A sustainable alternative of exploiting Nepal's water resources to benefit the riparian countries

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Abstract. *This article suggests that inter-basin transfer of water from larger rivers by tunneling is a sustainable and ecosystem friendly method of utilizing Nepal's water resources which will benefit the riparian countries. It proposes to divert water from eastern rivers to the western by gravity, coupled with generating hydropower. It will transfer 20* km^3 *water annually to the Mahakali river from the Karnali which can be supplied to most groundwater overdraft affected areas of west and south India. About 15* km^3 *will be transferred from the Koshi to the Gandak and from the Gandak to the Karnali, 10% of which will be used for Nepal's Terai and the rest will be supplied to India. The proposed plan will help groundwater recharge and spring flow generation at numerous drains in the basin by three ways :1) the link canals pass over the porous zone ,2) due to the provision of storage in local reservoirs and 3) expansion of irrigated rice. It provides an alternate to large dams in Nepal, which cannot be justified in a high earthquake risk region like Nepal and having no solution to tremendous sediments in the rivers apart from the negative impacts they bring to the people and biodiversity of the affected area. Hence the method suggested in this study is a sustainable way of exploiting rivers. It is capable of preserving the river ecosystem, simultaneously opening ways towards integrated watershed management, conjunctive use of ground and surface water, and revival of traditional methods of storage in local reservoirs.*

Keywords. Ecosystem, groundwater, inter-basin transfer, local reservoirs, sediments.

1. Introduction

The conventional engineering methods applied in Nepal's irrigation and flood control in the years after 1950s are only partially successful in achieving the targeted goals. For example, the country has developed canal infrastructures to irrigate 1.121 million ha, whereas only 0.50 million ha is getting round the year irrigation (NWP, 2005). Increasing the year-round irrigated area in the southern plain of the country known as the *Terai*, is crucial for maintaining food security in the country. The fact that only 27% of lands in the *Terai* is getting year round irrigation, 38% gets irrigation during the rainy season only and the rest 35% is rain fed (WRSN, 2000) shows huge potentials for expansion of year round irrigation in the *Terai*. Until 1960s the importance of agriculture in the *Terai* was not realized in the scale of today due to which Nepal had agreed to supply unlimited volume of water to India from its Himalayan rivers through the *Koshi, Gandak* and *Mahakali* Treaties signed in 1954, 1959 and 1920 respectively. Nepal's civil society presently is dissatisfied with these water sharing treaties with India because they cannot address present requirements of the *Terai* and Nepal's large area is adversely affected from the diversion structures made by India. The recent breach of the *Koshi* embankment caused the two governments to agree to review the previous agreements and to correct the mistakes. Bangladesh from its 50 years long experience of flood control by cordon approach has felt the need of a new approach for sustainability (Islam, 2001).

The spread of groundwater pumping technology to the hands of millions of farmers during last decades and the observed weaknesses of traditional engineering concept require dramatic changes in the existing water resources planning approaches. In the same time, dams are questioned from sustainability and seismic stability considerations (WCD, 2000). Particular to the study area where the community had survived for millennia fighting floods and droughts using indigenous knowledge, the sustainability can only be achieved through integration of indigenous and modern technologies. This study attempts to provide an alternative solution by means of east west transfer of water thorough tunneling across the last hills in order to cover larger part of the *Terai*, supply water to most water deficit parts in western and southern India and to reduce floods in Bangladesh in a sustainable way. It advocates revival and promotion of traditional water harvesting in local reservoirs, recharging groundwater by expanding irrigated rice cultivation during the monsoon season and preservation of water bodies to achieve sustainability of water resources exploitation in the Ganges basin. The paper proceeds on the following order: Section 2 deals with the Nepal's renewable water resources and its utilization by Nepal and India. Section 3 describes the proposed River Linking Project in India, basically concentrating on the Himalayan component that concerns rivers flowing from Nepal. Section 4 covers in detail the proposed transfers and associated parameters. Section 5 presents points regarding sustainability of the proposed solution and Section 6 as a concluding section provides discussions and recommendations.

2. Nepal's water resources and its utilization

The annual renewable water resources of Nepal is 210 km^3 .The country's total requirements in 2000 was 14 km^3 which is projected to reach 39 km^3 in 2027.Although the 2027 projections are only 18.56 % of the generation, there is a need of serious efforts to achieve the goal due to differences in the supply and demand periods. Eighty percent of the flows occur during the monsoon season (June-Sept) whereas the river flows decline dramatically during the peak demand months (March-May) with highest evapotranspiration. The average annual flow of the nine large and medium rivers of Nepal flowing to India is 5,675 m^3/sec as shown in Table 1. Comparing with the average discharge of the *Ganges* river at the Indo-Bangladesh boarder: the *Farakka* it can be seen that Nepal's contribution to the Ganges average flow is 47% which reaches to 75% for the driest months of March to May (Mishra et al., 2007; WECS, 2002). This shows the importance of Nepal's water resources for both downstream countries. Even with great contribution to the Ganges flows, the volume of water that Nepal is getting to irrigate its *Terai* from the three diversions made under Indo-Nepal agreement is extremely low.

Nepal and India have signed four water resources treaties. The first was the *Mahakali* treaty signed in 1920 between British India and Nepal. The *Koshi* treaty was signed in 1954, the *Gandak* treaty in 1959 and the *Pancheshwor* treaty in 1996 (Parajuli et. al, 2003) which envisaged preparing the Detailed Project Report (DPR) within 6 months. However, even after 12 years of the treaty the DPR could not be prepared because Nepal's civil society still considers that the treaty is still detrimental to Nepal. Soon after the *Koshi* and the *Gandak* treaties it was realized in Nepal that both treaties were detrimental for the country. The *Gandak* treaty was most harmful because that deprived Nepal to withdraw water at the upstream affecting the water requirements of the *Gandak* Project, which meant virtual end of the future prospects for irrigation development in the *Gandak* basin within Nepalese territory. However, the treaty was revised in 1964 by which Nepal got the right to withdraw for irrigation or any purposes from the river or its tributaries. Learning lessons from the past agreements, there is a need to work seriously in order to find ways of fulfilling Nepal's requirements first while making any joint water resource development schemes with India in the future.

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Table 1: Average monthly flows of nine rivers of Nepal, m^3/sec.

River name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
Mahakali	167	156	149	182	266	560	1579	1332	1489	577	227	198	658
Karnali	370	335	348	445	702	1520	3290	4370	3020	1320	632	446	1410
Babai	19	15	13	10	15	56	222	241	232	95	36	23	82
W. Rapti	28	23	18	14	15	93	298	388	355	147	57	33	123
Narayani	351	286	264	348	568	1610	4210	4970	3420	1600	790	492	1590
Bagmati	19	17	15	17	32	214	539	513	338	137	51	27	161
Kamala	7	5	4	3	8	46	130	160	102	45	17	11	45
Saptakoshi	364	315	318	424	705	1660	4110	4340	3460	4160	795	501	1550
Kankai	12	9	8	11	21	72	198	145	106	51	23	15	56

(Source: Thapa and Pradhan 1995, as cited in Mishra et al., 2007)

3. The Indian river linking project Himalayan component

India is implementing the River Linking Project (RLP) to satisfy growing water demands and to combat the severe groundwater overdraft at its western and peninsular parts. The RLP Himalayan Component intends to divert surplus water of the Himalayan rivers to the western and peninsular parts for which several large dams within Nepal and Bhutan are proposed. In this regard a 300 m rock fill dam at the *Koshi* River is being studied. Bangladesh also favors constructing dams in Nepal for flood controls as well as increasing the lean season Ganges river flows. The proposed high dams in Nepal around the fault lines are neither sustainable nor free from high earthquake risks. The ever increasing sediment loads in the rivers due to human encroachment on the hill slopes and landslides needs careful assessment and consideration before deciding on a dam construction. Most importantly the dams themselves may be the cause of bigger earthquakes due to dramatic increase in water pressure in the faults. It is really a daunting task for the planners to find sustainable solutions in a fragile geology with seismic risks which could address or satisfy these very different interests of the three countries affected by flows in Nepal's rivers.

The present version of the RLP is based on the conventional approaches adopted in industrialized countries in last two centuries. It is being criticized by the civil society in India itself. There is a growing demand to modify plans to make them environment friendly, sustainable and socially acceptable and capable to preserve the river ecosystem. Experience of the past has shown that the conventional engineering developed in the west cannot address the problems existing in the region. Developing countries do not have to repeat the mistakes that early industrialized countries have made, and instead can make fruitful use of the accumulated experience (Islam, 2006) Sustainable solution will only be possible if modern engineering concept could be integrated with old traditions of the community to behave with rivers. For example, the traditional design considers the design life of dams as a limited period of about 100 years. However, the rivers will flow for ever and traditional engineering does not have answer to the question: what to do with the dam after its design life? Particular to Nepal there is a need to consider various typical aspects like steep hill slopes and steep river beds, tremendous suspended and bed sediments carried out from the mountains and deposited at the *Terai*. Failure to consider these aspects during the design of the *Koshi* Barrage resulted to the situation of embankment breach and flooding in August 2008 affecting 3 million people which provides important lessons for future planning and shows how a technically incorrect choice was made by the designers of the *Koshi Barrage*.

The RLP is criticized by various NGOs and civil society in India for its erroneous basic premise, faulty concept, doubtful technical feasibility, doubtful financial feasibility, doubtful flood mitigation, doubtful economic feasibility, irreparable ecological damage and other non economic costs, exacerbation of conflicts. The governing concepts in the RLP planning are still the traditional 19th and 20th century methods leading to unsustainable solutions. The recently introduced concept of sustainable development requires applying ecological approach to rivers where the river itself is to be treated as an important stakeholder. Existing groundwater overdraft in western and southern India and the anticipated expansion of urbanization, increase in the living standard of population will eventually make water transfers from surplus basins to deficit basins an unavoidable option in the future. This is supported by Shah et al., 2003: "as groundwater becomes more scarce and more costly to use in relative terms, many ideas- such as trans basin movement or using surface water systems exclusively for recharge- which in past years were discarded as not feasible or unattractive can now offer new promise, provided that Asia learns intelligently from these ideas and adapts them appropriately to its unique situation".

4. Transfer by tunneling: beneficial for all countries

The concept of inter basin transfer through tunneling was forwarded in Nepal in 1970s during the reconnaissance study of the *Babai* Irrigation Project. To cope with the water shortage in the *Babai* river, a proposal to divert 35 m^3/sec of water from the nearby *Bheri* river by making a 8 km long tunnel. Soon after the *Sunkoshi- Kamala* diversion was identified to irrigate dry lands of the central *Terai.* However, both of them could not be materialized due to financial constraints. Now almost all the viable surface irrigation projects have been constructed and the inter-basin transfer is in the priority in Nepal. Adhikari et al., 2007 have suggested a gravity canal from the *Karnali* river, which is a very economic replacement to the *Bheri Babai* diversion. Considering this fact this study proposes the following three diversions as the most viable schemes from point of view of covering maximum areas of the *Terai* and transferring large volumes of water from east the west absolutely by the gravity to attain the RLP goals.

4.1 Sunkoshi – Bagmati- Kamala Diversion (Diversion 1)

The proposed diversion site is located at 2 km downstream from the *Beni Ghat*, the confluence of the *Sunkoshi* and the *Tamakoshi* rivers. At the beginning, a 18 km long tunnel as indicated by tunnel 1A in Figure 1, will deliver water to the *Bagmati* basin, By constructing another tunnel of about 8 km length, indicated as tunnel 1B in Figure 2, it is possible to further divert the flow to the *Kamala* river basin as well. The satellite image of the diversion site obtained from GoogleEarth showing the tunnel 1A alignment has been presented in Figure 2. Salient parameters of the proposed diversion work have been presented in Table 2. The catchment area of the *Sunkoshi* river at the diversion site is 11,000 km^2. The monthly flows have been estimated based on the measured discharges of the *Narayani* river due to the similarity of the conditions between the *Sunkoshi* and the *Narayani* basins. The *Saptakoshi* river flows at the *Chatara* is influenced by the significant basin area of the *Arun* river part of which contains the rain shadow areas of Tibet, due to which the specific discharge of the *Saptakoshi* is less than that of the *Narayani* and the *Karnali*. However, the *Sunkoshi* basin area at the proposed diversion site is 11,000 km^2 whereas the *Kaligandaki* river has a basin area of 11,400 km^2 at the diversion point. Hence the flows of the *Sunkoshi* are taken same as those of the *Kaligandaki* .

Table 3 shows the available and divertible monthly discharges at the diversion site and at *terai exit* **TE1**. This arrangement can divert 14 km^3 of water annually from the *Koshi* basin to the *Gandak* basin without making any negative impact to the downstream ecosystem. The available head of 200 m between the tunnel exit and the proposed link canals at the *Bagmati* can be used to generate hydropower. It is proposed to share the diverted flow half-half by Nepal and India during the dry season while major flows of the months June to December will be transferred to the *Gandak* river. During the summer period additional flow augmentation from other small rivers is also possible. Out of total 14 km^3 diverted water Nepal will consume only 2 km^3 which is just 11.60% of the diverted flow.

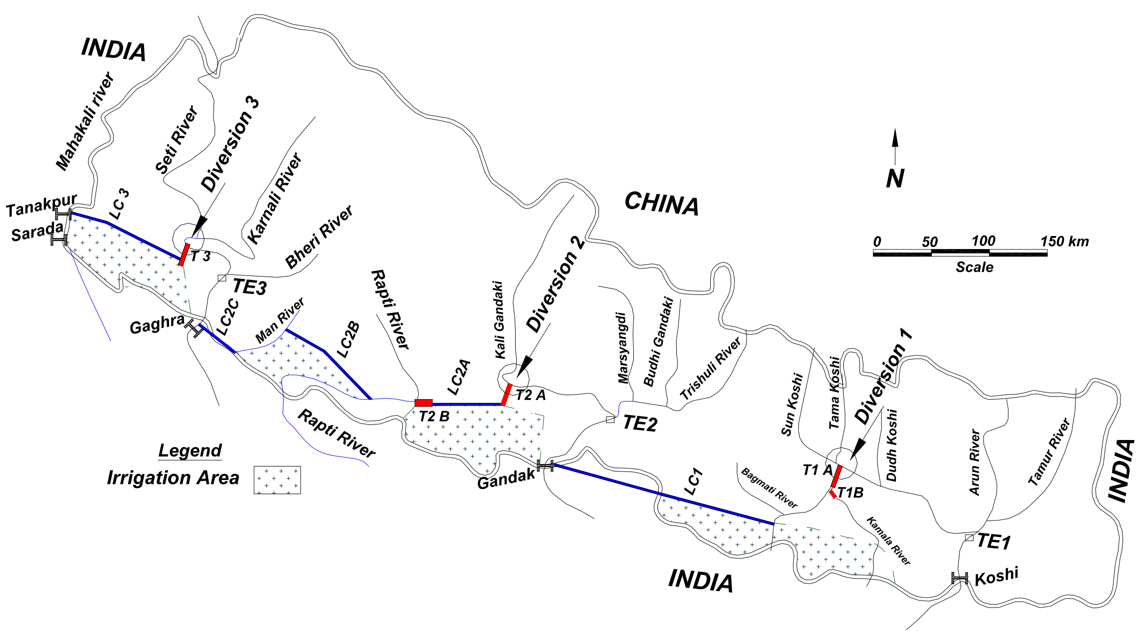

Figure 1: Map of Nepal showing major rivers draining to India from Nepal, proposed diversion tunnels and link canals, area to be irrigated and the existing barrages at the *Koshi*, *Gandak* ,*Karnali* and *Mahakali* rivers.

Table 2: Salient Parameters of the *Sunkoshi-Bagmati-Kamala* Diversion.

S.No.	Parameters	Unit	Value
1.	River bed level at diversion site	m	460
2.	Tunnel exit level at Bagmati basin	m	412
3.	Tunnel 1 A length	km	13
4.	Tunel 1 B length	km	6
5.	River level at the Bagmati barrage	m	137
6.	Bagmati- Gandak distance	km	200
7.	Narayani river level at the Gandak	m	122

(Source: Google Earth 2008)

Figure 2: GoogleEarth image of the *Sunkoshi- Bagmati-Kamala* diversion site showing the tunnel alignment.

(Source: Google Earth 2008)

Table 3: monthly discharge at the *Sunkoshi* river at the diversion site, m^3/sec

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunkoshi flow	129	105	97	128	208	591	1545	1824	1255	587	290	181
Divertible discharge	80	80	80	100	150	500	1000	1,500	1,000	500	250	150
D/S Flow after diversion	49	25	17	28	58	91	545	324	255	87	40	31
Saptakoshi flow(TE1)	364	315	318	424	705	1,660	4,110	4,340	3,460	1,460	795	501
Flow at the *Saptakoshi (TE1)* after diversion	284	235	238	324	555	1,160	3,110	2,840	2,460	960	545	351

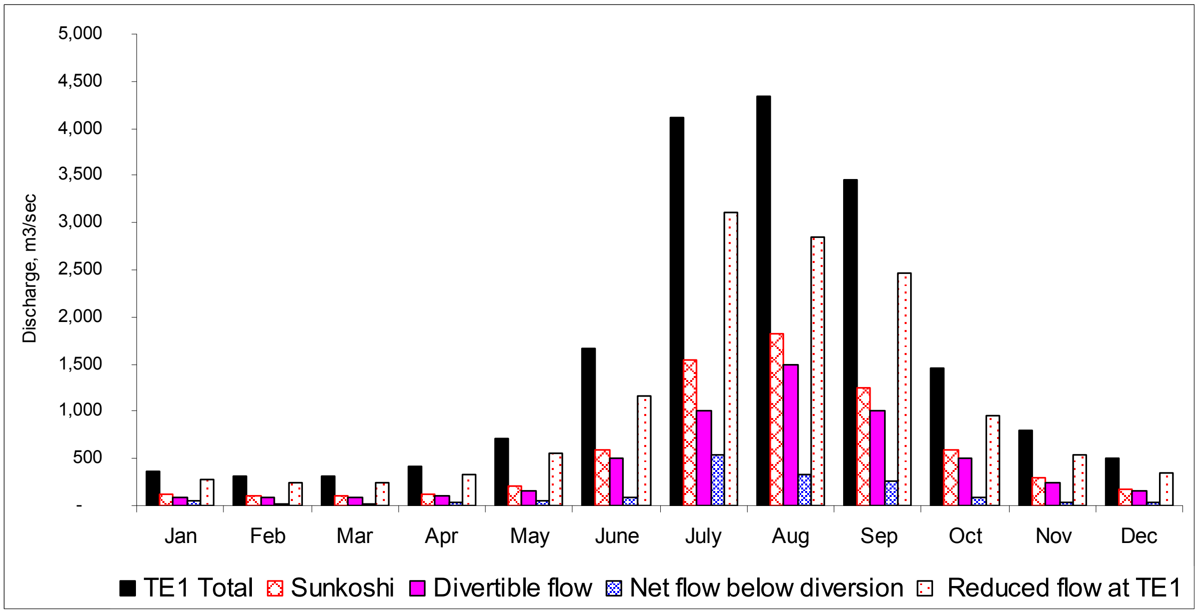

Figure 3: Monthly discharge at the TE1 (Chatara) and at the diversion 1 site before and after the project and the divertible discharge.

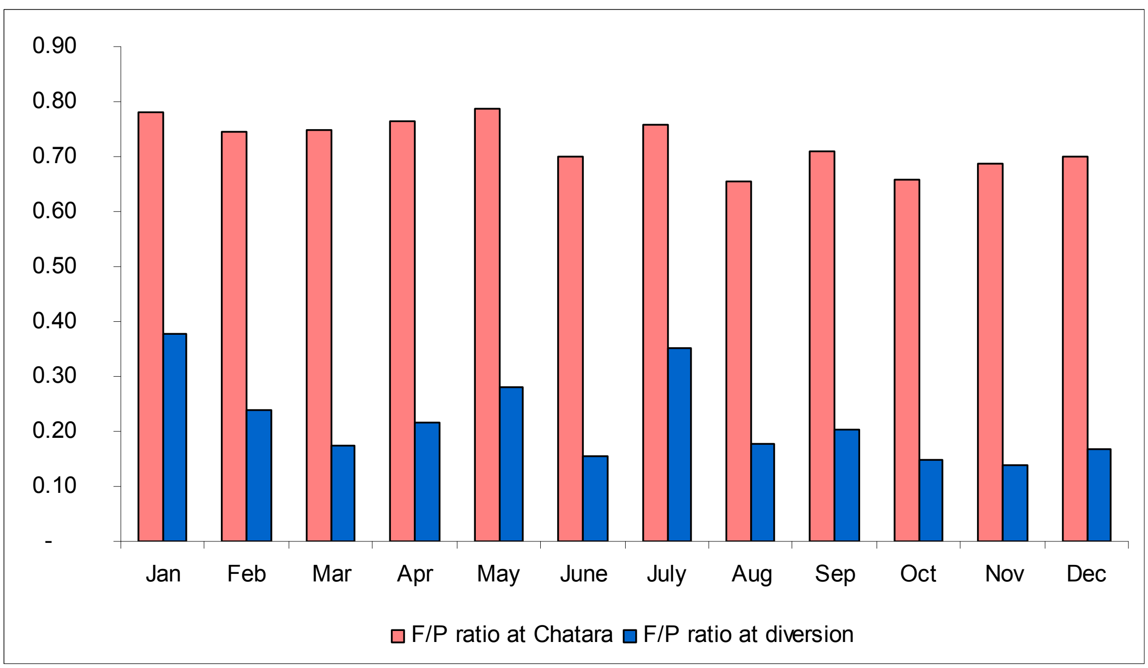

Figure 4: Future and present discharge ratios at the diversion site and at the TE1 (*Chatara)*.

Figure 3 shows the monthly distribution of the discharges available at the diversion site, divertible flow, and discharge at the Sapta Koshi. Figure 4 shows the future and present (F/P) discharge ratios at various months at the *Chatara* of the *Saptakoshi* and at the diversion site in *Sunkoshi* rivers which indicates that the dry season discharge at the *Saptakoshi* will be maintained at 70 to 80%. In the period from June to October the discharge in the *Sunkoshi* river remains very high, as can be seen from Figure 3, indicating the possibility to increase the diversion volume.

4.2 Kaligandaki Tinau-Rapti Diversion (Diversion 2)

The proposed diversion will transfer water from the *Kaligandaki* river to the *Tinau* river through a 18 km long tunnel initially, and will join the *Rapti* from Link Canal 2A and Tunnel 2B as shown in Figure 1. From the *Sikta* barrage in the *Rapti* River which is under construction now, a link canal, as indicated by Link Canal 2B in Figure 1, will supply water to the *Man River* after which Link Canal 2C will finally drop water upstream of the *Gaghra* barrage. GoogleEarth image of the diversion site with the tunnel alignment is shown in Figure 5 and the salient parameters of the diversion are presented in Table 4.

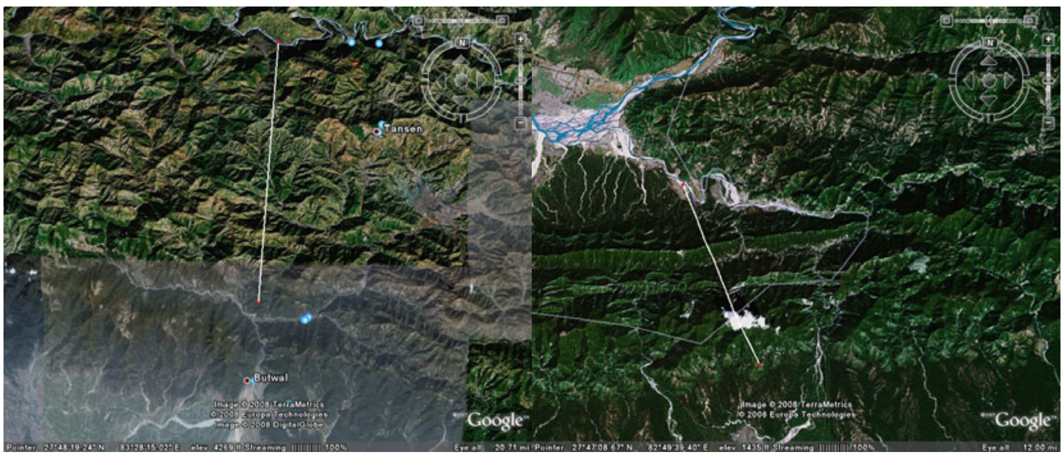

Figure 5: Satellite image of the *Kaligandaki Tinau* diversion site (left) showing the tunnel alignment and the link to the *Rapti* river (right).
(Source: Google Earth 2008)

Table 4: Salient Parameters of the Kali Gandaki-Rapti-Gaghra Diversion.

S.No.	Parameters	Unit	Value
1.	River bed level at diversion site	m	463
2.	Tunnel exit level at Tinau river	m	450
3.	Tunnel 2 A length	km	18
4.	Tunel 2 B length	km	8
5.	River level at the Rapti bridge	m	305
6.	Tinau Rapti distance	km	160
7.	Gaghra river level at the barrage	m	122

(Source: Google Earth 2008)

Table 5: monthly discharge at the Kali Gandaki river at diversion site, m^3/sec

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Available flow	129	105	97	128	208	591	1,545	1,824	1,255	587	290	181
Divertible discharge	100	80	50	50	100	500	1,200	1,500	1,000	500	200	150
D/S Flow after diversion	29	25	47	78	108	91	345	324	255	87	90	31
Narayani (TE2) total flow	351	286	264	348	568	1,610	4,210	4,970	3,420	1,600	790	492
Flow at Narayani after abstraction	251	206	214	298	468	1,110	3,010	3,470	2,420	1,100	590	342

This component contains the transfer from the *Kaligandaki* to *Tinau* where after a 160 km long open channel at about 315 m elevation the flow will be transferred to the *Rapti* river through a 8 km long tunnel. The head difference between the *Tinau* and the *Rapti* may be used for hydropower generation. Monthly discharges are shown in Figure 6, while the future present discharge ratios are presented in Figure 6. Out of 14 km^3 water Nepal will be entitled to only1.5 km^3, which is 10.6% of the diverted flow.

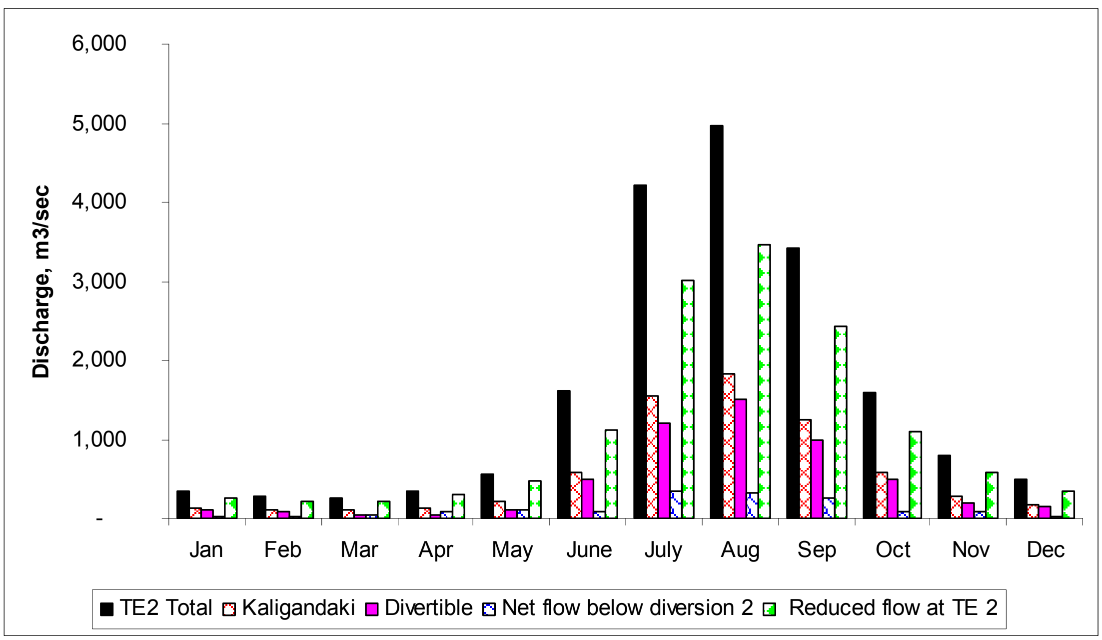

Figure 6: Monthly discharge at the TE2 and the diversion 2 before and after the project showing the divertible monthly flow.

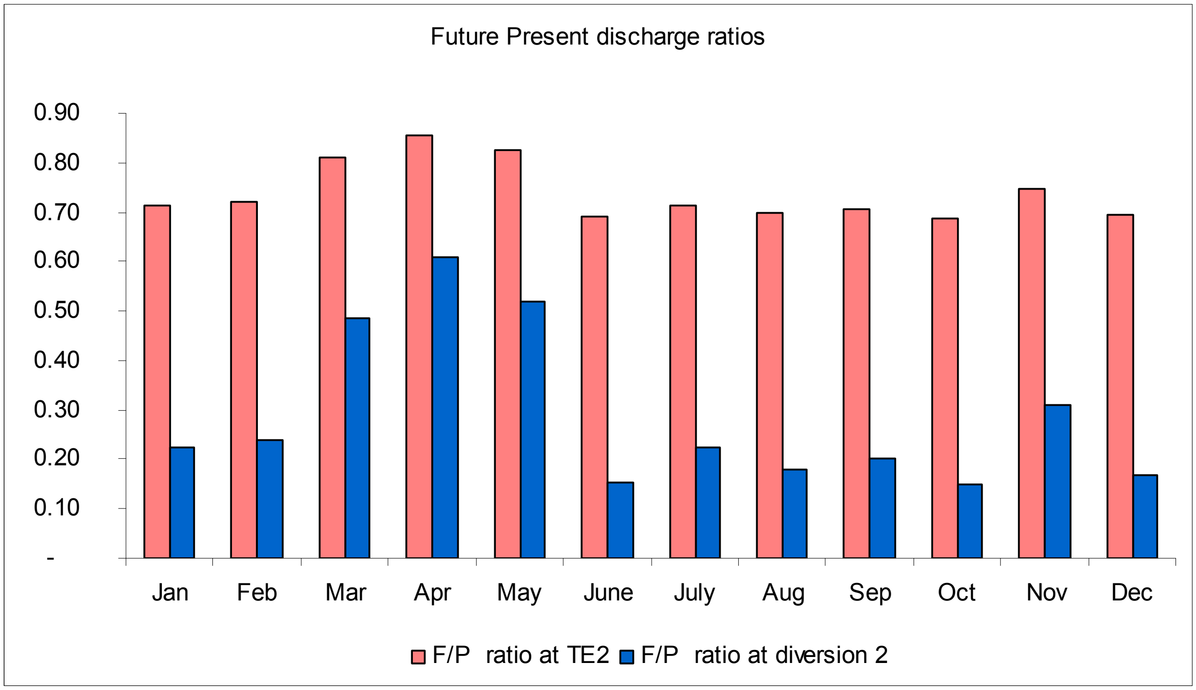

Figure 7: Future and present discharge ratios at the diversion 2 site and at the TE2 of the *Gandak* river.

4.3 Karnali Mahakali diversion (Diversion 3)

The proposed diversion site with the tunnel and link canal are shown in Figure 1 by indicating T3 and LC3 while the GoogleEarth image of the diversion site and tunnel alignment is presented in Figure 8. Relevant parameters of the proposed diversion are presented in Table 6. The proposed tunnel length is 14 km and the length of the link canal will be 110 km. It is proposed to allocate 2.1 km^3 of water for Nepal's usages out of 20 km^3 which is 10.60% of the total diverted discharge. The available and divertible monthly discharges are presented in Table 7. The future present discharge ratios at different places are shown in Figure 10 which shows that the discharge at the TE3 (*Chisapani)* will drop by about 60 per cent. Figure 9 shows monthly discharges at the diversion site and at the *Chisapani* at before and after diversion scenarios, including the divertible discharges.

Figure 8: Map of the *Karnali* diversion site showing the proposed tunnel alignment.
(Source: Google Earth 2008)

Table 6: Salient parameters of the Karnali River at the diversion site and Chisapani.

S.No.	Parameters	Unit	Value
1.	River bed level at diversion site	m	296
2.	Tunnel exit level	m	270
3.	Tunnel length	km	14
4.	Link canal length	km	110
5.	*Mahakali* river level at *Tanakpur*	m	250

(Source: Google Earth 2008)

Table 7: monthly discharge of the Karnali river at the diversion site, m^3/sec

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karnali at diversion site	261	236	245	314	495	1,072	2,319	3,081	2,129	931	446	314
Divertible	100	100	100	100	100	800	1,700	2,000	1,500	500	400	250
Net flow below diversion	161	136	145	214	395	272	619	1,081	629	431	46	64
Karnali Chisapani, TE3	370	335	348	445	702	1,520	3,290	4,370	3,020	1,320	632	446
Reduced flow at Chisapani, TE3	270	235	248	345	602	720	1,590	2,370	1,520	820	232	196

Figure 10 shows the discharge ratio in the TE3 at the future and present situations. In the *Koshi* and the *Gandak* the reduction is likely below 30% whereas in the case of the *Karnali* it is between 50 to 60 percent in months from June to December. In all the diversion sites at least 20 percent discharge is released for sustaining the downstream ecosystem. The farmers' systems in the *Rajapur* may be affected during the dry season from the reduced flows. Negative impacts to the farmers' systems from the proposed diversion during the dry period can be mitigated by carrying out sediment removal around the side intakes whereas during the rainy season generous amount of flow will enter the farmers' canals and these systems will be safer due to possible reduction of floods from the proposed arrangement.

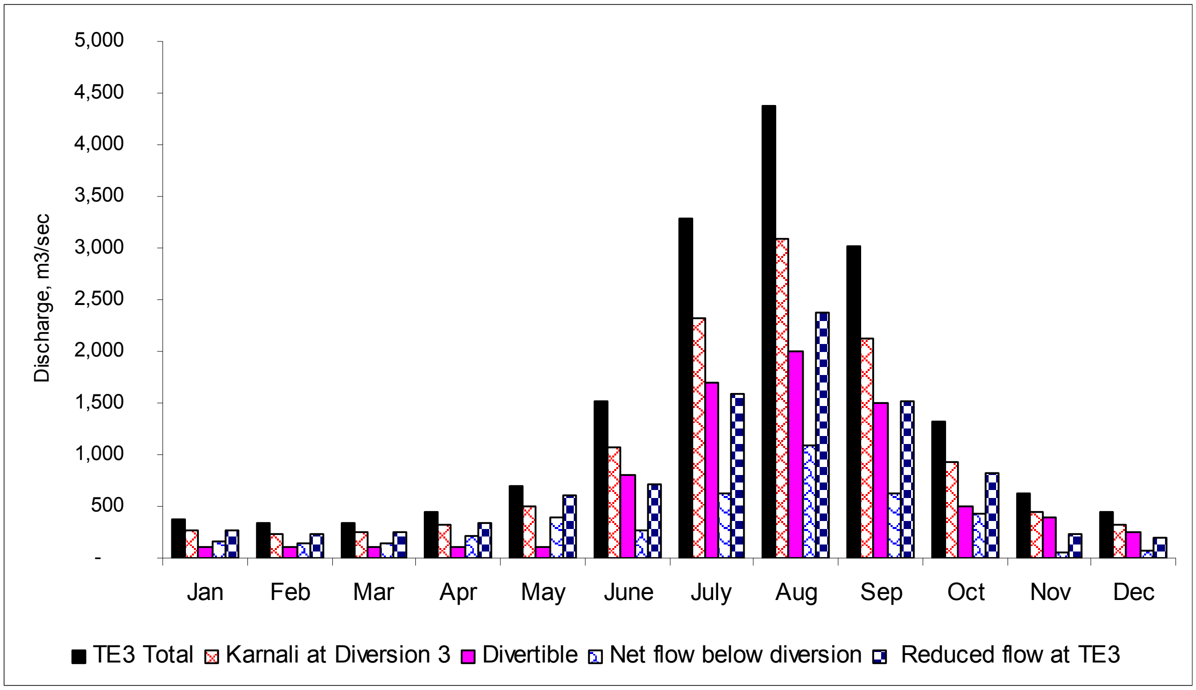

Figure 9: Monthly discharges at the diversion 3 site and at the TE3 (*Chisapani)* before and after the project showing the divertible monthly flows.

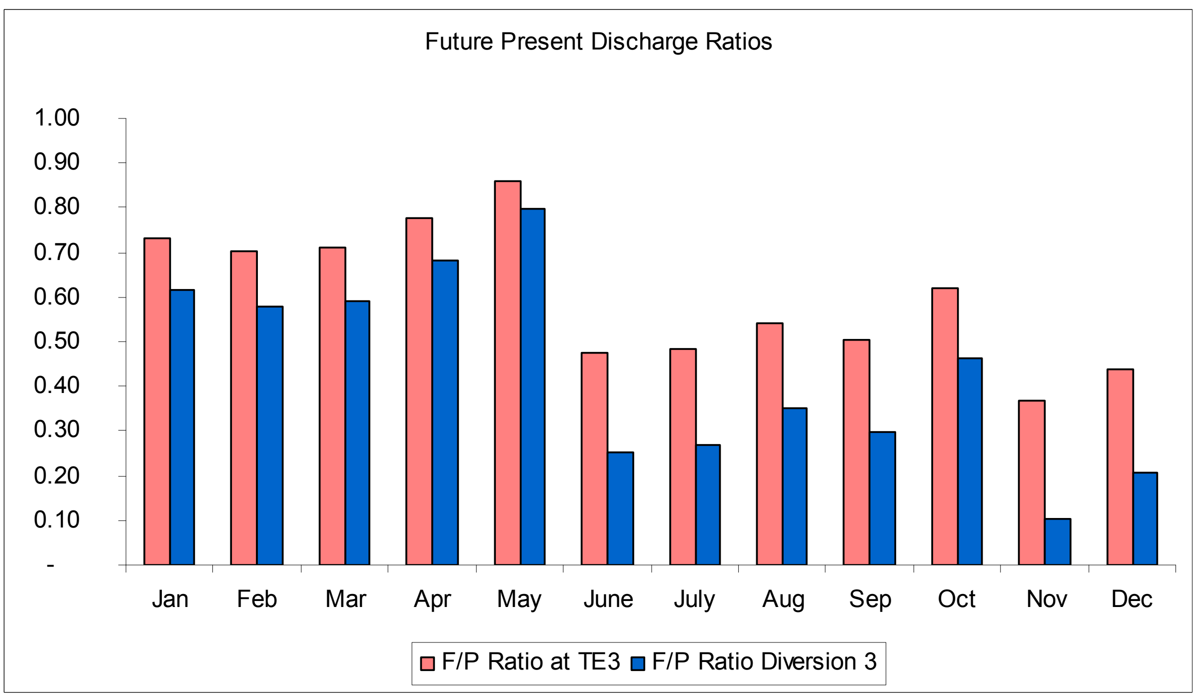

Figure 10: Future and present discharge ratios at the diversion 3 site and at the TE3 (*Chisapani)*.

5. How the proposed solution is sustainable?

The conventional water storage behind dams across the rivers is highly risky and unsustainable for Nepalese context. Dams can never be justified in a fragile and steep mountainous and a highly earthquake prone zone. Seismologists expect a major earthquake in the near future of devastating magnitude like 1834 and 1934 shakes. Sediment loads in Nepalese rivers is another serious question. It is estimated that the *Koshi* River carries about one billion cubic meter of sediment in a year. In case of damming, the sediment deposition will occur in the pond. A front of delta formed by the sediment deposition will proceed towards the dam, eventually converting the total pounding area into a sediment deposition zone in a very short time span which would be a great burden afterwards. The traditional dam design concepts and assumptions cannot seriously consider this aspect. The run off the river type diversions proposed in this study are capable to address both the above concerns simultaneously favoring hydropower generation. Another important factor unseen by the dam proponents is that the weight of the reservoir catalyzes an earthquake by creating huge pressure in faults. Increase in soil moisture in the hill slope around the reservoir may induce hill slope failures of unimaginable extent which hardly gets any consideration during the design of dams. One can just imagine the worst situation of slope failure during severe shakings. A huge landslide behind the *Vaiont* dam in northern Italy in 1963 took the lives of 2500 people when a wave of water and debris spilled over the dam and swept away a small town. This bitter experience shows that the run off the river type diversion is far appropriate than dams for fragile Himalayan conditions of Nepal. The diverted sediment free water can be stored in thousands of local traditional reservoirs or small check dams covering the total service area. This would enhance groundwater recharge and would generate perennial spring sources. Revitalized water bodies means favorable condition for preserving aquatic ecosystem. Another vital space of storing water is the groundwater aquifer. For this purpose spread of the irrigated rice cultivation plays key role. The percolation occurring during rice cultivation eventually contributes to groundwater recharge helping ground water table stabilization.

5.1 No significant negative impact on the downstream ecosystem

All the proposed diversion points are situated in a tributary of the main river comprised of several rivers. The Koshi river has seven tributaries and hence named as the *Saptakoshi* which means seven *Koshi*. Similarly the *Ganda*ki or *Narayani* river is called as *Saptagandaki*. The proposal of withdrawing about half of the flows during summer and about eighty percent flows during dry season will always maintain more than 80 percent flows in the main stream. The twenty percent discharge released for preserving fish spices in the tributary will be sufficient because there are no other utilization of river at the downstream area which is comprised of mainly hard rock outcrops without any wet lands or any type of natural habitats. Settlements in the river bank use other small sources to fulfill their requirements. The supply of water to Indian large irrigation projects located at the boarder will be maintained nearly in their present level because the *Gandak* will get diverted water from the *Sunkoshi* and the *Karnali* will get water from the *Kaligandaki*. Moreover, surplus water of other small rivers like the *Bagmati* and the *Rapti* will also be diverted to west eventually increasing the water volume in the western river during the monsoon season.

Significant expansion of irrigation in the *Terai* coupled with the seepage from the link canals passing over thick gravel deposits will enrich the groundwater aquifer. The seepage and infiltration are normally considered as losses, but for particular case of the vast Ganga plain it might be the right method of storing water in the underground reservoir to use it during the lean period. This would help generating perennial flows in numerous downstream streams .The stored groundwater can be pumped in required amount at required time. Although various sources mention that the dry season flow from Nepal's rivers contribute more than 75% of the Ganges flow at the *Farakka*, but that is not happening in a straightforward way because all the tributaries of the Ganges are captured and diverted to irrigate vast lands in Bihar and Uttar Pradesh leaving practically no flows at the downstream. Then the general question arises: from where the flow at the *Farakka* comes? The dry season flow in the *Ganges* should be the result of groundwater spring occurring in its huge plain which is one of the largest groundwater reservoirs on the earth. Keeping this huge groundwater reservoir full and saturated should be more efficient than storage in dams to benefit Bangladesh by increasing the lean season flow at the *Farakka*.

5.2 Ecosystem not affected

The proposed solution is a complete environment friendly water resource development plan. The river ecosystem will not be affected from the proposed interventions. Sufficient flow will be released downstream to sustain the ecosystem, mainly to preserve the fish spices. The river passes along the rock outcrops and hence does not contain any wetlands, or withdrawals for irrigation or other purposes. Hence the reduction of the discharge will not provide any harm to downstream population and ecosystem. Any unforeseen harms if observed during the detailed study and during the mandatory public hearing process can be mitigated. This scheme does not contain any resettlement works and thus can be taken as a very environment friendly proposition which is capable of fulfilling Nepal's requirements as well as beneficial for India and Bangladesh.

5.3 No risk of earthquake induced disaster

The proposed transfer is completely free from the earthquake induced disasters and hence deserves special attention. Conventionally conceived high dams in Nepal to store large volume of water are not appropriate solutions due to risk of failure from earthquakes. Nepal lies in highly earthquake prone zone and the fault line passes along the east west flowing rivers. Dams themselves can be the cause of earthquakes due to the increased water pressure at the fault lines. Loss of life and property from reservoir failure will be enormous. If imagine the scenario at the upstream and downstream end after the failure of the dam, one becomes compelled to think on the alternatives of such type of so called development. The proposed diversion is completely out of the risks of such type and magnitude. Canals and tunnels if cracked and leaked due to the however big earthquake, can be easily repaired without much difficulty and there is no risk of damage to life and property.

5.4 No sedimentation problem

Our proposal of transferring water will not create any sedimentation in the source river and in the canals. As there is enough discharge released during the high flow period and the diverted water will be sediment-free using a suitable deposition device, sediment transportation and deposition at the downstream will get continuity. Sediment free water carried from the link canals can be stored in tanks and the process can be continued for centuries without any silt problem. Fertile sediment which is spread over the Ganges plain by the floods is an important nutrient for keeping high fertility and yield of the basin. This aspect will not be affected from our proposal.

5.5 No need of resettlement and no loss of lands from impoundment

It will be very hard to convince Nepalese public for high dams construction submerging fertile river valleys and settlements. And only the agreement between governments will not be sufficient to launch the project. Even till now many families displaced by the *Koshi* Project in 1960s have not got the land compensation and resettlement costs. In 1996 a treaty between Nepal and India was signed fro the development of water resources in the *Mahakali* river basin which had envisioned to construct a high dam at the *Pancheshwor*. The Detailed Project Report (DPR) was said to be prepared in six months. However after even 11 years there is no sign of producing the DPR. That is why both the countries need to do intensive homework and reach mutually agreeable and transparent option of project development before making any treaty. In the 1960s Nepal's technocrats and leaders trusting the draft prepared by the Indian counterparts signed the treaty which soon after was realized to be harmful for the country. Now the situation has changed. Even inside India one state's surplus water is being a matter of selling to the deficit state, Nepal will and should not sign treaties which would be harmful to her interest.

5.6 Flood control at Bangladesh is not possible from damming Nepal Rivers

During the 1988 floods, the maximum discharge of the Brahmaputra corresponded to a 100 year return period flood, and the Ganges river reached its peak discharge, a 40 year return period flood, three days later. At the *Goalundo* stream gauging station, the maximum discharge 132,000 m^3/sec was measured. In the same flood period, the *Karnali* river recorded the peak discharge of 11,000 m^3/sec and the *Mahakali* river 4,079 m^3/sec (Nippon, 1993). The above data show that even large dams in all the larger rivers in Nepal will not be able to control floods in Bangladesh territory. Floods are mixed blessings. They spread fertile soil over the Ganges plain and make significant contribution in groundwater recharge and soil moisture retention. Hence a degree of flooding is even required at certain intervals. That is why our view is that floods should be managed but not completely controlled and stopped. Diversion and retention in traditional water bodies and groundwater recharge in an integrated way and a careful flow dispersion mechanism might be a sustainable solution to flood protection.

6. Discussion and Conclusions

Careless application of the conventional engineering developed in 19th century for damming rivers and making canals is inappropriate for Nepal's context. Many unavoidable specific features should be considered before making a final decision on intervention to rivers. In South Asia where annual precipitation exceeds 1000 mm, there is a great possibility of storing rain water making small reservoirs. That will increase flow in the local streams, contribute to more groundwater recharge, in addition to providing surface irrigation. In those areas where groundwater overdraft needs to be countered by recharging of transferred water, the transfer will be unavoidable. So, firstly it is extremely important to find out the most groundwater overdraft affected areas and asses the volume of water for transfer duly considering the possible contribution by rainwater harvesting and other water management practices.

High dams in Nepal are subject to high risk of failure due to earthquake, the prevailing principles of dam design are not sound in view of long term performance and sustainability. And hence Nepal cannot accept high dams. This view is in line with the WCD studies of dams. The proposed solution is free of all shortcomings and simultaneously serves a large part of the *Terai*. It also contributes to the groundwater recharge in the *Ganga* plain which will ultimately increase lean period discharge at the *Farakka*, as desired by Bangladesh. Although this study at the first hand gives direct benefit to Nepal *Terai,* for which this is the most appropriate solution, the RLP of India which largely relies on the surplus water of rivers flowing from Nepal, should be modified to the concept suggested in this study.

The alternative to the conventional design and management of the water resources suggested by this study is a sustainable solution appropriate for geological, topographical and ecological condition of the Ganges basin. Construction of small reservoirs at the remote areas of the Himalaya may be a possibility for increasing the dry season flow to some extent. While with the proposed approach tremendous groundwater storage will be achieved at the upstream area, it also will be effective to increase the dry season flow in the Ganges, simultaneously serving the agriculture with conjunctive use of ground and surface water.

References:

Adhikari B., Verhoeven R., Troch P., 2008 Fair and sustainable irrigation water management in the Babai basin, Nepal. Accepted for publication in "Water Science and Technology."

GoogleEarth image 2008.

Islam N, 2001. The open approach to flood control: the way to the future in Bangladesh. Futures 33 pp 783-802.

Islam N, 2006 The Commercial Approach vs. the Ecological Approach to rivers: An essay in response to the Indian River Linking Project (IRLP). Futures 38 pp 586-605.

Mishra A. K., Yaduvansi M., Bhadauriya Y., Saxena A., Mishra A., Thakur A., 2007. Proposed river-linking project of India: a boon or bane to nature. Environ Geol 51: pp 1361-1376.

National Water Plan (NWP) Nepal, 2005. Water and Energy Commission, Kathmandu, Nepal.

Nippon Koei Co. Ltd., Tokyo 1993, Master Plan Study for Water Resources Development of the Upper Karnali River and Mahakali River Basins.

Parajuli U., Miah M., Rahman K., Hamid S., Mukherjee S., Verghese G., 2003 Water sharing conflicts between countries, and approaches to resolving them. Global environment and energy in the 21st century, Honolulu, Hawai.

Shah T., Roy A.D, Qureshi A., S., Wang J., 2003 Sustaining Asia's groundwater boom: An overview of issues and evidence. Natural resources forum 27 pp 130-141.

World Commission on Dams, Dams and Development: A new Framework for Decision Making (Report of the World Commission on Dams), Earthscan Publications Ltd, London, 2000.

Water Resources Strategy, Nepal (WRSN), 2000. The Water and Energy Commission, Government of Nepal.