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Inter-Basin Water Transfers: Balancing Water Scarcity Solutions with Environmental and Socio-Economic Impacts from Nepalese Perspective

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Abstract

Inter-basin water transfer (IBWT) involves moving water across drainage divides to address water scarcity, support agriculture, industry, recreation, and generate hydropower. While practiced since ancient times, modern IBWTs gained momentum in the 19th century and have since expanded globally. These projects range from small-scale transfers to large water transfer megaprojects (WTMPs). IBWTs can help mitigate water shortages, enhance food and energy security, and support ecosystem restoration, but also pose risks such as habitat degradation, biodiversity loss, and socio-economic disruptions. Though Nepal has practiced IBWT since the 17th century, the complex environmental and socio-economic consequences observed globally have yet to be fully assessed in the country. Furthermore, a number of IBWTs in the country are in pipeline. Therefore, this review is an attempt to shed light on different aspects of IBWTs including a brief historical perspective; the scale; and to evaluate the environmental and; socio-economic impacts globally and describe the scenario and associated implications in Nepalese context. This study selected articles based on IBTWs, their relevance to environmental impacts, socio-economic effects, and the role of IBWTs. Sources include peer-reviewed journals, government reports, and case studies, focusing on global examples and specific challenges in Nepal. The major findings of this study is that IBWTs are gaining popularity and are becoming important in water-food-energy nexus despite their environmental and socio-economic implications. However, if such projects are undertaken with comprehensive environmental assessments, sustainable water management practices, with inclusive policy frameworks, countries can leverage IBWT projects to meet their growing demands for water, energy, and food, while safeguarding ecological integrity and community welfare.

Keywords: *Environmental impacts, inter-basin water transfer, socio-economy*

Introduction

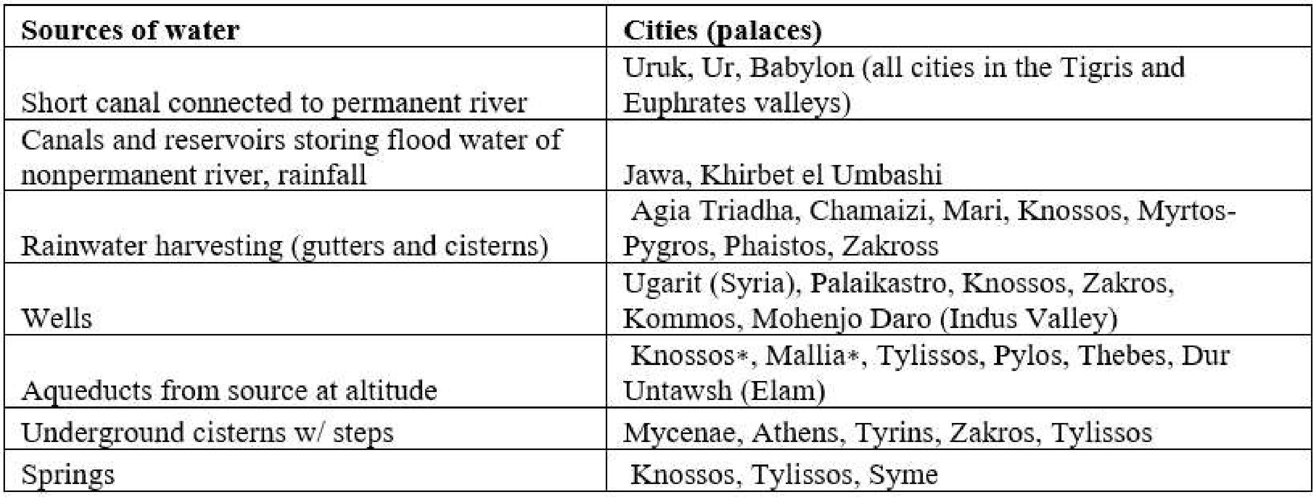
Freshwater ecosystems cover less than 1% of Earth's surface, yet it is incredibly diverse encompassing more than 400 large-scale ecoregions harbouring at least 10% of the earth's species (Grooten & Almond, 2018). Inland waters and freshwater biodiversity constitute a valuable natural resource, in economic, cultural, aesthetic, scientific and educational terms (Arya, 2021). The global distribution of freshwater shows tremendous spatio-temporal variation (Rodell et al., 2018; Wetzel, 2001) attributed to seasons, locations, total precipitation events (Qin et al., 2019; Zhang et al., 2014) along with the magnitude and frequency of extreme climatic events (Kalyan et al., 2021; Yu & Ma, 2022). The present world is facing a lot of challenges to ensure the access of sufficient water resources because of the increasing dependency of human societies on water (Larsen et al., 2016); and non-uniform distribution of freshwater (Somlyódy & Varis, 2006) and climate change (Heino et al., 2009). This is further exacerbated by humans' developmental activities (Cosgrove & Loucks, 2015; Pittock et al., 2009). Humans have explored and developed several ways to minimize the issues of water scarcity such as recycling wastewater, damming rivers, groundwater extraction, cloud seeding, seawater desalination, virtual water trade, inter-basin water transfer, adoption of rain water harvesting technologies, and restoration of wetlands (Hutchinson et al., 2010; Opare, 2012; Zhuang, 2016). Out these different practices, the concept between river basins and implementation of IBWT peaked in the 1980s. IBWT is defined as "the *purposeful arrangement of natural hydrologic patterns via engineering works (dams, reservoirs, tunnels and pumping stations) to move water across drainage divides to satisfy human and other needs*' (Micklin, 1984). Therefore, IBWTs have been recognized as engineering solutions to store, redistribute and treat water resources and involves transfer of excess water over extended distances (Rollason et al., 2021) from geographically separated water-surplus basins to water deficit basins (Golubev & Biswas, 1978; Snaddon et al., 1999) to cater to water needs for irrigation, power generation, industrial development and recreation (Grant et al., 2012; Pittock et al., 2009; Rollason et al., 2021).

Although IBWTs prove to be beneficial, these projects come with price as they can have a number of environmental and socio-economic impacts (Liu et al., 2023). Environmental impacts include change upstream change in water quality; biotic assemblages; hydromorphology whereas the socio-economic impacts include water conflicts, community displacement associated with loss of livelihood (Annys et al., 2019). Despite their environmental and socio-economic implications, IBWTs are on the rise. In this context, this review attempts to shed lights on the brief history of IBWTs, their scales; associated environmental and; socio-economic implications of IBWTs globally with focus in Nepalese context as the latter has a number of IBWTs in pipeline. For this review, a range of peer-reviewed articles; national and international reports were cited relevant to IBWTs.

IBWTs: Past and present

Although IBWTs as modern engineering interventions peaked only in the 1980s (Rollason et al., 2021), different modes of water transfer were already in practice in ancient civilizations in Egypt, Jericho in Jordan, China during 3100 -2100 BC (Liang & Greene, 2019; Snaddon et al., 1999). In ancient Mesopotamia, it was practiced during the Bronze Age as early as 4000-11000 BC where several canals were connected from the Euphrates River for regions of Sumer and Akkad (Mays, 2010; Tamburrino, 2010). In those days, different water transfer practices included transfer through canals, aqueducts, underground cisterns, rainwater harvesting etc. (Table 1)

Table 1: *Sources of water for cities of the early civilizations (4000–1100 B.C.)*



Sources of water	Cities (palaces)
Short canal connected to permanent river	Uruk, Ur, Babylon (all cities in the Tigris and Euphrates valleys)
Canals and reservoirs storing flood water of nonpermanent river, rainfall	Jawa, Khirbet el Umbashi
Rainwater harvesting (gutters and cisterns)	Agia Triadha, Chamaizi, Mari, Knossos, Myrtos-Pygros, Phaistos, Zakross
Wells	Ugarit (Syria), Palaikastro, Knossos, Zakros, Kommos, Mohenjo Daro (Indus Valley)
Aqueducts from source at altitude	Knossos*, Mallia*, Tylissos, Pylos, Thebes, Dur Untawsh (Elam)
Underground cisterns w/ steps	Mycenae, Athens, Tyrins, Zakros, Tylissos
Springs	Knossos, Tylissos, Syme

Source: Ancient Water Technologies 2010.

Australia, the USA and India are considered as the 19th century pioneers of inter-basin water transfer. In Australia, the Goulburn Valley Irrigation Scheme implemented in 1886 is considered as one of the earliest irrigation schemes in the country aimed at diverting water from the Goulburn River to irrigate the fertile Goulburn Valley (Oldham & Moody, 1913). Likewise, in India, the Ganges Canal, completed in 1854, diverted water from the Ganges River to irrigate the fertile Doab region between the Ganges and Yamuna rivers (Lata, 2019). The Erie Canal in the USA completed on October 26, 1825, connected the Great Lakes with the Hudson River, facilitating transportation and commerce (Morton & Olson, 2019). Since then, a number of IBWTs have been developed and implemented in several other countries as well including Israel, Canada (Gleick, 2000; Shiklomanov & Rodda, 2004). In 2005, approximately 14% of the total water withdrawal from rivers in the world involved IBWT and the development of IBWTs; and water transfer in near future is expected to rise by different scales being operated in about 40 countries and regions across the world, with the total annual water transfer amounting to around 500 billion m^3 (Su & Chen, 2021).

Scales of IBWT

Scales of IBWT varies in terms of distance, regions, amount of water being transferred; accordingly, IBWTs maybe long-distance water transfer, inter-regional water transfer, large-scale water transfer, inter-catchment water transfer, inter-basin water transfer and intra-basin water transfer (Fang et al., 2015; Golubev & Biswas, 1978; Purvis & Dinar, 2020; Shumilova et al., 2018; Verma et al., 2009). In recent times, a newer concept on IBWT scale – water transfer megaprojects (WTMPs) - have been developed based on construction costs (>USD1 billion); distance of transfer (>190 km) or volume of water (>0.23 km^3 per year) (Shumilova et al., 2018). There are about 34 existing and 76 future (planned, proposed or under construction) WTMPs globally focusing on agricultural, domestic supply, hydropower development, mining, ecosystem restoration and transformational routes (Shumilova et al., 2018). Some of the notable WTMPs include the California State Water Project (SWP) which is one of the largest state-built water and power development and conveyance systems in the United States. Initiated in 1960 and managed by the California Department of Water Resources with an estimated cost of 9 billon US$, it involved the construction of 1128 km long canal, transferring about of 3.33 km^{3}a^{-1} of water. It provides water to over 27 million people and irrigates approximately 750,000 acres of farmland. It supports both urban and agricultural areas with generating hydroelectric power, contributing to the state's energy supply and helping to offset the project's operational costs (Sabet & Coe, 1986).

Likewise, the South-to-North Water Transfer Project (SNWTP) in China is one of the world's largest and most ambitious water diversion projects. It aims to connect the southern Yangtze River and northern Yellow River with a total of 2,700 miles tunnels and canals via three distinct routes through western, central and eastern China. The SNWTP has already significantly improved water availability in northern China, supporting urban and industrial growth and improving living standards in water-scarce regions (Berkoff, 2003; Miao et al., 2018). The National River Interlinking Project in India is another ambitious WTMP. It was first proposed in the 1970s by K.L. Rao but the project officially started to take shape only in 2002. It aims to divert a staggering 174 Billon m^3 of water through a canal network of 14900 km with an estimated cost US$120 Billon. It aims to connect 37 rivers across the nation through a network of nearly 3000 storage dams to build a gigantic South Asian Water Grid. This project is expected to irrigate around 35 million hectares of land, raising the ultimate irrigation potential from 140 million hectares to 175 million hectares and generation of 34000 megawatts of hydropower, apart from the incidental benefits of flood control, navigation, water supply, fisheries, salinity and pollution control (Alagh et al., 2006; Joshi, 2013). Considering the current global population growth and scarcity of land; but the growing needs of food, water and electricity for growing populations, IBWTs and WTMPs are gaining popularity and are becoming important in water-food-energy nexus.

Impacts of IBWT

IBWTs have been considered beneficial because of their multi-purpose uses and benefits (Laassilia et al., 2021; Sun et al., 2023). However, the current state of knowledge indicates that large dams, along with their positive impacts, inter-basin transfers and water withdrawal have a number of negative impacts on environment (Snaddon et al., 1999; Zhuang, 2016) as well as on economy and communities (Flyvbjerg, 2014; Gupta & van der Zaag, 2008). Any IBWT system can result in complex physical, chemical, hydrological and biological implications for both the donor and receiving basins (Davies et al., 1992). The Aswan High Dam (AHD) of the Nile in Egypt undoubtedly offers prime example of how river damming and diversion have complicating impacts (Biswas & Tortajada, 2011; Kashef, 1981; Zeid, 1989). The nature and the extent of the impacts vary widely depending on the type and characteristics of water transfer, biophysical and socio-economic factors. Positive impacts include adding new basins for water deficient areas (Purvis & Dinar, 2020; Shao et al., 2003), facilitating water cycle (Yano et al., 2018), improving meteorological conditions in the recipient basins (Khadem et al., 2021; Murgatroyd & Hall, 2020), mitigating ecological water shortage (Duan et al., 2022), repairing the damaged ecological system and preserving the endangered wild fauna and flora (Dadaser-Celik et al., 2009; Wang et al., 2014), generating hydroelectric power (Erskine et al., 1999), controlling flood (Khadem et al., 2021), irrigation (Wang et al., 2021), transport routes (Liang & Greene, 2019) and water recreation and tourism (Akron et al., 2017). However, the magnitude of recent water transfer projects in response to fast increased demand has overlooked the severe ecological, environmental, economic and social risks associated with water transfer (Daga et al., 2020; Li et al., 2017). Concerns about the environmental, societal and economic consequences of inter-basin water transfers has been raised in recent periods (Laassilia et al., 2021; Pittock et al., 2009; Wilson et al., 2017; Zhang et al., 2015). A large number of studies have examined the negative impacts of inter-basin water transfers on ecosystem impacts and socio-economic disruptions such as forest depletion, soil and water contamination, waterborne diseases, livelihood, human displacement and migration (Bui et al., 2020; Das, 2006; Gallardo & Aldridge, 2018; Gleick, 1993). Following sections briefly summarize the environmental and socio-economic impacts of IBWTs.

Environmental impacts

Environmental impacts of IBWT are mostly attributed to change in natural flow(Zhuang, 2016) and include change in different physico-chemical and biological parameters of both donor and recipient basins and water bodies. Global reviews on the negative impacts of IBWTs have revealed implications on terrestrial dynamics; biodiversity and water quality (Ghassemi & White, 2007; Snaddon et al., 1998; Snaddon et al., 1999; Zhuang, 2016).

Impacts on physico-chemical parameters

Changes in natural flow affects a range of water physico-chemical parameters such as water temperature, salinity, turbidity, erosion, sedimentation, waterlogging, mineral and nutrient concentrations, hydrology, oxygenation, inorganic substrate composition, sediment dynamics, land use changes in both donor and recipient basins (de Lucena Barbosa et al., 2021; Gallardo & Aldridge, 2018; Marak et al., 2020; Tian et al., 2019). The change in the flow conditions of rivers and lakes in the receiving basin although can lead to increased water levels but it can also cause potential flooding in areas adjacent to the water bodies (de Lucena Barbosa et.al., 2021). Furthermore, changes in flow can also affect the pattern and magnitude of sediment transport and deposition (Hamidifar, 2024). Likewise, changes in natural flow affect riparian eco-system health as it diminishes the water bodies' ability to assimilate pollutants and thus cause pollution, eutrophication, salinization and acidification (Zhuang, 2016). The transfer of water between basins can also introduce new geochemical elements and compounds into the receiving basin. This can affect the mineral composition of the water and sediments, potentially leading to changes in the aquatic chemistry (Jiao et.al., 2021). For instance, water transfer from the Yellow River to the Fen River in China has resulted in increase in the concentrations of Na^+ and Cl^+ ions along with increased conductivity values in the Fen River (Yuan et al., 2020). Apart from these, IBWTs result changes in water levels; and renewal rates decline in downstream main channels (Pittock et al., 2009); disrupt river connectivity and; flood plains and channels connectivity (Bunn & Arthington, 2002; Grant et al., 2012). Changes in water transparency, nutrient and sediment loads, channel morphology and granulometry are some of the long-term physico-chemical effects of dams on environments downstream (Granzotti et al., 2018; Kamidis et al., 2021; Szatten et al., 2021; Yang et al., 2021), potentially leading to long-term nutrient loading (He et al., 2020; Stockner et al., 2000).

Impact on aquatic organisms

The changes in the physico-chemical parameters associated with IBWTs in turn affect the biological parameters and almost all groups of biotas are affected (Rehman et al., 2015; Sharma et al., 2016). Sediment deposition can result in excessive algal growth thereby compromising water quality resulting in eutrophication; affect the food web; alter habitats for organisms (Glibert & Burford 2017; Li et.al., 2023). The changes in water quality and hydrology can have cascading effects on the aquatic ecosystems and the associated biota (Li et.al., 2023).

Fish assemblages are one of the most affected communities due to IBWTs. A large number of studies have revealed change in fish assemblages both in the donor and recipient basins (Gallardo & Aldridge, 2018; Schmidt et al., 2020). IBWTs affect fish assemblages through isolation, alteration and degradation of habitats, blockade of migratory routes, change in nutrient concentrations and food webs, flow and temperature (Ghassemi & White, 2007; Snaddon et al., 1998). Habitat alteration and degradation are resulted because of the disruption of the river continuum (Doretto et al., 2020; Ward & Stanford, 1995) followed by drowning of channel and erosion of riparian habitats which often act as fish spawning pockets (Ghassemi & White, 2007). In addition, introduction of invasive species during IBWTs and spread of diseases also affect the fish assemblages. There are several reports of loss of native species and establishment of invasive/exotic species which are likely to be established in altered habitats (Dudgeon et al., 2006; Gallardo & Aldridge, 2018). Isolation of fish assemblages and populations can increase competition among the resident species for food and breeding sites (Andrades et al., 2021; Belmaker et al., 2005). It may also lead to decrease in genetic diversity and therefore puts species at greater risk from disease, altered predation pressure, behavioral changes and increased vulnerability to environmental changes (Coleman et al., 2018; Kano et al., 2016; Lymbery et al., 2020; Ruzich et al., 2019). Furthermore, long-term isolation could lead to interspecific hybridization and thus have serious consequences on fish biota genetic diversity particularly the native species (Allendorf et al., 2001). Studies suggest that reduction in the nutrient concentrations in reservoirs due to damming affect food webs resulting in the change in the structure of primary producer communities, detritivores as well as the consumers (Maavara et al., 2020; Macura et al., 2019; Wang et al., 2022). If fish movement occurs, it can lead to invasion or altered regional connectivity patterns, spread of non-native species which could induce biotic and genetic homogenization or synchronization (Li et al., 2022; Schmidt et al., 2020; Shao et al., 2019). In contrast, habitat alterations may favour introduce invasive species in recipient basins. For instance, five new fish species (*Labeobarbus aeneus*, *Clarias gariepinus*, *Labeo capensis*, *Austroglanis sclateri* and *Labeo umbratus*) have been transferred to the Great Fish River in the Eastern Cape from the Orange Orange/Vaal River (Zhang et al., 2015). Likewise, fish species like *Gobio gobio*, has been introduced into the Segura River from the donor Tajo River in Spain; *Catostomus fumeiventris*, was transferred to the Los Angeles Basin from northern donor rivers (Snaddon et al., 1999). The introduced species can become invasive and eliminate native fauna through predation, competition, and higher reproductive success (Mayfield et al., 2021). Furthermore, the invasive species can modify the behaviour (such as habitat usage, diel activity) of the native species. Thus, invasive species can have negative impacts on the native species attributed to disruption of food webs, loss of biodiversity, hybridization and spread disease (Bernery et al., 2022; Ellender & Weyl, 2014; Olden et al., 2022).

Impacts on macroinvertebrates include loss of headwater species (Clarke et al., 2008; Guerold et al., 2000), hindering of macroinvertebrate passage along a stream/river stretch (Guareschi et al., 2014), decreased macro-benthic diversity (Rolls et al., 2012), change in food webs (Murphy et al., 2019; Panikkar et al., 2021; van der Zee et al., 2016) and eventually altering the community composition (Ko et al., 2020). For instance, dominant Chironomidae, Hydropsychidae and Simuliidae taxa were replaced by *Simulium chutteri* in Great Fish River from Orange River, South Africa (O'keeffe & De Moor, 1988). Change in relative abundance of different functional feeding groups of macroinvertebrates have also been reported by several authors with increased abundance of scrapers and collector filterers (Brittain & Saltveit, 1989; Vallania & Corigliano, 2007). Thus, it is evident that IBWTs affect macro-benthic communities by changing the latter's assemblages.

Socio-economic impacts

Apart from the environmental impacts, IBWTs also have upstream as well as downstream socio-economic impacts (Liu et al., 2023; Snaddon et al., 1998). The socio-economic impacts vary from individual impacts to entire community and society attributed to construction work, influx of people and increased fringe urbanization (Mutanga et al., 2013). Individual impacts include loss of one's property and livelihood whereas impacts on communities include displacement of people and their homes, disturbance and loss of local livelihoods, loss of productive farmland, loss of cultural heritage sites and monuments, health hazards etc. (Das, 2006; Pittock et al., 2009; Zhuang, 2016).

Upstream communities relying on agriculture sector on donor basins often face negative consequences on their agricultural economy due to reduced quality and quantity of water (Gichuki & McCornick, 2008). Conflicts may arise mostly due to disputes in water sharing though other factors such as increased pollution has also been reported as a causal factor (Guardiola-Avila et al., 2018; Madani et al., 2011). Such conflicts may be global, regional or local depending on the scale, extent and impacts of IBWTs (Hernández-Mora et al., 2014; Yevjevich, 2001). For instance, construction of a dam on Ethiopian Nile resulted in conflicts between the neighbouring countries of Egypt, Sudan and other upstream nations (Madani et al., 2011); construction of the Farakka Barrage on the Ganges has resulted conflicts between Bangladesh and India as it compromised water availability and water demand for Bangladesh (Islam, 2012). The South-North Water Diversion Project (SNWDP) is one of the most recent transboundary water disputes over water sharing of the Brahmaputra River between the neighbouring countries of India and China (Ho et al., 2019).

IBWTs in Nepalese Scenario: Past, Present and Future

In the context of Nepal, the history of river diversion dates back to 17th century during the Malla regimes, when

1990; Parajuli & Sharma, 2003). A number of such canals still exist in different parts of the country such as Tikabhairav, Bageswori, Budhikanta Canal etc (Shrestha & Dahal, 2020). The first large water transfer project was constructed in 1923 AD and completed in 1928 AD which drew water from the Triyuga River in Udaipur District (Pradhan, 1989). However, the idea of large water transfer projects dates back only to the 1970s when the Government of Nepal commissioned a study to explore the Babai Irrigation Project to irrigate fertile land on the western plains of Nepal during the non-monsoon period. It involved the construction of highway weir cum bridge over the Babai River at Parewa Odar in western Nepal. A 5.5 km canal was constructed and it started feeding the traditional canals -Budhi *kulo*, Majro *Kulo*, Raj *Kulo* and Dhadhawar *Kulo* - and the water irrigated about 4000 ha land on the western plains during the non-monsoon period (GoN/BIP, 2001). Similarly, the Kulekhani Storage Hydropower project is the only storage-type hydropower project of Nepal which is the first project that transfers water from Kulekhani river of Bagmati basin to East Rapti river of Gandaki Basin (Pradhan et al., 2012).

The Government of Nepal (GoN) guided by the National Planning Commission has initiated more than 20 ambitious infrastructural developmental projects as National Pride Projects to enhance the quality of life in terms of social, economic, cultural and environmental aspects (GoN/NPC, 2022). These projects are strategically important for the development of different sectors viz. hydroelectricity, irrigation, transportation, tourism, cultures & religion, etc. Infrastructural development to improve socio-economic status of the country is a national agenda in Fifth Year Plan (GoN/NPC, 2020). With rich freshwater resources (WECS, 2011), Nepal has huge potential for hydropower generation, the and to expand irrigation (ADB, 2018; GoN/DWRI, 2019). Irrigation is given a third priority by the Water Resources Act (1992) after the use of water for drinking and domestic purposes. This clearly signifies the importance of irrigation to boost agriculture and achieve food security. Thus, water resource-based infrastructural development is being considered as an important component of food-water-energy nexus in the country. The Bheri-Babai Diversion Multi-purpose Project (BBDMP) is one such national pride project and construction began only in 2015 where water from the Bheri River is being diverted to the Babai River via a 12.3 km transfer with design flow of 40.0 m^3/s (GoN/BBDMP, 2018). The Sunkoshi Marin Diversion Multipurpose Project (SMDMP) is another IBWT project and the construction began in 2022 where water from the Sunkoshi River to the Marin River, a tributary of the Bagmati River transferred via a 13.3 km long tunnel which generate 31.07 MW of electricity (GoN/SMDMP, 2022)(GoN/SMDMP, 2022). Likewise, the Melamchi Water Supply Project (MWSP) was initiated by the Government of Nepal to divert a water volume of 1,70,200 m^3 /day through a 26 km underground tunnel from the Melamchi River (Koshi Basin) to Kathmandu Valley (Bagmati Basin) to ease the chronic water shortage situation within the Kathmandu Valley (Bhattarai et al., 2005). The project has been delivering water in the Valley through a temporary structure for certain months in a year. A number of IBWT projects in the country are in pipeline focusing on irrigation and hydropower generation (GoN/DWRI, 2019) (Table 2). However, the likely environmental and socio-economic impacts of these projects are yet to be observed and assessed. Migratory routes of fish species like *Tor putitora*, *Tor tor*, *Bagarius bagarius*, *Clupisoma gaura* and *Anguilla bengalensis* from many rivers have been reported to be affected by damming in the country (ADB, 2018). A recent baseline study on fish assemblages of the Bheri and the Babai at the diversion and release sites respectively failed to capture migratory species like *Anguilla bengalensis* implies that migratory routes of the species may well have already affected by the Babai Dam Weir cum Bridge at Parewa Odar at the Babai River constructed in 1993 (Khatri et al., 2024)

Table 2: Some IBWTs in Nepalese context

Name of Project	**Feature**	**Donor/Recipient Rivers/basins**
Karnali Diversion Project	19 km length tunnel (59 m^3/s), 80MW, for irrigation of about 46,000 ha	Karnali River to Mohana River
Madi-Dang Diversion Project	25 km length tunnel (24 m^3/s),61MW, for irrigation of about 17,000 ha	Madi River to Dang valley
Naumure Dam: Rapti-Kapilvastu Diversion Project	23 km length tunnel, 343MW, for irrigation of about 40,849 ha	West Rapti River to Kapilvastu
Kaligandaki-Tinau Diversion Project	25 km length tunnel (66 m^3/s),244MW, for irrigation of about 62,000 ha	Kaligandaki River to Rupandehi District,
Kaligandaki Nawalparasi Diversion Project	6 km length tunnel (17 m^3/s), 4mw, for irrigation of about11,500 ha)	Kaligandaki River-Nawalparasi- East District
Trishuli Shaktikhor Diversion Project	18 km tunnel (51m^3/s) (No hydropower production), for irrigation of about 13,000 ha.	Trishuli River to Chitwan District
Sunkoshi Diversion Project	a). 14 km length tunnel (77 m^3/s), 33MW, for irrigation of about 55,000 ha,	Sunkoshi River to the Marin Rivers
	b). 17 km length tunnel (72 m^3/s), 44MW, for irrigation of about 129,000 ha	Sunkoshi River to the Kamala Rivers
Tamor Morang Diversion Project	a). 31 km length tunnel, 90MW, for irrigation of about 45,000 ha in Morang District	Tamor River to the Chisang River
Kankai Multipurpose Project	Dam at Kankaimai River of 85-meter height,80MW, for irrigation of about 40,000 ha in Jhapa District	Kankaimai to Jhapa District
Chatara Barrage Project	Construction of Barrage at Koshi River (No hydropwer production), for irrigation of about 66,000 ha on Saptari District.	Koshi River at Chatara to Saptari District
Seti-Pandul Diversion Project	42 km length tunnel, 280 MW), for irrigation of about 300,000 ha.	Karnali Basin

Conclusion

Inter-basin water transfers (IBWT) serve as crucial solutions for addressing water scarcity, electricity generation, supporting agricultural and industrial demands, enhancing energy security and socio-economic upliftment. However, the review highlights that these projects often come with significant trade-offs, including habitat disruption, biodiversity loss, and socio-economic displacement. While IBWTs contribute to regional development by redistributing water resources, they can also lead to habitat alteration, biodiversity loss, and socio-economic disruptions, particularly affecting upstream and downstream communities. In Nepal, the implementation of IBWTs dates back to the 17th century and categorization of recent water resource-based infrastructural developments as national pride projects by the government suggests that roles IBWTs would play in socio-economy of the country is significant. However, the global evidence of IBWT's complex environmental and socio-economic consequences necessitates careful consideration before implementation in the Nepalese context. This review underscores the need for comprehensive environmental assessments, sustainable water management practices, and inclusive policy frameworks to mitigate the risks associated with IBWT projects. By balancing the potential benefits with the associated challenges, countries can leverage IBWT projects to meet their growing demands for water, energy, and food, while safeguarding ecological integrity and community welfare.

References

ADB. (2018). *Impact of Dams on Fish in the Rivers of Nepal*. Asian Development Bank. https://doi.org/10.22617/TCS189802

Akron, A., Ghermandi, A., Dayan, T., & Hershkovitz, Y. (2017). Interbasin water transfer for the rehabilitation of a transboundary Mediterranean stream: An economic analysis. *Journal of Environmental Management, 202*, 276-286. https://doi.org/10.1016/j.jenvman.2017.07.043

Alagh, Y. K., Pangare, G., & Gujja, B. (2006). *Interlinking of rivers in India: overview and Ken-Betwa link*. Academic Foundation

Allendorf, F. W., Leary, R. F., Spruell, P., & Wenburg, J. K. (2001). The problems with hybrids: setting conservation guidelines. *Trends in ecology & evolution, 16*(11), 613-622. https://doi.org/10.1016/S0169-5347(01)02290-X

Andrades, R., Joyeux, J.-C., Macieira, R. M., Godoy, B. S., Reis-Filho, J. A., Jackson, A. L., & Giarrizzo, T. (2021). Niche-Relationships Within and Among Intertidal Reef Fish Species. *Frontiers in Marine Science, 8*, 659579. https://doi.org/10.3389/fmars.2021.659579

Annys, S., Adgo, E., Ghebreyohannes, T., Van Passel, S., Dessein, J., & Nyssen, J. (2019). Impacts of the hydropower-controlled Tana-Beles interbasin water transfer on downstream rural livelihoods (northwest Ethiopia). Journal of Hydrology, 569, 436-448. https://doi.org/10.1016/j.jhydrol.2018.12.012

Arya, S. (2021). Freshwater biodiversity and conservation challenges: A review. *International Journal of Biological Innovations, 3*(1). https://doi.org/10.46505/IJBI.2021.3106

Becker-Ritterspach, R. (1990). Dhunge-dharas in the Kathmandu Valley: an outline of their architectural development. *Journal of the Department of Archaeology, 116-118*, 1-9.

Belmaker, J., Shashar, N., & Ziv, Y. (2005). Effects of small-scale isolation and predation on fish diversity on experimental reefs. *Marine Ecology Progress Series, 289*, 273-283. https://doi.org/10.3354/meps289273

Berkoff, J. (2003). China: the south–north water transfer project—is it justified? *Water Policy, 5*(1), 1-28.

Bernery, C., Bellard, C., Courchamp, F., Brosse, S., Gozlan, R. E., Jarić, I., Teletchea, F., & Leroy, B. (2022). Freshwater fish invasions: A comprehensive review. *Annual Review of Ecology, Evolution, and Systematics, 53*, 427-456. https://doi.org/10.1146/annurev-ecolsys-032522-015551

Bhattarai, M., Pant, D., & Molden, D. (2005). Socio-economics and hydrological impacts of melamchi intersectoral and interbasin water transfer project, Nepal. *Water Policy, 7*(2), 163-180. https://doi.org/10.2166/wp.2005.0011

Biswas, A. K., & Tortajada, C. (2011). Impacts of the high Aswan Dam. In *Impacts of large dams: A global assessment* (pp. 379-395). Springer.

Brittain, J. E., & Saltveit, S. J. (1989). A review of the effect of river regulation on mayflies (Ephemeroptera). *Regulated rivers: research & management, 3*(1), 191-204. https://doi.org/10.1002/rrr.3450030119

Bui, D. T., Asl, D. T., Ghanavati, E., Al-Ansari, N., Khezri, S., Chapi, K., Amini, A., & Thai Pham, B. (2020). Effects of inter-basin water transfer on water flow condition of destination basin. *Sustainability, 12*(1), 338. https://doi.org/10.3390/su12010338

Bunn, S. E., & Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental management, 30*(4), 492-507. https://doi.org/10.1007/s00267-002-2737-0

Clarke, A., Mac Nally, R., Bond, N., & Lake, P. S. (2008). Macroinvertebrate diversity in headwater streams: a review. *Freshwater Biology, 53*(9), 1707-1721. https://doi.org/10.1111/j.1365-2427.2008.02041.x

Coleman, R. A., Gauffre, B., Pavlova, A., Beheregaray, L. B., Kearns, J., Lyon, J., Sasaki, M., Leblois, R., Sgro, C., & Sunnucks, P. (2018). Artificial barriers prevent genetic recovery of small isolated populations of a low-mobility freshwater fish. *Heredity, 120*(6), 515-532. https://doi.org/10.1038/s41437-017-0008-3

Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges and research directions. *Water Resources Research, 51*(6), 4823-4839. https://doi.org/10.1002/2014wr016869

Dadaser-Celik, F., Coggins, J. S., Brezonik, P. L., & Stefan, H. G. (2009). The projected costs and benefits of water diversion from and to the Sultan Marshes (Turkey). *Ecological Economics, 68*(5), 1496-1506. https://doi.org/10.1016/j.ecolecon.2008.10.012

Daga, V. S., Azevedo-Santos, V. M., Pelicice, F. M., Fearnside, P. M., Perbiche-Neves, G., Paschoal, L. R., Cavallari, D. C., Erickson, J., Ruocco, A., & Oliveira, I. (2020). Water diversion in Brazil threatens biodiversity. *Ambio, 49*(1), 165-172. https://doi.org/10.1080/03610928808829784

Das, D. K. (2006). Environmental impact of inter-basin water transfer projects: some evidence from Canada.

Davies, B. R., Thoms, M., & Meador, M. (1992). An assessment of the ecological impacts of inter-basin water transfers, and their threats to river basin integrity and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems, 2*(4), 325-349. https://doi.org/10.1002/aqc.3270020404

de Lucena Barbosa, J. E., dos Santos Severiano, J., Cavalcante, H., de Lucena-Silva, D., Mendes, C. F., Barbosa, V. V., dos Santos Silva, R. D., de Oliveira, D. A., & Molozzi, J. (2021). Impacts of inter-basin water transfer on the water quality of receiving reservoirs in a tropical semi-arid region. *Hydrobiologia, 848*(3), 651-673. https://doi.org/10.1007/s10750-020-04471-z

Doretto, A., Piano, E., & Larson, C. E. (2020). The River Continuum Concept: lessons from the past and perspectives for the future. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(11), 1853-1864. https://doi.org/10.1139/cjfas-2020-0039

Duan, K., Caldwell, P. V., Sun, G., McNulty, S. G., Qin, Y., Chen, X., & Liu, N. (2022). Climate change challenges efficiency of inter-basin water transfers in alleviating water stress. *Environmental Research Letters, 17*(4), 044050. https://doi.org/10.1088/1748-9326/ac5e68

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A.-H., Soto, D., & Stiassny, M. L. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews, 81*(2), 163-182. https://doi.org/10.1017/S1464793105006950

Ellender, B. R., & Weyl, O. L. (2014). A review of current knowledge, risk and ecological impacts associated with non-native freshwater fish introductions in South Africa. *Aquatic Invasions, 9*(2), 117-132. https://doi.org/10.3391/ai.2014.9.2.01

Erskine, W. D., Terrazzolo, N., & Warner, R. (1999). River rehabilitation from the hydrogeomorphic impacts of a large hydro-electric power project: Snowy River, Australia. *Regulated rivers: research & management, 15*(1-3), 3-24. https://doi.org/10.1002/(SICI)1099-1646(199901/06)15:1/3<3::AID-RRR532>3.0.CO;2-R

Fang, X., Roe, T. L., & Smith, R. B. (2015). Water shortages, intersectoral water allocation and economic growth: the case of China. *China Agricultural Economic Review, 7*(1), 2-26. https://doi.org/10.1108/CAER-02-2014-0014

Flyvbjerg, B. (2014). What you should know about megaprojects and why: An overview. *Project management journal, 45*(2), 6-19. https://doi.org/10.1002/pmj.214

Gallardo, B., & Aldridge, D. C. (2018). Inter-basin water transfers and the expansion of aquatic invasive species. *Water research, 143*, 282-291. https://doi.org/10.1016/j.watres.2018.06.056

Ghassemi, F., & White, I. (2007). *Inter-basin water transfer: case studies from Australia, United States, Canada, China and India*. Cambridge University Press.

Gichuki, F., & McCornick, P. G. (2008). *International experiences of water tranfers: Relevance to India* Strategic Analyses of the National River Linking Project (NRLP) of India Series 2,

Gleick, P. H. (1993). *Water in crisis* (Vol. 100). New York: Oxford University Press.

Gleick, P. H. (2000). A look at twenty-first century water resources development. *Water International, 25*(1), 127-138. https://doi.org/10.1080/02508060008686804

Glibert, P. M., & Burford, M. A. (2017). Globally changing nutrient loads and harmful algal blooms: recent advances, new paradigms, and continuing challenges. *Oceanography, 30*(1), 58-69.

Golubev, G., & Biswas, A. K. (1978). Interregional water transfers. *Water Supply & Management, 2*, 59-65.

GoN/BBDMP. (2018). *Government of Nepal. Babai Bheri Diversion Multipurpose Project.* Retrieved 22 January from http://www.bbdmp.gov.np

GoN/BIP. (2001). *Government of Nepal. Babai Irrigation Project*. Retrieved 22 April from http://www.babaiip.gov.np/

GoN/DWRI. (2019). Irrigation Master Plan 2019.

GoN/NPC. (2020). The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24).Government of Nepal.

National Planning Commission, Singha Durbar, Kathmandu.

GoN/NPC. (2022). *National Pride Projects. Goverment of Nepal, National Planning Commission. Singha Durbar, Kathmandu.* Retrieved 14 th Nov 2022 from https://npc.gov.np/en/page/national_pride_projects

GoN/SMDMP. (2022). *Sunkoshi Marin Diversion Multipurpose Project (SMDMP)*. Retrieved 15 Jan from https://smdmp.gov.np/

Grant, E. H., Lynch, H. J., Muneepeerakul, R., Arunachalam, M., Rodriguez-Iturbe, I., & Fagan, W. F. (2012). Interbasin water transfer, riverine connectivity, and spatial controls on fish biodiversity. *PLoS One, 7*(3), e34170. https://doi.org/10.1371/journal.pone.0034170 shifts in benthic invertivorous fish assemblages. *Aquatic Sciences, 80*(3), 28. https://doi.org/10.1007/s00027-018-0579-y

Grooten, M., & Almond, R. E. (2018). *Living planet report-2018: aiming higher*. WWF international.

Guardiola-Avila, I., Martínez-Vázquez, V., Requena-Castro, R., Juárez-Rendón, K., Aguilera-Arreola, M., Rivera, G., & Bocanegra-García, V. (2018). Isolation and identification of Vibrio species in the Rio Bravo/Grande and water bodies from Reynosa, Tamaulipas. *Letters in applied microbiology, 67*(2), 190-196.

Guareschi, S., Laini, A., Racchetti, E., Bo, T., Fenoglio, S., & Bartoli, M. (2014). How do hydromorphological constraints and regulated flows govern macroinvertebrate communities along an entire lowland river? *Ecohydrology, 7*(2), 366-377. https://doi.org/10.1002/eco.1354

Guerold, F., Boudot, J.-P., Jacquemin, G., Vein, D., Merlet, D., & Rouiller, J. (2000). Macroinvertebrate community loss as a result of headwater stream acidification in the Vosges Mountains (NE France). *Biodiversity & Conservation, 9*(6), 767-783. https://doi.org/10.1023/A:1008994122865

Gupta, J., & van der Zaag, P. (2008). Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. *Physics and Chemistry of the Earth, Parts A/B/C, 33*(1), 28-40. https://doi.org/10.1016/j.pce.2007.04.003

Hamidifar, H., Nones, M., & Rowinski, P. M. (2024). Flood modeling and fluvial dynamics: A scoping review on the role of sediment transport. *Earth-Science Reviews, 253*, 104775. https://doi.org/https://doi.org/10.1016/j.earscirev.2024.104775

He, T., Deng, Y., Tuo, Y., Yang, Y., & Liang, N. (2020). Impact of the dam construction on the downstream thermal conditions of the Yangtze River. *International journal of environmental research and public health, 17*(8). https://doi.org/10.3390/ijerph17082973

Heino, J., Virkkala, R., & Toivonen, H. (2009). Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. *Biological reviews, 84*(1), 39-54. https://doi.org/10.1111/j.1469-185X.2008.00060.x

Hernández-Mora, N., del Moral Ituarte, L., La-Roca, F., La Calle, A., & Schmidt, G. (2014). Interbasin water transfers in Spain: Interregional conflicts and governance responses. In *Globalized water* (pp. 175-194). Springer.

Ho, S., Neng, Q., & Yifei, Y. (2019). The Role of Ideas in the China–India Water Dispute. *The Chinese Journal of International Politics, 12*(2), 263-294. https://doi.org/10.1093/cjip/poz005

Hutchinson, C. F., Varady, R. G., & Drake, S. (2010). Old and New: Changing Paradigms in Arid Lands Water Management. In G. Schneier-Madanes & M.-F. Courel (Eds.), *Water and Sustainability in Arid Regions: Bridging the Gap Between Physical and Social Sciences* (pp. 311-332). Springer Netherlands. https://doi.org/10.1007/978-90-481-2776-4_19

Islam, S. (2012). Bangladesh-India water sharing disputes: possible policy responses. *Journal of Bangladesh Studies, 14*(1), 38-49.

Jiao, L., Liu, R., Wang, L., Li, L., & Cao, L. (2021). Evaluating Spatiotemporal Variations in the Impact of Inter-basin Water Transfer Projects in Water-receiving Basin. *Water Resources Management, 35*(15), 5409-5429. https://doi.org/10.1007/s11269-021-03011-1

Joshi, N. M. (2013). National river linking project of India. *Hydro Nepal, 12*, 13-19.

Kalyan, A., Ghose, D. K., Thalagapu, R., Guntu, R. K., Agarwal, A., Kurths, J., & Rathinasamy, M. (2021). Multiscale spatiotemporal analysis of extreme events in the Gomati River Basin, India. *Atmosphere, 12*(4), 480.

Kamidis, N., Koutrakis, E., Sapounidis, A., & Sylaios, G. (2021). Impact of River Damming on Downstream Hydrology and Hydrochemistry: The Case of Lower Nestos River Catchment (NE. Greece). *Water, 13*(20), 2832. https://www.mdpi.com/2073-4441/13/20/2832

Kano, Y., Dudgeon, D., Nam, S., Samejima, H., Watanabe, K., Grudpan, C., Grudpan, J., Magtoon, W., Musikasinthorn, P., & Nguyen, P. T. (2016). Impacts of dams and global warming on fish biodiversity in the Indo-Burma hotspot. *PLoS One, 11*(8), e0160151. https://doi.org/10.1371/journal.pone.0160151

Kashef, A.-A. I. (1981). Technical and ecological impacts of the High Aswan Dam. *Journal of Hydrology, 53*(1-2), 73-84.

Khadem, M., Dawson, R. J., & Walsh, C. L. (2021). The feasibility of inter-basin water transfers to manage climate risk in England. *Climate Risk Management, 33*, 100322. https://doi.org/10.1016/j.crm.2021.100322

Ko, N. T., Suter, P., Conallin, J., Rutten, M., & Bogaard, T. (2020). Aquatic macroinvertebrate community changes downstream of the hydropower generating dams in myanmar-potential negative impacts from

Khatri, K., Jha, B. R., Gurung, S., & Khadka, U. R. (2024). Freshwater fish diversity and IUCN Red List status of glacial-fed (Bheri) and spring-fed (Babai) rivers in the wake of inter-basin water transfer. *Journal of threatened Taxa, 16*(1), 24535-24549.

Laassilia, O., Ouazar, D., Bouziane, A., & Hasnaoui, M. D. (2021). Justification criteria for inter-basin water transfer projects. E3S Web of Conferences,

Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. *Science, 352*(6288), 928-933. https://doi.org/10.1126/science.aad8641

Lata, S. (2019). *Irrigation water management for agricultural development in Uttar Pradesh, India*. Springer.

Li, H., Ding, L., Ren, M., Li, C., & Wang, H. (2017). Sponge City Construction in China: A Survey of the Challenges and Opportunities. *Water, 9*(9), 594. https://www.mdpi.com/2073-4441/9/9/594

Li, Q., Zhang, Y., Wang, R., Chu, L., Li, Y., & Yan, Y. (2022). Low-head dams induce biotic homogenization/differentiation of fish assemblages in subtropical streams. *Ecology and Evolution, 12*(8), e9156. https://doi.org/10.1002/ece3.9156

Li, L., Wang, L., Liu, R., Cao, L., Wang, Y., & Liu, Y. (2023). Evaluating the impacts of inter-basin water transfer projects on ecosystem services in the Fenhe River Basin using the SWAT model. Environmental Monitoring and Assessment, 195(4), 455.

Liang, S., & Greene, R. (2019). Inter-Basin Water Diversion Projects and Inland Waterways: The Case of the Eurasian Grasslands. *International Journal of Environmental Sciences & Natural Resources, 22*(4), 138-147. https://doi.org/10.19080/IJESNR.2019.22.556094

Liu, Y., Xin, Z., Sun, S., Zhang, C., & Fu, G. (2023). Assessing environmental, economic, and social impacts of inter-basin water transfer in China. *Journal of Hydrology, 625*, 130008.

Lymbery, A. J., Lymbery, S. J., & Beatty, S. J. (2020). Fish out of water: aquatic parasites in a drying world. *International Journal for Parasitology: Parasites and Wildlife, 12*, 300-307. https://doi.org/10.1016/j.ijppaw.2020.05.003

Maavara, T., Chen, Q., Van Meter, K., Brown, L. E., Zhang, J., Ni, J., & Zarfl, C. (2020). River dam impacts on biogeochemical cycling. *Nature Reviews Earth & Environment, 1*(2), 103-116. https://doi.org/10.1038/s43017-019-0019-0

Macura, B., Byström, P., Airoldi, L., Eriksson, B. K., Rudstam, L., & Støttrup, J. G. (2019). Impact of structural habitat modifications in coastal temperate systems on fish recruitment: a systematic review. *Environmental Evidence, 8*(1), 1-22. https://doi.org/10.1186/s13750-019-0157-3

Madani, K., Rheinheimer, D., Elimam, L., & Connell-Buck, C. (2011). A game theory approach to understanding the Nile River Basin conflict. In K. M. Person (Ed.), *A Water Resource' Festschrift in Honor of Professor Lars Bengtsson* (pp. 97-114). Lund University.

Marak, J. D. K., Sarma, A. K., & Bhattacharjya, R. K. (2020). Assessing the impacts of interbasin water transfer reservoir on streamflow. *Journal of Hydrologic Engineering, 25*(10), 05020034.

Mayfield, A. E., Seybold, S. J., Haag, W. R., Johnson, M. T., Kerns, B. K., Kilgo, J. C., Larkin, D. J., Lucardi, R. D., Moltzan, B. D., & Pearson, D. E. (2021). Impacts of invasive species in terrestrial and aquatic systems in the United States. In T. M. Poland, T. Patel-Weynand, D. M. Finch, C. F. Miniat, D. C. Hayes, & V. M. Lopez (Eds.), *Invasive Species in Forests and Rangelands of the United States* (pp. 5-39). Springer, Cham.

Mays, L. (2010). *Ancient water technologies*. Springer.

Miao, Z., Sheng, J., Webber, M., Baležentis, T., Geng, Y., & Zhou, W. (2018). Measuring water use performance in the cities along China's South-North Water Transfer Project. *Applied Geography, 98*, 184-200.

Micklin, P. P. (1984). Inter-basin water transfers in the United States. *International Journal of Water Resources Development, 2*(2-3), 37-65. https://doi.org/10.1080/07900628408722314

Morton, L. W., & Olson, K. R. (2019). Corridor of migration, navigation, and innovation: The New York State Canal System. *Journal of Soil and Water Conservation, 74*(5), 102A-108A.

Murgatroyd, A., & Hall, J. W. (2020). The Resilience of Inter-basin Transfers to Severe Droughts With Changing Spatial Characteristics [Original Research]. *Frontiers in Environmental Science, 8*. https://doi.org/10.3389/fenvs.2020.571647

Murphy, C. A., Arismendi, I., Taylor, G. A., & Johnson, S. L. (2019). Evidence for lasting alterations to aquatic food webs with short-duration reservoir draining. *PLoS One, 14*(2), e0211870. https://doi.org/10.1371/journal.pone.0211870

Mutanga, S. S., Simelane, T., & Pophiwa, N. (2013). *Africa in a Changing Global Environment: Perspectives*

O'keeffe, J., & De Moor, F. (1988). Changes in the physico-chemistry and benthic invertebrates of the Great Fish River, South Africa, following an interbasin transfer of water. *Regulated rivers: research & management, 2*(1), 39-55. https://doi.org/10.1002/rrr.3450020105

Olden, J. D., Chen, K., García-Berthou, E., King, A. J., South, J., & Vitule, J. R. S. (2022). Invasive Species in Streams and Rivers. In T. Mehner & K. Tockner (Eds.), *Encyclopedia of Inland Waters (Second Edition)* (pp. 436-452). Elsevier. https://doi.org/10.1016/B978-0-12-819166-8.00083-9

Oldham, H., & Moody, J. F. (1913). *Irrigation and Water Conservation in Western Australia*. A. Curtis, acting government printer.

Opare, S. (2012). Rainwater harvesting: an option for sustainable rural water supply in Ghana. *GeoJournal, 77*, 695-705. https://doi.org/10.1007/s10708-011-9418-6

Panikkar, P., Khan, F., Sarkar, U., & Das, B. (2021). Changing foodwebs of Indian aquatic ecosystems under the threats of invasive species: An overview. *Aquatic Ecosystem Health and Management, 24*, 24–32. https://doi.org/10.14321/aehm.024.02.06

Parajuli, U., & Sharma, K. (2003). Golden Jubilee Seminar on Five Decades of Planned Irrigation Development: Achievements and Future Challenges, proceedings of the seminar, Kathmandu, Nepal, 8 April 2003. Conference Proceedings, Kathmandu, Nepal.

Pittock, J., Meng, J.-h., & Chapagain, A. K. (2009). *Interbasin Water Transfers and Water Scarcity in a Changing World: a solution or a pipedream?* World Wildlife Fund Germany.

Pradhan, A. M. S., Dawadi, A., & Kim, Y. T. (2012). Use of different bivariate statistical landslide susceptibility methods: a case study of Khulekhani watershed, Nepal. *Journal of Nepal Geological Society, 44*, 1-12.

Pradhan, P. (1989). *Patterns of irrigation organization in Nepal: A comparative study of 21 farmer-managed irrigation systems*. IWMI.

Purvis, L., & Dinar, A. (2020). Are intra-and inter-basin water transfers a sustainable policy intervention for addressing water scarcity? *Water Security, 9*, 100058.

Qin, Z., Peng, T., Singh, V. P., & Chen, M. (2019). Spatio-temporal variations of precipitation extremes in Hanjiang River Basin, China, during 1960–2015. *Theoretical and applied climatology, 138*, 1767-1783.

Rehman, H. U., Akbar, N. U., Gul, I., Gul, N., Akhwan, S., Sajed, M., Khan, P., Khan, M. A., Hamidullah, S. B., & Wahab, A. (2015). Impacts of some physicochemical parameters of water and soil collected from Panjkora River, Pakistan. *Global Veterinaria, 15*(1), 57-61. https://doi.org/10.5829/idosi.gv.2015.15.01.9620

Rodell, M., Famiglietti, J. S., Wiese, D. N., Reager, J., Beaudoing, H. K., Landerer, F. W., & Lo, M.-H. (2018). Emerging trends in global freshwater availability. *Nature, 557*(7707), 651-659.

Rollason, E., Sinha, P., & Bracken, L. J. (2021). Interbasin water transfer in a changing world: A new conceptual model. *Progress in Physical Geography: Earth and Environment, 46*(3). https://doi.org/10.1177/03091333211065004

Rolls, R. J., Leigh, C., & Sheldon, F. (2012). Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. *Freshwater Science, 31*(4), 1163-1186. https://doi.org/10.1899/12-002.1

Ruzich, J., Turnquist, K., Nye, N., Rowe, D., & Larson, W. (2019). Isolation by a hydroelectric dam induces minimal impacts on genetic diversity and population structure in six fish species. *Conservation Genetics, 20*, 1421–1436 https://doi.org/10.1007/s10592-019-01220-1

Sabet, M. H., & Coe, J. Q. (1986). Models for water and power scheduling for the California State water project 1. *JAWRA Journal of the American Water Resources Association, 22*(4), 587-596.

Schmidt, B. V., Wang, Z., Ren, P., Guo, C., Qin, J., Cheng, F., & Xie, S. (2020). A review of potential factors promoting fish movement in inter-basin water transfers, with emergent patterns from a trait-based risk analysis for a large-scale project in china. *Ecology of Freshwater Fish, 29*(4), 790-807. https://doi.org/10.1111/eff.12530

Shao, X., Fang, Y., Jawitz, J. W., Yan, J., & Cui, B. (2019). River network connectivity and fish diversity. *Science of The Total Environment, 689*, 21-30. https://doi.org/10.1016/j.scitotenv.2019.06.340

Shao, X., Wang, H., & Wang, Z. (2003). Interbasin transfer projects and their implications: A China case study. *International Journal of River Basin Management, 1*(1), 5-14.

Sharma, R. C., Singh, N., & Chauhan, A. (2016). The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study. *The Egyptian Journal of Aquatic Research, 42*(1), 11-21. https://doi.org/10.1016/j.ejar.2015.11.004

Shiklomanov, I. A., & Rodda, J. C. (2004). *World water resources at the beginning of the twenty-first century*.

Shrestha, R., & Dahal, K. R. (2020). Disaster resilient construction of water spouts in kathmandu valley of nepal. *Journal of Civil, Construction and Environmental Engineering, 5*(4), 72.

Shumilova, O., Tockner, K., Thieme, M., Koska, A., & Zarfl, C. (2018). Global water transfer megaprojects: a potential solution for the water-food-energy nexus? *Frontiers in Environmental Science, 6*, 150. https://doi.org/10.3389/fenvs.2018.00150

Snaddon, C., Wishart, M., & Davies, B. (1998). Some implications of inter-basin water transfers for river ecosystem functioning and water resources management in southern Africa. *Aquatic Ecosystem Health and Management, 1*(2), 159-182. https://doi.org/10.1016/S1463-4988(98)00021-9

Snaddon, C. D., Davies, B. R., Wishart, M., Meador, M., & Thoms, M. (1999). *A global overview of inter-basin water transfer schemes, with an appraisal of their ecological, socio-economic and socio-political implications, and recommendations for their management* (Water Research Commission Technology Transfer report TT 120/00. Water Research Commission. Pretoria Issue.

Somlyódy, L., & Varis, O. (2006). Freshwater under pressure. *International Review for Environmental Strategies, 6*(2), 181-204.

Stockner, J., Rydin, E., & Hyenstrand, P. (2000). Cultural oligotrophication: causes and consequences for fisheries resources. *Fisheries 25*(5), 7-14. https://doi.org/10.1577/1548-8446(2000)025<0007:CO>2.0.CO;2

Su, Q., & Chen, X. (2021). Efficiency analysis of metacoupling of water transfer based on the parallel data envelopment analysis model: A case of the South–North Water Transfer Project-Middle Route in China. *Journal of Cleaner Production, 313*, 127952. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.127952

Sun, S., Tang, Q., Konar, M., Fang, C., Liu, H., Liu, X., & Fu, G. (2023). Water transfer infrastructure buffers water scarcity risks to supply chains. *Water research, 229*, 119442.

Szatten, D., Habel, M., & Babiński, Z. (2021). Influence of Hydrologic Alteration on Sediment, Dissolved Load and Nutrient Downstream Transfer Continuity in a River: Example Lower Brda River Cascade Dams (Poland). *Resources, 10*(7), 70. https://www.mdpi.com/2079-9276/10/7/70

Tamburrino, A. (2010). *Water technology in ancient Mesopotamia*. Springer.

Tian, J., Liu, D., Guo, S., Pan, Z., & Hong, X. (2019). Impacts of Inter-Basin Water Transfer Projects on Optimal Water Resources Allocation in the Hanjiang River Basin, China. *Sustainability, 11*(7). https://doi.org/10.3390/su11072044

Vallania, A., & Corigliano, M. D. C. (2007). The effect of regulation caused by a dam on the distribution of the functional feeding groups of the benthos in the sub basin of the Grande River (San Luis, Argentina). *Environmental Monitoring and Assessment, 124*(1), 201-209. https://doi.org/10.1007/s10661-006-9218-5

van der Zee, E. M., Angelini, C., Govers, L. L., Christianen, M. J., Altieri, A. H., van der Reijden, K. J., Silliman, B. R., van de Koppel, J., van der Geest, M., & van Gils, J. A. (2016). How habitat-modifying organisms structure the food web of two coastal ecosystems. *Proceedings of the Royal Society B: Biological Sciences, 283*(1826), 20152326. https://doi.org/10.1098/rspb.2015.2326

Verma, S., Kampman, D. A., van der Zaag, P., & Hoekstra, A. Y. (2009). Going against the flow: A critical analysis of inter-state virtual water trade in the context of India's National River Linking Program. *Physics and Chemistry of the Earth, Parts A/B/C, 34*(4-5), 261-269. https://doi.org/10.1016/j.pce.2008.05.002

Wang, H., Steyer, G. D., Couvillion, B. R., Rybczyk, J. M., Beck, H. J., Sleavin, W. J., Meselhe, E. A., Allison, M. A., Boustany, R. G., Fischenich, C. J., & Rivera-Monroy, V. H. (2014). Forecasting landscape effects of Mississippi River diversions on elevation and accretion in Louisiana deltaic wetlands under future environmental uncertainty scenarios. *Estuarine, Coastal and Shelf Science, 138*, 57-68. https://doi.org/10.1016/j.ecss.2013.12.020

Wang, J., Hou, B., Zhao, Y., Xiao, W., & Lu, F. (2021). Research on Scale Demonstration Technology of Inter Basin Water Transfer Project in Agricultural Irrigation. *Water Resources Management, 35*(15), 5243-5258. https://doi.org/10.1007/s11269-021-02999-w

Wang, X., Chen, Y., Yuan, Q., Xing, X., Hu, B., Gan, J., Zheng, Y., & Liu, Y. (2022). Effect of river damming on nutrient transport and transformation and its countermeasures. *Frontiers in Marine Science, 9*, 2398. https://doi.org/10.3389/fmars.2022.1078216

Ward, J. V., & Stanford, J. (1995). Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated rivers: research & management, 11*(1), 105-119. https://doi.org/10.1002/rrr.3450110109

WECS. (2011). *Water resources of Nepal in the context of Climate Change*. Water and Energy Commission Secretariat, Government of Nepal, Kathmandu.

books.google.com.np/books?id=no2hk5uPUcMC

Wilson, M. C., Li, X.-Y., Ma, Y.-J., Smith, A. T., & Wu, J. (2017). A review of the economic, social, and environmental impacts of China's South–North Water Transfer Project: A sustainability perspective. *Sustainability, 9*(8), 1489. https://doi.org/10.3390/su9081489

Yang, D., Yang, Y., & Xia, J. (2021). Hydrological cycle and water resources in a changing world: A review. *Geography and Sustainability, 2*(2), 115-122. https://doi.org/10.1016/j.geosus.2021.05.003

Yano, S., Okazumi, T., Iwasaki, Y., Yamaguchi, M., Nakamura, K., Kanayama, T., Ogawada, D., Matsumura, A., Gomez-Garcia, M., & Oki, T. (2018). How Inter-Basin Transfer of Water Alters Basin Water Stress Used for Water Footprint Characterization. *Environments, 5*(9), 105. https://www.mdpi.com/2076-3298/5/9/105

Yevjevich, V. (2001). Water diversions and interbasin transfers. *Water International, 26*(3), 342-348. https://doi.org/10.1080/02508060108686926

Yu, X., & Ma, Y. (2022). Spatial and temporal analysis of extreme climate events over Northeast China. *Atmosphere, 13*(8), 1197.

Yuan, R., Wang, M., Wang. S. & Song, X. (2020). Water transfer imposes hydrochemical impacts on groundwater by altering the interaction of groundwater and surface water. *Journal of Hydrology,* https://doi.org/10.1016/j.jhydrol.2020.124617

Zeid, M. A. (1989). Environmental impacts of the Aswan High Dam: A case study. *International Journal of Water Resources Development, 5*(3), 147-157.

Zhang, L., Li, S., Loáiciga, H. A., Zhuang, Y., & Du, Y. (2015). Opportunities and challenges of interbasin water transfers: a literature review with bibliometric analysis. *Scientometrics, 105*(1), 279-294. https://doi.org/10.1007/s11192-015-1656-9

Zhang, Q., Peng, J., Singh, V. P., Li, J., & Chen, Y. D. (2014). Spatio-temporal variations of precipitation in arid and semiarid regions of China: the Yellow River basin as a case study. *Global and Planetary Change, 114*, 38-49.

Zhuang, W. (2016). Eco-environmental impact of inter-basin water transfer projects: a review. *Environmental Science and Pollution Research, 23*(13), 12867-12879. https://doi.org/10.1007/s11356-016-6854-3