1.6°C in the aquaculture farms of the State of West Bengal in the Gangetic plains and the impact is manifested in the breeding failure of the Indian Major Carps (IMC) and a consequent decline in fish spawn availability in river Ganga (Vass et al. 2009). In a developing country like India, these factors could represent an additional stress on the fish biodiversity in the proposed river interlinking projects of this country.

Increased exposure to predation

Normal predation behavior may become modified with the installation of a dam; it appears that migrating species suffer increased predation in the vicinity of an installation, whether by other fish. This may be due to the unnatural concentration of fish above the dam in the forebay, or to fish becoming trapped in turbulence or recirculating eddies below spillways, or to shocked, stressed and disoriented fish being more vulnerable to predators after turbine passage. In some rivers or hydroelectric schemes, predation may affect a substantial proportion of the fish population. On the Columbia river, predator exposure associated to turbine passage was the major causes of salmon mortality. Tests at the Kaplan turbines indicated a mean loss of 7% and studies showed that the indirect mortality on juvenile coho salmon could reach 30% when indirect mortality from predation was included (Ebel et al. 1979).

Impact on fish production

Proposed interlinking of rivers would comprise more than 36 major dams and 30 canals links. In addition there will be many more irrigation canals and barrages. These major reservoirs, canals and other water harvesting structure will add to the potential fishery resources of the country. The river and lakes in the water recipient zone will brings benefit with increased water perennially, congenial habitat and consequently, higher fish production. Blockage of sediment and nutrient, re-regulation of streamflow, and elimination of the natural flood regime can all have significant negative effect on downstream fisheries. Marine or estuarine fisheries are also negatively affected when dams alter or divert fresh water flow. Along with subsistence agricultural, fisheries constitute an important livelihood activity among large rural population in the developing world. Many of the house holds depend on fisheries either as a primary or supplementary source of livelihood. In Senegal river system about 11,250 tonnes of fish were lost per year following dam construction. Dams can enhance some riverine fisheries particularly tailwater fisheries immediately below dams that benefit from discharge of nutrients from discharge of nutrients from the upstream reservoir. If the discharge is from the lower layer of water in the reservoir, lowered temperature in the receiving tailwater can curtail or eliminate warm-water river fisheries and require stocking with exotic coldwater species such as salmonids. Productive tailwater fisheries targeting these coldwater fish can result but generally require supplemental hatchery programmes and the introduction of coldwater invertebrates to serve as food for these fish (Jackson and Marmulla 2000).

In production terms, the harvest upstream of the reservoir remained stable for the first 10 years or more, but now appears to increasing (Fig. 3). Meanwhile, the downstream fishery has shown a continued downward trend. However, the reservoir fishery has expanded tenfold in the last 20 years, with the result that the total fishery (upstream, down stream and in the reservoir) has tripled in size to 4,700 tones per year since dam was created. In India, the yield of major carps are reported to have been reduced about 50% of the 1964 level in the lower Ganga following construction of Farrakka (Jhingran and Ghosh 1978). Shetty and Malhotra (1983) reported decline of *Tor tor* along with other fishes following construction of barrage at Tribeni on the Gandhak river. In a recent study by Pathak and Tyagi (2010) showed a major change in fish stock structure below the dam after the construction of Farakka barrage on river Ganga. Prior to Farakka, the hilsa used to be the main fishery (92.02%). With the commissioning of the barrage, hilsa contribution came down to merely 16.8% and the niche was replaced by other species. Studies made by National Bureau of Fish Genetic Resources, Lucknow on impact of Kosi barrage indicated reduction in catch, reduced species diversity, dominancy of low size groups, change in fishing profession and local extinction of an important riverine cat fish *Bagarius bagarius* (Anon 1999–2000). The National Academy of Agricultural Sciences, India (NAAS 2004) listed some recommendations to mitigate the adverse effect on aquatic ecology and biodiversity after interlinking. These are as follows:

Data mining: Large volume of raw data on water quality, productivity, aquatic ecology and fish biodiversity are available for river systems from various parts of the country. Most of these data are not properly analysed and interpreted. Hence, there is an urgent need for data mining and analysis using appropriate methodology to gather base line information on water quality, aquatic ecology, productivity and fish biodiversity for various river systems.

Modeling studies and scenario analysis: Software-aided modeling studies are required to assess the impact of changes in river runoff on water chemistry, productivity, aquatic ecology, biodiversity and fish production. The impact of interlinking of river basins on fisheries will vary from one river system to another and from region to region. Hence, detailed scenario analysis and simulation studies have to be carried out for each of the river systems to assess the impact under varying flow conditions.

River ranching: River ranching of fishes is being carried out in various parts of the country by different agencies. It is necessary to evaluate the usefulness of river ranching for enhancing the fish production in our river systems. River ranching with fish seed in

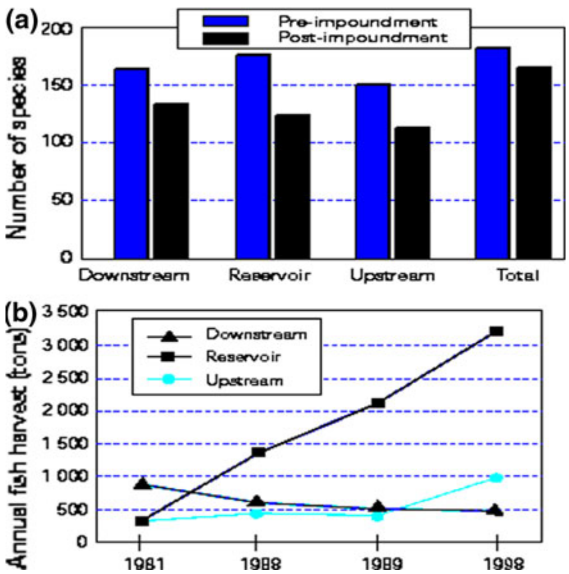


Fig. 3 Decline in species number but increase in fisheries productivity

altered scenario needs to be addressed in a proper perspective.

River siltation and dredging: The siltation pattern in donor and receipt rivers could change due to interlinking. Heavy siltation of rivers, canals and lakes is already an acute problem in the Himalayan region. There is urgent need to assess the usefulness of river bed dredging for improving the river ecology and fish production.

Biodiversity and taxonomic studies: It is necessary to study and identify the endangered species which could become extinct due to interlinking. Based on existing biodiversity lists of exotic and native species, it is necessary to identify the prevalent differences between the rivers likely to be linked and project the post-linking scenario. Taxonomists and taxonomy related studies are required to assess and document the aquatic biodiversity patterns. Hence, there is an urgent need to give stress to taxonomic studies and developing human resources in taxonomy.

Scaled-down approach: Before initiating large scale river basin linking at national level, it will be appropriate to conduct studies on linking adjacent river system with ten similar ecosystems. Such scaled—down approach will be very useful to assess and understand the environmental impacts of river linking on aquatic ecosystem.

Loss-gain statement: There is an urgent need to work out a loss gain statement on the possible impact of interlinking of river basins on fisheries, using the available data.

Other aspects

Hydrological aspects

The proposed river linking project has many impacts on environment and neighboring countries like Bangladesh and Nepal. Bangladesh has already shown strong protest against this project. Withdrawal or diversion of water in the upstream will directly affect the hydrosphere which being linked with the lithosphere and the atmosphere will imperatively cause tremendous effects in it. Biosphere being dependent on atmosphere, the lithosphere and hydrosphere will be affected as well. The hydrosphere scenario will be directly affected due to a dramatic reduction in the quantity of water in the major rivers. This reduction in quantity will brings immense effect to other sector related with hydrosphere. The affected sectors are discussed below.

Water supply

The picture of water supply of the whole country is going to change by transferring the ‘surplus water’ to water ‘deficit area’. The concept of ‘surplus water’ is itself faulty, as a reduction of surplus/flood water will affect the surface water supply in terms of quantity and quality as well. India has an average annual flow of 1,869 bcm of which 1,122 bcm is useable, distributed seasonally during the monsoon period (Environmental News Service 2003). To bridge the gap between continuously increasing demands to be rather good but at the same time the other side of the plan may cause increasing in the cost of water finally raising the cost of living. Reduction in the quantity of surface water will also cause reduction in ground water, i.e., lowering of ground water in one area, hampering the irrigation, and in other area causing the problem of water logging again affecting the crop yields.

Salinity

Majority of the rivers of the Ganga Plains and Northeast India originates from the Himalayan mountain ranges where there is generally high precipitation. Usually, in the mountain the concentration of total dissolve solid is low and most of the rivers flow through arid or semiarid regions of Ganga Plain. In such situation especially in their lower reaches the concentration of salt through evaporation rises steadily with distance downstream. If the proposal of interlinking of rivers is considered for other rivers or canals for irrigation, the salt concentration could be escalated by evaporation, and it will increase the dryland salinity. Increase in dryland salinity could affect the water quality, natural ecosystems and biodiversity.

Climate change

Studies have shown that the climate of the earth may be undergoing significant long term change. Such changes might adversely influence the reliability of the project and some of the components may fail to perform up to the mark and others may become redundant (Jain et al. 2005). India is witnessing the extreme climate events almost every year: the flood, drought, cyclones, snow avalanches, etc. Some of the observed changes of climate in India as reported by Indian National Communication 2004 (NATCOM) to United Nations Framework Convention on Climate Change (UNFCCC) indicate an increase of 0.4°C in surface air temperature over the past century. Moreover, the temperature range is also very wide of having over 45°C during May–June and as low as near 0°C during winters. The warming trends over India have been reported to be 0.57°C per 100 years (Rupkumar et al. 1999). Apart from these the complex and coupled situations necessary for the onset of monsoon and receding glacier of the country may greatly affected the future scenario of this project. Keeping this inconsistent scenario of rainfall in mind, it is important to look at the construction of large storage and checking the natural flow of the flowing water. But the emission of greenhouse gases (GHG) from reservoirs due to rotting vegetation and carbon inflows from the catchments is a recently identified ecosystem impact (on climate) of storage dams (WCD Thematic Review II.2). A first estimate suggests that the gross emissions from reservoirs may account for between 1 and 28% of the global warming potential of GHG emissions (St. Louis et al. 2000; Tremblay et al. 2005). This challenges the conventional wisdom that hydropower produces only positive atmospheric effects, such as a reduction in emissions of carbon dioxide, nitrous oxides, sulphuric oxides and particulates when compared with power generation sources that burn fossil fuels (Bosi 2000). All large dams and natural lakes in the boreal and tropical regions that have been measured emit greenhouse gases (carbon dioxide, methane, or sometimes both) (WCD Thematic Review II.2). These emissions may change significantly over time as the biomass decays within the reservoir during the first few years of impoundment. In other cases the emissions may depend more on carbon inflows from the catchment in the longer term and have greater stability over time, subject to catchments conditions.

River regime

There are large difference in river of the Himalayan and the peninsular rivers and topography. Most of the rivers in the Himalayas originate from the glacier, the Himalayan river and the groundwater- fed/perennial rivers and their regimes are dependent on the pattern of water supply both from the snowmelt as well as the rainfall. The regimes of the Himalayan rivers are monsoonal as well as glacial while that of the ground water fed perennial rivers of peninsular part are only monsoonal as they are controlled by rainfall alone.

Conclusion

The proposed river linking project of India is a most ambitious plan. It is obvious that water resources are essential for sustaining the life on the earth and all kinds of socio-economic developmental activities and therefore, appropriate planning and management of aquatic resources are important since India, already suffering from the increasing population and shortage of all kind of natural resources like water. There is need to visualize many relevant issues of the sustainable aquatic biodiversity conservation. The concepts like water and aquatic resource conservation, best regulation of existing facilities, rainwater harvesting, watershed and river basin management, water reuse etc. will continue to be highly relevant and this mega project will be an important supplement to this (Jain et al. 2005). The world wide example suggests that it is quietly difficult to predict precisely whether the implementation of proposed interlinking projects will be beneficial or harmful to nature and natural resources, is a matter of debate. Korse (2004) has raised the point for the need of case specific studies, citing the example of the Western Ghats, which is known for its unique flora and fauna, and implementation of such construction- intensive project will lead to biodiversity loss that would be beyond comprehension. Misra et al. (2007) pointed out the impact on the neighboring nations which are linked with India through the waterways, and share the common climate condition and economic status.

The potential implications of the proposed project on freshwater aquatic biodiversity and relevant issues have been discussed. Successful completion of the proposal will rapidly wipe out many curses of poverty since balanced distribution of water in space and time will increase productivity and a huge generation of employment. However, studies on the sustainability of the above in a holistic way and exploring the alternatives are important. The appropriate modern technology and conditions needs to be followed based on the biological requirements/behavior of fishes and other aquatic organisms with their tolerance limit. To tackle those huge projects designs, regulation of the system and analysis of databases skilled manpower will be required and therefore institutional strengthening and capacity building will have to be undertaken by the implementing agencies.

The National Bureau of Fish Genetic Resources (Indian Council of Agricultural Research), Lucknow has undertaken research programmes for generating baseline information on the status of diversity, species composition, abundance, richness, distribution, identification of potential breeding grounds along with assessment and GIS mapping of aquatic microhabitat characteristics of Ken–Betwa river and ex situ conservation measures. This would help to incorporate adequate control measure on the adverse affects from the project—planning phase to various other stages of development and could be useful to quantify the level of species and habitat change/loss after interlinking of Ken–Betwa rivers. It is expected that this study will be helpful for decision making tool for the assessment of factors related to proposed interlinking and conservation and management of fish, ecology and biodiversity.

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