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IMPROVING FARMERS' ACCESS TO IRRIGATION IN THE BUFFER ZONE: AN EFFECTIVE WAY TO CONSERVE BIODIVERISTY IN THE CHITWAN NATIONAL PARK[†]

K.R. ADHIKARI[1]*, Y.C. TAN[2], J.S. LAI[3], Z.S. CHEN[4] AND V.S. MISHRA[5]

[1]*Institute of Agriculture and Animal Sciences, Tribhuvan University, Rampur, Chitwan, Nepal*
[2]*Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan*
[3]*Centre for Weather Climate and Disaster Research, National Taiwan University, Taipei, Taiwan*
[4]*Department of Agricultural Chemistry, National Taiwan University, Taipei, Taiwan*
[5]*Department of Irrigation, Ministry of Water Resources, Kathmandu, Nepal*

ABSTRACT

Drawing results from multi-scale studies, this paper addresses the important coexistence between the Chitwan National Park and buffer-zone farmers' communities in the East Rapti River basin of Nepal. The relationship between the two is discussed using results of land use change (1978–2010) and water availability analysis (1976–2010). At basin level, though there are indications of losses of the government forest, the utilizable outflow of water in the river is still abundant because the process of depletion of water is very low. Scaling down to local level, irrigation systems originating in the river were evaluated and farmers interviewed across locations. There were statistical differences in irrigation system performance affecting water availability for crop production in the buffer zone. Because irrigation plays a disproportionately greater role in farm income and economic water scarcity could be removed, improvement in access to irrigation could effectively help improve food sufficiency and reduce income disparity in this basin. In the forest of the national park, encroachment seems to be low but frequencies of rhino poaching and timber pilferage have remained relatively high. As the buffer zone is the gateway to the park, and subsistence farm families live on the fringes of the park, helping irrigation development would strengthen farmers' cooperation in enhancing resource conservation of the park. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: buffer-zone poverty; national park; open basin; water scarcity

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RÉSUMÉ

Basé sur les résultats de plusieurs études à différentes échelles, ce document traite de l'importance de la coexistence entre le parc national de Chitwan et les communautés d'agriculteurs de la zone tampon, dans le bassin de la rivière Rapti à l'est du Népal. La relation entre les deux est discutée à partir des résultats de changements de l'utilisation des terres (1978–2010) et de l'analyse de la disponibilité en eau (1976–2010). Au niveau du bassin, bien qu'il y ait des signes de déprise des forêts d'état, le prélèvement potentiel d'eau dans la rivière est encore important, car le processus d'épuisement de l'eau est très faible. Au niveau local, les systèmes d'irrigation alimentés par la rivière ont été évalués, et les agriculteurs ont été interrogés par zone géographique. Il y avait des différences statistiques dans les performances des systèmes d'irrigation qui affectent la disponibilité de l'eau pour la production agricole dans la zone tampon. Parce que l'irrigation joue un rôle proportionnellement plus fort dans le revenu agricole, l'irrigation pourrait supprimer la pénurie économique liée au manque d'eau. L'amélioration de l'accès à l'irrigation pourrait contribuer efficacement à améliorer l'autosuffisance alimentaire et à réduire la disparité des revenus dans ce bassin. Dans la forêt du parc national, l'empiètement semble faible, mais les fréquences de braconnage de rhinocéros et de vols de bois ont gardé un niveau relativement élevé. Comme la zone tampon est la porte

* Correspondence to: K.R. Adhikari, Institute of Agriculture and Animal Sciences, Tribhuvan University, Rampur, Chitwan, Nepal. E-mail: keshav.adhikari2008@gmail.com
† Améliorer l'accès à l'irrigation pour les agriculteurs dans la zone tampon: un moyen efficace pour conserver la biodiversité dans le parc national de Chitwan.

d'entrée du parc, et que l'agriculture vivrière retient les familles d'agriculteurs dans la périphérie du parc, aider le développement de l'irrigation permettrait de renforcer la coopération des agriculteurs dans la conservation des ressources et l'amélioration du parc.

MOTS CLÉS: zone tampon contre la pauvreté; parc national; bassin ouvert; raréfaction de l'eau

INTRODUCTION

According to the World Geodetic System (WGS84), the Chitwan National Park of Nepal lies in the zone 27° 30′ 0″ N and 84° 20′ 0″ E. Analyzing rural farming communities in the buffer zone (750 km^2) of this park (932 km^2), Adhikari *et al.* (2009) report that several farmers' water user groups in these communities have faced varied water scarcities for irrigation, resulting in low crop productivities and a weak economy. It would be interesting to many that one of the richest national parks in the world such as this is surrounded by communities living in a meager economy where the opportunities for employment and alternate sources of income are few. It would then make a sense to ask: 'Is the water supply not sufficient to meet the irrigation demands of these farming communities to increase food production and improve the agricultural economy in the basin?'

A review of the literature shows that while a certain level of water must be maintained in the river for park activities, the crop lands on the other side of the river suffer during the dry season, giving rise to seasonal water scarcity (International Water Management Institute (IWMI), 2003). Besides issues linked to water allocation from the river, different kinds of other conflicts between the park authorities and a sizeable portion of the buffer-zone community have been noted (Paudel, 2002; Budhathoki, 2003; Mclean and Stræde, 2003; Agrawal and Gupta, 2005; Nagendra *et al.*, 2008). The most important of these are the illegal transaction of forest products, illegal hunting, livestock grazing in the park area, crop damage by wild animals of the park, livelihood concerns of indigenous people, threat to human and animal life by wild animal attack and lack of crop and life insurance (Nepal and Weber, 1995; Adhikari *et al.*, 2009).

The park presents an outstanding testimony of a unique natural environment. This is why UNESCO listed it as a World Heritage Site in 1984. The park forest is dominated by Sal trees (*Shorea robusta*) and tall grasses. This is the natural habitat of endangered animals such as Bengal tigers, one-horned rhinoceros, gharial crocodile, gaur (the world's largest wild cattle), four species of deer, leopard, wild dogs, fishing cats, python and Gangetic dolphin. There are over 50 species of mammals and 450 species of birds in the park. Before 1950, this area used to be the hunting reserve for the ruling class of Nepal. The hereditary prime ministers of the then Rana family, who ruled Nepal for 104 years, often used to invite their guests especially from England and India to hunt tigers and rhino (http://www.21cep.com/nepal/npark.htm).

The park is also a popular destination for global tourism. The government plows back a significant portion (30–50%) of annual park income for community development activities in the buffer zone. Some local people also earn income from tourism and community forestry on the riverside. But in a joint development effort made by the buffer-zone development committee and a park and people project as evaluated by Adhikari *et al.* (2009) and others, project objectives were partly met but the basic concerns of the disadvantaged were still not adequately addressed. In an earlier study, Paudel (2002) states that the weak and vulnerable groups lost the battle. It appears that although the buffer-zone concept evolved to accommodate the social needs of the people while protecting the ecology of the park, conflicts are likely to continue unless people can see a win–win situation. It means that the current incentive structures are not enough for people to participate in park protection which should be addressed by improving the existing park and buffer-zone management paradigm with a commitment to raise overall socio-economic wellbeing in the area.

Generally we do not think of simple solutions to complex problems, but despite several options, certain input items always win out and exhibit a greater impact on alleviating rural poverty. This concept could be used as an entry point to improve the park and people relationships. The importance of irrigation water, as a key contributor to food production (Schultz *et al.*, 2005) and household income (Masozera and Alavalapati, 2004) needs no further emphasis. Discussing the water–poverty nexus, Hussain and Hanjra (2004) report that water plays a disproportionately powerful role through its wider impacts on food production, hygiene, sanitation, food security and the environment. We therefore consider this input variable as an entry point to trigger the rural economy which is subject to its availability in the basin. In this river basin, the Government of Nepal (GoN) have invested a significant amount of resources on developing small-scale irrigation systems in the past (for more details, see Shukla *et al.*, 1997). The impact studies of irrigation development were mostly limited to individual canal or farm-level institutional analysis and water availability, but lacked a holistic basin-level approach to include whether water availability for irrigation, drinking, park, and industrial purposes was enough in this basin. Likewise, important anthropogenic processes such as deforestation or agricultural intensification trends affecting water availability downstream have not been documented. We believe that an understanding of the current status of water consumption by these competing sectors and trend of land use changes should be the point of departure to help set the stage for short- and long-term water management and development policies in the basin.

Therefore, central to this paper is the question of the delicate balance between water for food and water for park resources in the basin. In specific terms and guided by our own years of observations of this basin (between the authors), we ask three questions: (i) Over time how have the forest conditions changed in the basin? (ii) What is the availability of water in the basin? (iii) Given the forest condition upstream and basin-level water availability, what anomalies exist related to the water resource utilization pattern downstream?

THE BASIN CHARACTERISTICS

A gross estimate using ArcView GIS software showed that the East Rapti River basin is spread over 246 007 ha (Figure 1). The river originates in a mountain 1500 m + MSL (mean sea level) of Makwanpur District and flows 122 km to the west before leaving the basin at an elevation of 140 m + MSL in the Nawalparasi District. A large part of the basin where much of the potentially irrigated agricultural and park areas occur are located in the valley floor of Chitwan District. The major entry point for tourists and greater park activities are concentrated in the Chitwan valley.

The basin has a predominantly subtropical and monsoonal climate. Based on the 1976–2010 record (International Centre for Integrated Mountain Development (ICIMOD), 1996; Department of Hydrology and Meteorology (DHM), 2010), inflow of average annual rainfall varied from 1481 mm in a dry year to 2941 mm in a wet one, and 85% of the total rainfall occurred from June to October. Average maximum temperature reached 35 °C during the summer and below 5 °C in most years in the winter. Much of the basin upstream is remote hills and mountains, thus less important from the economic point of view. As the river descends abruptly from a high elevation to the valley floor of Makwanpur District, river flow is reduced drastically. It then starts accumulating more waters from tributaries where multiple users (especially in the Hetauda area, headquarters of Makwanpur District) begin to withdraw river water for drinking, irrigation, and industrial purposes. Further down to the west, as the river enters the valley floor of Chitwan District, fishing, boating and water withdrawal by farmlands and park activities become apparent.

According to an IWMI country report (2003), 75% of the basin population is engaged in subsistence agriculture where average per capita landholding is <1 ha and households with access to irrigation are <50%. Another study (Adhikari *et al.*, 2009) reports that although it varies by places, a significant

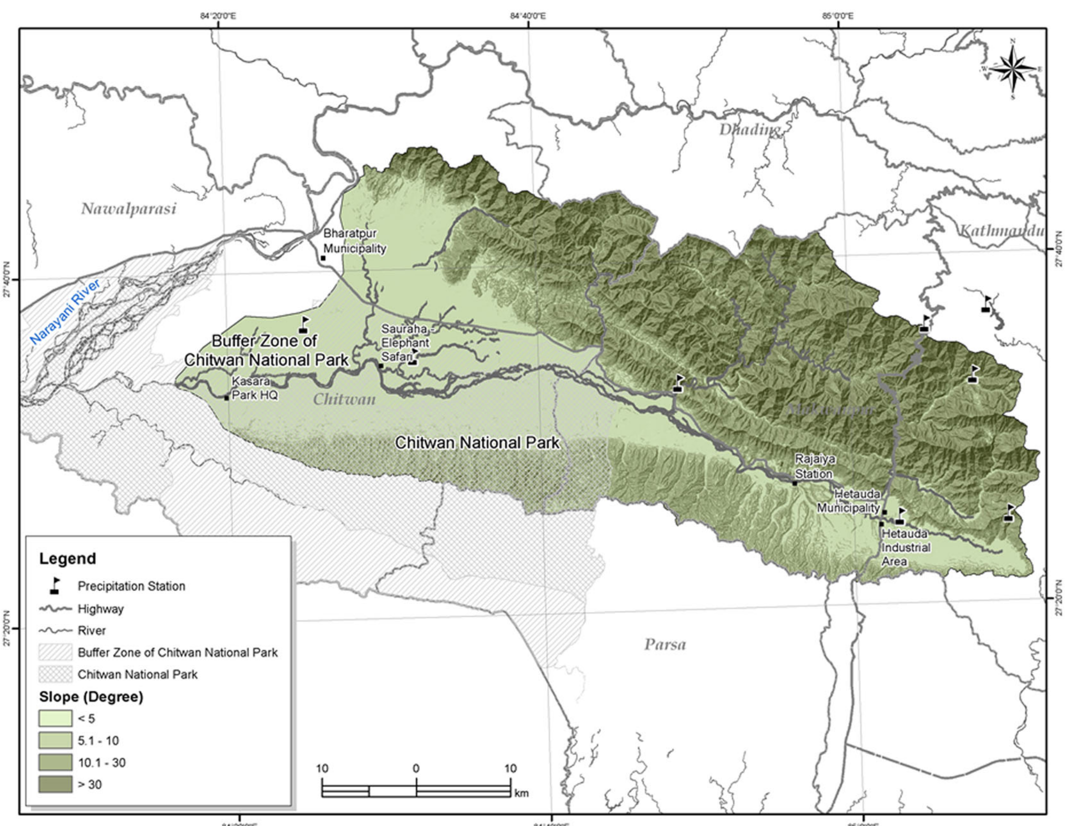

Figure 1. Terrain map of the study area showing relative locations of weather stations, National Park and buffer zone in the East Rapti River Basin of Nepal. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

portion of the buffer-zone communities near the park lives below food sufficiency level. In irrigated and lowlands, a rice-based cropping system predominates but corn and wheat are also principal staple crops primarily grown on the nearby upland areas. More recently, vegetables, fruit, dairy and poultry industries could be seen in the vicinity of the East–West National Highway, the areas quite way from the communities living near the park. This highway runs along the middle and bisects the Chitwan valley into two distinct regions (Figure 1) which are commonly called the North and South regions. Population has grown exponentially in every decade, at a rate much higher in Chitwan than in Makwanpur District (Table I). This is all the more important because of the fact that the population increased by over 200 000 between 1991 and 2011 in the Chitwan District alone. This increase should have had an effect on limited land and water resources availability in the basin.

METHODOLOGY

Determining basin level land use changes

Based on Landsat images, a land resource mapping project (LRMP) under the Department of Land Survey, GoN, had first produced nationwide land resource maps (1 : 50 000) in 1978 for regional planning, which are popularly called LRMP maps in Nepal. Similarly, based on aerial photographs (1 : 50 000), GoN had produced nationwide topographic maps (1 : 25 000) first in 1996. Referring to common geographical coordinates, these base maps were used to delineate the hydrological boundary of the basin and to extract polygons for four land use categories, namely, forest, agriculture, grassland plus shrubs, and others, for 1978 and 1996. A 30-m resolution Landsat image of 2010 was then digitized to extract a current time land use scenario for the same basin area. This allowed for temporal analysis between two time periods (1978 versus 1996; 1996 versus 2010). Analysis was limited to four categories because the forest and grassland conversions into types of agriculture had occurred at a greater scale in many parts of Nepal in the past. We invoked the ArcGIS version 9.3 platform in order to derive hectare areas to compare differences in land use changes across these three dates.

Table I. Population trends from 1961 to 2011 in the basin districts

	Chitwan District		Makwanpur District	
Year	Population	% increase	Population	% increase
1961	69 000	–	Not available	–
1971	184 000	167	164 000	–
1981	259 000	41	243 000	49
1991	355 000	37	315 000	29
2001	472 000	33	406 000	29
2011	580 000	23	420 000	3.5

Source: Central Bureau of Statistics 1993, 1999 and 2011, Government of Nepal.

Determining basin level water availability

A water balance approach (see Molden and Sakthivadivel, 1999, for a detailed conceptual framework) was used to compute basin-level water availability for two time periods (1976 versus 1996; 1990 versus 2010). This allowed the time frame of water availability analysis to be kept congruent with the time frame of land use change analysis. A slight overlap occurred between two time periods because the first set of analysis was already accomplished back in 2000 by Molden *et al.* (2000). In order to have the same length of time period in the second set of analysis, we had to go as far back as 1990.

The water balance approach takes into account the annual inflow and outflow from the basin computed for specified flow regimes. In these studies, three flow regimes were chosen to represent the above normal or wet year, normal year and below normal or dry year. For the first set of analysis, years 1978, 1979 and 1992; and for the second set of analysis, years 1999, 1993 and 1992; these represented the above normal or wet year, normal year and below normal or dry year, respectively. The operational definitions of wet, normal and dry years take into account the water storage change in the basin due to change in surface reservoir and soil moisture storage.

In this work, potential storage change for a given year was defined as the difference between storage at the beginning and end of the year. Since data were not available to compute both surface and soil moisture storage at the beginning and end of the year, it was assumed that storage at the beginning of a year is at full potential level of storage if the previous year is an above normal (wet) year, at 75% of its potential storage if the previous year is a normal year, and at 25% of its potential if the previous year is a dry year. For a detailed calculation of these terms, see Molden *et al.* (2000).

The climatic and hydrological data were obtained from ICIMOD (1996) and DHM (2010). Basin-level river flow at the confluence was not available. Therefore, the following equation of ratio of drainage areas was used to extrapolate the river flow record of the gauging station 'Rajaiya' in the upstream part. This was then used to compute the daily discharge at the confluence with the Narayani River in the downstream part, as follows:

$$Q_c = [Q_R]\,[A_c/A_R]\,[R_c/R_R]\,\left[S_c^{\,0.5}/S_R^{\,0.5}\right] \quad (1)$$

(Molden and Sakthivadivel, 1999)where

Q_c = Daily discharge at the confluence ($m^3\,s^{-1}$)
Q_R = Daily discharge at Rajaiya ($m^3\,s^{-1}$)
A_c = Area of the basin up to confluence (km^2)
A_R = Area of the basin up to Rajaiya (km^2)
R_c = Average daily rainfall up to confluence (mm)

R_R = Average daily rainfall up to Rajaiya (mm)
S_c = Basin average slope (%)
S_R = Basin average slope up to Rajaiya (%)

$^{0.5}$ = Since the flow velocity in the basin river mainly depends on the square root of the slope, the values 1/2 or 0.5 power to the slope of the basin is used in the above equation following Manning's ($V = 1/n * R^{2/3} * S^{1/2}$) and Chezy's ($V = C(RS)^{1/2}$) equations.

The difference between inflow into the basin and outflow from the basin represented the amount depleted in the basin for a given year. From the amount depleted in the basin and that exiting the basin as 'uncommitted and utilizable outflow', amounts of water consumed by four major water-use sectors (domestic and industry combined, agriculture, forest and non-beneficial, and utilizable outflow not in use) were derived (detailed calculations not shown). These categories were identified based on existing major water-use sectors in the basin. In making these calculations, it was assumed that at least 15 $m^{-3} s^{-1}$ flow rate would be required in the river to cater for park activities. For the operational definitions of the terms used in computing water quantities presented above, refer to the Notes at the end of this paper. The basin-level index of water availability was then calculated for normal years as follows:

Development potential = (Net inflow − process and nonprocess depletion) / Net inflow
Forest and nonbeneficial = (Nonprocess beneficial + nonprocess nonbeneficial) / Net inflow
Agricultural consumption = (Process depletion – domestic – animal – industry) / Net inflow
Domestic and industry = (Domestic + animal + industrial uses) / Net inflow

Determining irrigation system performance and surveying of park resources

In order to respond to the third objective of this paper, selected irrigation system performance was evaluated based on farmers' perceptions. Measured variables included crop productivity, intensity, profit, amounts and rate of input application, all of which are of primary concern to the farmers in this basin. A list of irrigation systems was prepared by visiting key water resource offices including the District Water Resource Development Committee, and support agencies such as the East Rapti Irrigation Project (ERIP) of GoN and the Park and People Project (PPP) of Chitwan National Park in the basin. Backed by aerial photographs and topographic maps, a rapid reconnaissance was carried out to realize a perception of spatiality of the listed irrigation systems along the river. For the performance analysis, this walk-through helped to broadly categorize irrigation systems into two major categories: (i) those off-taking water directly from the river ($n = 20$), and (ii) those off-taking water from the tributaries ($n = 17$).

Detailed data were collected in a retrospective manner by conducting an intensive household survey of water users from the head, middle and tail ends of the selected irrigation systems' service areas. Having done this, a paired *t*-test was carried out to evaluate whether there were significant differences between irrigation systems by type of water source. In this classification, crop productivity and income are assumed to be distinctly higher in river-fed systems than in tributary-fed ones due to differences in reliability of water (availability in required amount and time) needed for irrigation. Despite residing by the side of the park, several households in the community face a locational disadvantage such that they are deprived of a dependable water supply for irrigation and household purposes. Therefore, the bottom line of this comparative analysis is to demonstrate the need for conjunctive use of surface and groundwater to alleviate production and income disparity in water-deficit areas.

Furthermore, an extensive qualitative survey among farmers was also carried out to provide evidence for the assumption that improved livelihoods due to increased agricultural productivity would enhance the willingness of the people living in the buffer zone to help control illegal operations in the park. The length of the buffer-zone community living along the East Rapti River was divided into three sections, viz. head, middle and tail ends. From each of these sections, group interviews involving 10 farmers were conducted using an open-ended questionnaire. Farmers' responses are presented in the manuscript.

Since this paper is the second in a series, in line with the previous work (Adhikari *et al*., 2009) an attempt is made in this series to include the updated information regarding water availability in the basin and resource conservation status of the park. Trend lines were also developed using the frequencies of registered court cases such as smuggling of rhinos, illegal killing of animals including tigers, timber pilferage and forest encroachment from 1995 to 2010 in the park. This information was obtained directly from the Court Section of the Park Headquarters in Kasara, Chitwan. Registered cases before 1995 were not consistent and therefore not included in this paper.

RESULTS AND DISCUSSION

Basin-level land use change

Land use distribution of the basin in 2010 and the results of temporal analysis across 1978, 1996 and 2010 are presented in Figures 2 and 3, respectively. Across the study years, the Figure 3 reveals that the area under forest (59–63%), agriculture (25–29%), grassland (4–7%) and others category (4–6%) varied within a narrow range. Of the total 246 007 ha area in the basin, forest alone occupied 156 282 ha,

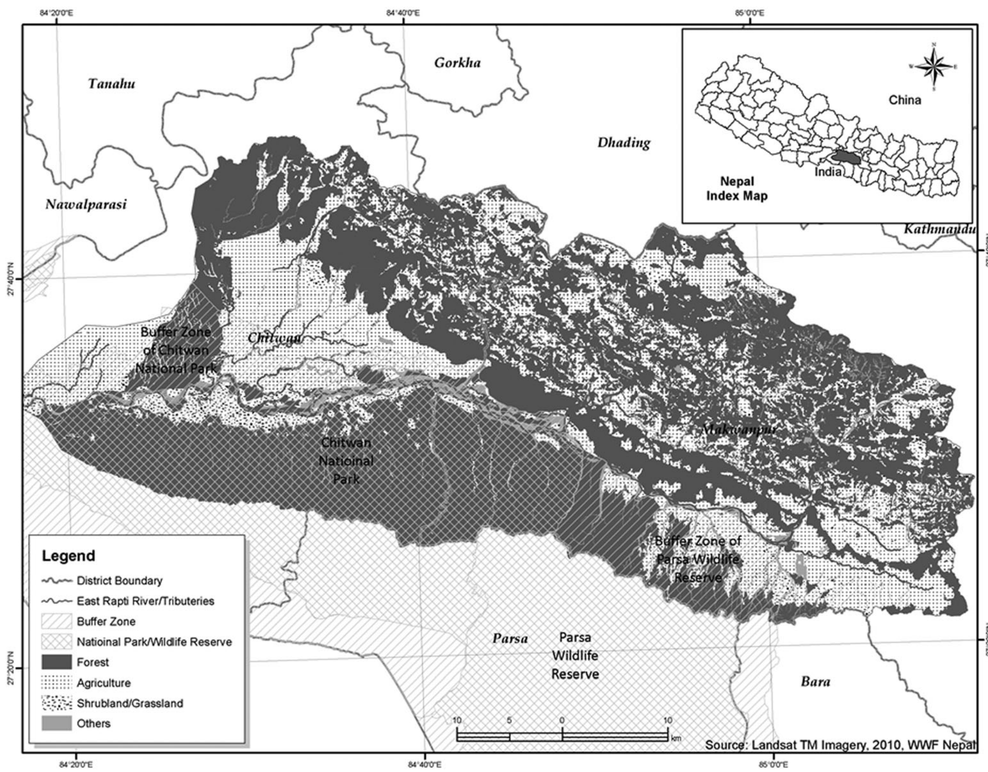

Figure 2. Spatial distribution of major land use categories in the East Rapti River Basin analyzed for the year 2010

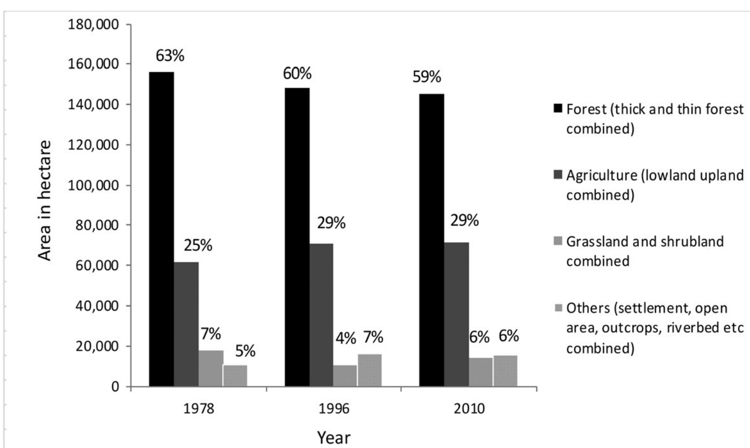

Figure 3. Results of land use change analysis across the years 1978, 1996 and 2010 in the East Rapti River Basin of Nepal

followed by agriculture (61 384 ha), grassland (17 488 ha) and others (10 853 ha) in 1978. In comparison with 1978, there were losses in forest (5%) and grassland (40%) areas, and gains in agriculture (15%) and others (51%) categories in 1996. Relative to 1996, the forest area did not change much in 2010; however, a significant area under grassland category (32.7%) was recovered.

Results must be interpreted carefully because one would get a different perspective when these values are compared in absolute terms. For example, the forest loss in 2010 relative to that of 1996 appears to be 2% which corresponds to 2971 ha. This might not be a significant loss if we agreed to consider a 5% error in spatial analysis. On the other hand, one would accept that some area expansion has occurred under ‘agriculture’ and ‘others’ categories. This is partly explained by the trend of high population growth over time (Table I), where the majority of the households (>75%) are smallholders (<1 ha) engaged in subsistence farming. Our earlier experiences in this basin (Schweik *et al*., 1997) suggest that such expansions usually occur by encroachment, involving a gradual process where individuals start using and taking possession of the forest and grassland in their vicinity. Such processes occur more in fairly remote and inaccessible areas of the basin where people lack access to public goods and services and where government monitoring of forest and grassland resources is weak. Kayastha (1991) attributed the human encroachment of commercially valuable forest to sociopolitical reasons. However, we understand that irrespective of the location where the farmers live, access to irrigation supply would make a difference to their livelihood conditions and contribute to reduced encroachment.

In order to evaluate where in the basin the encroachment is occurring more, an understanding of forest governance would be helpful. The forests in this basin are mainly of three types: (i) the forest in the park area which is protected by a number of government agencies including the Department of National Parks and Wildlife Conservation, the Ministry of Forestry, Ministry of Tourism, and the Nepal Army whose contingent help enforce many park regulations (Agrawal and Gupta, 2005), and here forest encroachment is low because of the army patrolling the forest (Figure 2); (ii) the government forest where the control mechanism is ineffective probably because only a few forest guards deputed by the District Level Government Forest offices monitor areas in the vicinity of their range posts, which leaves more isolated parts of the forest poorly monitored (Schweik *et al.*, 1997) and (iii) community forest (CF) where registered forest user groups of local farmers control, manage and use the forest. The CF, which is also called 'participatory forestry', presents testimony of a successful forest management model in Nepal as proven by increased forest protection and an improved overall environment (Gautam *et al.*, 2002). In this model, the government hands over to villagers the rights to protect and utilize the nearby forest to help meet their local demand for fuel, fodder and timber (Gilmour *et al.*, 1989) and in so doing it is assumed that the concept promotes sustainable use of forest. Since the area under CF is insignificant relative to the government and park-managed forests, we did not map it separately in this basin-level study. Therefore, forest areas shown on the northern side of the river on the map (Figure 2) combine both the CF and government-managed forests. It means the areas on the northern part of the river are the locations where most encroachment is likely to occur.

Given the signs of agricultural area expansion at the expense of natural forest and grassland, we now turn to the presentation of basin-level water availability.

Basin-level water availability

Annual water quantities calculated for typical years in both study periods are shown in Table II. Net inflows were 7171, 6120, and 4564 $m^3 \times 10^6$ and net outflows were 3848, 3576 and 2201 $m^3 \times 10^6$ for wet, normal, and dry years, respectively

Table II. Annual quantities and pathways of East Rapti River flow for wet, normal and dry years calculated for two time periods

Components	1976–1996			1990–2010		
	Above normal yr (Wet yr, 1978)	Normal yr[a] (1979)	Dry yr (1992)	Above normal yr (Wet yr, 1999)	Normal yr[a] (1993)	Dry yr (1992)
Gross inflow into the basin	7 297	5 993	4 564	8 804	6 574	4 695
Groundwater storage change	−126[b]	126	0	−126[b]	252	0
Net inflow into the basin	7 171	6 120	4 564	8 678	6 826	4 695
Depletion						
-Process depletion	284	249	234	284	249	234
-Nonprocess, beneficial	1 933	1 561	1 533	1 933	1 561	1 533
-Nonprocess, nonbeneficial	242	197	198	242	197	198
Outflow (runoff) from basin	3 848	3 576	2 201	3 848	3 576	2 201
-uncommitted	–	3 102	–	–	3102	–
-committed	–	474	–	–	474	–
Deep percolation	863	537	400	2 371	1 243	529

All units in $10^6\ m^3$.
Details of process and non-process depletion amounts of water by different crops, animals, industries, forest and grasslands are not shown in the table.
[a]Normal year relates to average rainfall in the basin.
[b]Negative sign indicates addition of water to storage to supplement the deficit of previous normal year.

for the period 1976–1996. Similarly, net inflows were 8678, 6826, and 4695 $m^3 \times 10^6$ and net outflows were 3848, 3576, and 2201 $m^3 \times 10^6$ for wet, normal and dry years, respectively for the period 1990–2010. Calculations showed that during the dry year, approximately one-half of water exited the basin and one-half was depleted in the basin during both study periods. The amount of process-consumed water also did not differ much (only 5.10 and 4.99% of the available water) between the two study periods. This means there is a great potential to increase agricultural production and the economy by investing more in process consumption. Industrial and domestic sectors largely depended on groundwater but the amounts used were very small in relation to the total available water in the basin. Molden and Sakthivadivel (1999) used the terms 'open or closed basin' to characterize whether there is utilizable outflow during a dry year to get a reflection of potential development of water resources in the basin. According to their definition, this is an 'open basin' as the utilizable outflow from the basin is not zero during a dry year which implies that there are tremendous opportunities to harness the utilizable outflow.

Data in Table II were also used to derive indices of water consumption level and to indicate the development potential for normal years (Figures 4 and 5). Results indicated that the water consumption levels of agriculture and domestic + industry sectors (<0.05) have been very low and have not changed much over the last three decades. A bulk of basin water is held by forest vegetation (0.26–0.34 between two time periods). In a regional comparison with China, Indonesia, Philippines and Sri Lanka using the data set of 1976 to 1996, Sakthivadivel and Molden (2001) found that the water resource development potential of this basin (>0.61) is very high. This means that this basin is in the early phase of water resource development where great potential exists to harness the utilizable outflow to meet the multiple water demands for the foreseeable future. Despite some indications of forest and grassland conversion into agriculture, the flow regime in the river is little affected in the downstream part. Does it mean that water availability and crop productivity are not adversely affected? To answer these questions, we scale down our observations to the presentation of selected irrigation system performance downstream.

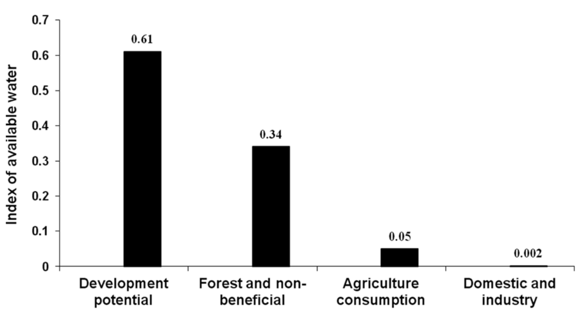

Figure 4. Sectoral water consumption and potential for water resource development in the East Rapti River Basin of Nepal calculated for the period between 1976 and 1996

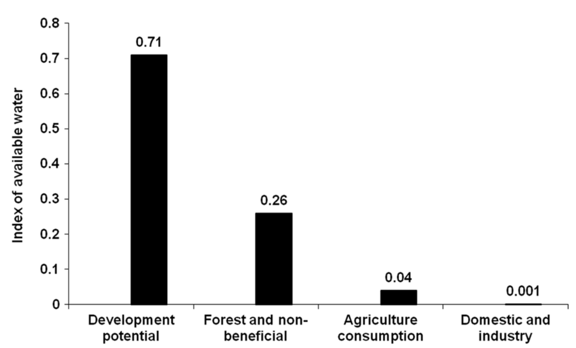

Figure 5. Sectoral water consumption and potential for water resource development in the East Rapti River Basin of Nepal calculated for the period between 1990 and 2010

Irrigation system performance

A comparison was made between irrigation systems that off-take water from the river and those from tributaries. Results of the paired *t*-test show that irrigation systems ($n = 20$) off-taking water from the river perform better (significant at $p = 0.05$) than those ($n = 17$) off-taking water from the tributaries (Table III). Indicators measured were the crop productivity, specifically the monsoon (main season) rice yield, and gross margin. It is not surprising that higher rice productivity in river-fed systems would have been related to a close interaction and complementarity between irrigation and inputs of plant nutrients such as nitrogen, phosphorus and manure application. There is a well-established body of science explaining the greater crop utilization of applied inputs in the presence of adequate moisture in soil (not talking about the 'bad water effect' in excess moisture situation). It implies that adequate availability of water in the river-fed systems influenced fertilizer application efficiencies.

A review of empirical evidence from small-scale irrigation systems (Bacha *et al*., 2011) shows a great impact on reducing household-level poverty by increasing farmers' access to diversified cropping systems, and more income. Likewise, a small-scale irrigation study in this basin (Adhikari *et al*., 2009) shows that productivities of all crops including rice, wheat and corn are systematically higher in irrigated areas than in unirrigated areas which, in turn, help improve household food sufficiency. A comparative review made by Hussain and Hanjra (2004) substantiates these findings, saying that increased crop productivity is because of increased land productivity due to irrigation.

The crux of the matter

People had free access to the forest before the government declared it a National Park in 1973. Since restrictions in the park affected their livelihood and income, many of the elderly

Table III. Mean comparison of irrigation systems performance by type of water source

Indicators of performance	Mean		Mean		Difference	*t*-test
	Off the river	*N*[a]	Tributary	*N*[a]		
Input of the system						
Nitrogen (kg ha^{-1})	56.2	20	38.4	17	17.8	3.59*
Phosphorus (kg ha^{-1})	20.3	20	12.5	17	7.80	2.20*
Animal manure (kg ha^{-1})	1 474	20	1 055	17	419	2.00*
Input cost (NRs[b] ha^{-1} yr^{-1})	17 121	20	14 498	17	2 623	2.39*
Output of the system						
Monsoon rice yield (t ha^{-1})	3.74	20	3.19	17	0.55	2.88*
Gross margin, rice (NRs ha^{-1})	20 123	20	15 181	17	4 942	1.79*

[a]Number of irrigation systems interviewed.
[b]Nepalese currency in rupees (NRs), US$1 = NRs 70 (approx.) at the time of surveying.
*Significant at $p = 0.05$ probability level.

still remember the failure of the government's commitment to provide them with viable alternatives of firewood, fodder, construction materials, space for animal grazing and watering including fishing and boating in the river. Because farmers can see a year-round flow of water in the river which could be diverted for irrigation, their voices saying 'we need irrigation first' could be heard by nine out of ten strangers travelling in this area. They know it is a powerful tool they believe would work to multiply benefits to improve living conditions. Bacha *et al.* (2011) emphasize irrigation development to reduce poverty and also consider the provision of complementary services. We therefore put the spotlight on harnessing the abundant surface and groundwater resources available in the basin while honoring the use rights of those on the park side, and the downstream users. We believe consumptive uses by them for irrigation would be the most viable approach to trigger a radical transformation in the agricultural economy.

Although irrigation is accused of being a low-value use of water (Perry, 2007), previous huge government investment in irrigation development in this basin deserves a mention here. Cases where government intervention was successful contributed to reducing household poverty and dependence on park resources. However, these donor-driven investment programs often led to the consequences of perverse outcomes. Such negative externalities could widen inequalities among users of successful and failure cases and give rise to unexpected conflicts in the community. Having said that, we do not claim that irrigation is the panacea to poverty and conflict resolution, but argue that where water is not limiting, the economic scarcity of water could be removed if the objective is driven by sincere and dedicated water management efforts.

For the park authorities, the concept of 'coexistence of park and people' is to reduce illegal activities and protect the core area of the park, which also needs the help of local people (Table IV). For the people, this concept has little meaning unless the park/GoN authorities respect the livelihood concerns of the communities. Table IV clearly shows the evidence that the farmers surveyed representing the head, middle and tail ends of the buffer zone do not appreciate the current buffer-zone management guidelines and regulations enacted in 1998 because they are less practicable. Farmers said that the members of the buffer-zone council have amended and submitted a new draft of the regulations to the cabinet for approval. Based on extensive field surveys along the river, four points appear to be critically important in order to conserve the national park resources effectively; *first*, introduce activities to promote farm productivity to meet food sufficiency; *second*, develop a wise and more pragmatic compensation package against crop damage by wild animals; *third*, help create bio-engineering structures to protect the buffer-zone community/farm areas upstream where the riverbed has been raised by recurrent floods of recent times; and *fourth*, depute administrative staff of the national park in each of the buffer-zone development unit offices to reduce farmers' burden of travelling to park headquarters at a distant location. Respondents said that investment in irrigation development and management should be the continued effort of the government.

Figure 6 shows that rhino poaching and timber pilferage have occurred at higher frequencies than the other illegal operations in the past 15 years or so. Despite patrolling by armed forces from over 29 posts in the park forest, to what extent was the government effort successful in overcoming this problem? Our discussion with the farmers led us to believe that buffer-zone people can meaningfully contribute to reducing illegal activities partly because the buffer zone is the major gateway from where infiltration of outsiders into the park occurs. Smugglers see the park as a hot spot for lucrative business. For example, selling rhino horns could fetch very high prices in the international markets. Therefore, it would be naïve for the national park

Table IV. Response of representative buffer-zone farmers to the questions related to the matters of their relationships with the Chitwan National Park

Focus of discussion with the respondent farmers	Head end ($n=10$)	Middle end ($n=10$)	Tail end ($n=10$)
	-----Number of respondents with + ve reply-----		
Does increased farm income help lessen the buffer-zone people's dependence on the park resources?	10	10	10
Is there still a need to develop more irrigation services in this area of the buffer zone?	10	10	10
Does financing irrigation development by park office improve the relationship between park and buffer-zone people?	8	9	9
Do the park authorities expect cooperation from the buffer-zone farmers for resource conservation of the park?	10	10	10
Are there clear provisions for investing in irrigation development in the buffer-zone development policy of the Chitwan National Park?	5	5	5
Do you think issues of water resource development and crop insurance are the two key conditions influencing resource protection of the park?	10	10	10
Do the buffer-zone management-related regulations of the park provide appropriate compensation against crop damage and attack by wild animals?	0	0	0
As per the buffer-zone concept, have park and people maintained the bottom line to help protect park resources and improve livelihood conditions in the buffer zone?	6	6	5

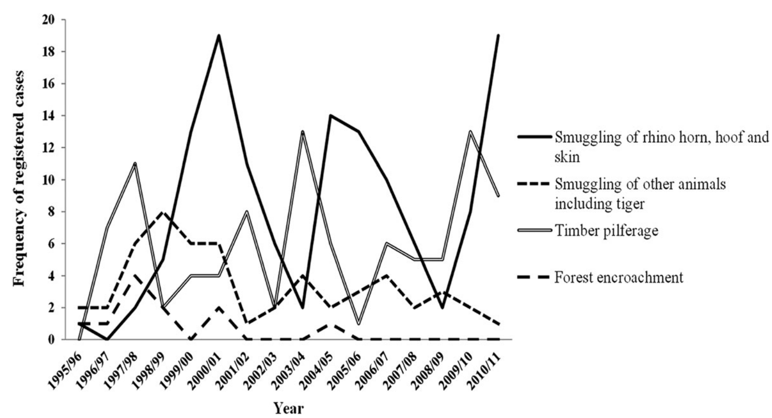

Figure 6. Frequency of cases registered in the Court Section of Chitwan National Park related to the illegal operations of valuable natural resources of the park by smugglers and other attempts at timber pilferage and forest encroachment (1995/96–2010/11)

authorities to think they can effectively protect these resources without the active participation of the people, which would be possible only by addressing their genuine livelihood concerns.

For a smallholder farmer community in this agrarian context, what could be more valuable than irrigation where the immediate target of the family is to improve food sufficiency? As per the park authorities, an important contributing factor to the great amount of smuggling seems to be the rise of criminal aggression due to the long-term political instability in the country. This is supported by the fact that national leaders and bureaucrats who have not yet revised the very old *Rani* Forest Protection Act of 1973 should take a large share of the blame. This Act was promulgated by the then king Mahendra and never revised. For the offenders, paying a nominal sanction written 40 years ago is no big deal. From the foregoing discussion, it appears that the future policy scheme of the park should demonstrate more robust means of developing farmers' confidence and participation by adequately addressing their food security problems, in which rrigation could play the central role in this water-abundant basin.

SUMMARY AND CONCLUSIONS

This paper presented a discussion around the water resources of the East Rapti River basin shared by both the Chitwan National Park of Nepal and the subsistence farming communities in the buffer zone. It first looked at the basin-level land use change scenario to provide empirical evidence of the magnitude of forest cover change that can have an impact on water resource availability downstream. Despite some indications of forest conversion and agricultural area expansion in the basin, the flow regime in the river has not changed much over the years (1976 ~2010). Scaling down, the study examined whether there were differences in farmers' irrigation systems in terms of water availability and crop productivities. Significant differences were observed in crop productivities and profitability which were partly related to differences in water supplies between systems that off-take water from the river and those from tributaries. It provides a clue that a spatial anomaly exists at local level which is not apparent at basin-level study of water availability analysis.

The study revealed that it is an open basin; water is not a limiting factor for any development purposes at least in the foreseeable future. The appearance of economic scarcity of water could be removed by irrigation through dedicated water management efforts. An extensive review has shown that expansion or augmentation of small-scale irrigation facilities could have a positive impact on farm production, profitability and income disparity. This is a genuine concern of equity that we spotlight in this basin. Achieving some level of equity or prosperity would then enable greater cooperation and participation of the farmers in the resource conservation program of the park because their decisions would be informed. Needless to say, the buffer zone is also the gateway to the park for all. Over the past 15 years, park records show a lot of smuggling of rhino and timber pilferage relative to other illegal operations. It signals that the current level of people's participation and the resource conservation policies of the park need revision. The kind of development approaches used to address the basic concerns of those living on the fringes of the national park will determine the extent of civilian guardianship which in a democratic society seems more powerful than armed forces alone to protect the park's resources.

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NOTES

[1] Net inflow to the basin = Gross inflow +/− storage change (surface/subsurface)

Where gross inflow = precipitation (average rate of annual rainfall × Thiessen polygon data), diversion from other basin, and surface and subsurface sources from outside the basin.

[2] Outflow from the basin = Surface + subsurface flow

This combines (a) committed water to other downstream users due to their water rights or an agreement to maintain minimum stream flow for environment, fisheries, and so on (b) uncommitted flow, which is part of stream flow that flows out of basin due to lack of storage or extra water in the basin.

[3] Process depletion

It is removal of water from a basin that renders it unavailable for further use. Evaporation, flow to sinks, pollution and incorporation into a product, i.e. crop uptake of water for building tissue, and industrial uses are examples of such depletion. But not all water diverted from the river/canal into the crop field is consumed. We therefore applied appropriate coefficients to convert diverted water for these purposes into consumed quantity.

[4] Nonprocess depletion

This includes evapotranspiration (ET) of all kinds from forest and grassland. Although their values vary greatly, they are considered to be beneficial, while ET from barren land and flood plains, etc. are considered as nonbeneficial parts of the nonprocess depletion.

[5] Outflow

Outflow from the basin = Net inflow − runoff

Deep percolation = Sum of net inflow − sum of depletion and surface runoff

REFERENCES

Adhikari KR, Tan YC, Lai JS, Pant D. 2009. Irrigation intervention: a strategy for conserving biodiversity and improving food security in Royal Chitwan National Park Buffer zone, Nepal. *Irrigation and Drainage* **58**: 522–537.

Agrawal A, Gupta K. 2005. Decentralization and participation: the governance of common pool resources in Nepal's Terai. *World Development* **33**: 1101–1114.

Bacha D, Namara R, Bogale A, Tesfaye A. 2011. Impact of small-scale irrigation on household poverty: empirical evidence from the Ambo District in Ethiopia. *Irrigation and Drainage* **60**: 1–10.

Budhathoki P. 2003. Nepal's conservation in crisis. Empowering people to secure natural resources. *Journal of Forest and Livelihood* **2**: 72–76.

Department of Hydrology and Meteorology (DHM). 2010. Climatic data of Nepal. Ministry of Environment. Government of Nepal: Babar Mahal, Kathmandu, Nepal.

Gautam AP, Webb EL, Eiumnoh A. 2002. GIS assessment of landuse/landcover changes associated with community forestry implementation in the middle hills of Nepal. *Mountain Research and Development* **22**: 63–69.

Gilmour DA, King GC, Hobley M. 1989. Management of forest for local use in the hills of Nepal. Changing forest management paradigms. *World Forest Resources Management* **4**: 93–110.

Hussain I, Hanjra MA. 2004. Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and Drainage* **53**: 1–15.

International Centre for Integrated Mountain Development (ICIMOD). 1996. Climatic and Hydrological Atlas of Nepal. Kathmandu, Nepal.

International Water Management Institute (IWMI). 2003. Institutional Arrangements for Water Management in the East Rapti River Basin, Nepal. Country Reports and Action Plans. Final report, vol. IV. Colombo, Sri Lanka; 50–61.

Kayastha BP. 1991. Elements of Community Forestry in Nepal. Nepal Lithographing of Savitri Devi: Kathmandu.

Masozera KM, Alavalapati JRR. 2004. Forest dependency and its implications for protected areas management: a case study from the Nyungwe forest reserve, Rwanda. *Scandinavian Jounrnal of Forest Research* **19**: 85–92.

Mclean J, Stræde S. 2003. Conservation, relocation, and the paradigms of park and people management—a case study of Padampur villages and the Royal Chitwan National Park, Nepal. *Society and Natural Resources* **16**: 509–526.

Molden D, Sakthivadivel R. 1999. Water accounting to assess use and productivity of water. *Water Resource Development* **15**: 55–71.

Molden D, Sakthivadivel R, Sharma KR, Mishra VS, Hemchuri HP, Adhikari KR, Prasad KC, Shilpakar RL. 2000. *Water Accounting for East-Rapti River Basin of Nepal*. Nepal Country report. International Water Management Institute: Colombo, Sri Lanka.

Nagendra H, Pareeth S, Sharma B, Schweik CM, Adhikari KR. 2008. Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology* **23**: 41–54.

Nepal SK, Weber KE. 1995. The quandary of local people park relations in Nepal's Royal Chitwan National Park. *Environmental Management* **19**: 853–865. DOI: 10.1007/BF02471937

Paudel NS. 2002. Integrating people and nature: a perspective for environmental conservation and livelihoods in the context of Nepal. *Journal of Forest and Livelihood* **2**: 62–67.

Perry C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. *Irrigation and Drainage* **56**: 367–378.

Sakthivadivel R, Molden D. 2001. Linking Water Accounting Analysis to Institutions: Synthesis of Five Country Studies. Report presented during a regional workshop, Integrated Water-Resources Management in a River-Basin Context: Institutional Strategies for Improving the Productivity of Water Management, Malang, Indonesia, January 15–19; 1–29.

Schultz B, Thatte CD, Labhsetwar VK. 2005. Irrigation and drainage: main contributors to global food production. *Irrigation and Drainage* **54**: 263–278.

Schweik CM, Adhikari KR, Pandit KN. 1997. Land-cover change and forest institutions: a comparison of two sub-basins in the southern Siwalik hills of Nepal. *Mountain Research and Development* **17**: 99–116.

Shukla A, Shivakoti G, Poudel R, Joshi NR. 1997. A process documentation study explaining dynamics water rights in East Chitwan. Nepal. In *Proceedings of an International Conference on People and Participation in ustainable Development held at Rampur Chitwan, Nepal*, Verugase G, Shivakoti GP, Ostrom E (eds); March 17-21; 146-162.

