Physics and Chemistry of the Earth 34 (2009) 99–106

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Water rights of the head reach farmers in view of a water supply scenario at the extension area of the Babai Irrigation Project, Nepal

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ARTICLE INFO

Article history:
Received 30 October 2007
Received in revised form 9 March 2008
Accepted 9 April 2008
Available online 22 April 2008

Keywords:
Crop water requirement
Farmer managed irrigation systems
Indigenous technology
Priority water rights
Social capital

ABSTRACT

The farmer managed irrigation systems (FMIS) represent those systems which are constructed and operated solely by the farmers applying their indigenous technology. The FMIS generally outperform the modern irrigation systems constructed and operated by the government agencies with regard to the water delivery effectiveness, agricultural productivity etc., and the presence of a sound organization responsible to run the FMIS, often referred to as the 'social capital', is the key to this success. This paper studies another important aspect residing in the FMIS: potentials to expand the irrigation area by means of their proper rehabilitation and modernization. Taking the case study of the Babai Irrigation Project in Nepal, it is demonstrated that the flow, which in the past was used to irrigate the 5400 ha area covered by three FMIS, can provide irrigation to an additional 8100 ha in the summer, 4180 ha vegetables in the winter and 1100 ha maize in the spring season after the FMIS rehabilitation. The "priority water rights" of the FMIS part have been evaluated based on relevant crop water requirement calculations and is found to be equal to 85.4 million m^3 per year. Consequently, the dry season irrigation strategy at the extension area could be worked out based on the remaining flow. By storing the surplus discharge of the monsoon and autumn in local ponds, and by consuming them in dry period combined with nominal partial irrigation practice, wheat and mustard can be cultivated over about 4000 ha of the extension area. Furthermore, storage and surface irrigation both contribute to the groundwater recharge. The conjunctive use of ground, surface and harvested water might be the mainstream in the future for a sustainable irrigation water management in the region.

1. Introduction

Sustainable water resources management in the world of the 21st century is a great challenge requiring a radical change in the manner in which water is perceived and managed till now. A number of global initiatives and reports have documented the dramatic impact of human-induced water withdrawals from the world's lakes, rivers and aquifers. Total annual global freshwater withdrawals at present are estimated at 3800 km^3 – twice as much as just 50 years ago (WCD, 2000). The water crisis caused by natural water resource shortage and serious water pollution has become one of the most rigorous problems in China (Zhang et al., 2007). 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. Most of the surface irrigation systems constructed in the past have failed to attain the targeted irrigated area and cropping pattern. An ADB evaluation of 35 irrigation projects found actual cropped areas generally at 60–85% of appraisal estimates, with only four exceeding the targets. A World Bank study of seven irrigation projects found all but one with crop intensities less than expected. A 1990 evaluation by the World Bank of 21 irrigation projects 5–12 years after completion showed that the irrigated area was reduced in 11 of the projects and that cropping intensity was lower than at completion in 18 of the projects. These studies show the need for a dramatic change in the present irrigation practices in order to make them sustainable and capable of meeting the food and fibre requirements of the ever growing population.

Various studies have shown that the traditional irrigation systems constructed and operated by the farmers using their indigenous technology, known as the farmer managed irrigation systems (FMIS), generally outperform the modern irrigation systems run by the government units with regard to the physical condition of the system, the water delivery effectiveness and the agricultural productivity (Lam, 1996). Presence of a strong users' institution valued as "social capital" of the FMIS, is the key element of their sustainability and better performance. These research findings inspired the management transfer to the users and participatory approach of irrigation planning from the 1990s. Nepal has a long history of FMIS and thousands of FMIS exist in the country at present. In addition to the 'social capital', the FMIS deserve

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doi:10.1016/j.pce.2008.04.004

potentials for expansion of irrigation area by means of their proper rehabilitation and modernization because the canals in these systems carry much higher discharge than the actual crop requirements in order to cope with the leakages caused by temporary structures. Now the FMIS are facing challenges due to depletion of local materials, competition for water between irrigation and other sectors and change in the social structure of the farmer community demanding their proper rehabilitation and modernization which could simultaneously raise the water productivity and expand the irrigated area.

As a case study we have considered the Babai Irrigation Project (BIP) in Nepal which comprises of two distinct parts: (1) head reach area (5400 ha) covered by three FMIS constructed and run solely by the local community since1940s and (2) extension area (8100 ha) which is getting irrigation after the construction of a diversion weir and a 28 km long main canal by the government in 2000. The government intervention on the farmers' systems raised two critical questions among the farmers of the FMIS part: (1) how to organize the distribution in the FMIS part in the new context? And (2) what are the water requirements for the existing crops in the FMIS area, claimed as the "priority water rights"? The FMIS farmers agreed to release the discharge to the extension area only after fulfilling the requirements for their existing crops, which was accepted by the farmers of the extension part as well. The BIP, after a long debate and several public hearing meetings, agreed to rehabilitate the existing FMIS *kulos* mainly by constructing permanent concrete diversions, and to annul the design of an entirely new canal system prepared in 1982. However, the vital issue of "priority water rights" of the FMIS area has remained unsolved and the water availability scenario at the extension area is quite unclear. The present study focuses on finding a solution to the priority water rights issue of the head reach farmers by performing their crop water needs calculations, and seeking for an irrigation strategy at the extension area based on available flow and analysing the possibility of increasing winter crops by applying harvested water in local ponds, and with marginal deficit irrigation practices.

The article is organized as follows: Section 2 contains the description of the study area, a short introduction on the technical aspects of the BIP and the problems that emerged after the government intervention. Sources of various information and data collection methods have been described at the end of the section. In the beginning of Section 3 we carry out river flow and rainfall analyses. Then the reference evapotranspiration (ETo) calculations have been performed by different methods. The crop water requirements for existing crops in the FMIS area have been estimated using the present crop varieties and effective rainfall. After determining the "priority water rights" of the FMIS part, we proceed to determine the fully irrigated cropping pattern at the extension area. The possibility of cultivating various wheat-mustard combinations with marginal deficit irrigation and by applying water harvesting techniques in local ponds has been investigated at the end of the section. Section 4 contains discussion and conclusions where we hint the viability of applying the proposed approach for a sustainable irrigation water management in other parts with similar climatic and topographic conditions.

2. Study area description, methods and materials used

2.1. The study area

The study area is the Babai Irrigation Project (BIP) in Bardiya district of Nepal, which is located between 81°15′ and 81°32′ E longitude and 28°04′ and 28°30′ N Latitude. The East West Highway, running almost parallel to the main canal, forms the northern boundary and the international border between Nepal and India makes the southern boundary of the study area. At the east and west two rivers, viz. the Man *khola* and the Orai *khola* are situated. The Babai river is the source with a catchment area of 3270 km^2, 1 in 100 years probability peak discharge of 7500 m^3/s and average discharge of 72 m^3/s (Shivakoti and Bastakoti, 2007). Total five FMIS were developed in the past by the farmers, three of them namely the Majhara *kulo*, the Budhan *kulo* and the Raj *kulo* are situated at the left bank and the remaining two: the Jhamti *kulo* and the Dhodhari *kulo* are situateted at the right bank of the Babai river. The present study attempts to find an irrigation strategy at the left bank area comprised of 5400 ha covered by three FMIS and the 8100 ha by extension part as shown in Fig. 1. In the past all the FMIS had separate temporary diversions in the source river and they used to supply the required discharge to all canals during the monsoon season due to the availability of enough flow at the source river. During the dry season the east and the west sides have been practicing equal division of the available flow with consensus.

In 1992 the government constructed a weir cum bridge across the Babai River and the first 5 km of the main canal which are shown in Figs. 1 and 2. As the bridge on the weir was a part of the national highway, the location of the bridge forced the designers to plug the existing intakes of the *Budhan kulo* and the *Raj kulo* and to construct the first 5 km part of the main canal to release for these *kulos* regulated flow from the headwork. The outlets B1 and S1 shown in Fig. 1 were provided to release water to the *Budhan* and the *Raj kulo*, respectively. Between 1995 and 2000 the BIP extended the main canal from 5 km to 28 km which brought 8100 ha of dry area, referred to as the extension area, under irrigation. The extension area consists of a modern distribution system comprising of branch, secondary and field channels getting water supply from ten outlets at the main canal. While the construction of the canal network at the extension area was nearly completed during field visit in November, 2006, the mode of intervention at the FMIS part was agreed only in 2004 after discussing the issue in several public hearing meetings. By November, 2006 the BIP had completed detailed survey of FMIS *kulos* and detailed design of a few structures was completed.

The farmers of the extension area have no objection to allocate the "priority water rights" of the FMIS part and this aspect has got place in the constitution of the water users' association (WUA) of the BIP. In order to preserve the present water management practices at the FMIS area, the head of each *kulo* has been designated as a member of the WUA committee. This arrangement is fully compatible to the present socio-institutional context of the study area. The BIP having no solution to the problems at the FMIS part, had intensified the construction of branch canals in the extension area in 2002, and by 2006 all branches and secondary canals were substantially completed. This has resulted into an increase in demand of water at the extension part. Running the canals without solving the issue of priority water rights of the FMIS part and without determining the available canal flows at the extension area might be the cause of a serious water use conflicts between the FMIS part and the extension area. The present study aims to assess the priority water rights by conducting the river flow and rainfall analyses, evapotranspiration and crop water requirement calculations using recent measurements and cropping pattern information at the FMIS area so that the WUA could manage the available water resources in a sustainable manner serving the stakeholders of both parts.

2.2. Field study and data collection

The analyses presented in this paper are based on the investigations performed by the first author during his tenure in the BIP as

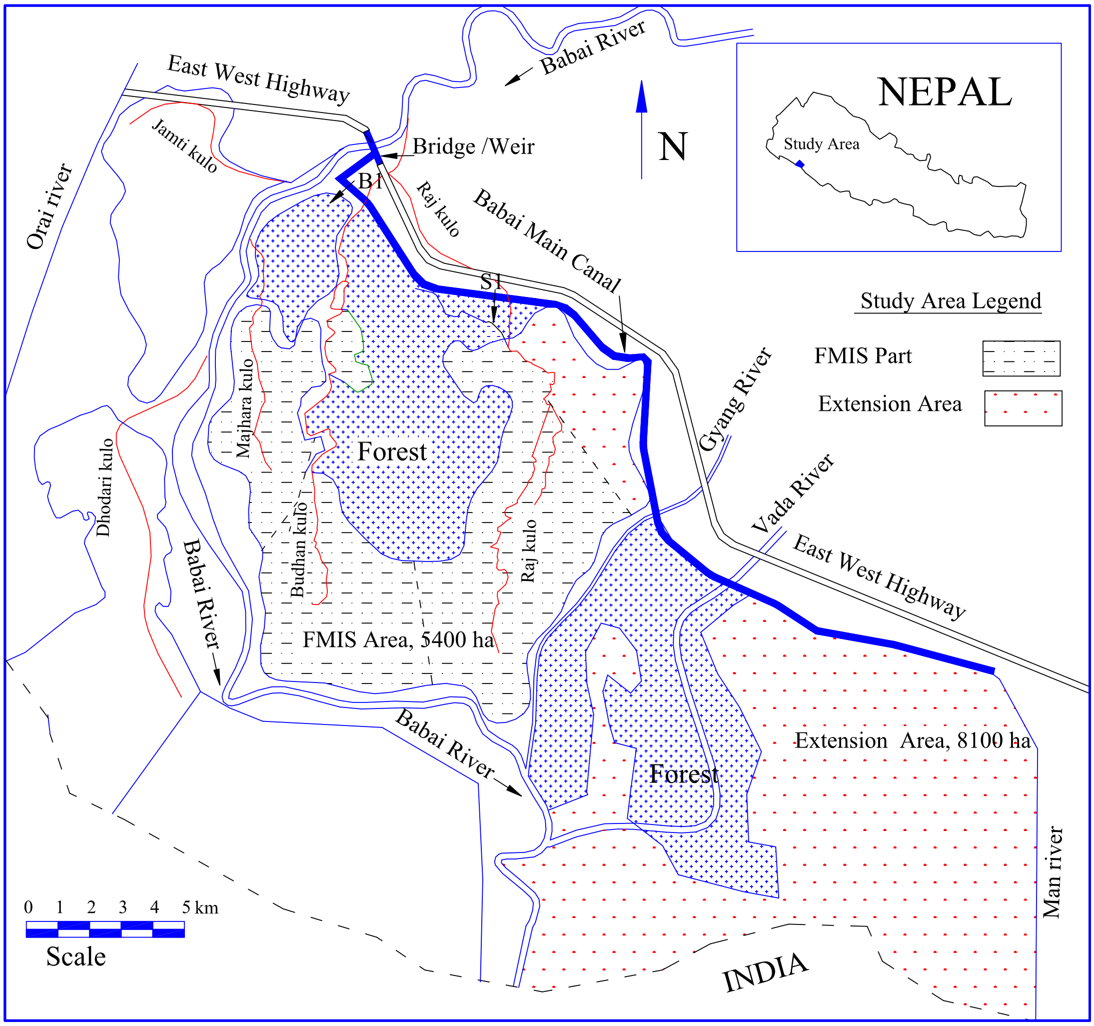

Fig. 1. The map of the study area showing the Babai river, headwork, the main canal, FMIS with *kulos* and the extension area.

Fig. 2. The weir cum bridge across the Babai river (left) and the main canal (right).

an irrigation engineer from 2002 to 2004 and his recent field study in November, 2006. Participatory approaches were used to identify the irrigation related problems of the farmers, which included focus group discussions with the farmers of different *kulos*, the local intellectuals like teachers, the WUA chairman, political leaders and local government representatives. Site visits accompanied by the head of the farmers' institution called the *kula pani choudhari* were conducted along all FMIS *kulos*.

The following activities were performed by the first author during the field visit in November, 2006:

- River flow: The discharge record of the Babai river at the headwork site from 1969 to 1986 was collected from the Department of Hydrology and Meteorology (DHM), Kathmandu.
- Rainfall records from 1976 to 2005 of the district headquarter *Gulariya* and the headwork site *Bargadaha* and temperature,

relative humidity and sunshine hours of the nearest station (*Nepalgunj*) were collected from the DHM, Kathmandu.
- The BIP office provided the latest survey data, topographical maps and drawings and previous study reports of the BIP.
- Focus group discussions were held in all three FMIS in order to get farmers' feed back on the works performed by the BIP so far and on priority water rights issues.

3. Results and analyses

3.1. Discharge and rainfall

The frequency analysis method has been applied to determine the 80% probability of exceedance (80% reliable) discharge and rainfall using the following relationship:

$$Q_{80} = Q_{\text{mean}} - S * 0.8414 \quad (1)$$

where, Q_{80} is the 80% reliable value, Q_{mean} is the mean value and S is the standard deviation. The 80% reliable discharge calculated based on the flow measurement records of the source river from 1969 to 1986 is presented in Table 1. There is a long established tradition of sharing the available water half–half between the east and the west sides. Hence the east side has the right to only 50% of the flow. The water resource assessment carried out during the reconnaissance study of the BIP in 1977 had eliminated from the analysis half of the flow in the Babai river saying as "the requirements of existing utilities". The irrigation planning in the 13,500 ha at the east side was carried out based on the east side's 50% share only. Strangely, the same study had recommended to bring 35 m^3/s of water from the Bheri river to the Babai river through a inter basin transfer requiring a 9 km long tunnel to irrigate 21,000 ha area available at the west. Thus the irrigation development at the west side relied on the implementation of a diversion scheme and the construction of a 500 m long siphon across the Babai river afterwards. The diversion scheme was financially viable only with a 24 MW hydropower generation which required 184.40 million US dollars investment. Further studies indicated that the diversion project had "potential to raise an issue of natural environment" (Nippon Koei, 1993) being located deep into the Bardiya National Park. Similar to the east side, the west side as well deserves equal potentials for irrigation development using its share of the Babai river flows. This aspect has been overlooked by all previous studies and needs a deep consideration. To preserve the existing water sharing tradition between the east and west sides, we have taken only half of the 80% reliable flow of the Babai river as the available discharge at the east side for further analyses which is shown in the last row of Table 1.

The rainfall records obtained from the DHM of the period between 1976 and 2005 of the Bargadaha, the headwork site, and the Gulariya have been used for the frequency analysis. The 80% reliable rainfall of both stations has been determined applying the widely used in Nepal Medium Irrigation Project method of frequency analysis (DOI, 1990). The average of the two stations presented in Table 2 has been considered as the design rainfall in determining the crop water requirements for the study area.

3.2. Temperature, relative humidity and sunshine hours

The average monthly values of maximum and minimum temperature, relative humidity and sunshine hours of the nearest station (Nepalgunj) used to determine the ETo are presented in Table 3.

3.3. Reference evapotranspiration (ETo) calculation

A good estimation of the reference evapotranspiration (ETo) is vital for a reliable crop water requirement calculations. We have calculated the ETo using the Penman-Monteith method recommended by the Food and Agriculture Organization (FAO-56), the 1985 Hargreaves equation, and the Blaney-Criddle method. Results

Table 1
80% Reliable discharge of the Babai river and the east part's share, m^3/s

Description	January	February	March	April	May	June	July	August	September	October	November	December
Q_{80}	13.9	12.3	7.2	7.2	7.5	21.8	82.3	157.6	139.0	35.9	24.8	17.6
East side's share = $0.5^* Q_{80}$	6.9	6.1	3.6	3.6	3.7	10.9	41.1	78.8	66.5	17.9	12.4	8.8

Table 2
Monthly values of the 80% reliable rainfall at the Gulariya, the Bargadaha and the mean value, mm

Description	January	February	March	April	May	June	July	August	September	October	November	December
Gulariya	18.1	16.0	5.3	12.7	45.7	146.1	366.6	281.7	158.7	14.0	0	0
Bargadaha	20.3	16.8	7.7	14.1	56.2	162.1	316.4	327.7	155.9	10.2	0	0
Average	19.2	16.4	6.5	13.4	50.9	154.1	341.5	304.7	157.3	12.1	0	0

Table 3
Temperature, relative humidity and sunshine hours of the nearest station (Nepalgunj)

Description	Unit	January	February	March	April	May	June	July	August	September	October	November	December
T_{max}	°C	20.2	25.1	30.9	36.5	37.8	36.5	33.6	33.0	32.7	31.7	28.1	23.4
T_{min}	°C	8.9	11.6	15.8	20.9	24.9	26.7	26.6	26.4	25.2	21.0	15.1	10.6
RH_{max}	%	93.2	88.0	78.0	61.8	65.9	77.8	88.3	90.9	91.4	89.1	89.6	92.1
RH_{min}	%	70.7	60.3	45.8	39.4	49.2	59.6	76.6	80.2	78.6	71.9	63.0	67.8
Sunshine	H/day	4.6	7.7	8.5	9.3	9.8	7.4	5.5	4.7	5.9	8.4	7.5	6.6

Source: DHM, 2006.
T_{max}: average maximum temperature.
T_{min}: average minimum temperature.
RH_{max}: average maximum relative humidity.
RH_{min}: average minimum relative humidity.

Table 4
Monthly reference evapotranspiration values determined from different methods, mm/day

Methods	January	February	March	April	May	June	July	August	September	October	November	December
FAO-56	1.62	2.92	4.75	6.81	6.78	6.18	4.57	3.83	3.66	3.41	2.27	1.63
1985 Hargreaves	2.26	3.33	4.82	6.39	6.63	5.95	4.80	4.36	4.05	3.83	3.41	2.27
Blaney-Criddle	3.53	4.18	5.06	6.15	6.86	7.12	6.77	6.41	5.97	5.23	4.38	3.70

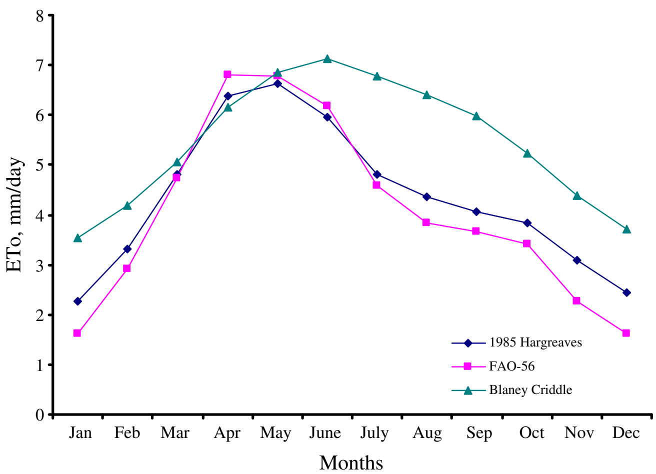

Fig. 3. Reference evapotranspiration values given by various methods.

of the calculations have been presented in Table 4 and Fig. 3. Allen et al. (1998) in the FAO Irrigation and Drainage Paper No. 56 recommended applying the FAO-56 method in all climatic zones as a sole method to determine the ETo values. FAO-56 is the replacement of the Penman method suggested by the FAO in 1977 through the Irrigation and Drainage Paper No. 24 (FAO-24). Fig. 3 shows that the ETo determined by the FAO-56 method is very close to those given by the 1985 Hargreaves method. This is consistent with the findings of Hargreaves and Allen, 2003, that the values given by these two methods are "surprisingly equivalent over a wide range of climates". Nandagiri and Kovoor, 2006, while comparing the ETo values given by the FAO-24 and FAO-56, found that the FAO-56 method yielded consistently lower estimates than the FAO-24 method at all the four Indian locations studied. Relying on these findings we have selected the ETo values given by the FAO-56 method for further calculations.

3.4. Existing cropping pattern and its water requirements

The existing cropping pattern of the study area was determined in 2004 during the Environmental Impact Assessment (EIA) study of the BIP by means of a questionnaire survey of farmers from all villages representing the FMIS area. The cropping pattern was found to be 179% which is shown in Fig. 4. The total cultivated area was 5400 hectare (ha), out of which 5100 ha was covered by rice and 300 ha by vegetables during the summer season. In the winter mustard, wheat, pulses, vegetables and potatoes covered 700, 665, 1000, 600 and 200 ha, respectively. Maize was the only crop cultivated in 1100 ha of lands in the spring season.

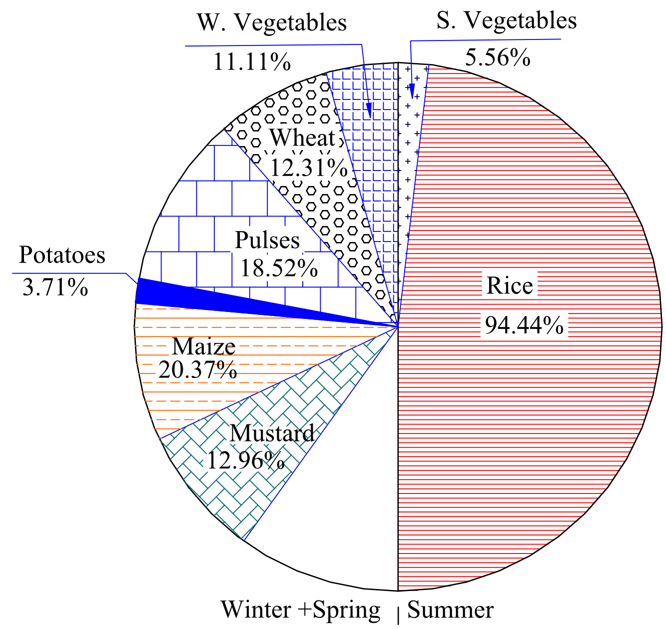

Fig. 4. Existing cropping pattern at the FMIS area.

The crop water requirements (CWR) per hectare of different crops other than rice have been determined assuming field application efficiency at 0.60. Due to the existence of a constant water pool in rice fields, the CWR calculation has been performed taking the deep percolation equal to 3 mm per day during the growth and 55 mm of water consumption during the two weeks needed for the preparation of the crop area. The combined main and branch canal efficiency has been taken at 50% in determining the intake water requirements considering the poor performance of existing *kulos*, significant seepage losses through porous bed at the upstream and leaky structures over there. The monthly water requirements of the FMIS area and the available water in the main canal are presented in Table 5. The annual water requirements of the FMIS area to continue the existing cropping pattern is 85.4 million cubic meter (MCM) whereas the total available water for the eastern part is 683.2 MCM. Fig. 5 shows the available water in the main canal and the priority rights of the FMIS area. It clearly shows the plenty of surplus water from June to January. February and March are found to be the most stressed months, reflecting the real field situation.

The BIP has started the rehabilitation of FMIS *kulos* which is expected to be completed in 3–4 years period. In the future situation with the permanent diversions and concrete lining at the porous parts the farmers' *kulos* one can expect a sharp increase in the canal efficiency. In the mean time, the farmers will be trained for

Table 5
Monthly water availability and requirements of the FMIS area, $10^6 m^3$

Months Months	January	February	March	April	May	June	July	August	September	October	November	December	Total
Available	18.4	15.4	10.2	9.4	12.0	35.8	109.1	189.0	166.4	61.4	32.8	23.8	683.2
Required	3.6	8.1	9.3	3.1	5.4	2.1	22.2	4.2	9.7	15.8	0.2	1.7	85.4

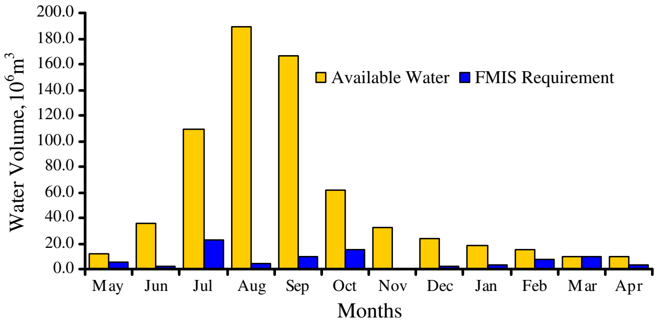

Fig. 5. Water supply and demand scenario at the FMIS area.

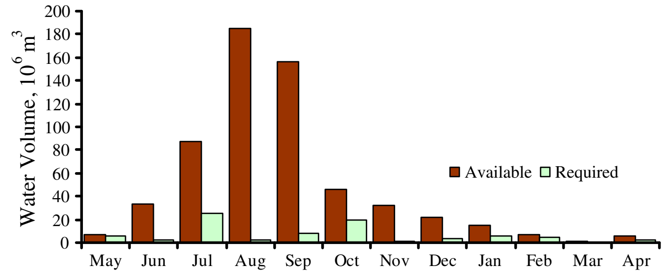

Fig. 6. Water supply and demand for the designed fully irrigated cropping pattern at the extension area.

efficient water management practices. Higher canal efficiency supplemented by the opportunity of reusing water from the cascades of diversions and efficient water management practices will result in higher water productivity and subsequent increase in the cropping intensity at the FMIS area without drawing additional water from the main canal. On this ground our study has considered the remains of the east side's share of the flow after deducting the priority rights of the FMIS part as the reliably available discharge for the extension area. The designed cropping pattern for the extension area is based on the above mentioned condition accepted by the farmers of both areas during focus group discussions.

3.5. Fully irrigated cropping pattern at the extension area and possibilities of cultivating crops other than vegetable in the winter

The same crop varieties as that in the FMIS part have been considered in designing the fully irrigated cropping pattern for the extension area. The water balance study shows that 7700 ha of monsoon rice, 400 ha of summer vegetables, 4180 ha of winter vegetables and 1100 ha of maize in spring season can be cultivated with full irrigation. The designed cropping intensity is 165.18% which is shown in Table 6. The monthly water requirement and availability is shown in Fig. 6 which indicates the immense availability of water in the monsoon and autumn, showing the possibility of further expansion of the monsoon rice area. However, in the late winter, it becomes scarce from January and there is no water available for the extension area in the second half of February. Due to this the cultivation of wheat, mustard and pulses with full irrigation has become impossible at the extension area. The only possibility is to cultivate vegetable, in 4180 ha that is harvested in the first half of February. However, vegetable production in a large scale depends on the assured demands from the market which the study area lacks at present. Alternatively, cereal crops like wheat, pulses and mustard should be grown with deficit irrigation or by providing irrigation from other alternatives such as groundwater or by storing surplus discharge of rainy season in local reservoirs to apply them during the scarce period.

There are many private and public ponds in the extension part covering 170 ha area where surplus discharge of the monsoon and autumn can be stored. The local pond called the *Badhiya tal,* situated in the extension area is being utilized by the farmers for rain water harvesting since long ago. The pond is a source of fishery development as well as irrigation in the surrounding area. Now the pond has been linked to the main canal and it stores enough water to serve the fishery development as well as the dry season agriculture. As the winter vegetable cultivation in a large scale seems to be impractical for the present socio-institutional context and market situation, taking a basic, relevant to the farmers' practices, cropping intensity (CI) of 118.50% composed of rice, summer vegetable, maize and winter vegetable in 7700 ha, 400 ha, 1100 ha and 400 ha, respectively, we have determined the deficit volume of water to grow various wheat-mustard combinations in addition to the basic CI. Table 7 shows the cropping intensities, total and deficit volumes for various options of wheat-mustard combination. The relationship between the storage requirements and cropping intensity for various options has been presented in Fig. 7. More than 3 million m^3 of water can easily be stored by raising water levels in ponds by 2 m which needs minor bank strengthening works only. The fully irrigated cropping intensity can then easily reach 150% with wheat and mustard each covering more than 2000 ha. Furthermore, winter crops coverage can be raised either by applying ground water or getting slight deficit irrigation. Ali et al. (2007) found that deficit irrigation in wheat with 39% less water resulted in only 16% decrease in yield. Storage in reservoirs and irrigation both contribute to groundwater recharge. Gradual

Table 6
Fully irrigated cropping pattern at the extension area

Crops	Monsoon rice	Summer vegetables	Winter vegetables	Maize	Total
Area, ha	7700	400	4180	1100	13,380
%	95.06	4.94	51.60	13.50	165.18

Table 7
Storage requirements for various wheat-mustard combinations

Combination	Unit	Basic CI	Option 1	Option 2	Option 3	Option 4
Cropping intensity	%	118.50	143.20	155.50	161.70	167.90
Storage requirements	MCM	0	1.73	5.23	6.86	9.31
Total required water	MCM	72.10	86.80	94.10	97.10	101.50

Notes:
Basic CI: rice: 7700 ha, summer and winter vegetables: 400 ha each, maize: 1100 ha.
Option 1: basic CI plus wheat and mustard: 1000 ha each.
Option 2: basic CI plus wheat and mustard: 1500 ha each.
Option 3: basic CI plus wheat and mustard: 1500 ha and 2000 ha.
Option 4: basic CI plus wheat and mustard: 2000 ha each.

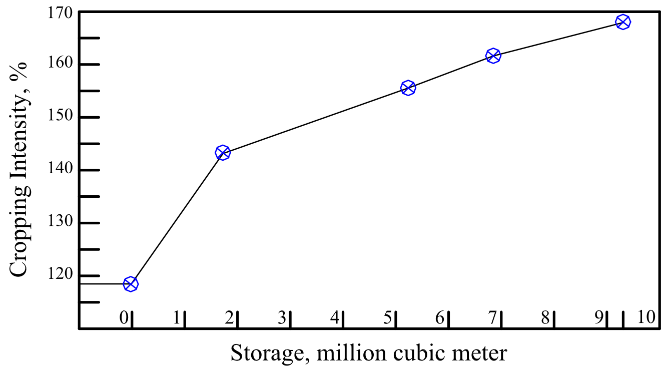

Fig. 7. Cropping intensity–storage requirements relationship.

rise in the groundwater table at the extension area has been observed by the farmers in the course of drinking water tube well installations. In the FMIS part the ground water table is already at 3–4 m below ground which indicates the possibility of its use for irrigation during the dry season. Hence the future strategy for sustainable dry season irrigation might be the conjunctive use of surface and ground water supplemented by water harvesting in local reservoirs.

4. Discussion and conclusions

4.1. Sustainability of system rehabilitation and irrigation water management

The FMIS rehabilitation plan being implemented now is an alternate to the design of an entirely new canal network which was prepared in 1982. Several public hearing meetings were conducted to discuss with the farmers and local governments about the mode of irrigation development in the FMIS area. The public hearings overwhelmingly supported the farmers' demand to rehabilitate the existing canal network and rejected the design of a new canal network which would not only curtail the irrigated lands by consuming huge areas for their construction, but also would destroy the farmers' irrigation institutions running smoothly for decades. The cost of construction of a new system would be many times higher than that of the farmers' system rehabilitation. Assessment of the priority water rights of the FMIS part was the demand of farmers from both areas and thus the solution given by this study is based on the demand of the user society which is not only suitable to the existing socio-cultural context but can serve as a driving force for introducing efficient water management practices in the study area. Regarding economic viability, the study focuses on the optimum application of water through the network which is already in place. Hence the proposed solution does not need additional investment for infrastructure development. However, a significant economy has already been achieved while choosing the option of FMIS rehabilitation instead of a new canal system.

The study has suggested ways to achieve a sustainable irrigation water management at the extension area by combining canal flows and storing in local reservoirs. Additionally, there is the possibility of conjunctive groundwater use which should be fully investigated in the future. The solutions suggested in this study resulted from the demand of farmers of both areas which has cleared ways for the farmers of the extension area to plan a future agriculture development strategy. In that sense it can be stated that the solution given by this study is economically viable and is fully compatible to the socio-cultural and institutional context.

4.2. Exemplary for other projects in the region

The present study has provided an answer to the FMIS farmers' question of assessing their priority water rights which is extremely important to determine the farming possibility at the extension area using the remaining water. The assessment has created a favourable atmosphere for making further water sharing arrangements between the FMIS and the extension areas. There is a great possibility of saving water and increasing the cropping intensity at the FMIS area without demanding additional water from the main canal after the construction of permanent diversion structures, carrying out necessary canal lining works and applying efficient water management practices in the course of system modernization. The BIP can serve as an example of optimum and efficient irrigation water management, combining the social and the physical capitals of irrigation system. The analyses show that the water which was solely used by the FMIS area covering only 5400 ha of lands, can provide full irrigation in a 13,500 area in the monsoon season and deserves potentials to expand winter crops in about 4000 ha with storing water in local ponds combined with a slight deficit irrigation in February and March. The strategy suggested in this study is applicable in other irrigation projects situated in the Terai of Nepal and other parts of the Gangetic plain.

4.3. Potentials of irrigation development at the right bank area

While conducting the water resources assessment, it has been observed that the west side (right bank) farmers have been using fifty percent of the Babai river flow to irrigate their fields by two FMIS The equal water rights of the east and the west sides is the historically accepted fact. Hence the right bank area too deserves similar potentials of irrigation development as the left bank. However this aspect has been found to be overlooked by all previous studies. Similar to the east side, we see a great possibility of increasing the irrigation area on the west side, using their genuine share of the Babai river flows and hence recommend to carry out further investigations in this respect.

Acknowledgements

The authors are thankful to two anonymous reviewers for their comments and suggestions, to Mr. Khadka D.R., the Chairman of the WUA, for arranging site visits and meetings with the beneficiaries and to Mr. Jaiswal S.P., the Project Manager of the BIP for providing survey and design data, previous study reports and logistic supports during the field works.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration – guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. FAO, Rome, 1998.

Ali, M.H., Hoque, M.R., Hassan, A.A., Khair, A., 2007. Effects of deficit irrigation on yield, water productivity and economic returns of wheat. Agriculture Water Management 92, 151–161.

Department of Irrigation (DOI), 1990. Design Manuals for Irrigation Projects in Nepal, M3: Hydrology and Agro-meteorology Manual. DOI, Kathmandu, Nepal.

Hargreaves, G.H., Allen, R.G., 2003. History and evaluation of Hargreaves evapotranspiration equation. ASCE Journal of Irrigation and Drainage Engineering 129 (1), 53–63.

Lam, W.F., 1996. Improving the performance of small scale irrigation systems: the effects of technological investments and governance structure on irrigation performance in Nepal. World Development 24, 1301–1315.

Nandagiri, L., Kovoor, G.M., 2006. Performance evaluation of reference evapotranspiration equations across a range of Indian climates. ASCE Journal of Irrigation and Drainage Engineering 132 (3), 238–249.

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

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, 130–141.

Shivakoti, G.P., Bastakoti, R.C., 2007. Understanding institutional dynamics and performance of irrigation systems: some methodological considerations. In: Proceedings of the Fourth International Seminar Held on 6–7 November 2006. Farmer Managed Irrigation Systems Promotion Trust, Kathmandu, Nepal. pp. 127–148.

World Commission on Dams (WCD), 2000. Dams and Development: A New Framework for Decision Making. Earthscan Publications Ltd, London, Sterling V.A.

Zhang, Y., Chen, X., Zhao, J., Sun, Y., Zhang, X., Ju, Y., Shang, W., Liao, F., 2007. Review of water reuse practices and development in China. Water Science and Technology (1–2), 495–502.

Glossary of local terms used in this paper

kulo*:* canal
khola*:* stream
tal*:* pond