Fair and sustainable irrigation water management in the Babai basin, Nepal

B. Adhikari, R. Verhoeven and P. Troch

ABSTRACT

This paper attempts to find a strategy to provide year-round irrigation for cultivating three crops per year in the southern plains of the country taking a case study of the Babai basin. Despite having enough flows during the summer for growing rice in total 27,000 ha area, the dry season flows of the Babai river can irrigate only 6,300 ha in winter and 4,000 ha in spring limiting the cropping intensity to 138.50%. It is proposed to irrigate the 7,500 ha southern dry area at the right bank bringing water from a large snow-fed river: the Karnali. Water balance study of the three irrigation regions to be irrigated from the Babai source preserving their existing water rights showed that the year-round irrigation at the west with the proposed arrangement will fall short of only 13.9 million m^3 water volume. At the east side, the head reach area and the tail portion will fall short of 19.4 and 66.4 million m^3 of water to insure a cropping intensity of 250%. The deficits can be fulfilled by means of capturing the excess river water of rainy season in local reservoirs and by making conjunctive use of groundwater. The proposed solution is financially, environmentally and socially viable being a cost effective, user friendly and should be the linchpin towards attaining a sustainable year-round irrigation in the region.

Key words | conjunctive use, cropping intensity, groundwater, local reservoirs, year-round irrigation

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INTRODUCTION

Agricultural lands in the southern plain of Nepal, called the *Terai,* plays a vital role in maintaining food security in the country. The potential irrigable area in the *Terai* is 1.338 million hectare (Mha) among which 0.368 Mha receives year-round irrigation and 0.521 Mha receives irrigation during the rainy season only (WECS 2002). Year-round irrigation in the Terai makes it possible cultivate three crops a year. Despite the fact that four large snow-fed rivers transfer enormous volumes of water from Nepal's mountains to the Ganges river crossing the Terai, only a small portion of the Terai receives irrigation water from these rivers, while irrigation in most of the Terai depends on another medium and small rivers and groundwater exploitation. The realization of the Nepal government's plan to increase year-round irrigation from 41% to 90% of irrigated lands in the period between 2002 and 2027 (WECS 2002) is a daunting challenge requiring optimal utilization of surface water sources supplemented by groundwater exploitation by dramatically changing the prevailing methods of irrigation water management.

This paper, taking the Babai river basin in the Bardiya district of Nepal as a case study, explores methods of securing year-round irrigation in the area preserving the farmers' institutions and irrigation practices. Initially the paper analyzes water balance scenario to attain a cropping intensity of 250% in total 27,000 ha area using the flows of the Babai river after releasing 10% of the flows for the downstream ecosystem. To cope with the great water deficit

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during the dry season the study proposes to irrigate the 7,500 ha southern dry area at the west side by constructing a 20 km link canal from another large snow-fed river. Then three irrigation regions namely the east side farmer managed irrigation system (FMIS), east side extension area and the west side requiring irrigation from the Babai river are identified and the possible cropping patterns at each region based on run-of the river type flows preserving water rights of each region have been determined. By increasing wheat and maize areas during the winter and spring, the study analyzes water supply and deficit scenarios for different cropping intensities and seeks for a sustainable deficit make up strategy to attain a cropping intensity of 250% at each region.

STUDY AREA AND METHODS APPLIED

The study area is situated at the right and left banks of the Babai river in Bardiya district of Nepal, which is located between 81°15′ and 81°32′ E longitude and 28°04′ and 28°31′ N Latitude. The study area (shown in Figure 1) is surrounded by: the Main Canal at the north, the Nepal-India international border at the south, the *Man* river at the east and the river Karnali at the west. Six FMISs are situated in the study area, five of which are supplied from the Babai river and one from the Karnali. Among the 30,600 ha available lands, the FMISs cover 12,900 ha which is being irrigated by the local community applying their indigenous technology since the 1940s. A reconnaissance study of 1977

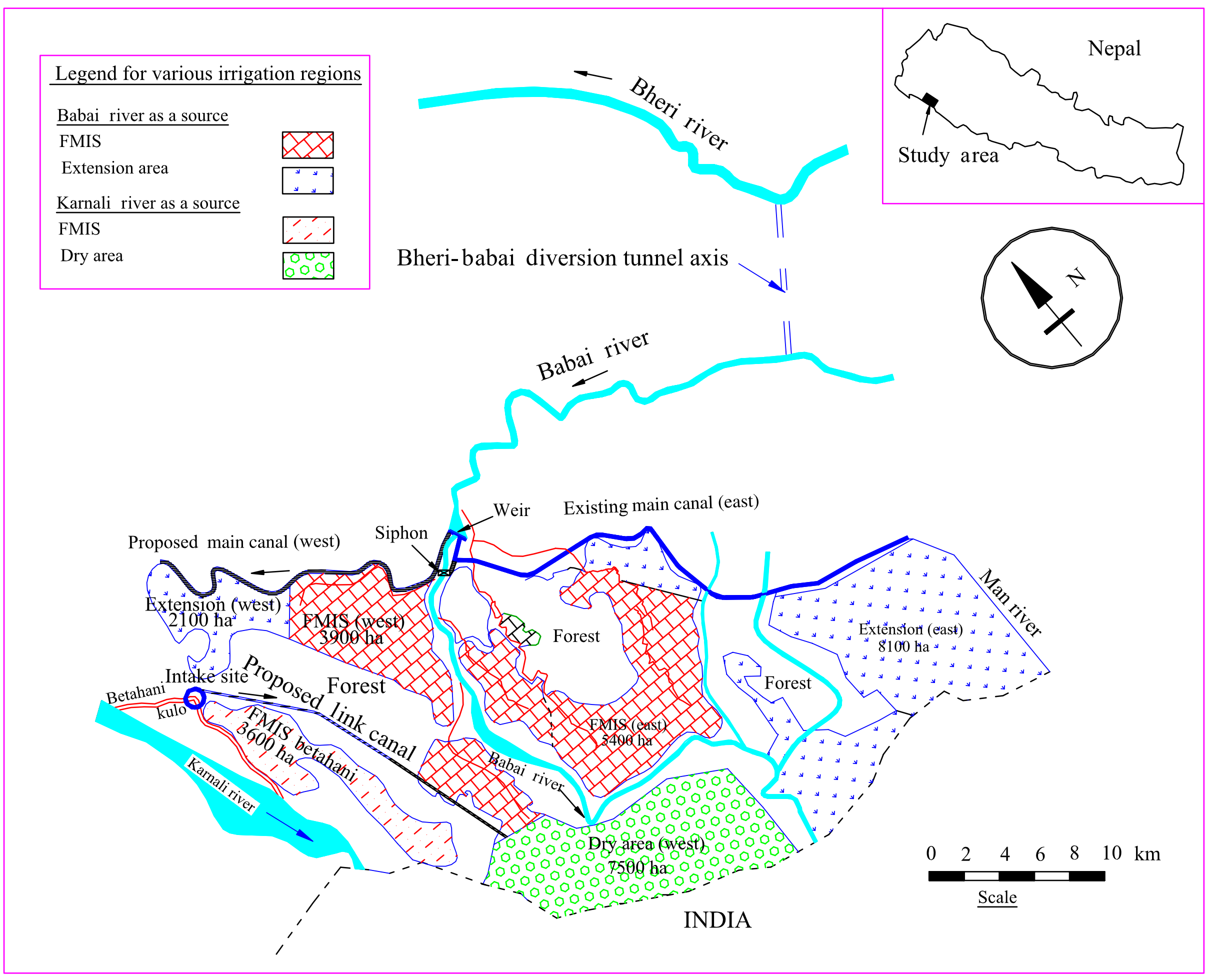

Figure 1 | Map of the study area showing the Babai, Bheri and Karnali rivers, various irrigation regions, the Bheri-Babai diversion tunnel and siphon locations and existing and proposed canals.

Table 1 | Categorization of irrigation regions in the study area, ha

Description	East Side	West Side	Total	Remarks
A. The Babai as a source				Proposed
1. FMIS	5,400	3,900	9,300	Existing
2. Extension	8,100	2,100	10,200	
Sub-total	13,500	6,000	19,500	
B. The Karnali as a source				
1. Dry area	-	7,500	7,500	
2. FMIS *Betahani kulo*	-	3,600	3,600	
Sub-total		11,100	11,100	
Grand total	13,500	17,100	30,600	

Source: Department of Surveys, Topographic maps of the study area.

for extending irrigation to dry areas at both banks of the Babai river suggested a two-phase development plan. The Phase 1 consisted of a weir in the Babai river and a 28 km long Main Canal with distribution system in 13,500 ha lands at the east side (left bank) using the available flow in the Babai river. The Phase 2 works comprised of an 8 km long tunnel to transfer 35 m^3/s water from the *Bheri* river to the Babai river, among which 30 m^3/s was proposed to supply the west side through a siphon across the Babai river at about 1 km downstream from the weir after depositing sediments in a 1 km long settling basin at the left bank (Figure 1).

While most of the Phase 1 works have already been accomplished resulting into the expansion of irrigation to an additional 8,100 ha of farmland comprising the extension area at the east side, Phase 2 could not even be initiated due to technical, financial and environmental constraints. The diversion project is likely to raise the issue of natural environment (NIPPON KOEI 1993) being located deep into a National Park. The farmers at the west side during several meetings have repeatedly demanded a contour canal from the Babai river to the west side for a fair and proper utilization of their share of the flows of the Babai river. It has become urgent to explore an appropriate irrigation infrastructure development as well as the water management strategy for the west side area to avoid possible water use conflicts between the east and west side farmers.

Intensification of government activities at the east side created a great dissatisfaction among the farmers at the west side who are the counterparts with fifty percent rights on the Babai river flows. It was observed by the first author in his field visits and several interactions with the stakeholders in the period between 2002 and 2004 during the Environmental Impact Assessment study of the distribution system at the east side and the siphon across the Babai river to deliver 30 m^3/s of discharge to the west side from the Main Canal at the east. During the public hearing meetings the stakeholders at the east side were concerned about sharing available water between the FMIS part and the extension area after allocating the requirements for existing crops at the FMIS part. However, the stakeholders at the west side rejected the proposed siphon and demanded for a direct Main Canal to the west from the weir. They have even withdrawn their past consent for siphon saying "regardless of whatever had been agreed in the past, now we demand a direct main canal from the weir" (East Consult 2001). A field study was carried out in November, 2006 by the first author to collect information regarding river flow, rainfall, cropping pattern, crop areas and to seek an alternative to the questionable Bheri-Babai inter-basin transfer scheme and the siphon across the Babai river.

The demand of the farmers at the west side prompted to seek an alternative for not only the siphon but to work out a new plan, which, preserving existing water rights of all stakeholders, can provide year-round irrigation to the total area in a sustainable manner. Using the recently produced topographical maps of the study area by the Department of Surveys, Nepal it has been determined that the *Betahani*

Table 2 | Mean and 80% probability of exceedance discharges of the Babai and the Karnali river, m^3/s

Values	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Babai Mean	19.5	16.2	13.0	9.1	13.5	56.1	235	255	266	100	35.3	23.2
Babai 80% Exceedance	13.9	12.3	7.2	7.2	7.5	21.8	82.3	158	139	35.9	24.7	17.6
Karnali Mean	370	335	348	445	702	1,520	3,290	4,370	3,020	1,320	632	446

FMIS, which provides irrigation to 3,600 ha lands taking water from the Karnali river, can be extended to irrigate the 7,500 ha dry area at the west which has been supposed to be irrigated only after implementing the inter-basin transfer from the *Bheri* river. This arrangement can significantly reduce the farmlands at the west side requiring water supply from the Babai river to 6,000 ha. The irrigation regions to be formed as a consequence of this arrangement are listed in Table 1.

The present study involves the following investigations:

- Assessment of mean and 80% probability of exceedance discharge of the Babai river and the divertible flow after deducting 10% discharge for downstream ecosystem's requirements.
- Analysis of the water balance scenario in the total area supposed to be supplied from the Babai river to attain a cropping intensity of 250% considered as the datum for a year-round irrigation.
- Evaluation of the technical, social and financial feasibility of a gravity link canal from the Karnali river, as an extension of the *Betahani* FMIS to irrigate 7,500 ha dry area at the west side.
- Evaluation of the water needs of FMIS at the east side to sustain their existing agriculture, and determination of cropping pattern at the extension area using the remaining discharge.
- Taking wheat and maize as representative crops of the winter and spring the water supply and deficit for various wheat-maize combinations have been analyzed for all parts.
- Analysis of various alternatives to make up the deficit in order to achieve a sustainable and socially compatible year-round irrigation water management strategy in the study area.

RESULTS AND DISCUSSION

Babai and Karnali river discharges

Table 2 contains the mean and 80% probability of exceedance discharges of the Babai river and the mean monthly discharge of the Karnali river (Mishra *et al.* 2007; Adhikari *et al.* 2009). From the table it is seen that the snow-fed river, the Karnali carries enormous water round the year, and wherever feasible, water from the snow-fed river should be diverted to irrigate surrounding lands.

Crop water requirements

The half monthly crop water requirements at the field channel outlet to cultivate the selected six crops are determined from the following formula:

$$CWR_{ij} = \sum_{l=1,6} IRA_l\left[(ETo_{ij}{}^{*}kc_{lij} + DP - ER_{ij})/FE_l\right] \quad (1)$$

where CWR_{ij} is the total crop water requirement during jth half month of ith month, IRA_l is the irrigated area of the lth crop, ETo_{ij} is the evapotranspiration in jth half month of ith month, kc_{lij} is the crop coefficient of the lth crop at jth half month of the ith month, DP is the deep percolation and

Table 3 | Evapotranspiration (*ETo*) and 80% probability of exceedance rainfall (P_{80}) in the study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo, mm/day	2.14	3.15	5.16	6.85	7.20	6.06	4.71	4.17	3.83	3.25	2.46	1.87
P_{80}, mm	19.2	16.4	6.5	13.4	50.9	154.1	341.5	304.7	157.3	12.1	0	0

Table 4 | Monthly water balance scenario for the total area based on the Babai river flows, $10^6\,m^3$

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Available	33.1	27.7	18.3	16.9	21.6	64.4	196.3	340.2	299.5	110.5	59.0	44.3
Required	32.5	61.3	60.1	42.6	87.6	34.7	108.4	24.1	46.9	75.2	0.6	18.7
Balance	0.6	−33.6	−41.8	−25.7	−66.0	29.7	87.9	316.1	252.6	35.3	58.4	25.6

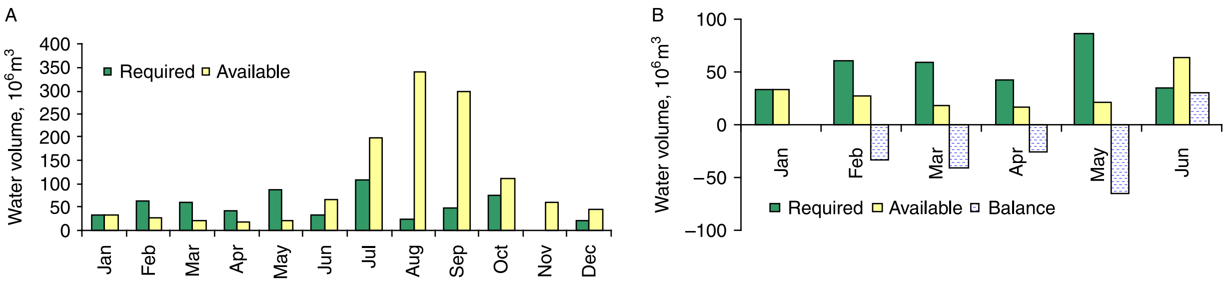

Figure 2 | Water supply and deficit at a cropping intensity of 250% from the Babai source only.

equals 3 mm per day for rice and zero for other crops, ER_{ij} is the effective rainfall of corresponding periods and FE_l is the field application efficiency for crop l. The land preparation requirements for rice and wheat are considered separately.

The effective rainfall ER is determined using the relationship:

$$ER = \begin{cases} 1)\, 0.70^{*} P_{80}, & \text{or} \\ 2)\, 0.85^{*} P_{80}, & \text{or} \\ 3)\, ET_O{}^{*} k_c + DP \end{cases} \quad (2)$$

where, P_{80} is the 80% probability of exceedance rainfall. In Equation 2 condition 1) is valid for all dry season crops and also for monsoon rice if $P_{80} > 100$ mm but less than $ETo * k_c + DP$; 2) is valid for monsoon rice if $P_{80} < 100$ mm and less than $ETo * k_c + DP$ and 3) is valid for monsoon rice if $P_{80} > ETo * k_c + DP$. The crop coefficients of six selected crops are taken from the Design Manuals for Irrigation Projects in Nepal (DOI 1990). The monthly ETo and P_{80} values of the study area determined by Adhikari *et al.* (2009) are presented in Table 3.

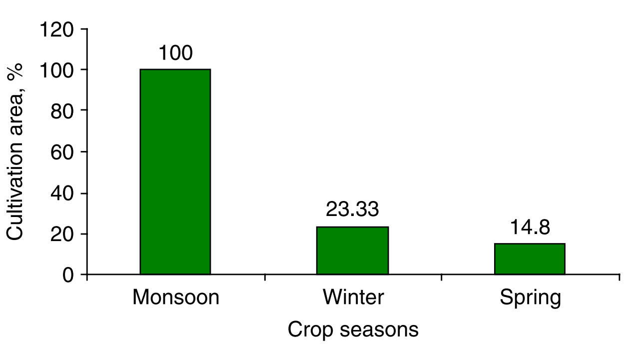

Figure 3 | Fully irrigated cropping pattern in the study area using the Babai source only.

Water balance for the total area: without link canal

The water balance calculation has been carried out to maintain a cropping intensity of 250% in the total area with 27,000 ha rice, 18,500 ha wheat, 19,000 ha maize, 2,000 ha winter vegetable and 1,000 ha pulses considering the canal efficiency at 50% showed surplus water in the source river during July–December, which can be seen from Table 4 and Figure 2A. However, there is a great deficit of water in period from January to May that can be seen from Figure 2B. The fully irrigated cropping pattern using the run-of-the river type diversion at the Babai river is 27,000 ha monsoon rice, 6,300 ha winter crops and 4,000 ha maize in spring giving a cropping intensity of 138.50% as shown in Figure 3.

Water withdrawals from the Karnali river to irrigate the FMIS and dry area

The proposed Link Canal to irrigate the dry area provides full irrigation to 7,500 ha rice during the monsoon, to 3,000 ha wheat, 3,000 ha pulses and 1,000 ha vegetables during the winter and to 4,000 ha maize and 2,500 ha spring rice during the spring season, resulting into a total cropping intensity of 280%. The monthly water withdrawals from the Karnali river to irrigate the *Betahani* FMIS and the dry area have been presented in Table 5. There is no problem to withdraw the required water volume from the Karnali river due to the availability of enormous discharge as given in Table 2.

Water balance at three irrigation regions to be irrigated from the Babai river

Allocating 10% of the Babai river flow for downstream ecosystem's requirements and preserving existing water

Table 5 | Monthly water withdrawals from the Karnali river, $10^6\,m^3$

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry area	8.34	18.08	23.75	28.24	32.63	14.14	30.12	6.69	13.03	20.89	0.32	4.50
FMIS Betahani	4.00	8.68	11.40	13.56	15.66	6.79	14.46	3.21	6.25	10.03	0.15	2.16
Total	12.34	26.76	35.15	41.80	48.19	20.93	44.58	9.90	19.28	30.92	0.47	6.66

rights between the east and west sides, and between the FMIS and extension parts at the east side the basic cropping intensities at all parts have been determined. The basic CI at the east side FMIS is 179% whereas the extension area has only 18% coverage in the dry season. The scenario at the right side seems easier to satisfy because of the availability of half of the Babai river flow to irrigate only 6,000 ha of lands, 83% of which can be cultivated in the dry season. Table 6 shows cropping intensities at different irrigation regions at various options. The water deficit scenario for different wheat-maize combinations for the FMIS and the extension areas at the east and west sides are analyzed and presented in Tables 7 and 8.

Strategy to make up deficit

Figure 4 and Table 8 clearly indicate that October, November and December are the months with surplus water. The east side FMIS and the west side experience no deficit of water even in January. February to May is the most deficit period at the east side for option 2 through 4. May is the deficit month for all options in all areas. It is possible to compensate the deficit by various means. (A) Harvest water in local ponds during surplus months in order to apply water during scarce periods. The farmers of the extension area at the east side are practicing water harvesting in various ponds since long ago. The *Badhaiya* Lake situated at the extension part of east side is famous in this endeavour. There are about 70 ha of pond area at the east side extension part only. (B) Conjunctive use of ground water is the second and most viable option to provide a reliable irrigation. The deficit volume at each part is only a small fraction of the deep percolation which occurs in the summer from the rice fields on the one hand, and the field deficit is only 50% of the gross deficit given in Table 8 and hence there will be a need to pump only half of the deficit volume. (C) Adoption of marginal deficit irrigation practices is also an option because a small deficit in irrigation water will not significantly reduce the yield. Rather, mature plants with fully developed roots have the capacity to extract required water from the soil moisture.

With the new arrangement the deficit water volume at the east side FMIS for option 4 is $19.37 \times 10^6\,m^3$ which can be compensated by storing surplus water of that region from November to January. This region can supply its surplus water of October for storing at the extension area which experiences a deficit in January as well. However this deficit is possible to be set off by diverting surplus water from west side's 50% share during that month. The total water deficit at the east extension is $66.36 \times 10^6\,m^3$ for option 4, whereas the surplus water of the period October-December is only $26.6 \times 10^6\,m^3$. The surplus volume at the west side during November and December can be diverted to the east for storing at the extension area. Groundwater pumping is another low cost and easily available technology getting

Table 6 | Crop areas at various parts for different options, ha

Location/Crops	Basic	Option 1	Option 2	Option 3	Option 4
A. East FMIS	Fixed areas: Rice 5,400; Pulses 700 and vegetables 1,000				
Wheat	1,465	2,300	2,800	3,300	3,300
Maize	1,100	1,500	2,000	2,500	3,200
Total	9,665	10,900	11,900	12,900	13,600
B. East extension	Fixed areas: Rice 8,100 and vegetables 500				
Wheat	–	1,500	3,500	5,500	6,500
Maize	1,000	2,000	3,000	4,500	5,200
Total	9,600	12,100	15,100	18,600	20,300
C. West side	Fixed areas: Rice 6,000; Pulses 500 and vegetables 500				
Wheat	2,000	2,500	3,000	3,500	4,000
Maize	2,000	2,500	3,000	3,500	4,000
Total	11,000	12,000	13,000	14,000	15,000

Table 7 | Water requirement and deficit scenario at various cropping intensities, $10^6 m^3$

Options	FMIS East Area ha	CI%	Deficit	Extension East Area ha	CI%	Deficit	West Side Area ha	CI%	Deficit
Basic	5,400	179	0	8,100	118	0	6,000	183	0
Option 1		202	3.1		149	10		200	1.8
Option 2		220	8.1		186	28.8		217	5.3
Option 3		239	14.6		230	53.9		233	9.7
Option 4		252	19.4		250	66.4		250	13.9

wide spread in recent years in the Terai. This technology can supplement the storage arrangement in securing year-round irrigation in the study area. Detailed planning of local reservoirs or groundwater pumping arrangement in the whole area requires intensive interaction with stakeholders which is beyond the scope of this study.

Financial and socio-institutional strengths of the proposed solution

The Bheri-Babai diversion project has an estimated cost of 260 million US dollars. Alternatively, the cost of the proposed 18 km west main canal and 20 km link canal from the Karnali is about 8 million US dollars, and this can be easily managed from Nepal's internal resources. The government expenditure made so far in the BIP, about 20 million US dollars, has been arranged without foreign assistance and hence the proposed solution is financially viable and manageable. The farmers of the west side area have repeatedly requested to construct a main canal similar to that which has been provided in the east side, and the solution devised in this paper not only supports the farmers' demands but also further proposes to deliver sufficient water round the year to the southern dry area from the

Table 8 | Water surpluses and deficit at different regions during the dry season, $10^6 m^3$

Options	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
A. East FMIS								
Basic	8.84	14.51	10.64	5.92	3.04	0.67	1.86	0.56
Option 1	8.84	14.51	10.31	4.59	0.48	−1.82	0.96	−1.29
Option 2	8.84	14.51	10.12	3.80	−1.05	−3.31	−0.16	−3.59
Option 3	8.84	14.51	9.93	3.01	−2.59	−4.81	−1.28	−5.90
Option 4	8.84	14.51	9.93	3.01	−2.59	−4.81	−2.85	−9.12
B. East Extension								
Basic	8.84	14.51	9.19	5.92	3.04	0.67	1.86	0.56
Option 1	8.84	14.51	7.82	3.54	−1.56	−3.81	−0.57	−4.05
Option 2	8.84	14.51	5.99	0.38	−7.70	−9.77	−2.63	−8.66
Option 3	8.84	14.51	4.17	−2.79	−13.83	−15.73	−5.99	−15.58
Option 4	8.84	14.51	3.25	−4.37	−16.90	−18.72	−7.56	−18.81
C. West side								
Basic	38.57	29.33	30.61	12.38	5.93	0.73	3.93	1.58
Option 1	38.57	29.33	30.16	11.59	4.40	−1.03	3.08	−0.73
Option 2	38.57	29.33	29.70	10..80	2.86	−2.26	1.69	−3.03
Option 3	38.57	29.33	29.25	10.00	1.91	−4.32	0.57	−5.34
Option 4	38.57	29.33	28.79	10.47	−1.47	−4.24	−0.55	−7.64

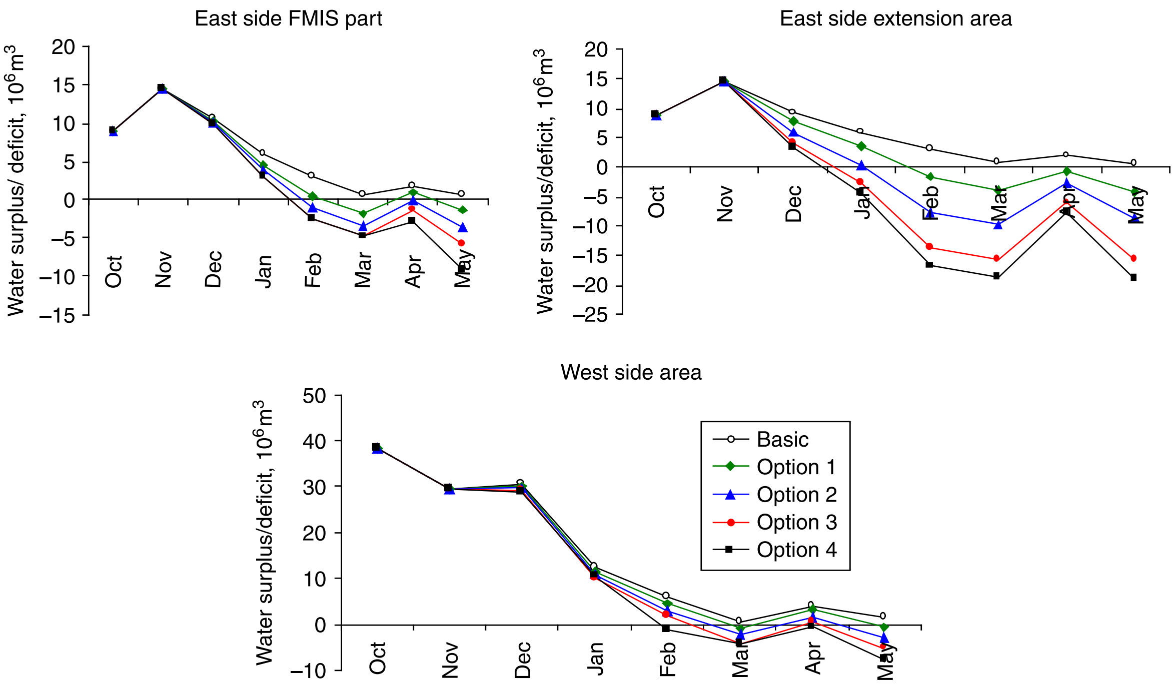

Figure 4 | Water surpluses and deficit during the dry season at the three irrigation regions to be fed from the Babai river.

Karnali which is one of the largest snow fed rivers of the country. The fairness is ensured by preserving existing irrigation institutions and their water rights during carrying out water balance study.

Shah *et al.* (2003) state that some 10% of the world's food production depends on yearly overdraft of groundwater of 200 km^3, out of which 100 km^3 most likely occurs in India. Irrigated rice fields are artificial wetlands which contribute to groundwater recharge. The proposed solution additionally envisages storing the surplus river water in local reservoirs, which makes significant contribution to groundwater recharge. In the Ganges plain the ancient indigenous knowledge had developed a flood water harvesting system called "Ahar-Pyne". The excess water from the Ganges was driven by channel called "Pyne" deep inside the land, up to 30–40 km to fill tanks called "Ahar" which ensured long lasting retention of water throughout the year (Miza 2008). Spreading the proposed technology of water harvesting and fully irrigated rice cultivation in the Terai or elsewhere in the Ganges plain can significantly contribute to solving the minimizing groundwater overdraft problem and preserving the river ecosystem in the region.

CONCLUSIONS

Seeking alternatives to a single engineering solution is vital to arrive at a sustainable solution. The Environmental Protection Rules, 1997 have made it obligatory to carry out public hearing meetings and get their consent on the proposal. The idea of the proposed solution was inspired by the repeated demand of the farmers to construct a canal from the diversion to the west, whereas all previous studies focused on very costly and questionable inter basin transfer. The proposed solution provides a financially, environmentally and socially viable and justified alternative to the diversion scheme and should be the lynchpin in securing year-round irrigation in the region.

The suggested solution fits the existing socio-institutional set-up of the local community as it preserves prevailing the water rights and institutions of all farmer groups.

The dry season water demands can be met using harvesting techniques and conjunctive use of ground water. Harvesting water in local reservoirs is the traditional technique of local people of the region, it is beneficial for ground water recharge and provides opportunities for fishery development.

The proposed approach has a potential of spreading over the whole Terai region of the country. The ground water development needs no government investment as the farmers will develop it on their own based on the intensification of the dry season crops.

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