CPWF Project Report

Improving water productivity, reducing poverty and enhancing equity in mixed crop-livestock systems in the Indo-Gangetic Basin

Project Number 68

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

The CGIAR-CPWF Project "**Improving water productivity, reducing poverty and enhancing equity in mixed crop-livestock systems in the Indo-Gangetic Basin**" was designed and conducted by the International Water Management Institute (IWMI), in partnership with international and national partners, to address the relative neglect of livestock water needs of crop-livestock farming systems.

The primary objective of this project was to optimize the productive use of water in the crop-livestock farming systems of semi-arid areas to enhance livelihoods, reduce poverty, contribute to gender equity, and protect the environment. This was addressed through an integrated approach led by a multi-disciplinary team across three States of the Ganga Basin.

CPWF Research Report series:

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LIST OF ABBREVIATIONS USED

AI	Artificial Insemination
ATMA	Agricultural Technology Management Agency
BDO	Block Development Officer
BWt	Body Weight
CIMMYT	Cientro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CLS	Crop Livestock System
CPR	Common Pool Resources
CPWF	Challenge Programme for Water and Food
CWP	Crop Water Productivity
DMI	Dry Matter Intake
DPC	District Planning Committee
ET	Evapotranspiration
GP	Gram Panchayat
GSLF	Gendered Sustainable Livelihood Framework
ICAR	Indian Council of Agricultural Research
IGB	Indo-Gangetic Basin
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
LW	Live Weight
LWP	Livestock Water Productivity
ME	Metabolizable Energy
MOH	Men Outside the Household
MWH	Men Within the Household
NREGA	National Rural Employment Guarantee Act
PRI	Panchayati Raj Institutions
SLU	Standard Livestock Unit
SWP	System Water Productivity
WP	Water Productivity

RESEARCH HIGHLIGHTS

Whereas the water needs of major grain and cash crops have been extensively studied, scientific knowledge regarding the water requirements of livestock is relatively poor and underdeveloped. Yet mixed farming systems, combining crop cultivation with livestock production, engage a significant part of the world rural population and represent a significant share in the production of agricultural products. Meeting the water needs of these systems is thus essential – not only for food security but as well for sustaining the livelihoods of millions of small and marginal farmers, for whom livestock holds multiple economic and non-economic (i.e. social, environmental and religious) values.

This project has increased the awareness of farmers, NGOs, government officials at the district, state and national level, as well as among the scientific community, on the actual water needs of livestock. The key highlights of the study which were communicated to these various stakeholders are the following:

- Water scarcity is a major problem experienced on a seasonal or regular basis by more than 80% of farmers in all field sites. Water scarcity is the most acute in the study area with the highest rainfall, where more than 50% of the population experiences water shortage all year round and the remaining experiences significant shortage on a seasonal basis. This is an economic and institutional/physical water scarcity due to lack of infrastructure, poor delivery of public services and inequitable access to water resources.

- The present livestock water requirement to produce a unit of product (milk) was higher in the case study areas than the world average. There was a strong variability of livestock water productivity (LWP) not only among different farming systems but also among farmers within the same system. This suggests a large scope for improvement. This scope was confirmed by the wide gap observed between current and potential LWP. For instance, in the semi-intensive system in West Bengal, current LWP was evaluated at 16000 L water per L milk whereas the potential is estimated to be slightly below 800 L water per L of milk. Potential for improvement was found to be particularly high among the poorest farmers of the community with no or poor access to land and water in paddy rice systems. Within the farming systems, the scale of variability across farmers' livelihood typology was system specific and largely influenced by farmers' access to milk and feed market.

- There was a great variation of feed availability among and within districts. For example districts with intensive systems had surplus feed (> 30%) whereas feed deficit (>50%) was observed in the district with semi-intensive system. This variation was largely related to the degree of agricultural intensification and to farmers' access to land and water. Mechanisms to improve farmers' access to key assets and their capacity to prepare optimum-mixes of green, dry and concentrated feed needs to be encouraged. Marketing support and the development of feed storage facilities are some of the key interventions that would support a better feed access. In regions where agricultural land per capita is small, it is particularly important to support the protection of existing common grazing land as well as the improvement of waste and fallow land.

- Most technological innovations to intensify livestock production at the household level increase women's workload, especially for animal feeding. For instance, in the trans and middle Gangetic zone, stall feeding with zero grazing has increased the workload of women of 1-2h/day in terms of weed chopping and feed mixing.

- All proposed interventions require a better adaptation of the interventions of government bodies to local needs and farmers differentiated access to land and water, which could be supported by a greater decentralization of development planning to local elected bodies. A better integration of food-feed water requirements, favoured by a coordinated action among relevant line departments at the state and district level would also greatly support the improvement of water use in crop-livestock systems (CLS).

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EXECUTIVE SUMMARY

Rationale and objectives

The livelihood of millions of farmers in the Ganga Basin depends on mixed crop livestock farming systems. Livestock is particularly important for the landless and the small landholders for which incomes from land are not sufficient to meet their basic needs. Although water requirements of crops have been the object of long-term and in-depth studies, the water needs of livestock have been, in general, largely underestimated. More particularly, the water requirements for animal feeding have been neglected. Yet they represent the most important part (>90%) of animal water needs and several studies indicate that there is a high potential for water savings by improving animal feeding. Increasing the water use efficiency of animals has thus emerged as a highly relevant research question, all the more topical in the context of increased climatic variability and growing demand for crops and livestock products.

The project "Improving water productivity, reducing poverty and enhancing equity in mixed crop-livestock systems in the Indo-Gangetic Basin", funded by the CPWF, was implemented by the International Water Management Institute (IWMI), in partnership with international and national partners, to address the relatively neglected livestock water needs in crop-livestock farming systems.

The objectives of the project were:
1. Improve the understanding of total water needs of crops and livestock in crop-livestock systems
2. Identify institutional and governance arrangements, and gender and poverty variables that support integration of crop-livestock water needs in the basin
3. Identify viable entry points and practical methods for improved water productivity in crop-livestock systems that are economically and environmentally sustainable
4. Evaluate gender, livelihood and poverty impacts of recommended technological and management options
5. Increase local capacity and develop policy, technology and governance recommendations for improving water productivity in crop-livestock systems

Methodology

The project adopted a multi-disciplinary approach combining three pillars: first, a biophysical analysis of LWP at the district and community scale, exploring variability among regions, farming systems and farmers' livelihood typology. This analysis allowed defining entry points for improving LWP. The selected biophysical interventions were proposed with the institutional (including market-based) reforms that are required for their adoption.

The second pillar examined the contribution of livestock to livelihoods across farming systems and among different groups of farmers, defined by their livelihood typology. This component also identified the different forms of capitals which are essential for farmers to improve LWP and the differentiated access to these forms of capitals between men and women. Lastly, we evaluated the potential impacts of selected biophysical interventions on livelihoods, poverty reduction and men and women.

The third pillar addressed the institutional and political context in which farming systems currently operate and examined to which extent this context is favourable for an efficient, equitable and sustainable use of water in CLS. It particularly explored the issue of access to water, collective action, decentralisation, and integration of crop, livestock and water issues in the state interventions. This component allowed the identification of institutional and political changes which would support improved LWP, poverty reduction and enhanced equity in the Ganga Basin.

All objectives were fully achieved as evidenced by the detailed assessment of LWP across regions, farming systems and livelihood typology (Section Objectives 1, 3), the institutional, gender and poverty analysis (Section Objectives 2 and 4), which results were combined for the development of sound recommendations (Section Objective 5).

Results

Major findings, presented in the research highlights, emphasised the widespread economic and institutional water scarcity experienced by a large majority of farmers in the case study area. It means that improving water productivity often requires first to improve access to water sources and/or distribution of water. The livelihood and gender analysis indicated that improved livestock and feed management have a high potential to enhance the livelihoods of the landless and land-poor. Women contribute significant labour to livestock activities but their access to the benefits of livestock activities is diminished in some areas by mobility restrictions and by a lack of inclusion in decision-making processes at the community and household level.

The evaluation of LWP at the district and household level indicated that there was a high potential to enhance water use efficiency in the CLS of the Ganga Basin. It was evidenced by the high variability of LWP across farming systems in the region and among farmers within the same farming system. Furthermore, there was a large difference between observed and potentially achievable LWP values. Results show that higher LWP gains will occur when interventions target the poorest households with low access to land and water and agricultural systems with lower LWP. For instance, by increasing the current milk yield level of mixed herd model to the potential, it is possible to reduce by more than 50% the amount of water used to produce 1 L of milk.

We proposed a mix of technical and institutional recommendations for farmers, development practitioners and policy-makers to improve feed, animal and water management in order to support the increase of LWP and improve livelihoods. These interventions are region-specific (e.g. rainfed/irrigated areas) and system-specific (intensive/extensive). Our recommendations were also tailored to farmers' livelihood and notably on their access to land and water and ownership of livestock. We defend the need for flexible interventions adapted to the local biophysical, socio-economic conditions and to farmers' diverse access to capitals. These have a higher potential to achieve their objectives and respond to farmers' differentiated needs and capacities than a state-wise blanket programme or unique intervention.

Recommendations are proposed for three domains.

1) Feed management: Interventions would include the higher use of agricultural by-products and crop diversification towards water productive and dual-purpose varieties (e.g. pulses), the treatment of crop residues, such as low cost chaff cutting, chemical treatments, mixing and densification. These actions are particularly relevant for rice systems in rainfed areas for the poorest farmers with no or limited access to water in wheat-cotton, wheat-rice and millet systems of irrigated areas. In regions where agricultural land is scarce, over-seeding of wasted land and communal grazing areas, green fodder planting on bunds and fallow lands could be promoted. Such interventions must be linked with adequate community-led institutions for the management of common land.

2) Animal management: To increase milk yield, programs for upgrading non descriptive cows and buffaloes with high yielding indigenous and exotic animals on selective basis could be encouraged. It entails creating efficient service

delivery mechanisms for artificial insemination and improving farmers' access to veterinary services, through for instance the training of paravets in villages. Such interventions have to be coupled with better linkages to feed and livestock products markets to offer sufficient incentives for the poor and medium rural households to adopt upgraded breed.

3) Water management: Better water management requires first a sufficient, timely and secure water supply – which is not the case for a large majority of farmers in the case study areas, whether in the rainfed or irrigated regions. Access to water is a large issue which goes beyond the scope of this study, but we proposed several recommendations for rainfed and irrigated areas which details can be found in the policy briefs. These include facilitating farmers' access to pumps in the rainfed areas of West Bengal through adequate institutions (e.g. giving/renting at a low rate pumps to Self-Help Groups which would take care of their management and maintenance). Other interventions contributing to water savings include building farmers' knowledge and capacity regarding the adoption of water productive feed, crop rotation and diversification (e.g. agroforestry).

Impacts and outcomes

The project has certainly contributed to raise the awareness of district level officials, NGO partners and, to a less extent, among national and state government civil servants on actual livestock water requirements and the need for adopting an integrated approach, simultaneously considering crop/fodder water requirements, livestock management and water supply. The participation of NGOs in the project was a crucial element to translate research results into development actions on the field with tangible impacts for farmers. As underlined in Section 2, there are structural and institutional constraints within the current planning process and the sectorisation of state development schemes which need to be addressed for positive changes to occur on a large scale. We advise for more grounded approaches designed at the district level and tailored to local needs proposing an integrated package of interventions such as capacity building, technical and marketing support. Such initiative requires a pro-active dialogue between the Animal Husbandry, Agriculture, Horticulture and Irrigation Departments to develop synergies between the development of crop cultivation and livestock activities. It would also be supported by the devolution of funds and decision-making power to panchayati raj institutions (PRIs).

These are sensitive political and bureaucratic issues which have been debated for a long time in India – and elsewhere – but we hope that the quantified evidence we provide on the scope for saving water and improving livelihoods through interventions increasing LWP can contribute to further debates. We also hope that the concept of LWP can encourage a coordinated approach among state line Departments. We militate in favor of locally-grounded, integrated approaches to rural development which go beyond considering farmers as passive recipients of welfare action but give them an active role in their development.

INTRODUCTION

The Ganga Basin[1] is one of the largest drainage basin areas in the world. Spreading from the Himalayan-Tibetan area in the west to the Bengal Delta in the east, it crosses nine states[2], covering 1,089,370 km^2, among which 872,769 km^2 in India, i.e. more than one fourth of the total land area of the country. The alluvial and fertile plains of the basin have been, since the dawn of civilization, one of the most populated and extensively farmed areas of the world.

From a macro scale perspective, water and food security have emerged as major concerns for national policy-makers, due to the high population density and growth rates in the region. The gap between water supply and demand in 2030 in the Ganga Basin has been estimated to 53% of the local demand (The 2030 Water Resources Group 2009). The sustainability of current water resource use has also arisen on the policy agenda. In several states, e.g. in Uttar Pradesh, whereas the net canal irrigated area has been declining since the mid-1980s, groundwater use has sharply increased (Shah et al. 2009). Groundwater exploitation is uneven across the basin, with high extraction rates and groundwater depletion, in western states such as Uttar Pradesh and Haryana, and low rates, due to high electricity rates and stringent regulation, in West Bengal. Noticeably, these differences are more related with the political economy of the regions rather than with the actual availability of groundwater (Mukherji 2006). Lastly, the Ganga and its tributaries provide water for a large number of competing uses: domestic, environmental, industrial, irrigation and spiritual – with irrigation accounting for around 90% of annual water withdrawals. Competition among sectors is likely to increase over the coming decade.

Identified avenues for reducing the water demand-supply gap, meeting food demand and improving livelihoods have included interventions to increase water productivity. Extensive research has been previously conducted to assess crop water productivity (CWP) and to develop practices and techniques that can reduce the number of drops used per crop. However, these studies have usually overlooked the nexus between water needs for crop and livestock. The water requirements of livestock have been either ignored or largely underestimated. Only the drinking water demand of animals has generally been considered, neglecting the largest consumption of water by animals: feed.

To address this research gap, Peden et al. (2007) have developed during a project of the CGIAR Challenge Program on Water and Food PN37, 'Nile Basin Livestock Water Productivity', in collaboration with the CGIAR Comprehensive Assessment of Water Management in Agriculture, the concept of livestock water productivity (LWP) together with a framework to estimate water exchanges between different components of the crop-livestock system. This framework was applied to CLS in the Nile Basin and results indicated that the productivity of both crop and livestock enterprises were low compared to their potential, partly because water crop livestock

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[1] The geographical scope of the present research project was initially set up as the Indo-Gangetic Basin. However, because the three case study states that were selected for fieldwork are located in the Ganga Basin, the discussions will primarily focus on the Ganga Basin region of the Indus-Gangetic plains.

[2] The 9 States that fall under the Ganga Basin are: Bihar, Delhi, Haryana, Himachal Pradesh, Madhya Pradesh, Rajasthan, Uttar Pradesh, Uttarakhand, West Bengal

linkages were ignored and because the multiple needs of water (particularly for growing crops and feeding and watering livestock) had not been integrated. Subsequently, a BMZ funded project improving water productivity of crop-livestock systems, developed Peden et al.'s framework into a quantitative tool for evaluating LWP and exploring the water use implications of various scenarios for improving LWP (Descheemaeker, et al. 2009 under review). This project has applied the operational tool in order to explore the scope to improve LWP in the Ganga Basin. The latter has been often described as a "low productivity – high potential" region, with, on the one hand, a high concentration of poverty and, on the other hand, the capacity and capability to increase agricultural production and productivity (Sharma, Amarasinghe, and Sikka 2008).

Improving LWP has implications not only for the overall objective of food and water security but also for poverty reduction and livelihood improvement. Most of the mixed CLS are managed by small and marginal farmers. Often, but not always, a source of income, livestock also provide valuable physical assets used for agriculture or as a safety net. Livestock also produce inputs for domestic and agricultural use and form an important cultural (e.g. religious) asset. Water scarcity is a major constraint for the development of these mixed farming systems. Improving the water productivity of such systems through an efficient, equitable and sustainable use of resources thus holds a great potential to contribute to enhanced livelihoods and reduce poverty.

PROJECT OBJECTIVES

The overall goal of the project is to optimize the productive, equitable and sustainable use of water for crop-livestock systems in semi-arid areas to improve livelihoods, reduce poverty and conserve the environment. Although the foundational concept used in this analysis is LWP, productivity has been attached with equity and sustainability, as increase in productivity is neither necessarily equitable nor sustainable. The notion of equity is to be understood as equity between gender, among social classes and water users. The notion of sustainability and the related goal of environmental preservation have been addressed by considering the physical value of LWP together with its financial value. These issues are outlined in the next sub-sections.

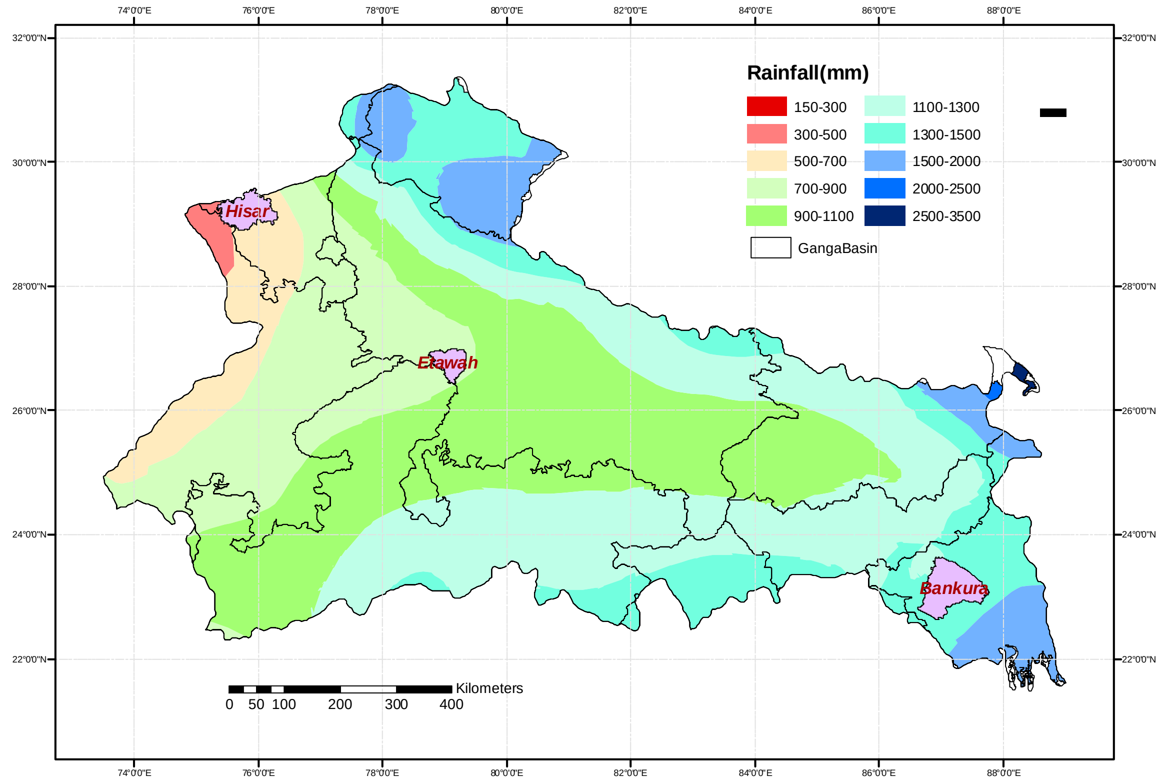
This section is organized into five sub-sections, according to the five objectives of the project.

1. Improve the understanding of total water needs of crops and livestock in crop-livestock systems;
2. Identify institutional and governance arrangements, and gender and poverty variables that support integration of crop-livestock water needs in the basin;
3. Identify viable entry points and practical methods for improved water productivity in crop-livestock systems that are economically and environmentally sustainable;
4. Evaluate gender, livelihood and poverty impacts of recommended technological and management options;
5. Increase local capacity and develop policy, technology and governance recommendations for improving water productivity in crop-livestock systems.

Before presenting in detail each of these objectives, the methodology and results, the next paragraphs briefly introduce the general methodology which guided all the research activities of the project. It includes site selection and data collection in the case study areas. The study frameworks and specific methodologies that were used for the LWP, gender, livelihood and institutional components of the project are presented later in their respective sub-sections.

Site selection and characterization

We selected the study states according to a rainfall gradient in the Ganga Basin (Map 1).



Map 1. Location of case study states and districts in the Ganga Basin along a rainfall gradient

Erenstein et al. (2007) assessed crop-livestock interactions from a livelihoods perspective, and mapped their spatial and seasonal diversity. It provided the base to build strata for this study and choose the study districts and villages. The districts were selected depending on climatic conditions, livestock composition and crops grown (Table 1). Major determinants for site selection included the degree of agricultural intensification, access to markets and access to irrigation water (Table 2). Detailed characteristics of the case study districts and criteria for the selection of case study areas are presented in Tables 1 and 2 respectively.

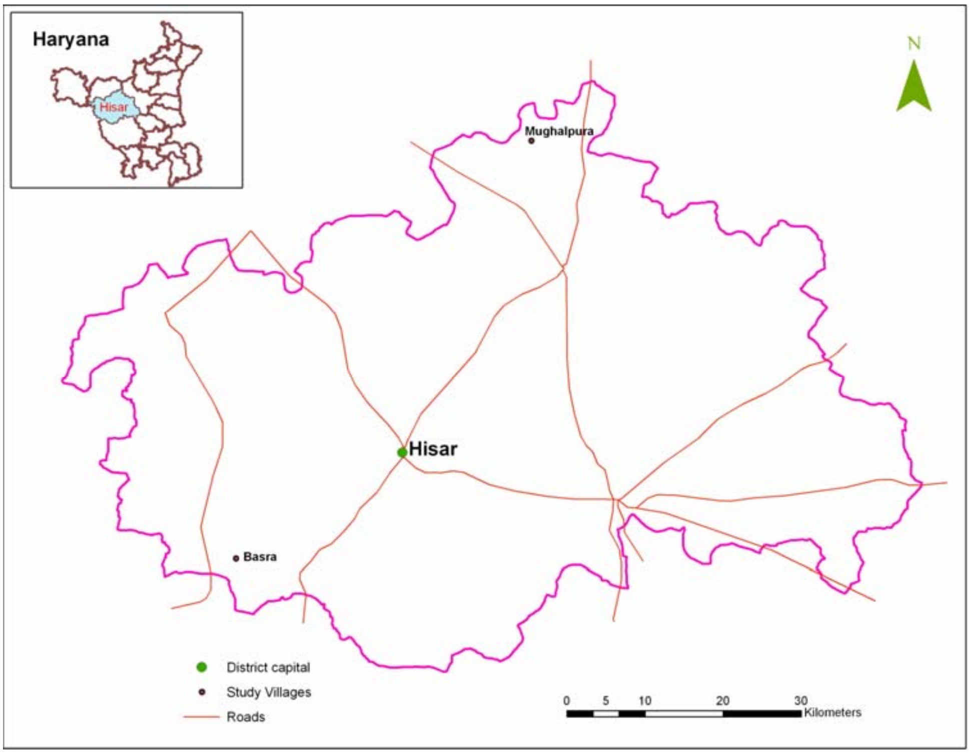
Table 1. Major characteristics of the three case study districts

District Name	Hisar	Etawah	Bankura
Area (km^2)	4,072	2,212	6,936
Population (inhab.) (2001)	1,536,417	1,340,031	3,191,822
Population density (inhab/km^2) (2001)	386	586	464
Agro ecological zone	Arid	Semi-arid	Sub-humid
Average annual rainfall (mm)	400-500	700-900	1400-1600
Livestock	Buffaloes, cows, camel, sheep	Cows, buffaloes, goats	Oxen, desi cows, some buffalo, goats, sheep, poultry
Major crops in *kharif* (monsoon season)	Cotton, rice, guar and Pearl millet sorghum for green fodder	Rice, pearl millet vegetables	Rice and vegetables
Major crops in *rabi* (dry season)	Wheat, potatoes, mustard	Wheat	Vegetables
Major Rivers	No rivers	Chambal, Yamuna and Kuvari	Damodar, Dwarakeswar, Silabati and Kasai

Table 2. Key criteria for the selection of case study sites in the three districts

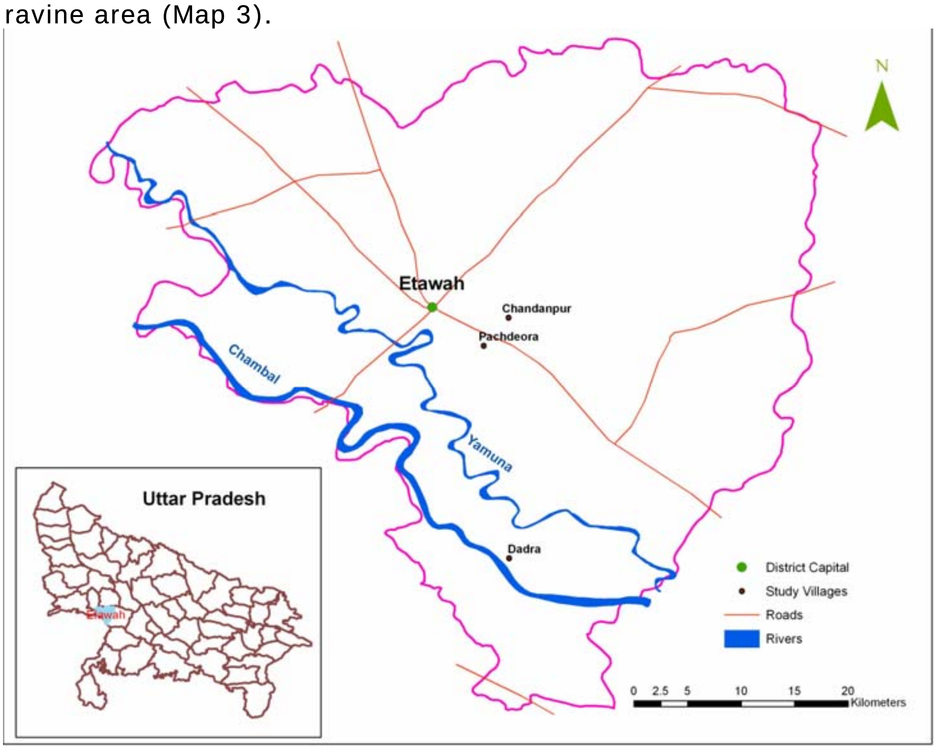
	Hisar	Etawah	Bankura
Annual rainfall range	Low (500-700 mm)	Medium (700-800 mm)	High (1,300-1,500 mm)
Access to irrigation water in study villages	Canal Canal + tube wells	Tube wells Canal + tube wells	Dug wells, streams, ponds
Degree of agricultural intensification	Intensive	Intensive	Semi-intensive
Access to market	Good	Good	Poor

In Hisar District, one case study village was chosen in each of the two agro-ecological zones of the district: Mugalpura, in the north-eastern part of the district, part of the Yamuna alluvial plain, characterised by a hot and semi-arid climate. And Basra, in the south-western part (Map 2), in the agro-fluvial plains, characterised by a hot and dry climate.



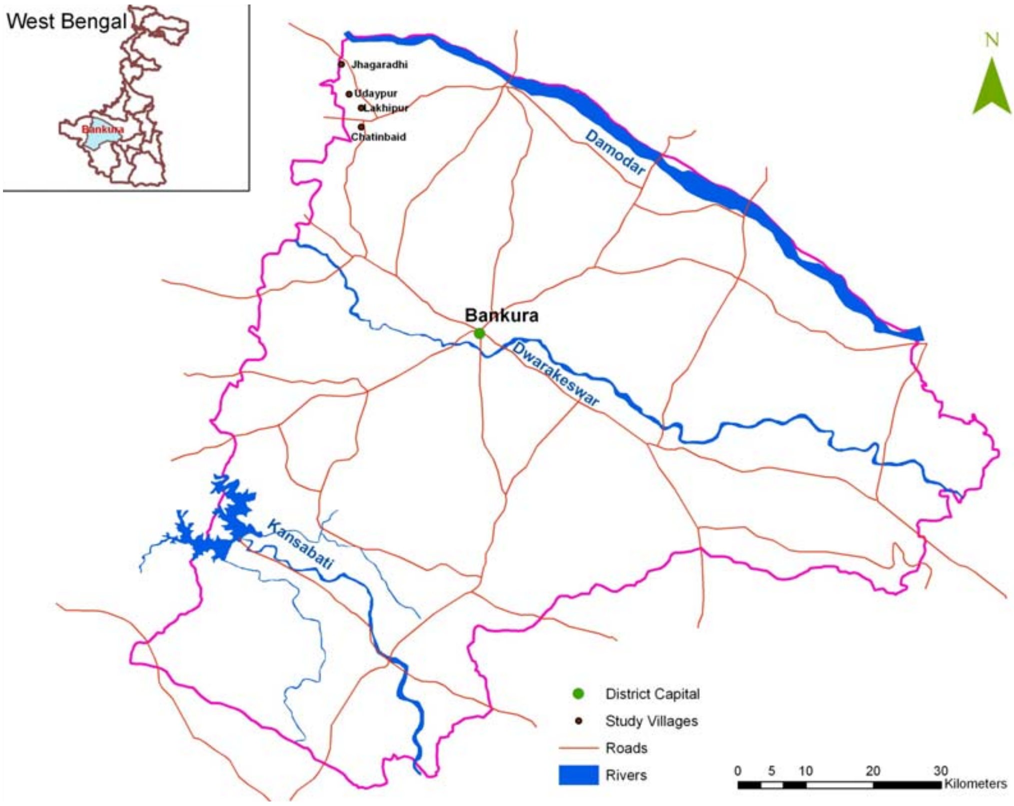
Map 2. Location of case study sites in Hisar District, Haryana

In Etawah District, three case study villages were chosen, Chandanpur and Pachdeoara lying in a loamy plain and canal command area and one, Dadra, in a ravine area (Map 3).



Map 3. Location of case study sites in Etawah District, Uttar Pradesh

In Bankura District, four hamlets were selected in Saltora Block: Chatinbaid, Jhagradihi, Lakhipur and Udaypur (Map 3). All hamlets were selected in this particular block, because of the absence of canal and tubewell irrigation in this area. Other blocks in the Yamuna plain rely on canal and groundwater irrigation, as in Hisar and Etawah Districts. In addition, Saltora Block has a relatively high forest cover compared to other blocks of West Bengal (15% and on average 8% of total land area in 2001 respectively), following a remarkable increase (+25%) between 1991 and 2001 (though forests in other blocks of the state had on average slowly increased by 3% only) (Bankura Primary Census Abstract, 2001). Forests thus play a great role for livelihoods as well as crop-livestock systems – unlike in the sites selected in Hisar and Etawah. This particular block was thus chosen as a representative area of rainfed farming systems with a high reliance on forest resources.



Map 4. Location of case study sites in Bankura District, West Bengal

Mixed CLS are commonly found across the study villages. In general these villages represent 5 CLS under different intensification gradients and cropping system. The following sections briefly characterize these.

a) *Paddy rice system (semi-intensive)*: this system is found in the study area of Bankura District, West Bengal. In this system, a single rice (*Oryza sativa)* crop is cultivated, with monsoon rainfall as the major water input to the system. Very few households produce paddy surplus and subsistence farming dominates in the area. Farmers manage different livestock species and breeds: cattle (e.g. *Bos indicus*), sheep (*Ovis aries*), goat (*Capra hircus*). Common grazing land forms a major feed source particularly for the landless poor farmers.

b) Irrigated wheat-cotton and wheat-rice systems (intensive): these systems are found in the study villages of Hisar District, Haryana, and Etawah District, Uttar Pradesh respectively. Wheat (*Triticum durum* and *Triticum aestivum)* are major winter (*rabi*) crops, while cotton *(e.g.Gossypium hirsutum*) has significant area coverage in *kharif*. In the *wheat-rice* variant, rice (*Oryza sativa*) dominates in *kharif*. Irrigation (from canal and ground) is a major supplementary water source for cotton and rice and the sole source of water for wheat. Compared to the paddy rice system, these two systems are characterized by a higher crop diversity and cropping intensity. But Rodell et al. (2009) suggest that the current groundwater extraction exceeds the natural recharge and thus threatens sustainable water use. The dairy structure and the presence of higher milk yielding breed (compared with the paddy rice system) reflect the underlying investment trends in livestock. Shortage and unsustainable use of irrigation water coupled with increasing costs of livestock feed are some of the major challenges in these systems.

c) Millet-pulse and millet-mustard systems (intensive): the millet systems studied are pocket areas in Etawah and Hisar Districts. The millet system in Hisar District was originally a wheat-based system which shifted to traditional crops such as millet (*Pennisetum glacum*) and chickpea *(Cicer arietinum)* mainly because of a shortage of irrigation water. The one in Etawah District has no access to canal irrigation and thus depends on *kharif* season rain and tube-wells. In both cases, farmers have a better access to feed and milk markets than in paddy rice systems and investments in dairy are comparable with the wheat-cotton and wheat-rice systems.

Data collection and sample farm clustering

The first stage of fieldwork consisted of a census survey conducted in each case study village to identify basic attributes including land and livestock ownership, off-farm activities, access to water, and water scarcity. Collected data aimed at assessing the level of disparity of these different attributes within each community and between communities. The results of this survey were used to select a sample of households representative in terms of farming system, access to water and livelihood strategy. Selection criteria included size of livestock and land owned, access to water, household size and caste.

In a second stage, more detailed surveys were undertaken among the selected sample in each case study site. One component was a detailed questionnaire, to collect in-depth information on cropping patterns and practices, feed access and management, water access and use, as well as other general questions on off-farm activities, physical assets, and social capital. In parallel, semi-structured household interviews and focus group discussions were led with another sample of farmers in each site to explore livelihood strategies, intra-community differentiation of access to capitals and capabilities, characterise the access to gender distribution of labour and income, and identify the key institutions governing access to, control over and management of land, water, agricultural products and outputs and livestock. Interviewed farmers were grouped into similar livelihood typology (poor / medium / better-off) detailed below.

Farmers were grouped according to their livelihood strategies and vulnerability. The latter were represented by their access to key forms of livelihood capitals: land, livestock and water.

This led to the creation of four groups:

1. Landless without any farming activity (no livestock and who do not produce any crop) – called further in the report "**off-farm poor**" and referred to as **Group 0**
2. Landless with livestock or who work on land sharecropped in/ rented in – called "**poor farmers**" and referred to as **Group I**
3. Landowners with 0 to 1 asset – called "**medium farmers**" and referred to as **Group II**
4. Landowners with 2-3 assets – called "**better-off farmers**" and referred to as **Group III**

Assets were the following:

1. Land size above the average of surveyed farmers in the district
2. Livestock Index above the average of surveyed farmers in the district
3. Access to irrigation water

Lastly, interviews with stakeholders were led at the district, block and panchayat or village level.

1 Objective 1: Understanding livestock feed and water nexus in the mixed crop-livestock systems (CLS) of the IGB

The crop-livestock mixed farming system covers 2.5 billion ha of land globally, and is widespread especially in South Asia and Sub-Saharan Africa. The CLS produces 92% of the global milk supply and 70% of the small ruminant meat and most of the projected future demands for meat and milk are expected to be met from this system. Given the increasing demand for agricultural products and subsequent pressure on land and water resources, how producers in CLS respond to these circumstances and how their decisions regarding the use of natural resources affect Water Productivity (WP) are points of research interest (Singh 2000).

There are different degrees of intensification in the IGB, increasing from south-east (e.g. West Bengal) to north-west (e.g. Haryana) (Erenstein et al. 2007). The north-west part has benefited from India's green revolution, a massive agricultural expansion fuelled, largely, by the increased use of groundwater for irrigation (Rodel, Velicogna, and Famiglietti 2009). During the 1960s to 1980s, the planting, in the irrigated fields, of high-yielding wheat and rice varieties, combined with the application of fertilizer, resulted in much improved cereal production. As a result, changes in the livestock functions and herd structure were observed. For example the intensification of dairy production was accompanied by a decrease in the ratio of working animals to milk cows and a more intensive use of water for growing feed and fodder (Singh et al. 2004). The point is whether such intensification pathways are water efficient. Contrastingly, in the south-eastern part of the basin, crop production is mainly rainfed and the increase in yield was mainly achieved from area expansion. Livestock are managed on communal grazing land and mainly provide draught power. Now, both the rainfed and irrigation-based CLS suffer from severe water shortage and degrading soils (Singh 2000). The per capita water availability in the IGB under projected water demand, for 2025, will be less than 1,700 m^{-3} $head^{-1}$ yr^{-1} which is considered as the cut-off point where water stress starts.

Increasing Livestock Water productivity (LWP) and Crop water productivity (CWP) are widely advocated strategies to mitigate the impacts of water scarcity (Rodel, Velicogna, and Famiglietti 2009). Recent findings suggest that improving WP is not *per se* an increase in crop yield or animal products (kg ha^{-1}). A sustainability-focused approach must involve interventions that address multiple use of water by identifying an interface between crop and livestock compartments in a crop-livestock mixed system (Haileslassie, Peden, Gebreselassie et al. 2009). This study presents an analysis of the livestock-feed-water nexus across a crop-livestock intensification gradient in the IGB of India. The overarching objectives were to (i) understand the spatio-temporal dynamics of water requirements for livestock feed production, (ii) explore the magnitude of LWP across intensification gradients.

1.1 Methods

1.1.1 System definition: production systems and level of intensification

The IGB is described as a "hotspot" area in South Asia, where increased WP can benefit the basin community at large. Livelihood strategies in the three study districts are predominantly based on crop and livestock production. Based on chief management interventions (e.g. land preparation; nutrients; and water), Gregory et al. (2002), categorize the intensification levels into three. Type I intensification usually follows land clearance for crop production and is characterized by the limited management inputs that are available ("pre-green revolution"). Type II intensification is largely dominated by the features of the "green revolution", such as high fertilizer and water inputs, use of high yielding crop varieties, etc. Type III intensification ("doubly-green revolution") is a reaction to the perceived defects of type II intensification and seeks to provide a production system that is both high-yielding with efficient resource use. In this study, we applied these concepts to group the study districts. Accordingly, the study districts fell under type I (*Bankura*) and type II (*Hisar* and *Etawah*), which we designated as *semi-intensive* and *intensive* systems, respectively. A detailed production system characterization is reported by Parthasarathy and Birthal (2008) and Singh (2005).

1.1.2 Water productivity concept and framework for analysis

Generally, Molden (1997) relates WP to the value or benefit derived from the use of water. For example, CWP is defined as crop production per unit of water used. Recent views in WP of agricultural systems are focusing on producing more food with the same or less amount of water investment. The concept of water productivity (WP) allows understanding the interfaces between different system elements (e.g. livestock and crop) and thus creates an enabling environment for a better understanding of System Water Productivity (SWP).

LWP, like its counterpart CWP, is based on principles of water accounting (Haileslassie, Peden, Gebreselassie, Amede, Wagnew et al. 2009; Peden, Tadesse, and Misra 2007; Haileslassie, Peden, Gebreselassie et al. 2009) and is defined as the ratio of livestock beneficial outputs and services to the amount of water depleted and degraded in producing these products and services. The LWP framework is a tool that can be used to explore various researchable issues related to WP. It can be applied at different scales ranging from region to farm. Peden et al. (2007) developed a LWP assessment framework for the Nile basin, with the intent of understanding how livestock affect basin water resources in different production systems. This framework was further developed into a quantitative tool in the sub-Saharan Africa context (Descheemaeker et al. Under review; Haileslassie, Peden, Gebreselassie et al. 2009) introducing other concepts like agricultural water partitioning (between residue and grain, using harvest index) to more accurately reflect the actual water needs of livestock. The authors further developed the quantification of livestock products, to include e.g. manure and other benefits beyond meat and milk. We applied this framework to our study and also introduced methods such as using feed Metabolizable Energy (ME) to partition agricultural water. We further linked the LWP estimation to feed demand-supply balance to explore how it affects the interpretation of LWP values.

1.1.3 Data requirement, generation and flow

Livestock data: value of products and services

In calculating LWP and CWP, four major data sets were required: livestock, crop/land use, land productivity and climate. Each of these data varied in details and was linked to each other. In the following sections we present detail on how these data were generated for each of the required data sets.

The estimation of livestock products and services requires information on the livestock herd structure (Gebreselassie, Peden, and Haileslassie 2009; Haileslassie, Peden, Gebreselassie, Amede, Wagnew et al. 2009). Firstly, therefore, we established the livestock herd structure by breed, age group and level of activity and production (e.g. lactating cows and working oxen) for the period 1992-2003, drawing on district-level livestock-data (Ramachandra et al. 2007). Secondly, we converted these structured population data into Standard Livestock Units (SLU) (SLU equivalent to 350 kg) and Live Weight (LW) using the conversion coefficients employed by Ramachandra et al. (2007).

Data for milk production, number of lactating cows and length of lactation period across years derived from DAHDF (2006), which also provides detailed data on meat yield and the number of animals slaughtered at registered slaughter houses for the different animal groups (e.g. large and small ruminants). There are multiple gaps in this data, and the missing values were calculated based on relationships between the variables for other years. To convert these data into financial values, we collected prices for the different products, from every district, and applied a constant value across the temporal scale.

Manure production is one major livestock product across the study systems. It is a source of household energy and also a means to recycle and redistribute nutrients among farms and landscape (Erenstein and Thorpe 2009). Manure production and its nutrient concentration vary significantly by season, feed, level of production and animal activity. Complete data sets addressing these variabilities were lacking and thus we applied literature values of dung productivity of different animal groups (e.g. Parthasarathy Rao et al. 2004). We estimated the financial value of manure by converting it to N, P and K and considering respective fertilizer equivalent prices.

Draught power is important mainly in the semi-intensive system. The calculation of the value of this service requires variables such as the number of bullocks involved, the hiring costs per day and the number of working days per year. But district scale comprehensive data in this regard are not available. We combined information from the literature (Parthasarathy Rao et al. 2004) and discussions with key informants to estimate the value of draft power.

Feed supply-demand and related land uses

Ramachandra et al. (2007) reported four main categories of feed supply in the study systems: pasture from native grazing lands, crop residue, irrigated/rain-fed green fodder and concentrates (e.g. bran and cakes). Ramachandra et al. (2007) also calculated feed biomass production from crop yield using harvest index. We converted these data sets, on feed biomass, to metabolizable energy (ME, in MJ kg^{-1}) using literature data on energy content (e.g. Kearl 1982) and linked to areas required to grow them to calculate the energy productivity (MJ ha^{-1} Yr^{-1}).

The total energy requirements of an animal were calculated as the sum of the maintenance energy requirements and additional energy to account for the effect of standing and walking, milk production and body weight gain and draft power. We applied ME estimation techniques for tropical regions as reported in King (1983). Maintenance energy requirement was calculated according to Equation 1:

$$\mathrm{MEx} = \frac{0.343 * \mathrm{LW}^{0.73}}{\mathrm{K_m}} \text{.........(Eq1)}$$

Whereby MEx is Metabolizable Energy (MJ day^{-1} $animal^{-1}$) for maintenance; LW is the bodyweight and was calculated as the standard livestock units and number of animals. K_m (MJ kg^{-1}) is the efficiency with which ME is used for maintenance and related to forage metabolizability. For each of the study systems, the average dry matter (DM) digestibility value was considered based on the dominant diet quality (i.e. 55% for intensive and 45% for semi-intensive).

One of the productive uses of feed energy is for lactation. The ME required for lactation was calculated as in Equation 2

$$ME_l = \frac{DMy * NE}{K_l} .... (Eq2)$$

in which ME_l is Metabolizable Energy for lactation (MJ day^{-1} cow^{-1}); DMy is for daily milk yield; NE is Net Energy for milk calculated as function of butter fat content ($g.kg^{-1}$), and solids-non-fat content ($g.kg^{-1}$). We assumed a constant value of fat content across study regions but differentiated between livestock group (i.e. buffalo and cattle). K_l is the efficiency with which ME is converted to milk.

In estimating ME requirement for weight gain, we used Equation 3 whereby MEg is Metabilizable Energy for weight gain; LWG is live weight gain (kg day^{-1} $animal^{-1}$) and W is the actual live weight of an animal (Kg).

$$ME_g = \frac{LWG\ (6.28 + 0.0188W)}{(1-0.3LWG)} .... (Eq3)$$

Calculating the energy requirements of draught animals is data intensive and varies considerably with the duration of work and age of the animal. Given diverse draught power demands subjected to differences in land owned by farmers and cropping pattern, accurate calculation is often difficult. We considered, however, 10% of the MEx as suggested by IPCC (1996). The differences between study sites are captured by the differences in the number of working animals. A certain amount of energy is also required by livestock for walking. But information on these input variables were lacking in the study sites and thus ME for walking was not taken into account.

Assuming that all the ME requirements by the different animal groups are satisfied from the current diet composition (i.e. both in quality and quantity), we distributed the total energy requirements to the different feed sources (as a function of their percentage share on the supply side of ME). This was then converted to land requirements for every feed source based on the respective energy productivity of the latter (MJ ha^{-1} Yr^{-1}). The ME supply and demand data was also used to show the feed demand supply and its implication for LWP.

Feed related livestock water requirements

In this study, the water lost through evapotranspiration (ET) in the process of feed production, was considered as the water input to livestock feed production. The amount of ET water to produce animal feed depends on several factors: livestock diet composition, crop specific parameters (e.g. Kc), biomass yield, quantity of livestock feed intake, length of growing period and climatic variables in the region where the feed is produced. To calculate ETo, we used the Reference Evapotranspiration (ETo) calculator (Raes *et al.*, 2006). It estimates ETo on a daily basis using climatic variables (maximum and minimum air temperature, humidity, wind speed and sunshine hours). We applied the $K_{c*}ET_0$ approach (Allen *et al.*, 1998) to calculate the ET. We used Kc values for different crops and feeds as reported in Allen et al., (1998). For those crops without established Kc value, we applied mean values of their family (for example, the mean values of *leguminosae* for chickpeas). To reach the total ET per cropping season, it is vital to know the length of growing period for each crop's growing stages. We established these based on literature values (Allen et al., 1998) and discussion with farmers in the study area. Length of growing period for different varieties (i.e. short, long, and medium) was not taken into account as the district scale production data was aggregate.

The water invested in crop production includes grain and residues (Haileslassie et al., 2009). In order to understand the water productivity of enterprises at household or system scale, partitioning the total ET water between feed and grain is important. Some study assumed that the water used for the production of a unit of grain and residues was equal and thus it applying harvest index to partition total ET (Haileslassie et al., 2009a; Descheemaeker et al., 2010 under review). Other studies apply the ratio of cost of crop byproducts and grains (Singh et al., 2004). The question is whether the harvest index and economic value approaches reflect the differences in water investment for grain and crop by-product.

In this study we partitioned total agricultural water using two approaches: harvest index and metabolizable energy. The partitioned water was then linked to the land demand for livestock feed production (see previous section) to establish data on total water demand of SLU per year. Further we linked the partitioned water to the current land use from which the available feed is collected and supplied to the livestock. With those data sets we estimated LWP for both demanded and supplied ME.

1.2 Results

1.2.1 Assessment of herd dynamics, feed quality and quantity

In the study systems, livestock population showed a high degree of diversity in its composition. According to the 2003 census, aggregated for all study areas, cattle dominated with 1.3 million Standard Livestock Unit (SLU) (51% of total livestock population), followed by buffalo with 1.1 million SLU (44%), goats with 0.94 million SLU (4%) and sheep 0.17 million SLU (1%). At the system's scale, the importance of these livestock groups varied. Buffalos constituted circa 80% in the *intensive* systems, whilst in the *semi-intensive* systems cattle had the major share (81%). Analysis of livestock population, for the period 1992–2003 (combined for all study systems) indicated that the total population did not change spectacularly. But when we disaggregated to system scale, a different picture emerged. The mean values for the two *intensive* systems showed a steep drop in total SLU (with increasing trends for buffalo in Etawah), while in *semi-intensive* system an increasing trend for all livestock groups was observed.

Overall, dry matter and associated ME from green fodder (irrigated, rain fed) and crop residues were the most important feed resources for the study period (1992-

2003). For the *semi-intensive* region, major feed sources were residues (mainly from rice, 29%), greens (mainly grazing and open forest, 61%) and concentrates (5%). In the *intensive* regions, the feed composition was more diversified and consisted of green fodder (55% mainly irrigated), concentrates (9%) and residues (33%) (Table 3). Between 1992 and 2003, the ME share of concentrates did not show remarkable changes (Table 4). However, in *intensive* systems, a change in the relative contribution of cultivated fodder was notable (23% increase for Hisar and 29% increase for Etawah). This expansion was attended by a proportional reduction in the crop residues' relative contribution to the overall ME.

Table 3. Temporal and spatial variability of different feed source contributions to overall ME supply (figures in bracket are for share of biomass) in intensive and semi-intensive systems of the case study districts

Study region	Temporal scale	% share of ME from different feed sources		
		Greens	*Residues*	*Concentrates*
Hisar*	1992	51(45)	39(48)	10(7)
	1997	58(52)	33(42)	9(6)
	2003	67(63)	24(31)	9(6)
Etawah*	1992	40(37)	53(58)	7(5)
	1997	45(42)	50(55)	5(3)
	2003	51(48)	41(47)	8(5)
Bankura**	1992	56(45)	38(51)	6(4)
	1997	54(43)	43(53)	6(4)
	2003	61(54)	29(42)	5(3.5)

*Greens are: (1) grasses from pasture, wetlands, forests and fallow lands, and (2) green fodder from irrigated/rainfed fodder; Residues are (1) cereal straw/stover: (2) slender straw from rice and wheat, (3) coarse straw from coarse grains such as sorghum, millet and maize and (4) haulms from legumes such as pulse and oil seeds; Concentrates are: (1) agro industrial by-products from cereals, legumes and oil seeds, and (2) cereal grain including sorghum millets, broken rice; * represents intensive; ** represents semi-intensive systems;*

Between 1992 and 2003, the overall ME demand for livestock in the *intensive* region dropped by 35% for Hisar and increased by 55% for Etawah District, whilst in the *semi-intensive* systems, it grew only by 3%. The energy balance remained increasingly positive for part of the *intensive* region (i.e. Hisar District). The energy balance for the *semi-intensive* system has remained negative since 1992 but with a decreasing magnitude between 1997 and 2003 (Figure 1).

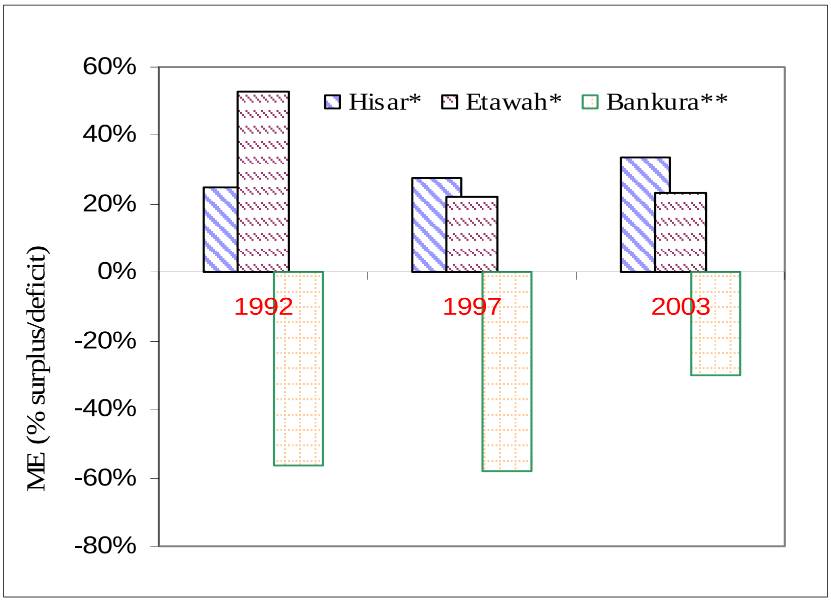


*Figure 1. Feed demand supply balances (over time) in *intensive and **semi-intensive CLS in the case study districts*

1.2.2 Livestock and feed water productivity across an intensification gradient

The volume of water depleted for livestock feed production varied among the study systems and was highly affected by the type of feed and the attendant agronomic practices (e.g. cropping pattern, yield) (Table 4). The value of depleted water for feed production ranged from 300 to 2300 m^{-3} ha^{-1} yr^{-1} for the *intensive* system and from 100 to 4600 m^{-3} ha^{-1} yr^{-1} for the *semi-intensive* system (Table 4). The highest water consumer in the *intensive* system was green fodder (2350 m^{-3} ha^{-1} yr^{-1} for Hisar and 4190 m^{-3} ha^{-1} yr^{-1} for Etawah), and similar trend was observed in the *semi-intensive* system (e.g. for pasture from grazing land ~ 4680 m^{-3} ha^{-1}). Contrastingly, concentrates depleted the smallest volume of water followed by residues.

Table 4. Mean values of feed water depletion and biomass water productivity for water partitioned by harvest index in the case study districts in 2003

Study regions	Depleted water (10^3 m^3 ha^{-1} yr^{-1})			Feed water productivity (kg m^{-3})		
	Greens	Residues	Concentrates	Greens	Residues	Concentrates
Hisar*	2.35	1.24	0.32	2.61 (21)	3.33(18)	2.72 (35)
Etawah*	2.70	1.01	0.20	0.43 (3.54)	5.01 (26)	2.07 (24.3)
Bankura**	4.68	1.21	0.06	0.34 (2.78)	3.11(21)	0.46(7.40)

* represent intensive; ** represent semi-intensive systems; numbers in brackets are for ME water productivity (MJ m^{-3})

LWP is strongly linked to the water productivity of feeds. Most noticeable from our results was the strong variability of feed water productivity across and within systems (Table 4). Overall high mean values were observed for the *intensive* system. Among the groups of the different diet components, residues showed the highest feed WP values followed by concentrates. The least water productive feed sources were those making up the greens (grass from grazing, fallow land, grazing under forest).

The mean value of LWP, using harvest index partitioning and ME demanded for 2003 for all study systems, was USD 0.06 M^{-3}. For the same year, LWP was ~10% higher for the ME based partitioning approach. The calculated variability of LWP based on ME-required and ME supplied was also remarkable (Figure 2a and b). The supply side LWP value showed lesser values compared to the demand side values for the regions with *intensive* systems. Contrastingly, in the *semi-intensive* system, LWP for the supplied ME was higher than LWP from demand side (Figure 2a and b). Differences among the study systems were also prominent, with intensive systems (e.g. Hisar) showing significantly higher value than the *semi-intensive* one, across time (Figure 3).

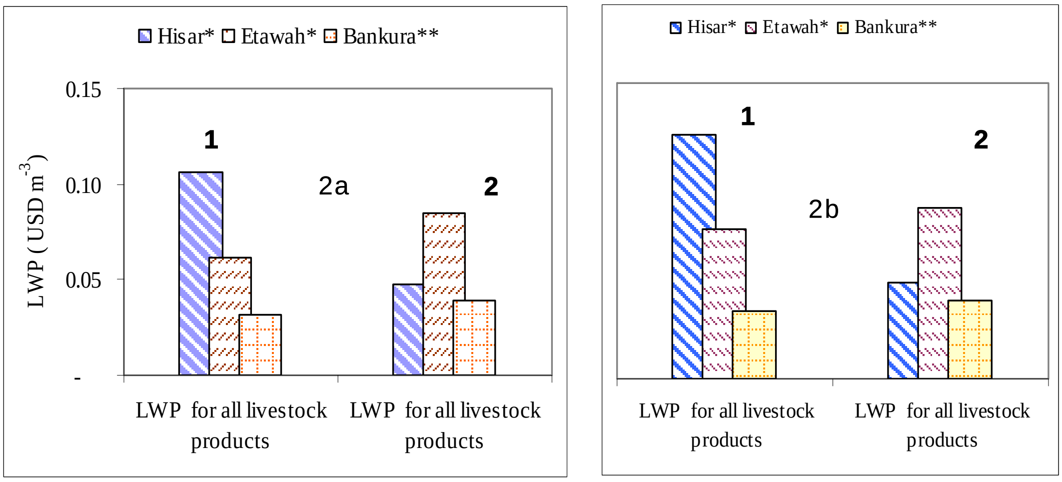


*Figure 2. LWP as affected by the type of water partitioning (2a harvest index on left; 2b ME on right) and demanded feed ($2a^{-1}$ and $2b^{-1}$)/supply feed ($2a^{-2}$ and $2b^{-2}$) in intensive and semi-intensive CLS in the case study districts. * represent intensive; ** represent semi-intensive systems*

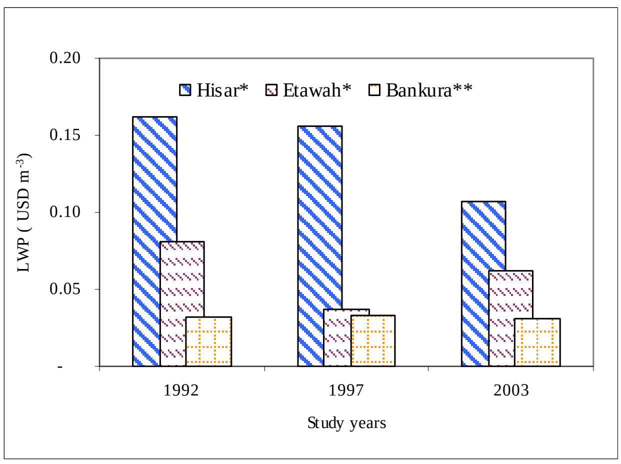


*Figure 3. LWP over time in intensive and semi-intensive CLS in the case study districts. * represents intensive, ** represents semi-intensive systems; LWP was calculated only for demanded ME and agricultural water was partitioned by harvest index*

To explore more in-depth the dairy system of the study areas, we estimated the average water requirement of a cow to produce 1 litre (L) of milk. The mean value was within the reported range (800-5000 L of water per L of milk) indicating both the current low level of dairy water productivity and the potential to increase it. But this system scale is aggregate and a closer look at farm level gives better insight.

1.3 Discussion and conclusion

1.3.1 Effects of livestock population dynamics on demand for land and water

Past increases in agricultural production in the study systems have occurred as the result of increased use of external inputs (*intensive*) and expansion of agricultural land (*semi-intensive systems*). In both cases, changes in the structure and productivity of the livestock population have occurred. The impacts of these transformations on land and water requirements of livestock and sustainability of ecosystems have been points of discussion (Gregory et al. 2002). The focus of farmers on a certain livestock group and the resulting modification of the herd structure were influenced by a number of factors (e.g. market for livestock products and feed availability). The point is how does this driver evolved and how does it affected the herd structure and levels of productivity?

For example, there was an increase in rice and wheat yield from 0.63 Mg ha^{-1} in 1995-1966 to 1.37 Mg ha^{-1} in 1991-1992, in the *intensive systems*. This has, in turn, expanded available livestock feed from crop residues. As incomes have risen with increasing yields, food habits have changed to more nutritious and more diversified diets (e.g. dairy products) and this has in turn created market opportunities (Molden 2007). The increase in buffalo and cross breed livestock population and the reduction in low milk yielding indigenous cows in the *intensive systems* could be accounted for by these farmers' investment determinants. Thomas et al. (1997) also suggested that the size of land holding and the level of intensification affected the herd structure. On the farms bigger than 3 ha, more female than male animals were kept and more buffaloes than cows, together with a shift to semi-mechanization. This might explain the observed higher population of working animals in the *semi-intensive* system, where the arable land holding is low and land preparation based on draught power (Erenstein et al. 2007). The point is understanding implication of such shifts in herd structure and level of specialization on land and water requirement, particularly in terms of losses of multiple livestock functions and increasing focus on irrigated green fodder.

Since 1992, the area of land under feed production (e.g. fallow and irrigated green fodder) has increased (particularly *intensive system*). This contrasts with the decreasing trends in livestock population, in particular, for the *intensive* systems. The increased rate of green fodder in the animal diet (16% for Hisar and 11% for Etawah) with intent of increasing milk productivity has resulted in additional water requirements per animal. Particularly this is true given the fact that the dry matter yield is low compared to the potential. This is can be also accounted for by the lower WP of green fodder as compared with crop residues-based feed, for which the total depleted water was shared between food grain and livestock feed. Overall, during the last decades, there has been a trend of increased milk production per animal as the result of improved feed (DAHDF, 2006) and, during the same period; there was an increase in water investment per cow to produce 1 L of milk. This also explains that the increase in milk is at the expense of higher water investment(e.g. in intensive system) and such approach departs from the current suggestions of producing more agricultural products using the same or lower quantity of water input (Molden et al. 2001). This evokes the need to optimize increasing agricultural products per unit of area and per unit of water investment and improving the biomass productivity of green fodder.

1.3.2 Feed demand and supply: the role of residues and implications on water for feed production

Adequate feed supply largely determines livestock productivity while the way feed is produced affects sustainable use of water (Blümmel et al. 2009). However comprehensive data on feed demand-supply balances are very scarce. The result of this study suggested an overall feed supply increase by ~3% (2.8-2.9 Mg SLU^{-1} $year^{-1}$) between 1992 and 2003. This gain in feed supply was low compared with the value (37%) reported by Parthasarathy and Birthal (2008) for the whole of India. This difference can be accounted for by a strong counter balance between the increase and decline in feed availability between systems. Similar to the nation-wide feed assessment by Ramachandra et al. (2007), our findings suggest a strongly negative ME balance for the *semi-intensive* region and surplus ME for the *intensive* systems.

The question is, however, how livestock can survive and produce in states of negative ME balances. Thomas et al. (1997) share these apprehensions and argue that demands might be overestimated and supplies underestimated due to inconsistencies of the methods used. Equally important is the discrepancy and aggregation of dry matter yield for different land uses on annual basis and the demand is also most often aggregated on annual basis and does not match with livestock activities and attendant ME demand which varies seasonally. In general, such wide ranges of values demonstrate the uncertainty in feed demand and supply estimations and the care needed while interpreting the results.

The feed sources and the efficiencies with which feed is utilized within the animal determine the amount of water required to produce livestock products and services. Recent studies indicated that an average of 3400 L of water was required for the production of 1 L of milk (Singh et al. 2004). Obviously this quantity can vary based on the livestock feed sourcing strategies: such as feed from food-feed crops or from fully irrigated fodders or pasture from grazing lands. Our results also illustrate that LWP positively correlates with the percent share of crop residues in the diet composition and thereby support the observations reported by Singh et al. (2004). This raises issues about what the sequential impacts of increased uses of crop residues can be on ecosystem services (e.g. protective services like erosion) and how livestock contribute to improved water productivity of a system with minimum tradeoffs.

Blummel et al. (2009) argue that focusing on the WP of residues *per se* does not warrant gain in milk production and therefore does not necessarily improve the livelihoods of the poor livestock keepers. According to these authors, there are two severe disadvantages associated with feeding livestock with crop residues: (a) low levels of livestock productivity because of low intake and feed energy conversion into meat and milk; and (b) high emission of greenhouse gases by the livestock. Therefore, this suggests the need to have closer insight into selective and optimum uses of residues and improved the WP of green fodder. Opportunities exist in focusing on those that have higher digestibility (e.g. pulses) and those that are water productive and supplement low digestible residues. But this requires diversification of the current cropping pattern in *semi-intensive* system, which is largely dominated by paddy rice. For *intensive* systems, a recent study suggested that as much as 60% of the residues are burnt every year (Erenstein et al. 2007). These residues could have been traded with feed deficit regions after improving its quality through physical treatment (urea treatment) or could have been used as mulch to reduce the evaporative losses from irrigated fields. In conclusion by taking water productivity, cost and ME density of feed into account, the optimum rationing of available feed resources is important to enhance sustainable use of water resources.

1.3.3 LWP: variation among systems and over time

We calculated LWP based on the supplied and demanded ME for 2003 (Figures 2a and 2b). The differences of results between the feed demand and supply based calculation were accounted for by the allocation of extra feed to the livestock in case of surplus feed (in *intensive system*) or share of the available feed by larger number of livestock in feed deficit region (*semi-intensive* system). In reality, however, the sustainability of both systems is in threat. Therefore, LWP values must be interpreted with care and compared *vis-à-vis* the livestock feed demand-supply balance.

At the system scale, LWP was estimated to be higher in *intensive* systems (USD 0.11 m^{-3} in Hisar in 2003) (Figure 3). This value was on the lower range of LWP reported by Haileslassie et al. (2009) using available feed for a strongly feed deficit area in Ethiopia. In addition to variations in climate, cropping patterns and product prices, the differences in LWP values can be explained by its overestimation by the supply-side-based calculation in feed deficit regions.

Between 1992 and 2003, LWP values showed a decreasing trend for the *intensive* systems. Although increase in milk productivity reported by DAHDF (2006) contradicts this finding, the following pieces of evidence support our conclusion: firstly, the focus on green fodder and reduced share of crop residues contributed to higher water consumption per unit of products. Secondly, the reduction in multiple uses of livestock such as draught power played an important role in the decrease of LWP over time. This is worrisome in times of increasing concern over water depletion and environmental degradation and suggests a need for optimization and balanced feeding to improve LWP. For this to be realized feed rationing practices must take the water productivity, nutritive value and cost of feed into account.

Estimation of LWP values using ME and harvest index agricultural water partitioning approaches showed apparent differences: slightly higher LWP value for ME partitioning. The key points are: what are the logical relations between ME and the volume of water flowing to the different parts of a dry matter and why higher LWP for the ME partitioning approaches than the harvest index?

The harvest index approach assumes that water used to produce a unit of dry matter of grain and residue is equal and for major crops the value of the harvest index is higher for residues than for the grain. This implies higher share of water for livestock and thus lower LWP. In reality the concentration of ME in residues is less compared to the grain and thus the actual benefit that goes to livestock is low. Therefore, the water that factored into the LWP needs to consider ME concentration. Also when we look at the process of photosynthesis we comprehend the logical link between photosynthesis-water-energy concentrations in plants dry matter. Energy exists in many forms: such as the kinetic energy, chemical energy, electric city and heat.

Among these various forms, conversion occurs. Biological photosynthesis, for example, converts solar photonic into chemical energy forming biomass (Gerbens-Leenes, Hoekstra, and van der Meer 2009). It is this chemical energy that is used by animal body to yield the different products and services. The availability of fresh water is a prerequisite for the biomass growths and solar radiation is a principal driving force behind transpiration. The fact that the latter is highly related with the quantity of energy produced by plants and available water forms a coherent relation between water investment and energy concentration in different part of biomass (i.e. grain and residues). This argument was revealed in recent quantitative analysis of water foot print of energy from biomass (Gerbens-Leenes, Hoekstra, and van der Meer 2009). They argued that the water invested in energy carrier crop is not only the function of biomass that is used for energy production; but also it involves combustible energy in the specific biomass. Therefore they combined both the energy content and biomass quantity to estimate the volume of water used to produce energy. The argument here is that the LWP calculation exercise can be benefited from such biomass and energy combining approaches instead of using only the harvest index.

2 Objective 2: Identify institutional and governance arrangements and gender and poverty variables that support equitable and sustainable water use for CLS in the Ganga basin

Previous studies of LWP evidenced the role of institutional and governance arrangements as supporting factors for the adoption of practices and technologies improving LWP (e.g. Descheemaeker, Amede, and Haileslassie 2009; Mapedza et al. 2008; Amede, Geheb, and Douthwaite 2009). By institution, we mean “the prescriptions that humans use to organize all forms of repetitive and structured interaction including those within families, neighborhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales” (Ostrom 2005, p. 3). Institutions are thus distinguished from organisations as emphasised in new institutional economics (North 1990). They include all kinds of formal and informal prescriptions stemming from, among others, legal documents issued by central governments, implicit norms governing policy implementation or collective rules-in-use orally shared by a community.

There are four main characteristics of institutional and governance arrangements which we identified as particularly important to explore for this endeavour. Firstly, interventions addressing water productivity have often assumed that farmers have full access and control over water use and management. However, it might not be the case, especially for the poorest farmers. Limited access to and control over water are not only a major constraint for improving water productivity (Amarasinghe, Sirinivasulu, and Samad 2009) but are also often coupled with inequity, vulnerability and poverty. Analysing access to water thus constituted the first step of our analysis.

Secondly, collective action has been acknowledged to be in some contexts, a strong determinant of the productivity of farming systems. For instance, farmers might informally exchange agricultural products through monetary or non-monetary payments. They might form groups or cooperatives to sell their products (cf. Brannstrom 2009; Sabates-Wheeler 2002), or to lobby for defending their rights. New form of labour relationships can emerge informally (Assaad 1993) as well as new institutions governing exchange of services. The form and importance of collective arrangements depend among other factors on the degree of competitiveness, importance of monetary exchanges and proximity to markets

(Platteau 2006), on the level of trust and cooperation within communities, their size (Agrawal and Goyal 2001), heterogeneity and cultural values (Klooster 2000; Cleaver 2000). To which extent and under which context collective action supports the water productivity of crop-livestock systems was the second focus of analysis of the institutional component.

Thirdly, decentralisation policies play an important role insofar they directly determine the degree of choice and control local elected bodies and citizens have over the management of key resources such as land, livestock and water. According to its proponents, decentralisation has the potential to increase downward government accountability and responsiveness, foster participation and adaptation to local needs (Larson and Ribot 2004; Manor 1999). Since the water needs of crop-livestock systems show a high spatial variability and sensitivity to the local context (Haileslassie, Peden, Gebreselassie et al. 2009), it is essential that the institutional and governance structure supports the subsidiarity principle for a better adaptation to these variations and better response to local needs. The outcomes of most decentralisation policies around the world have been mixed because, in reality, little power has been devolved to local governments (Larson and Ribot 2007; Ribot, Agrawal, and Larson 2006). How the current decentralised system of *panchayati raj* institutions (PRIs) in India and the action of state line departments operate together for rural development thus arose as a key issue.

Lastly, the strong interactions between water use, crop cultivation and livestock development calls for an integrated and coordinated approach by the concerned actors. Whereas, most stakeholders working in agriculture and animal husbandry recognise the strong interaction between crops and livestock at the farm level, in practise development actions have addressed these components separately with limited dialogue. We have studied (1) whether the current institutions encourage or hinder the integration of interventions from different sectors and administrative bodies and (2) which forms of institutional change could lead to increase consultation and collaborative work (this second aspect will be addressed in section Objective 5).

As underlined by Ereinsten et al. (2007), enhancing water, crop and livestock interactions in a way that contributes to decrease poverty and enhanced environmental sustainability requires a thorough understanding of livelihood strategies. Particularly, it is important to assess the potential of livestock as a livelihood option and its contribution to poor people's well being. It entails evaluating how the economic, cultural and social values used to enhance men and women's capabilities to benefit from livestock vary over space and time and understanding the drivers for these variations. Thomas and Rangnekar (2004) indicated that poor farmers have to overcome technical, economic and social constraints to exploit the growing livestock product demand in the market and benefit from it. We assessed the costs that various livestock production systems generate for men and women by analyzing the gendered access to and control of different forms of capitals. The gendered livestock utilization and distribution of inputs and outputs was also linked to governing structures.

2.1 Methods

Because of their tight relationships, institutional analysis and livelihood and gender analysis were conducted simultaneously as related components. For this task, we built a multi-level methodology encompassing a range of analytical tools and methods.

The institutional and policy analysis combined two frameworks. The Capitals and Capabilities framework (Bebbington 1999) was used to identify which forms of capitals are the most important to sustain livelihoods among case study sites and different groups of farmers (Figure 4). The framework is based on the five capitals (or assets) upon which people draw to base their livelihoods: the natural capital, produced capital (or physical capital), social capital, cultural capital and human capital[3]. Produced capitals mean man-made capitals and include physical and financial capitals. In addition, it acknowledges the dynamic process of how the different forms of capitals are continuously being used, transformed or reproduced (Figure 4). These capitals are translated into a set of capabilities, among which we specifically examined the capability 1) to access and control over water and, 2) to participate to decision-making and change the rules that govern the use and control of resources (see the decentralisation sub-section).

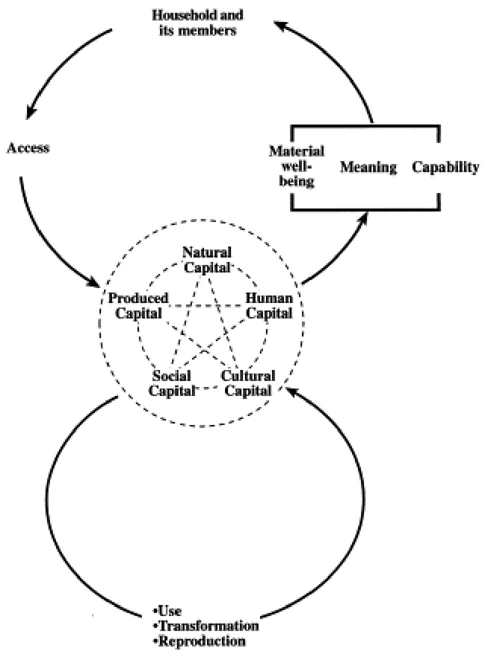


Figure 4. Capitals and capabilities framework showing assets, livelihoods and poverty linkages (Bebbington, 1999)

This framework was complemented by the Actors, Power and Accountability framework (Agrawal and Ribot 2000) to relate farmers' livelihoods with higher decision-making levels. This analytical tool is particularly suited to explore the actual extent of decentralisation, by assessing three key features of decentralisation: who are the actors to whom power has been devolved, what form of power has been devolved and to whom and to which extent are actors accountable. This assessment was used to investigate how the current governance arrangements are contributing to enhanced access and control over resources, equity and poverty alleviation. Primary data collection was complemented for this specific component by a literature

[3] These are slightly different from the five capitals originally defined by Carney (1998) which are human, social, natural, physical and financial capitals.

review to characterise the political context and institutional characteristics of each state where the study sites are located.

A gendered assessment of crop-livestock systems contributions and costs to livelihoods has been conducted for poor livestock keepers in the Nile basin using the Gendered Sustainable Livelihood Framework (GSLF), developed by Van Hoeve and Van Koppen (2006). We have also used it as a guiding tool to analyze the importance and role of livestock in the livelihoods of rural households. We found of particular interest to apply and test the framework in the Indian context. Though their focus is slightly different, the GSLF and Capitals and Capabilities framework share the same foundation regarding access to different forms of capitals to build upon a common analysis.

Van Hoeve and Van Koppen (2006) describe the GSLF as a tool that combines the Sustainable Livelihood Framework and the gender analysis framework developed by Feldstein and Poats (1989). The latter specifically addresses three questions for gender analysis:

1. labour; who does what?
2. incentives and benefits; who benefits? and
3. governing arrangements; who has access to and control over resources?

Livestock are looked at as an asset and their contribution to livelihoods are considered as productive activity. To undertake livestock keeping men and women use various forms of resources (called capitals) such as land, water, labour or money. The cost to access these capitals is referred to as "livelihood costs" in the GSLF (van Hoeve and van Koppen 2006). In return, livestock provides outputs of different values to households i.e. men, women and their relatives and dependants, which support them in pursuing and modifying their livelihood strategies. These are termed as "livelihood benefits". Households exhibit variation on entitlement rights (access to capitals) and permission on mobility along gender lines dictated by family and community institutions, like marriage, which affects the optimization and benefit sharing of livestock outputs. To some extent in this study, we have also captured the seasonal trends and shocks which affect livelihood strategies. As our focus is on identifying avenues to better integrate livestock and crop water needs and to improve LWP, we have conducted a detailed assessment of the differentiated access to water, fodder, breeds and veterinary services between men and women and between household groups of different livelihood typologies.

In addition to the data collected through surveys, detailed questionnaire and household interviews presented earlier in this report, the livelihood and gender analysis was based on group discussions with farmers using different participatory tools (Table 5).

Table 5. List of participatory tools used to collect data for livelihood and gender analysis

Tool	Type of interaction	Objective	Gendered
Village livelihood mapping	Focus group discussion (FGD)	Identify groups with distinct livelihoods and strategies	No
Time mapping	FGD	Evaluate time spent on livestock activities	Yes

Importance ranking	FGD	Assess importance of different livestock species for livelihood	Yes
Trend line mapping	FGD	Assess changes in livelihood patterns and livestock role	No
Annual seasonal calendar	FGD	Identify seasonal activities performed by men and women, variation of price of agricultural products and seasonal shocks and trends	Yes
Decision making matrix	Household+ key informant interviews	Assess water costs and benefits for livestock feed and drinking related to access to capitals	Yes
Venn diagram	FGD	Identify different structures and process that determine and influence livestock keeping	Yes

A very large part of the information collected for the institutional, livelihood and gender studies is thus qualitative. The objective was to gain a thorough understanding of the processes and mechanisms behind the figures and trends identified by the quantitative methods.

2.2 Results

2.2.1 Addressing poverty in CLS

Benefits of livestock to different livelihood typologies

First we assessed the contribution of livestock to livelihoods across household typologies and crop-livestock systems (Table 6).

Table 6. Benefits of keeping livestock for different livelihood typologies across farming systems

	Paddy Rice	Wheat Cotton/Rice	Millet Pulse	Millet Mustard
I	Sale of goats, sheep, poultry and eggs to meet daily expenses during unemployment Bride price Rituals Milk for infant children	Milk for home consumption and sale Sale of dung cakes Sale of sheep, goats poultry (*)	Milk for home consumption and sale to cover feed and daily expenses	Sale of goat, sheep to meet sold during unemployed days or occasionally Goat milk used for self consumption and sale for daily expenses.
II	Transport and traction Manure Sale of goats, sheep, calf for hefty expenses: rituals, health care Poultry and eggs: home consumption Bride price Milk for infant children Rituals and feasts	Transport and traction Dung cake Manure Male calf, sheep goat, and poultry for hefty expenses (*) Milk sale and consumption, income used in feed and daily expenses	Transport and traction Dung cake Manure Milk for home consumption and sale for feed and daily expenses	Dung cake Manure Sale of goats, sheep for daily and exceptional expenses Milk sale for feed and daily expenses

III	Dung cake Manure Male calf sold for hefty expenses, Milk sale and consumption, income used to purchase concentrates, gifts or as pocket money for children and as savings	Not applicable / no households in this group

** Source: focus group discussions, livestock preference ranking, key informant and household interviews.*
** For wheat-rice system only*

There is a clear difference in terms of assets, capabilities and livelihood strategies within and among the case study communities. For the landless households (group I), livestock incomes are solely used to meet daily expenses. There is no extra benefit for investment in agriculture or for savings. Expenses for feed are kept at a minimum. For instance, landless farmers often keep small ruminants rather than cattle (except in Mugalpura village, Hisar, where small ruminants are not found), fed by freely collected grass and leaves or led for grazing on common land or in forest land. In intensive systems, medium households' incomes from livestock are used both for daily expenses and feed purchase. One can note that better-off households in intensive systems use part of livestock benefits to purchase high quality feed like concentrates. Another major difference between medium and better-off farmers is that the former keep animals as a source of power for traction or transport, whereas the latter only keep milch animals for income generation – at the exception of the paddy rice systems where mechanisation is very limited, even among better-off farmers. Lastly, it is important to notice that for Santhal people (paddy rice system) livestock form also an important cultural and social capital. Goats and poultry are used as an object of sacrifice and donation during rituals and festivals. Villagers also identify the number of animals sacrificed or donated as an indicator of wealth and well-being. Apart from their occasional consumption by the family, eggs, goat and poultry meat are also consumed to mark festivities and joy during family gatherings and ceremonies. Lastly, small and large ruminants are used as a bride price.

To sum up, as we move along the livelihood/vulnerability line from poor to better-off farmers, the contribution of livestock to livelihoods shifts from non-financial forms of capitals (social, cultural) and cash for subsistence needs to financial capital exclusively for savings and investment in agricultural inputs (e.g. concentrates). As the contribution to financial capital increases, the level of direct interaction between livestock and cultivation becomes weaker, because of the intensification (use of chemical fertilisers) and mechanisation of agriculture – at the exception of the paddy rice system.

Access to capitals
Farmers derive different benefits from the same activity (livestock keeping) because they do not have similar access to capitals. Table 7 summarises the main constraints regarding access to capitals among groups of households in different farming systems

Table 7. Constraints regarding access to capitals for keeping livestock among different livelihood typologies across farming systems of the case study sites

	Paddy Rice	Wheat Cotton/Rice	Millet Pulse	Millet Mustard
0	Credit Arable Land Good breeds Veterinary services Information and extension services Markets	Credit Sufficient common land suitable for grazing Veterinary services Information and extension services Human capital	Credit Common land suitable for grazing Information and extension services Veterinary services	Credit Common land suitable for grazing Information and extension services
I	Credit Sufficient water for agriculture Arable land Good breeds Veterinary services Information and extension services Access to markets	Credit Sufficient water for agriculture Sufficient common land for grazing Veterinary services Information and extension services	Credit Sufficient water for agriculture Sufficient common land for grazing Information and extension services Veterinary services	Credit Sufficient water for agriculture Sufficient common land for grazing Information and extension services
II	Sufficient water for agriculture Small land holding Good breeds Credit Information and extension services Markets Veterinary services	Sufficient water for agriculture Small land holding Fertilizers Good quality seeds Credit Information and extension services	Sufficient and good quality water for agriculture Arable land with high soil fertility Fertilizers Good quality seeds Credit Information and extension services Veterinary services	Sufficient water for agriculture Arable land with high soil fertility Fertilizers Good quality seeds Credit Information and extension services
III	Sufficient water for agriculture Small land holding Good breeds Information and extension services Markets Veterinary services	Fertilizers Good quality seeds Good breeds (wheat rice system)	Sufficient water for agriculture Fertilizers Good quality seeds	Sufficient water for agriculture Fertilizers Good quality seeds

Across all study sites, the most limiting asset for developing crop and livestock activities is water for crop cultivation. Even in irrigated areas, men in all systems (expect paddy rice) reported their inability to shift crops according to market demand because of a poor water supply. The latter results in irrigated areas from a poor public service supply: unreliable or insufficient canal water supply and erratic supply of electricity for pumps in the groundwater dependent areas of Etawah District. In rainfed areas, the major constraint is the lack of infrastructures to store water. In both irrigated and rainfed regions, inequity in water access is the most serious factor affecting the poor and some of the medium farmers' livelihoods.

A particular constraint for poor landless farmers and medium small landholders is the lack of access to financial capital. A minimum landholding size of 2 acres of irrigated land or 5 acres of un-irrigated land is one of the eligibility criteria for bank loans. Furthermore, they are also not given the capability to enhance their human capital (information/ knowledge /skills) due to poor extension services. On the contrary, for medium large landholders and better-off farmers, the main constraint to improve the productivity of the farming system and their livelihoods is the sufficient and reliable access to produced capital, e.g. agricultural inputs of good quality. Lastly, poor and medium farmers are more affected by the limited access to public veterinary services than better-off farmers due to their lack of financial capital to pay for private services. The next sub-section examines the gendered contribution of livestock to livelihoods and gender variables which affect men and women benefits.

2.2.2 Gendered analysis of CLS

The institutions of marriage and culture define the social positioning of gender in all studied areas. Men are considered as the breadwinner, representative and leader of the household. Marriage and family institutions also govern the division of labour, access, rights to and control of resources, mobility, participation in decision-making and socialization. Different rules operate within the marriage and culture institutions along the lines of socio–economic position and caste. For instance, the mobility of wives in Brahmin families is strictly limited – and their involvement in agricultural labour forbidden, whereas, in the same community, women from lower castes do not have to follow such restrictions.

Labour
In the districts of Etawah and Hisar, where livestock are stall-fed, livestock keeping is considered to be an activity that productively engages women within the boundary and security of their home. Women thus contribute significant labour for livestock, around 2-5 hours of their time daily. In these districts, there is a clear division of labour between men and women, mostly driven by women's (lack of) mobility outside the village. The role of men in animal care includes the activities outside the home (e.g. fodder production) while women are mostly responsible for home-based livestock activities. Women from poor and medium households fetch water and cut and carry fodder from the fields but within the village settlement boundaries.

Variation in women's labour contribution across case studies mostly comes from the type of feed and feeding system and the household typology – women in poor and medium farmers' groups have to spend more time towards livestock activities when their husband or other male members are engaged in off-farm activities (agricultural labour or off-farm activities). The latter often entails daily migration. To which extent women derive benefits and participate in decision-making is the major research question addressed in this section.

Benefits
Money earned from livestock product sale and livestock sale is usually kept under women's custody at home. As shown in Table 7, these incomes are for all members of the household among poor and medium households, as they are used for immediate or future daily household expenses. In better-off households, livestock-derived incomes mainly benefit children and women. For instance, women in wheat-cotton and wheat-rice systems reported that they use between one fourth to half of the income from milk sales for purchasing gifts or giving pocket money to their children. A similar share of money is set aside monthly as a saving for purchase of jewels or dowry. However, some households of better-off farmers in the wheat-cotton system deposit money in a bank account – which is operated by men.

Women's control over decision and resources
As shown in Table 8, though both men and women contribute labour, participation in decision-making for livestock related activities is highly dominated by men.

Table 8. Gendered intra-household decision-making for livestock-related decisions

Activity in livestock keeping	Who decides	Decision-making process	Who contributes labour
Animal type	Man or man and woman	Consults with men within (MWH) and outside the household (MOH) or women	Man
Where to buy animals	Man	Consults MOH	Man
Number of animals	Man	Consults their wife	Man
Feed type	Man	Consults MOH	Woman
Feeding frequency and quantity	Man	Consults MOH and elders	Woman
Purchased quantity	Man	When women express the need	Man
Purchased feed quality	Man	Consults MOH	Man
Land area for fodder cultivation	Man	Consults MWH and wife	Man
Type of fodder grown	Man	Consults MWH and wife	Man+Woman
Type of crop grown	Man	Consults MWH and wife	Man+Woman
Cultivation practices	Man	Consults MWH	Man+Woman
Agricultural inputs	Man	Consults MWH	Man+Woman
Water for irrigation	Man	Consults MWH	Man
Water for animal	Woman	Consults husband	Woman
Use of money from milk sale	For household daily expenses: woman For bulky expenses – man or woman	Consults or informs husband	Woman
Use of money from animal sale	Man	Consults wife and/or MWH	Man or woman
Use of dung	Woman	/	Woman+Man

** Source: consolidated from decision-making matrixes led in three of the eight locations with validation from representatives of both gender*

Animal ownership is not clearly defined between men and women. However, the responsibility and decision to purchase or sell the animal lay in the hands of men since they are the breadwinners and investors in assets – including animals.

In Etawah and Hisar Districts, women mentioned that the restriction on their mobility and socialization are major constraints to increase income from livestock activities. Because of their confining to home or within village, they have to sell milk to middlemen who go from house to house, although women are aware that middlemen purchase milk at a low price. On the other hand, men reported that it was more cost effective to sell milk to middle men than to sell it on formal markets, where the study sites were not covered by dairy collection units.

Another issue of importance for women among poor and medium households is their lack of financial independence. It has limited their capacity to make investments for maintaining good breeds of animals. Women across all farming systems also reported their concerns to be able to keep good breeds because of illiteracy and poor access to information, organisations and schemes which can support them in the management of improved livestock species. Women in the paddy rice system also mentioned their lack of knowledge and skills in maintaining these breeds. They are also not aware of where to purchase these animals and organizations / officers can support them on these issues.

Lastly, women expressed that since they are busy throughout the day and also cannot freely move out of the home and village, their participation in social activities, including meetings held by government agencies, is low. Most often government agricultural extension and veterinary officers come unannounced and prefer to talk to men. Door to door or neighbourhood-based training and capacity building could help to overcome these social barriers. The timing should also match with women's limited free time (often afternoon).

The following sub-sections investigate the role of institutions and governance in poverty reduction, livelihood improvement and gender.

2.2.3 Control and access over water for crop-livestock systems

First, we examined to which extent farmers perceive water as a scarce resource. Water scarcity was reported during focus group discussions and household interviews as the major problem that farmers face to sustain their livelihoods, in all case study villages and among all farmer categories (poor/medium/better-off). It was perceived by farmers as the main constraint for good quality feeding and milk productivity. Water scarcity was also evidenced in the census survey led among all households of the case study villages (999 households). The question farmers were asked was whether they usually experience shortage of water for agriculture (1) all year round, (2) only during some periods of the year, or if (3) they do not experience any shortage. Figure 5 shows the results aggregated per district.

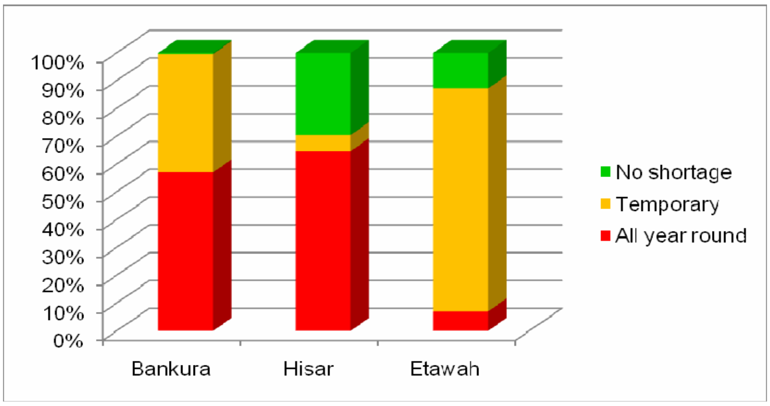


Figure 5. Farmer's perception of water scarcity in the three case study districts

Despite the case study villages of Bankura being located in the highest rainfall region among the three districts, it is the area where farmers experience water scarcity the most acutely, due to the absence of canal infrastructure and limited groundwater extraction in Saltora Block. It is also remarkable that, even in irrigated areas, a significant number of farmers also experience water shortages either continuously or on a seasonal basis. Access and control over water resources thus emerged as a critical issue to address for improving water productivity of crop-livestock systems and contributing to poverty reduction. It is discussed for the rainfed and irrigated areas respectively.

In the rainfed areas of Bankura, there are a variety of sources that farmers use to irrigate their fields: river, dug wells and rainwater harvesting structures (ponds or *happas*[4]). Secure access to these sources is important during the monsoon season as dry spells are frequent and seriously threaten crop survival and growth. During the dry season, access to water also makes a significant difference in the range of livelihood options available to farmers as those with water access can cultivate vegetables thereby having a supplementary source of income.

One could assume that there is a greater equity to access rainwater than canal water or groundwater, for which inequity problems have been highlighted in previous studies (Pant 1984; Lam 1998). However, the way rainwater is stored and shared might lead to inequities. As shown in Figure 6, forms of access to water sources vary largely among farmers. A high share of farmers relies on CPR. The farmers who rely only on rainfall are those who cannot access to these CPR or to private sources.

[4] A *happa* is a ditch constructed according to the five percent technique, i.e. with 5% land of the total land holding in rectangular shape with stairs up to a depth of 10 feet.

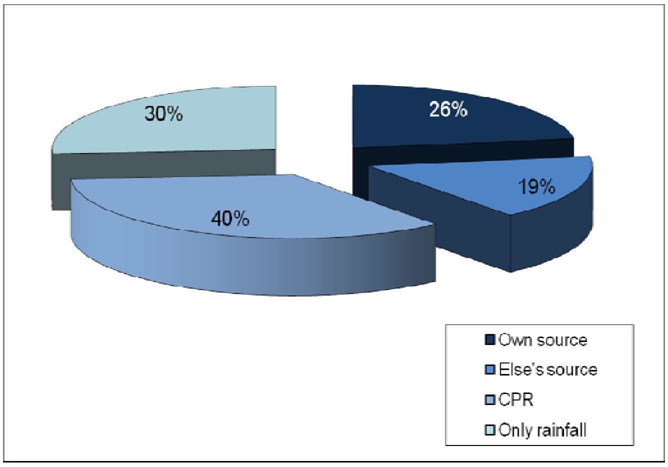


Figure 6. Forms of access to water sources in the four villages of Bankura District

Household's capabilities to access water for irrigation depend largely on land asset (size, elevation and land type) and on the financial capital necessary to build a structure. It is also suspected that social capital favours access to government subsidies – though there is a lack of evidence to demonstrate this. The access of those who cannot secure such capital depends not only on physical accessibility (location vis-à-vis the water source), but also on the capital required to extract water (pump or cash to rent the pump). It was found during interviews that access to pump is one of the key factors to access irrigation water for the poor (as CPR such as rivulets are otherwise freely accessible). In Lakhipur, several pump owners rent their equipment against a payment of 50-60 Rupees (Rs)[5]/hour (it does not include the price of diesel, around 20 Rs/litre). It is the equivalent of one-day wage of unskilled work in construction. In Jhagradihi, the access to the pump is driven by social capital. Only one pump is available in this small village and the access is controlled by one family. This pump was originally given to the whole community by the government, but the lack of adequate institutions for the maintenance of the pump led to the pump being monopolised by one household. The households who have tight links with the "pump owner" have privileged access to the pump. It led to reduced cooperation and collective action in the village (see Clement et al. forthcoming).

In the irrigated case study areas of Hisar and Etawah Districts, a large majority of farmers make a conjunctive use of tube wells and canal water (Figure 7).

[5]100 Rs is equivalent to c. 2.1 US dollar (conversion rate 25/05/2010)

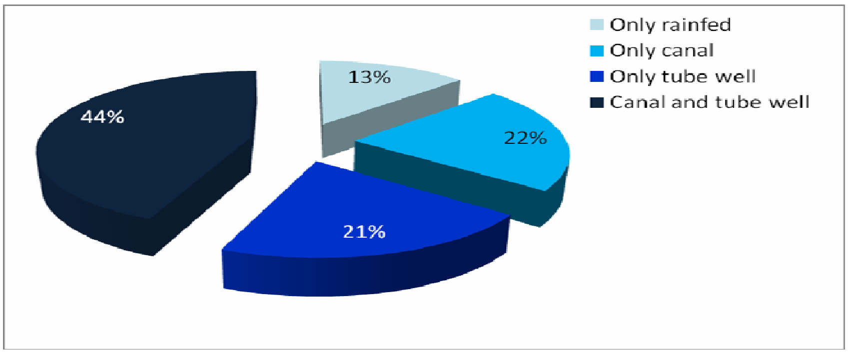


Figure 7. Sources of water in Hisar and Etawah Districts

Collected data shows that a very large proportion (70%) of the farmers who have access to canal water also use groundwater. The main reason is that canal water delivery services are poor and do not allow farmers to timely meet crop water requirements. These findings are in agreement with observations from other scholars regarding the decline of canal irrigated command areas and the sharp increase of groundwater extraction in North India (Shah, Burke, and Villholth 2007). Regarding distributional aspects, access to canal water depends of course on the field's location relative to the canal, but the study evidenced that the type of institutional arrangements could also play an important role (Clement et al. forthcoming). It was also observed in Basra Village that the lack of flexibility farmers have over canal water supply affects the performance of the system. According to the rules of the warabandi system fixed by the Irrigation Department, each farmer is allowed to withdraw water once within the period of time water flows in the canal (7 days once a month from November to February). Farmers are assigned a specific time slot by the Irrigation Department. In the minor branches, when the water flow is very low, water takes more time to travel in the system and reaches the tail of the branch after the time slot allocated – the tail farmers thereby lose their access to water.

2.2.4 Existing formal and informal local governance arrangement related to resource use in crop-livestock systems

Appendix A presents the different forms of institutions identified in the case study areas, in the following categories: state-led, market-based, community-led, or vested in individuals such as private ownership. Bankura District is remarkable by the importance of collective action and the predominance of informal institutions. These informal arrangements greatly contribute to the improved productivity of the farming system and of LWP. Among relevant examples, households have formed groups for taking animals for grazing. The group either hires a shepherd and shares his salary among the group members, or one person of each member household will act as the shepherd for the group on a rotational basis. When households have limited financial capital, the purchase of animals is shared between two households. The household who keeps the animal will in exchange offer half of the offspring to the co-buyer.

Such types of arrangements are less common in Hisar and Etawah Districts. In the latter, exchange of labour among kin group is practised and private sources of water are informally shared among neighbours and kin. An example of collective action was also found in Basra, when villagers decided to collect funds to solve a serious collective issue (drinking water quality problems during the monsoon season). The importance of collective action in Bankura is related with locally-specific factors: the high reliance on common-pool resources, low access to markets, low financial capital, the existence of a customary governance system and the strong homogeneity and norms of the surveyed communities. The replication of similar institutions is therefore highly contingent to the socio-environmental context.

2.2.5 Decentralisation

In 1992, the Government of India passed a series of amendments to the Constitution designed to empower local political bodies, called the *panchayati raj* institutions (PRIs). These bodies are elected at the district, block (sub-district administrative level) and village (or group of villages) level and called *zilla parishad*, *panchayat samiti* and *gram panchayat* (GP) respectively. The subsequent process of decentralisation has greatly differed among states, with varying degrees of devolution of political, administrative and fiscal authority to local *panchayats*.. The state of West Bengal has been pioneer in the decentralisation process by devolving discretionary powers over spending and staff to *panchayats*. Table 9 gives an overview of the PRI structure set up in each study state.

Table 9. Number of key informants at different administrative levels in the 3 case study states

	Haryana	**Uttar Pradesh**	**West Bengal**
Area (km^2)	44,212	294,411	88,752
Population (millions inhab.)	21.1	166.1	80.2
Population density	477.2	564.2	903.6
Number of PRIs**	6,293	52,890	3,705
Number of *Zilla Parishads*	19†	70	18
Number of *Blocks Samitis*	119	820	341
Number of GPs	6,155	52,000	3,346
Number of inhab*/GP	3,428	3,194	23,969
Number of km^2/GP	7.2	5.7	26.5

** Source: 2001 Census*
*** Source: Lok Sabha Unstarred Question No. 950, dated on 10.07.2009*
† The number of districts is now 20, but the elections for PRIs have not been held yet in the most recently created district

Table 9 shows that on average one GP covers a much larger population and geographical area in West Bengal than the two other case study states. It has of course implications regarding the proximity, responsiveness and representativity of the PRIs. On the other hand, West Bengal stands out comparatively better among the three studied states in regard to the actual extent of administrative decentralisation, with all 29 subjects devolved to PRIs (Table 10). One should note however that, out of the 29 subjects, only 12 have been entrusted with funds and functionaries.

Table 10. Degree of administrative and political decentralisation in the 3 case study states

	Haryana	**Uttar Pradesh**	**West Bengal**
Number of subjects entrusted to PRIs	16 (none with funds or functionaries)	13 (including 12 with funds and 9 with functionaries)	29 (including 12 with funds and functionaries)

Source: India Panchayat Raj Report, 2001, Volume-I, National Institute of Rural Development

The 73rd and 74th Amendments to the Constitution provide arrangements for setting up a state finance commission (SFC) in each state to decide on the level of fiscal transfer to local bodies. In West Bengal, expenditure assignment for local governments remains a decision of the State government (Bahl, Sethi, and Wallace 2010) and in all states across India, PRIs rely almost exclusively on funds delivered by the central and state governments. Even when empowered by the State to levy taxes, most elected bodies are reluctant to take such initiative because of its unpopularity (Society for Participatory Research in Asia (PRIA) 2004).

The 73rd amendment envisions PRIs as key actors of planning for local development. It requests states to form a district planning committee (DPC) at the district level. However not every state has created a DPC. In Uttar Pradesh, the DPCs were constituted only recently following the DPC (amendment) Act 2007. The accountability of the chairmanship also varies, the latter being given either to elected (like in West Bengal to the head of the *zilla parishad*, the *sabhadhipati*) or non-elected officials (e.g. in Haryana the deputy commissioner[6] and Uttar Pradesh the district in charge minister).

Planning has been decentralised down to the village level. The Government of India has supported through the GPs the design of village development plans. These plans are to be elaborated by villagers, assembled in the *gram sabha*[7], and present the interventions that will contribute to the development of their village. Then, the village development plans are sent to the GP, transferred to the block development officer (BDO) and finally integrated into the district plan by the DPC. On the ground, villagers' participation to the meetings of the *gram sabha* is mediocre. Among the 59 farmers who were asked if they were going to the *gram sabha* meetings, only 47.5% said they were participating. The primary reason mentioned for their non participation is a lack of interest and a lack of perceived benefits.

For most interviewed villagers, the GP does not have any role in planning for the development of their village. For instance, in Bankura, half of interviewed farmers do not know what is the village development plan – though some of them participate to the *gram sabha* meetings. Some issues of concern to farmers, like water scarcity, are discussed, but farmers feel they have difficulties to make their voices heard (*group discussion, January 2010*). In the case study area of Bankura, many hamlets are under one GP and there is not a member of the GP in every village. In Etawah District, the participation of interviewed farmers to the *gram sabha* meetings is relatively higher than in the other districts. Farmers attend the meetings to receive information on crops, seeds and agricultural practices. They do not perceive the GP as a representative organisation responding to their needs but as an executive agent which role is limited to ensure the cleanliness of the streets, install hand pumps and build roads (*semi-structured household interviews, June 2009*). The *gram sabha* meetings currently do not provide a venue for discussing rural development or the specific issues they feel need to be addressed to improve or sustain their livelihoods. Similarly, interviewed heads of the GP perceive the role of the GP as implementing government schemes and distributing benefits – i.e. a top down approach rather than the bottom up process claimed by the government.

From a gender perspective, few women participate to the meetings of the *gram sabha*. The reservation of 33% of women in PRIs was also observed to be often meaningless, as elected women represented *de facto* their husband. Therefore, even

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[6] The deputy commissioner is the administrative head of the district – he is also called district collector or deputy magistrate (in West Bengal) depending on the state.
[7] The *gram sabha* is constituted by all members of a village over the age of 18 years

when the sarpanch of the village was a woman, women reported that local development schemes did not have any benefit for women in particular. There were however exceptions, e.g. among the Santal community which is more egalitarian regarding men and women's roles (Bhattacharya 2004).

Even when village development plans exist and represent the voices of the local population, a major limitation is that the local needs expressed in the plan have to fit within existing state and central government schemes. The deputy commissioner of Hisar District was explaining that this was not an issue because: "*There is a scheme for every need*" (*interview, May 2009*). However, these schemes are generally blanket programmes, with little flexibility and room for adaptation to local specificities. Furthermore, these government interventions primarily focus on infrastructure development, firstly, because it offers an easy way to spend public funds, secondly because a large emphasis has been given to the implementation of the national rural employment guarantee act (NREGA), a major central programme which guarantees 100 days of work to every household in India. The scheme aims at giving employment to poor people in rural areas and limiting seasonal migration by the construction of structures (roads, ponds, etc) which require low-skilled labour force. Most subsidised interventions are thus infrastructures, thereby neglecting other interventions which would contribute to enhanced LWP (see Section 3), such as the development of feed and livestock markets, extension and capacity building, as well as the improvement of public services (e.g. veterinary).

2.2.6 Integration and coordination of water, crops and livestock in formal institutions

At the district level, several state line departments conduct interventions and hold responsibilities related to water. These are the Departments of Irrigation, Horticulture, Agriculture, Animal Husbandry and Rural Development[8]. Each department separately implements its own programmes (decided at the state or central level) and is concerned with meeting the targets set up at the state/central level. There is thus a lot of room for building an integrated approach of water management. The heads of the district departments have some interaction as they meet once a month under the leadership of the Deputy Commissioner. However the objective of these meetings is primarily to review the implementation of the different programmes and these interactions contribute little to develop a strategic and proactive planning. Under the *Zilla Parishad,* there are no incentives to support a concerted reflection on water management as there is no committee dedicated to water issues.

In Etawah and Hisar Districts, the Departments of Irrigation consults the Department of Agriculture to evaluate the water necessary for irrigation depending on crop areas. However, there is no dialogue with the Animal Husbandry Department for integrating the feed and water needs of livestock and addressing local variations. For instance, whereas there is feed surplus in Hisar at the district level, there are areas where farmers have to travel on average 30 kilometres (km) and up to 100 km to buy wheat straw. Such variability could be better addressed by an integrated – or at least coordinated – action from the relevant line departments (Agriculture, Husbandry and Irrigation) with a locally sensitive approach.

[8] Their designation might vary depending on the district.

A new centrally-designed programme, called Agricultural Technology Management Agency (ATMA), has been launched recently all over India. It is led jointly by the Departments of Agriculture, Animal Husbandry and Fisheries and is therefore remarkable compared to other schemes for its efforts towards an integrated approach. Furthermore, whereas all government schemes follow a top-down process, district line departments design their own plan under this programme. Lastly, it relies on local capacity building by creating a network of farmers in each block who will disseminate information from the district departments to other farmers.

2.3 Discussion

All households across study sites are engaged in livestock activities but the benefits they get in return vary considerably across sites. Notably, livestock-related benefits tend to be non-financial capitals for poor and medium households. Access to and control over water emerged as a crucial issue for improving farm productivity among a very large majority of farmers across all study sites. Because the households who have secure access to water are usually better-off farmers[9], the water productivity interventions which neglect equity in water access are likely to benefit only the better-off. More efficient use of water by better-off farmers will not automatically result in improved water access for other farmers. Water access is linked to several processes which go beyond the issue of physical availability. Therefore, whereas past state and NGO interventions have focused on infrastructure development, often considering it as a purely technical issue, there is a need to address the structural roots of inequities.

Results also show that LWP interventions would benefit a greater attention to mechanisms enhancing collective action in the following contexts: high reliance on CPR, low market integration, low financial capital, or strong norms. This component has been hitherto neglected by research on crop and livestock WP and by government initiatives. Findings also imply that in areas where forms of collective action are more present, it is essential to ensure equity in access to capitals as inequity might reduce collective action (Clement et al. forthcoming). Such interventions would also particularly benefit the poor who have fewer private capitals than the better-off.

Lastly, because of their limited financial autonomy and decisional power, PRIs are mere executing agencies rather than self-government institutions as initially envisioned by Gandhi. It means that farmers have little power over the management of their resources. It leads to several issues resulting in reduced productivity and equity. For example, in the case of canal irrigation, the rigidity of a top-down water supply can reduce efficiency and equity. What is more, the fact that there is a high variability in LWP values across systems and farmers suggests that locally-grounded approach would be more effective than top-down centrally planned interventions. It would allow the development of interventions adapted to local needs such as the development of feed markets in areas of feed unbalances. In this respect, enhancing democratic decentralisation to PRIs could offer a promising avenue.

[9] The causal relationship between the two factors is circular, i.e. a better-off farmer usually has access to the required capitals to gain a secure access to water and a farmer who has managed to gain a secure access to water gets more income from agricultural products and usually develops his financial and physical capitals.

2.4 Conclusion

Firstly, results indicate that there is scope to improve the contribution of livestock activities to financial capital among poor and medium households thereby allowing investments to improve the productivity of their farming system. However, it is important that interventions to improve the financial capital derived from livestock do not undermine the other important roles of livestock for these households regarding for example social and cultural capital.

Secondly, women contribute significant labour for livestock activities. This is especially true for women in poor households whose husband and sons are more heavily engaged in off-farm activities. These women are however those who less benefit from livestock activities as livestock-generated incomes barely cover daily household expenses. Women's reduced mobility and participation in decision-making at the community level are essential factors to take into account when designing LWP interventions that benefit women.

Thirdly, results show the importance of institutions, notably in ensuring equitable water access, in poverty reduction. Institutions are not only important to consider at the recommendation stage in order to foster the adoption of new practices, but are essential to analyse at the outset of the project in order to identify the drivers of existing practices. Institutional analysis allows understanding the roots of inequities and thus helps to design or select interventions which benefit marginal groups, notably women and the poorest farmers of the communities (Clement et al. forthcoming).

The key findings regarding institutions and governance arrangements and the implications for the design and implementation of LWP interventions are summarised below:

1. Practices and technologies aiming at increasing water efficiency are likely to contribute to enhance the livelihoods of better-off farmers because they usually presuppose access to water – and do not address the lack of access and control over water. When one aims at reducing poverty and enhancing equity, it is crucial to first promote actions which improve water access of the poor. These go beyond building new infrastructures and needs to analyse capitals and capabilities that different households use to access water and how institutional and governance change impact on these capitals and capabilities.

2. Collective action is a key component of farming systems in areas with low access to markets, low financial capital, high reliance on common-pool resources and strong norms. It often enhances productivity and could be promoted or used by water productivity interventions in these contexts.

3. The current form of decentralisation does not support enhanced LWP by the lack of flexibility to spatial variations in LWP values and the lack of local means to respond to local needs in an equitable way.

4. Despite the recognition of the need for a coordinated and collaborative approach between line departments at multiple administrative levels, the integration of initiatives directed to agriculture, animal husbandry and water management among government organisations remains limited. LWP

interventions require a greater dialogue among decision-makers for identifying the optimized strategies for crop and feed production under water resource constraints at the district level.

3 Objective 3: Micro-scale LWP: identifying viable entry points to improve water productivity in mixed CLS

Widespread water scarcity in different parts of the world is expected to be further aggravated by a number of emerging treats, among which climate change and increasing population demand for water. The Ganga Basin, where this study was conducted, shares similar concerns and several studies led in the region suggested that the agriculture sector has to produce more food with less water to mitigate climate change impacts (Haileslassie, Blümmel et al. 2009; Singh 2005).

Livestock contribute to the livelihood of farmers but also require large volume of water through feed production. The system scale study led in the Ganga Basin (Haileslassie, Blümmel et al. 2009) indicated higher LWP values for intensive systems than the semi-intensive systems. The authors suggested that the current LWP value is low compared to the potential of mixed CLS and they underlined the need to improve LWP through demand management based adaptive strategies. But, these large scale studies are not well suited to identify viable entry points for water demand management. Usually the results are aggregate and do not allow to consider the community and farming systems, which are the unit of interest for designing practical recommendations. Therefore, the objectives of this study component were: i) to examine the effects of smallholder's access to resources on LWP, and ii) to identify viable entry points to improve LWP and assess interventions' impact on sustainable water use.

3.1 Methods

3.1.1 LWP estimation for farm clusters

The concept and practices of LWP have been elaborated by Peden et al. (2009); Haileslassie et al. (Haileslassie, Blümmel et al. 2009; Haileslassie, Peden, Gebreselassie et al. 2009; Haileslassie, Peden, Gebreselassie, Amede, Wagnew et al. 2009)and Descheemaeker et al. (2009). According to these authors, evaluation of LWP can be carried out as a ratio of livestock outputs to water inputs (ET) for feed production. In this study, only milk was considered as an output and was estimated as a function of the number of lactating cows in the farm cluster, their lactation period and daily milk production. This was converted to financial values of milk, based on 2009 farm gate price.

Estimation of the feed-water requirement of livestock needs linking ME demand of the livestock to ME water productivity of different feeds (Haileslassie, Blümmel et al. 2009). The total ME requirement of the livestock (e.g. production, activities and maintenance) was estimated using King (1983). We determined the water flow on the different land uses using the soil water balance model BUDGET (Raes et al. 2006). Data sets required to run BUDGET were collected both from study areas and literature (Allen et al. 1998). BUDGET produced results on water flows (e.g. ET). Normally ET is for grain and residues (i.e. feed). In mixed CLS, crop residues form an important ingredient of livestock feed and therefore total agricultural water (ET) must be partitioned between grain and residues. We used harvest index and ME ratio (of grain to residues) to quantify water that must be factored into the livestock feed and grain (Haileslassie, Blümmel et al. 2009). To establish ME water productivity ($MJ.m^{-3}$), the partitioned water was combined with different feed biomass yields in terms of ME ($MJ\ ha^{-1}$). To estimate volume of water required by livestock, ME demand and ME water productivity were linked. Finally LWP values were estimated using the partitioned water as the denominator and the livestock products (e.g. volume of milk or its financial value) as the numerator.

3.1.2 Identification of interventions and assessing their impacts on LWP

Peden et al. (2007) suggested three basic strategies to increase LWP: i) enhancing animal productivity; ii) improving feed sourcing and iii) conserving water. The goals of these strategies and underlying interventions are generally increased milk yield, improved supply of sufficient and quality feed, and improved water productivity of feed respectively (Descheemaeker, Amede, and Haileslassie 2009). After calculation of LWP, we identified key interventions pertinent to these three strategies. We followed a participatory process to understand potentials and limitations of these interventions from farmers' perspectives. For these interventions that were preferred by farmers, we made productivity gap analysis to have insight on the existing and achievable potentials. For the impact (sustainability) assessment, we used the value of these potentials as an indicator and built the same into the LWP spreadsheet model in a scenario fashion. Those scenarios can be summarized as follows:

i) *Base line*: We used the current LWP value as a control.

ii) *Achieving the potential milk yield*: In this scenario we considered achieving potential milk yield of 15L day^{-1} $animal^{-1}$ in a mixed herd model (e.g. improved artificial insemination and veterinary services). We separated the levels of milk yield into three: 9, 12, and 15Ls of milk day^{-1} cow^{-1}. Blümmel, et al., (2009) suggested that achievements of this potential milk yield can be only through changes in Dry Matter Intake (DMI) from current 2.8% body weight (BWt) to 4.8% for low-medium quality feed. Thus we applied a DMI of 2.8% for the control, 3.6% for 9Ls, 4.2% for 12Ls, and 4.6% BWt for 15 Ls milk yield. The point is whether the increased milk output outweighs the water input from increased DMI.

iii) *Improving feed quality*: In this scenario, we assumed that the improvement in milk yield should be accompanied by good feed quality (~8.5 $MJ\ kg^{-1}$). According to Blümmel et al., (2009), DMI will be less under good feed quality and they thus suggested a 3.1% for 9Ls, 3.6% for 12 Ls and 4.2% BWt dry matter intake for the 15Ls milk production per day per cow. We applied the same value of DMI at respective level of milk increase.

iv) *Achieving higher ME per unit of water input*: This scenario takes the current crop and feed yield and respective water productivity gap into account. In a mixed CLS where agricultural by-products serve as animal feed, increasing CWP and feed ME water productivity are interdependent. For example >100% gap between current practices and potential yield of rice and wheat is reported in the Ganga Basin. Even stronger gaps are reported for water productivity of green fodder. We assumed 20, 60 and 100% increases in water productivity of ME corresponding to the three levels of milk increase and we used the current level of feed quality feed and applied DMI as scenario ii.

3.2 Results and discussion

3.2.1 Baseline water productivity for dairy cows: implications for systems resilience to climate change

Physical and financial LWP for dairy are indicated in Tables 11, 12 and 13 below. Milk water productivity in the wheat–rice, wheat-cotton and millet systems showed higher values than in the paddy rice system. This could be accounted for by the difference in the milk productivity of cows and the feed water productivity. In wheat-rice systems, the volume of water used to produce 1L of milk showed lesser magnitude and narrower range (across breed) when compared with Singh et al. (2004). Contrastingly the values for the millet-pulse system were in agreement with this previous study. In general, the variation can be related to a difference in methodologies. For example, Singh et al. (2004) used life time milk productivity of cows and total irrigation water as an input. It should be also noted that Singh et al. (2004) estimation was on the supply side.

What was more remarkable here was the intra and intersystem variation. Although values in the wheat-cotton and millet-pulses systems were in agreement with the higher spatial scale studies (Haileslassie, Blümmel et al. 2009), values for paddy rice system showed a very high volume of water to produce 1L of milk (>16000L). This figure deserves particular attention in times of increasing concern over water scarcity and rainfall uncertainty. Given that the present circumstance prevails, it will be a challenge for farmers in semi-intensive system to cope with the impact of climate change. This is particularly true for farmers in the poor livelihood typology and owners of indigenous cows (Table 3). To explain this trend, we examined the feed sourcing strategies in the different systems and farm clusters. For example, the feed source for the poor (in *semi-intensive* paddy rice system) was primarily focused on communal grazing, fallow land and grazing in forest. These feed sources show the lowest ME water productivity (MJ m^{-3}) and thus impact the volume of water required to produce 1L of milk. LWP variations between farm clusters were system specific: in paddy rice system, remarkable differences exist between the better-off and the poor, while, in other study systems, these differences were not strong. The former substantiated the findings of Haileslassie et al. (2009) who studied LWP on farm households with different access to resources in the rainfed farming systems in Ethiopia.

In intensive systems, farmers in all livelihood typologies have access to feed and livestock product marketing. Farmers in intensive system sell 25-100% of their milk products while only 3% farmers in the paddy rice system reported to sell milk products (at a share of 20% of the total production). When we look at the market access of feed: in intensive systems 82% and 81% of the sample farmers are trading for dry fodder and concentrate respectively. In the paddy rice system only ~36% sample farmers are involved in dry fodder exchange. We argue the market to be an incentive for the poor farmers to buy feed and invest on high milk yielding breeds and thus maintain LWP comparable with the better–off farms. This means also that, in systems where feed was exchanged, LWP values for the different farm typologies can be interdependent as the feed water productivity at feed sources (i.e. surplus producing better-off and medium farms) may influence the sink (i.e. the landless poor farms). These relations revealed the co-dependency of farm clusters in market-oriented intensive systems and thus suggest the need to improve system level resource flow and virtual water trading to increase LWP and system resilience to climate change.

Table 11. LWP of dairy cows across farm clusters and farming systems (intensive systems, Hisar)

Systems	Parameters	Landless			Medium			Better off		
		Cross	Local	Buffalo	Cross	Local	Buffalo	Cross	Local	Buffalo
Wheat-cotton	Milk L day^{-1}	7.50	-	7.75	8.80	4.50	7.09	8.50	-	8.50
	Milk USD day^{-1}	2.63	-	2.72	3.09	1.58	2.49	2.98	-	2.98
	ME Demand MJ day^{-1}	68.90	-	95.90	85.30	62.97	73.27	71.98	-	67.58
	ME WP MJ m^{-3}	5.63	-	5.63	5.88	5.88	5.88	6.15	-	6.15
	Water requirement m^{-3} day^{-1}	12.23	-	17.02	14.51	10.71	12.47	11.70	-	10.98
	Volume water per L milk (10^3 L)	1.6	-	2.2	1.7	2.4	1.8	1.4	-	1.3
	LWP_PHY	0.61	-	0.46	0.61	0.42	0.57	0.73	-	0.77
	LWP_FIN	0.22	-	0.16	0.21	0.15	0.20	0.26	-	0.27
Millet-pulses	Milk lit day^{-1}	-	-	7.50	5.00	6.00	7.50	12.00	7.00	6.70
	Milk USD day^{-1}	-	-	2.63	1.76	2.11	2.63	4.21	2.46	2.35
	ME Demand MJ day^{-1}	-	-	82.22	70.82	70.43	102.81	100.96	74.70	83.97
	ME water productivity MJ m^{-3}	-	-	4.52	4.65	4.65	4.65	3.70	3.70	3.70
	Water requirement m^{-3} day^{-1}	-	-	18.20	15.24	15.15	22.12	27.26	20.17	22.67
	Volume water per L milk (10^3 L)	-	-	2.4	3.1	2.5	2.9	2.2	2.8	3.3
	LWP_PHY	-	-	0.41	0.33	0.40	0.34	0.44	0.35	0.30
	LWP_FIN	-	-	0.14	0.12	0.14	0.12	0.15	0.12	0.10

LWP_PHY is physical LWP (volume of milk (L) per m^3 of water); LWP_FIN is for financial LWP (USD m^{-3} of water).

Table 12. LWP of dairy cows across farm clusters and farming systems (intensive systems, Etawah)

Systems	Parameters	Landless			Medium			Better off		
		Cross	Local	Buffalo	Cross	Local	Buffalo	Cross	Local	Buffalo
Wheat-rice	Milk L day^{-1}		-	7.00	7.80	5.50	7.00	11.50	5.50	6.33
	Milk USD day^{-1}	-	-	2.46	2.74	1.93	2.46	4.04	1.93	2.22
	ME Demand MJ day^{-1}	-	-	64.00	70.00	60.62	71.05	93.50	60.62	68.86
	ME WP MJ m^{-3}	-		5.26	8.71	8.71	8.71	5.99	5.99	5.99
	Water requirement m^{-3} day^{-1}	-	-	12.16	8.04	6.96	8.16	15.61	10.12	11.50
	Volume water per L milk (10^3 L)	-	-	1.7	1.0	1.3	1.2	1.4	1.8	1.8
	LWP_PHY	-	-	0.58	0.97	0.79	0.86	0.74	0.54	0.55
	LWP_FIN	-	-	0.20	0.34	0.28	0.30	0.26	0.19	0.19
Millet-mustard	Milk L day^{-1}	6.00	-	8.00	-	5.00	7.07	9.00	6.00	6.80
	Milk USD day^{-1}	2.11	-	2.81	-	1.76	2.48	3.16	2.11	2.39
	ME Demand MJ day^{-1}	55.78	-	55.53	-	66.94	74.06	85.30	50.27	53.60
	ME water productivity MJ m^{-3}	6.21	-	6.21	-	5.28	5.28	6.86	6.86	6.86
	Water requirement m^{-3} day^{-1}	8.99	-	8.95	-	12.67	14.02	12.43	7.33	7.81
	Volume water per L milk (10^3 L)	1.5	-	1.1	-	2.5	2.0	1.4	1.2	1.2
	LWP_PHY	0.67	-	0.89	-	0.39	0.50	0.72	0.82	0.87
	LWP_FIN	0.23	-	0.31	-	0.14	0.18	0.25	0.29	0.31

LWP_PHY is physical LWP (volume of milk (L) per m^3 of water); LWP_FIN is for financial LWP (USD.m^{-3} of water).

Table 13. LWP of dairy cows across farm clusters and farming systems (semi-intensive systems, Bankura)

Systems	Parameters	Landless	Medium	Better off	
		Local	Local	Cross	Local
	Milk L day^{-1}	1.0	1.2	3.5	1.9
	Milk USD day^{-1}	0.36	0.43	1.27	0.69
Paddy rice	ME Demand MJ day^{-1}	45.3	45.5	61.0	45.4
	ME WP MJ m^{-3}	1.54	1.75	2.33	2.33
	Water requirement m^{-3} day^{-1}	29.40	26.0	26.2	19.5
	Volume water per L milk (10^3 L)	29	22	7	10
	LWP_PHY	0.03	0.056	0.13	0.10
	LWP_FIN	0.01	0.02	0.05	0.04

LWP_PHY is physical LWP (volume of milk (L) per m^3 of water); LWP_FIN is for financial LWP (USD m^{-3} of water).

3.2. *Entry points to improve LWP: A scenario analysis*

In the earlier sections, the present values of LWP and their drivers were presented. Many key issues have been raised from this exercise: i) what are the potential and plausible interventions; ii) what will be the impacts on LWP, if these potential can be achieved; and iii) which of these interventions can bring maximum gain in LWP and which of the study systems and farm cluster must be prioritized for higher system resilience at basin scale? The following sections will explore into these issues.

3.2.1. Livestock management based interventions

Scenario ii) indicated that stepwise improvement in milk yield (e.g. through cross breeding and improved veterinary services) can bring a significant increase in LWP. Despite associated increase in the feed intake and therewith increased water input to the livestock feed, the gain from milk was substantial and thus showed improved LWP values from the current > 20,000L of water per L of milk to 2000L of water per L of milk in the semi-intensive system (Figure 8B). For the intensive systems, we also observed a remarkable increase in LWP (Figure 8A). Among the livelihood typology, those farms in the medium and poor clusters showed a greater gain compared to the better-off in all study systems. The difference in the volume of water saving across intensification gradient can be accounted for by the current low level of ME water productivity. In general our finding suggested that for basin-wide livelihood improvement and higher gain in water saving, interventions at low productivity regions and poor farm cluster are more important. This is in good agreement with the findings from the Comprehensive Assessment on Water Management in Agriculture (Molden 2007).

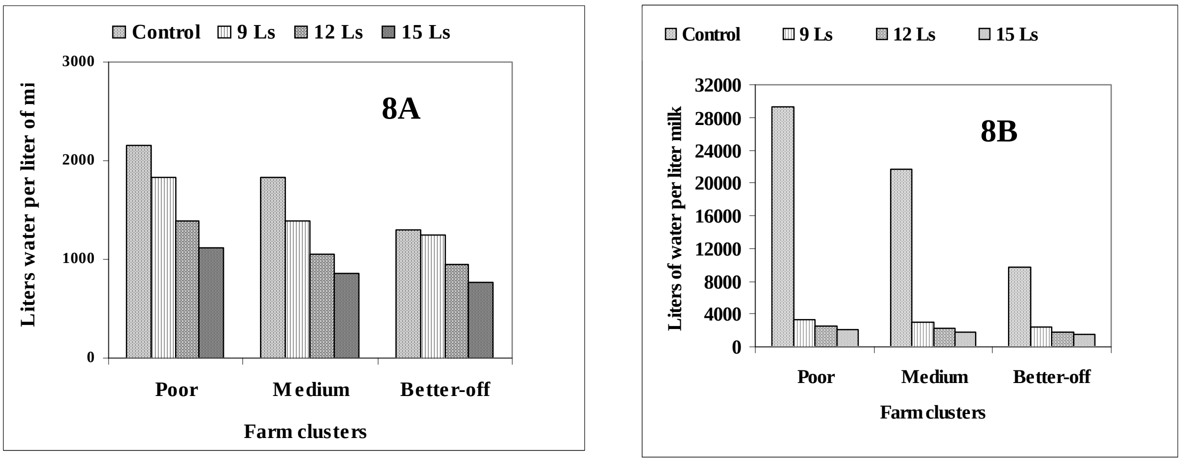

Figure 8. Impact of improving livestock management for a mixed herd model and achieving three potential milk yields (9Ls; 12Ls and 15Ls) on dairy WP compared to the control yield. Fig 8A shows the impact in intensive CLS and Fig 8B in semi-intensive CLS in the case study districts for the three livelihood groups. Ls stands for Liters of milk.

3.2.2. Feed based interventions

Blümmel et al. (2009) argued that there are considerable opportunities to improve the LWP by focusing on cultivars with higher ME values and Dry Matter (DM) digestibility. This is particularly true when crops like pulses (digestible and energy denser) constitute an important feed ingredient. Sethi et al. (1999) recommended a feeding schedule using locally available feed material in intensive system. When the DM of recommended ingredients was converted to ME values (weighted by their proportion in daily ration), it gave a feed density of 9 MJ kg^{-1}. This suggested the possibility of achieving medium energy density level with locally available feed sources. This intervention can include urea treatment, chopping, mixing, block making and diversification of cropping systems. The point is how much water can be saved from such interventions?

Generally, such improvement in feed quality impacts the volume of water required to produce a unit of animal products such as milk. The result showed that as much as $120m^3$ of water per year per cow can be saved from this intervention (Figure 9A and 9B). Like for the milk yield scenario, more LWP improvement was observed for the semi-intensive system. The gain from this intervention was low compared with livestock and water management based interventions.

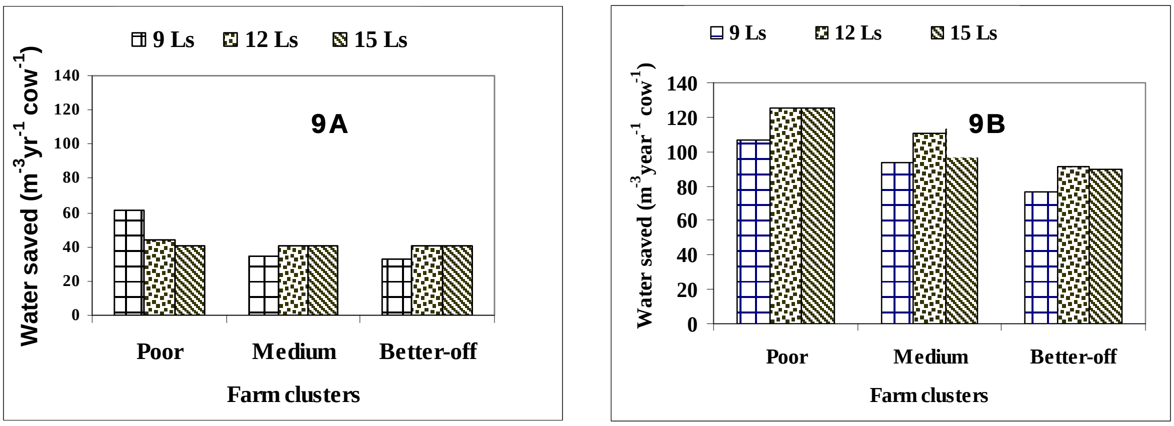

Figure 9. Annual volume of water saved per cow through improved feed quality for three potential milk yields (9Ls; 12Ls and 15Ls). Fig 9A shows the volume saved in intensive CLS and Fig 9B in the semi-intensive CLS in the case study districts for the three livelihood groups. Ls stands for Liters of milk.

3.2.3. Water management based interventions

Cai and Sharma (2009) showed a huge gap between potential and biological yields in the IGB for major food-feed crops. For example, they indicated as high as 6.18 Mg ha^{-1} yields for rice in bright spots and as low as 1.18 Mg ha^{-1} in hot spots. According to these authors, the average rice WP in the IGB is 0.84 kg m^{-3} with minimum and maximum values ranging between 0.2 and 2.4 kg m^{-3}. However, they showed a mean value of 1.36 for wheat with maximum and minimum ranging between 0.2 and 3 kg m^{-3}. Our WP study for selected districts representing major farming systems (Hisar, Etawah and Bankura, e.g. Haileslassie, Blümmel et al. 2009) indicated a WP range of 0.19-0.72 kg m^{-3} for wheat.

In terms of feed WP, Singh et al. (2004) reported a considerable variation for the WP of green fodder crops in the State of Gujarat in India. For example for alfalfa, (*Medicago sativa*) they indicated WP values ranging between 2.3 to 9.1 kg m^{-3} and for maize (Zea *mays*) 2.12.to 6.39 kg m^{-3}. Haileslassie et al., (2009) and Blümmel et al. (2009), reported a huge intra and intersystem variation for aggregated feed ingredients in the study systems. A marked picture was particularly observed between the irrigated and green fodders from grazing lands. Comparing these figures with literature values (Singh et al. 2004) for commonly grown food-feed crops (e.g. ground nut, *Arachis hypogaea),* which are water productive (14.04 kg m^{-3}) and superior in feed quality, demonstrates scopes for feed WP improvement.

Achieving potential yield means increasing the ME WP of feed by a similar magnitude. The result of impact assessments of these interventions is depicted on Figure 10A and 10B. For the poor, those interventions showed strongest improvement in LWP compared with all other interventions. The point is, however, that poor farmers have less access to land and their capability to improve the feed yield and, as a result, ME WP is unrealistic under the current setting. A more relevant option is to improve access to feed market: feed that is produced through judicious water use. For the paddy rice systems, improved management of CPR - on which the poor in the semi-intensive system mainly depend - will also help improving LWP and mitigating the impacts of climate change.

In general the LWP model is more sensitive to change in feed WP compared with improved feed quality and animal productivity. Those findings confirm a previous study (Descheemaeker et al., 2010, under review) which suggests that improvement of WP of feed changes LWP value significantly, compared with other interventions.

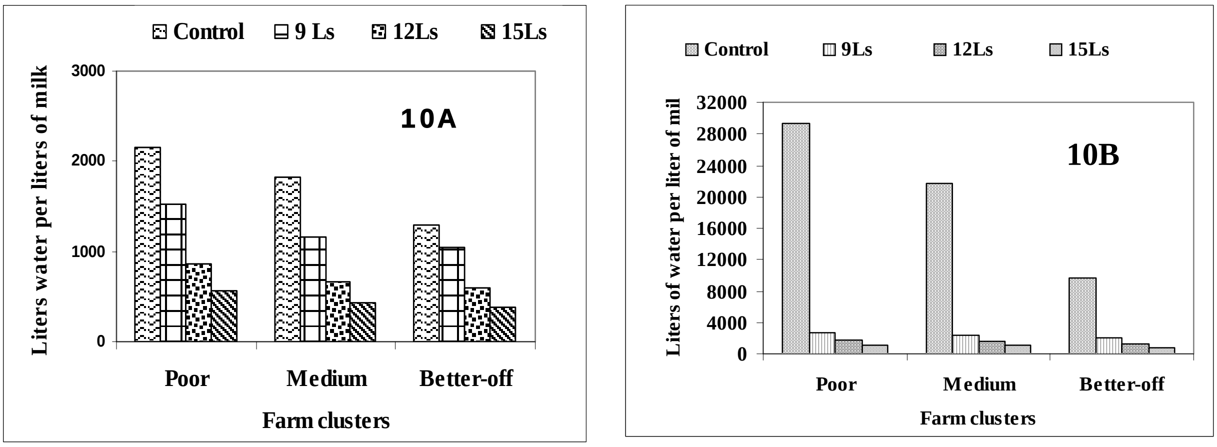

Figure 10. Impact of improving Metabilizable Energy (ME) Water productivity (WP) of feed and achieving three potential milk yields (9Ls; 12Ls and 15Ls) on dairy WP compared to the control yield. Fig 10A shows the impact in intensive CLS and Fig 10B in the semi-intensive CLS in the case study districts for the three livelihood groups. Ls stands for Liters of milk.

3.3 Conclusion

The overarching objectives of this study were to explore the effects of smallholder access to feed resources on the magnitude of LWP and to assess interventions that can meet livelihood demands and, at the same time, save water. In view of the results detailed previously, the following conclusions can be drawn:

- The present livestock water use to produce 1L of milk is higher than the world average. However intra and intersystem variation in LWP indicates opportunity for improvement in water demand management and thus increasing community resilience to climate change. By increasing the current milk yield level of a mixed herd model to its potential, it is possible to reduce the amount of water required to produce 1L of milk to values less than the world average.

- There was a significant impact of feed WP interventions on LWP values. LWP gain from a unit increase in ME WP exceeded the gain from a unit increase of milk productivity for all study systems and farm typology. In general the highest gain of WP as the result of the different interventions was for the poor farm cluster. This shows the important role of CPR management and improving access to feed markets on which the poor farmers depend.

4 Objective 4: Evaluate gender, livelihood and poverty impacts of recommended technological and management options

4.1 Methods

We evaluated the potential impacts on gender, livelihoods and poverty of the proposed biophysical interventions on different farm typologies. Selected interventions are summarised below according to the three main categories.

1. **Enhancing animal productivity:**
   - Upgrading non descriptive cows and buffaloes with high yielding indigenous and exotic animals on selective basis

2. **Improving feed sourcing:**
   - Increasing the use of agricultural by-products and diversification of cropping patterns towards water productive and dual-purpose varieties (e.g. pulses).
   - Adopting of the treatment of crop residues, such as low cost chaff-cutting, chemical treatments, mixing and densification of agricultural byproducts
   - Using appropriate fodder varieties
   - Diversifying crops
   - Improving the management of common land through over-seeding of wasted land and communal grazing areas, green fodder planting on bunds and fallow lands

3. **Conserving water:**
   - Supplementary irrigation and timely water supply.

We have examined the differentiated impacts of these interventions on farmers' access to capitals and resulting capabilities and how these interventions are likely to fit within current farmers' strategies. For instance, whereas landless farmers (groups 0 and I) usually try to make best use of available resources to reduce production costs and to diversify their activities to reduce their vulnerability to risks (Ellis 1998), rich farmers with secure access to land and water (type III) mainly aspire to enhance the profit of their farming systems (Rangnekar 2006). Medium farmers (type II) adopt a middle path strategy, trying to expand their income while minimizing risks. In the following results sub-section, we discuss more particularly the impact of proposed interventions on the poorest farmers and on men and women.

4.2 Results

4.2.1 Enhancing animal productivity

Landless and land-poor households in intensive systems identified low animal productivity as a major issue affecting their livelihoods during problem ranking exercises. Low animal productivity is a high concern in intensive systems where dairy products are an important component of the household diet and where their sale constitutes an important source of income. In paddy rice systems, cattle and buffaloes are primarily kept for draught power and to some extent for infant milk consumption. Low milk productivity was therefore not highly ranked by farmers in this system during the problem ranking exercise.

The presence of crossbred cows is more marked in intensive systems. In the paddy rice system, a large majority of farmers keep desi cattle – only 6.7% of farmers own a crossbred cow and all of them are landowners.

In intensive systems, relatively fewer landless households keep crossbred cows compared to landowners, especially in Mugalpura village, Hisar District (Table 14).

Table 14. Percentage of landless and landowners owning at least one crossbred cow

	Etawah District (wheat and millet systems)	Basra, Hisar District (millet systems)	Mugalpura, Hisar District (wheat systems)
Landless (groups 0 and I) (%)*	6.7	12.5	3.9
Landowners (groups II and III) (%)*	8.1	15.5	7.7

** Source: we chose to use the results of the census survey for a greater sample size but it did not allow dividing the households into their typology and farming system*

Discussions were held with farmers on the potential cost of keeping high yielding breeds such as *Murrah or Holstein Friesian* (HF) or crossbred dairy animals.

Men and women from landless and land poor household across all farming systems are concerned by the impact of keep high yielding breeds on financial capital. In addition to the initial investment for animal purchase, maintenance costs are higher than for desi cattle, which in farmers' view, is due to the high quality feed and greater healthcare requirements of these animals. Feed supply is a major constraint for landless farmers as, contrarily to better-off farmers, they have to purchase feed off-farm. A cost benefit analysis should thus consider the costs from feed purchase compare with milk sales for different regions, as results depend on local feed availability and local milk marketing conditions, especially farm-gate selling prices. For instance, in regions where milk markets are limited, as in the study villages of Bankura, the adoption of productive animals will lead to increased incomes only if favourable marketing conditions are created (see also Kapse and Patil 1995).

Although women do not usually participate in decision-making on breeding (Table 9, Section Objective 2), the adoption of crossbred animals might have an impact on women, especially from groups 0 and I whose husband and sons are regularly engaged in off-farm activities. First, women fear that hybrid animals will necessitate more health care than desi cattle as, for instance, the animals are more sensitive to temperature fluctuation. They are thus concerned by their greater responsibility in case of disease in the absence of men, especially as these animals represent very costly assets. Also a change in feeding and the need to keep animals at a cooler temperature (with water for instance) might create extra work.

As a conclusion, the introduction of high milk yielding breeds and crossbred species is likely to benefit more the medium and better-off households unless special support to create fair feed and milk markets are created. This entails not only creating new markets like in Bankura Districts but also improving existing market conditions in intensive systems where middlemen often take advantage of farmers to make higher profit. The introduction of such interventions is likely to increase women's workload. Such interventions should thus be coupled with positive actions to respond to women's strategic needs. It could include providing information and training on AI knowledge for them to be able to take part in the breeding decisions, training and discussions with both men and women about animal maintenance activities, feeding and care to create a greater awareness on gendered labour division regarding livestock activities.

4.2.2 Improving feed sourcing

Improving feed quality entails either diversifying feed sources or improving the quality of existing feed.

Producing green fodder requires a reliable access and control over water – which is a prominent problem for many land-poor farmers. It is also the main constraint for crop diversification in paddy rice systems. Supplementing feed with concentrates is usually advised for lactating cows and buffaloes to improve milk yield as currently practised in intensive systems where feed and concentrates market exist. However high cost hinders many poor and medium farmers in our case study area to purchase concentrates. Further feed products like feed blocks are not commonly used in the study areas as they are not produced or sold locally. Because transportation costs from the supply zone significantly affect sale prices, it is essential to improve marketing and storage facilities to encourage local entrepreneurs to produce such products locally.

Most better-off farmers in intensive systems already make a physical treatment of fodder. In paddy rice systems, farmers currently feed animals with rice straw, either raw or cut into shoulder length pieces – but in both cases with no prior treatment. Treatment of low quality feed such as straw with urea (Patil et al. 1993) and the physical treatment of residue such as chaffing or feeding block (Berwal, Lohan, and Yadav 1997) can improve milk productivity but benefits depend on the costs of inputs and milk marketing conditions (Sharma, Dutta, and Naulia 2004). In paddy rice systems, medium farmers usually buy urea as fertilizer on a credit basis therefore the use of urea for straw treatment might not be a cost effective option unless its access is facilitated. For farmers to adopt mechanical processing also requires financial and institutional support to organize joint purchase of chaff cutting machines.

In some regions (Bankura and some areas in Etawah), the animals of landless livestock keepers extensively rely on grazing for their feed. The improvement of grazing land would therefore more particularly benefit the poorest farmers of the community. It requires the recognition of communities' access and control over forest land by the Forest Department, as per the Forest Rights Act 2006, GoI. Successful examples of partnerships between communities and state Forest Departments on multiple use of forest land exist. For instance, Gurung and Lama reported the lease of degraded forest for production of forage crop in Nepal through "The Hills Leasehold Forestry and Forage Development Project" (2008).

As for animal management, special attention should be given to the gendered division of labour for interventions related with feed improvement. For instance, whereas improvement of grazing land might be gender neutral, the cultivation of green fodder on common land might have a high impact on women's workload, as this might be added to their existing task of cutting and carrying green foliage from the forest for small ruminants along with the fuel wood they collect.

4.2.3 Conserving water

Crop rotation and diversification (e.g. agroforestry) was one of the suggested biophysical interventions to improve water use. However, diversification requires a secured access to and control over water, which has not been achieved yet for poor and some of the medium farmers, and particularly in Bankura. Even in irrigated systems, the lack of reliability (regarding timing and quantity) of canal supply is a major constraint for farmers who do not have physical or economic access to groundwater.

4.3 Discussion and conclusion

A major constraint for livestock based activity among landless and land-poor farmers in developing countries is low animal productivity, due to the poor performance of breed and poor access to quality feed, ultimately resulting from socio-economic factors (Akhter et al. 1995). Enhancing animal productivity is thus not only about the adoption of high milk yielding breed, but has to be coupled with interventions on feed and water access. The potential of these interventions to reduce poverty ultimately depends on a better access to water and feed availability, and particularly for landless off-farm households and poor farmers through virtual water trading. Initiatives to improve CPR are likely to have the highest benefits for the landless off-farm and poor households, who do not have access to land and water for fodder cultivation. Creating favourable feed and milk markets and improving access to credits are also critical for farmers to actually benefit from increased animal productivity.

For example, Shukla and Brahmankar (1999) indicated in their study of the national dairy programme “Operation Flood”, also referred to as the “White Revolution”, that marketing support was instrumental to decrease milk production costs. They also pointed out the importance of access to veterinary services and feed accessibility to improve animal productivity. Lastly, milk marketing conditions are also essential for that milk sale benefits cover farmers' increased production costs associated with high yielding breeds (Shukla et al. 1995).

According to better-off households, the creation of several local dairy collection centres would help to improve their bargaining power by enhancing competition. Many farmers, especially women from landless and land-poor households in millet pulse and millet mustard systems, are engaged in an exploitative relationship with middlemen who are also their moneylenders. Milk selling prices at the farm gate are generally low. Such exploitative systems can be broken by improving access to formal credit at market interest rates (Torsten, Otto, and Saha 2003). Such financial support could be joined with technical and marketing support in order to allow farmers to increase their benefits from livestock activities and thereby reduce failures to repay loans.

Women are the primary custodian of income from livestock activities and are thus likely to benefit from increased productivity. Most proposed interventions might result in increased workload and responsibilities for women, it is thus important to support structural changes in the division of labour between men and women through discussion with representatives of both genders in the communities. Women's training and capacity building is also important for women to participate more meaningfully in decision-making.

The impact of all technical interventions depends on social and institutional factors. The most essential requirements to improve LWP are to:

- develop institutions to support feed and livestock product storage, exchange and marketing,
- support livestock markets
- develop credit facilities, particularly for landless and small landholders
- improve extension and veterinary services
- improve water access
- improve control over grazing land

The next section Objective 5 discusses how the project team has conveyed these messages to relevant stakeholders.

5 Objective 5: Increase local capacity and develop policy, technology and governance recommendations for improving water productivity in crop-livestock systems

Translating research into practice is a key issue in all rural development projects. In the previous section, we have argued that institutional change is crucial for biophysical LWP interventions to be equitable between poor and better-off and men and women. Bringing up institutional change requires not only building capacity but also proposing sound policy recommendations to national and state decision-makers.

5.1 Methods

This component has built upon regular interaction with stakeholders, e.g. farmers, NGO partners, research partners and local officials throughout the project. The perception of each actor was taken into account in order to offer recommendations which are not only scientifically sound but also socially, economically and politically acceptable for all stakeholders. The involvement of local resource persons in the project activities was favoured whenever possible.

5.2 Results

5.2.1 Local capacity

Capacity building at the local level was based on the training of students, NGO staff and villagers from the case study sites as part of activities under Objectives 2, 3 and 4. The IWMI research team led a one-day and two-day training for enumerators conducting the census and questionnaire survey respectively. The research team also raised the awareness and knowledge of NGO partners' on LWP issues through several presentations during the project progress meetings.

Research activities particularly under Objectives 2, 3 and 4 have been conducted following a participatory approach with significant exchange of knowledge and information between researchers, NGO partners, and farmers. This has sensitized NGO partners to apply new tools and methodologies to enhance the capacity of CLS, farmers to interact with local government officers and innovate in their farming practices. Thirdly, the involvement of national scientists from the Indian Council of Agricultural Research (ICAR) in the development, validation and quantification of tools has improved their knowledge base thereby strengthening the national research capacity.

5.2.2 Integration of biophysical, livelihood and institutional findings across scales and regions

Integration of the results has occurred at four levels: 1) across disciplines, to integrate the biophysical and social outputs, 2) across research and development practice, to combine scientific expertise with field experience, 3) across scales, to link observed macro-level trends with micro-level practices, and 4) across states to compare findings and draw out generic lessons.

Our analysis of LWP in CLS has involved a multi-disciplinary research team composed of animal nutritionists, water and nutrient flow specialist, crop physiologist, agricultural economist, livelihood and gender specialist, and institutional and policy specialist. The integration of biophysical and social analyses has been supported by a regular interaction between the research team members: daily on an informal basis (meeting, phone, email) as well as in monthly meetings.

Secondly, a regular interaction between the NGO partners and the researchers team either at distance, in meetings or on the field proved to be particularly insightful in terms of knowledge sharing. Knowledge and experience regarding local politics or historical knowledge of local livelihood conditions have proved very valuable for the research team prior to fieldwork as well as when interpreting data.

Thirdly, evaluating LWP at different scales has proved very useful to convince policy-makers on the need for locally-grounded approaches. The feed surplus observed in Hisar District proved to hide high disparities within the district – LWP calculations at the community level were confirmed by household interviews and group discussions.

Lastly, policy-makers also showed a high interest for inter-state/inter-district comparison. This was a useful exercise to understand the factors explaining LWP variability and convince government officials on the relevance of different types of interventions for a particular biophysical and socio-economic context.

5.2.3 Translation of research for dissemination pathways

The project has followed two parallel communication strategies. The first one, led at the grassroot level, aimed at sensitizing farmers on issues related with LWP. It has included direct interaction with farmers while conducting activities under Objectives 1-4, and transfer of results to NGO partners who work with communities (cf. next section on Outcomes and Impacts).

The second one, led with local and national stakeholders, focused on the sensitization and knowledge building of policy-makers and other actors who might directly or indirectly impact on policy-making. Results and policy recommendations were summarised in a set of project briefs (available on internet: http://sawal.iwmi.org/publications--outputs.aspx) which were distributed to stakeholders at the district and national level. These briefs addressed the technical, livelihood and gender, and institutional aspects of LWP.

The set of recommended interventions was categorised into the following categories: 1) institutions, 2) extension services and capacity building, and 3) markets. As shown in Table 16, the success of an intervention depends not only on a single type of intervention but rather from a mix of interventions, combining institutional change across several administrative levels together with capacity building and changes in markets (Table 15).

Table 15. List of proposed domains of interventions according to the type of change / action required

	Domain of intervention	Community institutions	District institutions	State/National institutions	Extension services	Capacity building	Markets
1	Improve farmer's access to water on a sustainable and equitable basis	X	X	X			
2	Increase farmers' access to variety of feed	X	X				X
3	Increase farmers' knowledge on feed mixes and feed water requirements				X	X	
4	Improve the management of common land			X	X	X	
5	Improve public services for livestock		X	X	X	X	
6	Coordinate government action	X	X	X	X	X	X
7	Design interventions adapted to local variations	X	X	X			

5.3 Discussion and conclusion

It is essential to build capacity for continued learning and uptake of recommendations all along the project activities. In this sense, a major asset of the project was the involvement of local resource persons, national partners, both NGOs and research centres, who can continue development, advocacy and research after the end of the project.

The process of designing and disseminating policy recommendations would have probably benefited from a greater involvement of ministries, state line departments, District administrative heads and elected heads as well from the beginning of the project – however it was difficult to take this step considering the time frame (two years) and geographical scope (three states) of the project.

Awareness of actual livestock water requirements has certainly been raised among district level officials and, to a less extent, among national and state government civil servants. However, as underlined in Section 2, there are structural constraints within the development planning process and the current sectorisation of state development schemes which need to be addressed for positive changes to occur. These are sensitive political issues which have been debated for a long time in India. We hope that providing quantifiable evidence on the scope for improvement of LWP can contribute to further discussions and militate in favor of locally-grounded, integrated approaches to rural development which go beyond considering farmers as passive recipients of welfare action but give them an active role in their development.

OUTCOMES AND IMPACTS

The outcomes and impacts pathways followed three main avenues – with three distinct target groups. The first concern was the adoption of technical interventions and changes in practices at the grassroots level. This pathway relied on sharing research recommendations and practices with farmers, building capacity and skills through the involvement of our NGO partners. However, this project has highlighted the importance of political and socio-economic changes to enable farmers to translate recommendations into practice. For instance, interventions related with water management or crop/feed diversification are related with an equitable and reliable access to water. Similarly, adoption of improved breeds requires fair and supportive marketing conditions for animals, feed and livestock products. The second outcome and impact pathway was thus targeted to policy-makers and – to a less extent – to private dairy companies. The last pathway focused on the creation of a favourable knowledge context, by spreading research findings to the research community in India. As researchers interact with policy-makers, NGOs and farmers, a change in their perception can contribute to changes in perception among other stakeholders.

6 Outcomes and impacts main pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Farmers in Bankura	Requests for the construction of 2 water harvesting structures in Udaypur and Lakhipur (approved by the GP)	Greater confidence among farmers on the issue	Several group discussions with representative farmers of different livelihood typology, using participatory tools	2-3
	Some farmers have agreed to cultivate green fodder around the new water structures	Greater knowledge and understanding about fodder cultivation		2-3 with potential 4-5 in the coming year
	Some farmers have agreed to treat dry fodder to improve feed quality	Greater knowledge and understanding about feed quality improvement		2-3 with potential 4-5 in the coming year
Farmers in Etawah	Farmers are willing to replace flood irrigation by a water efficient technology, choose water efficient crops and fodder, if extension officers support them	Increased awareness on crop and water conservation, improved information on treatment of fodder and water efficient crops		2-3
Farmers in case study villages of Hisar	Farmers are willing to adopt water efficient technologies if they have reliable and secure access to water.	Increased awareness on crop and water conservation, improved information on treatment of fodder		

		and water efficient crops		
NGO Partners - PRADAN	New interventions will integrate livestock and will address the inter-relationship between crop/livestock systems and water Development of material in Bengali to sensitize communities to LWP and disseminate research results in Bankura District	Greater understanding of water productivity, and livestock, crop and water interactions	Regular interaction throughout the project, including technical presentations and discussions	2-3 with 4-5 on the short/medium term
NGO Partners - BAIF	Will use the knowledge generated from the project for improving existing livestock services to community. Will conduct a trial of the recommendations and assess improvement in livestock products and services. Plans to develop material in Hindi to disseminate knowledge generated from research findings to all the focus village of BAIF	Greater understanding of water productivity, and livestock, crop and water interactions	Regular interaction throughout the project, including technical presentations and discussions	2-3 with 4-5 on the short/medium term
Other NGOs		Greater awareness of high livestock water needs and knowledge of the types of interventions which can decrease livestock water use	National stakeholder workshop	1 to 2
Government officials in Bankura District Government officials in Etawah District	Greater inclination towards integrated planning of livestock, agriculture and small-scale irrigation	Increased awareness and better understanding of LWP issues Awareness of farmers' perceptions on water, agriculture and livestock	Stakeholder workshop and consultative meetings	1 to 2

Government officials in Hisar District				
National and State government officials		Greater awareness of high livestock water needs and knowledge of the types of interventions which can decrease livestock water use	National stakeholder workshop	1-2
Researchers	Greater inclination towards integrated research on livestock, agriculture and small-scale irrigation	Greater awareness of high livestock water needs and knowledge of the types of interventions which can decrease livestock water use	National stakeholder workshop	1-2

*Note: Change in Awareness= 0 to 1 Change in Knowledge – 1 to 2, Change in attitude = 2 to 3, change in skill = 3 to 4 and Change in Practice = 4 to 5

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

The dissemination of project interventions to farmers through relevant material and field demonstrations by NGO partners will support the adoption of practices by farmers among the communities. But ultimately, the change in perception and knowledge on livestock water needs and lack of/inequitable access to water among policy-makers and NGOs has the greatest potential to lead to improved water use at a macro-scale.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

The potential of actions led by NGOs to be translated into farmers' changes in practice ultimately depends on interventions need the institutional and economic support from state and private bodies.

NGO partners have initiated interventions which will continue to be implemented after the end of the project with farmers in selected sites and will continue the dialogue initiated with policy-makers. If successful, they might outscale interventions in other regions of India. NGO partners will also show interventions to district and State officials as successful examples, which hopefully will contribute to improved policies.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

Most impact pathways reached expectations.

Why were they unexpected? How was the project able to take advantage of them?

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

7 International Public Goods

The project has produced the following international public goods:

7.1 Project Insights

- LWP physical and economic values under different farming systems and livelihood typologies
- A number of papers for international publications on institutional and biophysical issues related with LWP
- A dedicated website containing all material and resources on http://sawal.iwmi.org

7.2 Tools and Methodology

- Refined methodology to evaluate LWP of crop-livestock farming systems
- New training material to sensitize and improve farmers knowledge on water use in CLS

8 Partnership Achievements

The partnership of with the grassroots organisations PRADAN and BAIF and with the Indian research centre for agricultural research (ICAR) proved to be very fruitful, because of the complementary skills and knowledge of these organisations with ILRI and IWMI. PRADAN and BAIF had developed privileged relationships with the local communities, thereby greatly facilitating the interaction of our research team with the farmers. They also provided useful insights on the local context on cultural, social, political and economic aspects. What is more, they played a crucial role in data collection, by conducting surveys and collecting secondary data collection from line Departments at the District and State level. The support of ICAR was also key for liaising with government officials, as they established in Hisar strong relationships with line Departments.

During the time of our project, we also created links with other research projects
1. "Improving water productivity of Crop-Livestock systems for benefiting the poor and the environment" led by IWMI, ILRI and ICRISAT in Ethiopia and Zimbabwe
2. The Basin Focal Project for the Indus-Gangetic Basin led by IWMI
3. A project on milk water productivity in Punjab, India led by IWMI-Delhi and supported by Nestle

A tight linkage was established from the onset of the project with the Project No 1 by defining a similar methodology. The detailed questionnaire we used for our project was adapted from the questionnaire developed by the IWMI/ILRI team in Ethiopia. We also chose the same framework for the analysis of decentralization by Agrawal and Ribot

(2000). Two members of the IWMI team participated to one-week writing workshop in Addis organized by ILRI, gathering researchers and students working on Project 1. Findings were shared and discussed among participants from the 2 projects

Views and ideas have been shared among the project teams through regular informal interaction in IWMI Delhi offices for projects 2-3, and during workshops and seminars organized by the project teams.

9 Recommendations

A set of ten policy briefs have been designed for each of the districts and for the national level (see http://sawal.iwmi.org/publications--outputs.aspx).

National level

- Multi-scale LWP Evaluation in the Indo-Gangetic Basin of India
- Institutions for a Sustainable and Equitable improvement of Water Productivity of Crop-livestock Systems in Hisar District
- Water supply for Crop-Livestock Systems in the Semi-Arid Canal Irrigated Areas of the Ganga Basin

Bankura District

- Potential of Livestock Based Livelihoods in Rarh – Bankura
- Improving Water Access for Crop-Livestock Systems in Rainfed Areas of India

Hisar District

- Institutions for a Sustainable and Equitable improvement of Water Productivity of Crop-livestock Systems in Hisar District
- Water supply for Crop-Livestock Systems in the Semi-Arid Canal Irrigated Areas of the Ganga Basin
- Potential of Livestock-based livelihoods in Hisar District

Etawah District

- Institutions for a Sustainable and Equitable improvement of Water Productivity of Crop-livestock Systems in Hisar District
- Water supply for Crop-Livestock Systems in the Semi-Arid Canal Irrigated Areas of the Ganga Basin
- Potential of Livestock-based livelihoods in Etawah District

10 Publications

Conference papers and abstracts of other papers are available on http://sawal.iwmi.org/publications--outputs.aspx. All project briefs and power point presentations of the National Workshop held in Delhi on 27th March 2010 are also available on the website.

10.1 Journals articles and other scientific publications

Clement, F., Haileslassie, A., Murty, MVR, Blümmel, M., Ishaq, S., Dey, S., Das, H., Samad, M., Khan, M.A., 2010. Increasing Water Productivity for Poverty Alleviation in the Ganga Basin: A livelihood and institutional perspective *(under revision, accepted as part of a special issue of Experimental Agriculture with other papers from BMZ project in the Nile Basin on crop-livestock productivity)*

Haileslassie A., Blümmel M., Murthy M. V. R., Samad M., Clement F., Anandan S., Sreeedar N. A. Radha A. V. and Ishaq, S. Understanding livestock feed and water nexus across mixed crop livestock system's intensification gradient: an example from the Indio-

Ganga Basin *(Under revision, accepted as part of a special issue of Experimental Agriculture with other papers from BMZ project in the Nile Basin on crop-livestock productivity)*

Haileslassie, A., Blummel, M., Samad, M, Clement, F., Ishaq, S., Adapting livestock water productivity to climate change, *(Under revision, accepted in the Journal of Climate Change and Management)*

10.2 Conference proceedings

Clement, F., Venot J-P., Assessing the environmental justice of water projects and reforms in the rural south: A co-exploration of institutions and myths (*to be presented at the workshop "Global Environmental Justice: Towards a new agenda", University of East Anglia, Norwich, UK, 2-3 July 2010, to be published in a journal special issue with other workshop papers in 2010*).

Haileslassie A., Blümmel M., Murthy M. V. R., Samad M., Clement F., Anandan S., Sreeedar N. A. Radha A. V. and Ishaq, S. 2009. Understanding livestock feed and water nexus across mixed crop livestock system's intensification gradient: an example from the Indio-Ganga Basin p. 98. In Chandrasekharaiah M., Thulasi A., Suganthi U. and Pal D. T. (Eds) 2009. Diversification of Animal Nutrition Research in the Changing Scenario, Volume I , 17-19 December 2009, Bangalore, India.

Haileslassie, A., Blummel, M., Samad, M, Clement, F., Descheemaeker, K., and Samireddypalle, A., (2010). Building resilience of rainfed production systems to climate change: livestock water productivity perspectives. Proceedings of the National Symposium of Climate Change and Rain fed Agriculture held at CRIDA, 2010, Volume II 398-400. Hyderabad, India.

Haileslassie, A., Blummel, M., Samad, M, Clement, F., Ishaq, S., Adapting livestock water productivity to climate change, Climate Change and Natural Resource use in Eastern Africa: Impacts, adaptations and mitigation, 19-21 May 2010, Nairobi, Kenya.

10.3 Papers in preparation

Clement, F., Haileslassie, A., Ishaq, S., Samad, M., Institutions for equitable and sustainable improved water productivity: The case study of crop-livestock systems in the Ganga Basin (*to be presented at the International Conference of the International Association of the Commons (IASC) "Sustaining Commons: Sustaining our Future", Hyderabad, India, 10-14 January 2011*)

Haileslassie, A., Blümmel, M., Clement, F., Samad, M., Acharya, N. S., Radha A. V., Ishaq S. Micro scale livestock water productivity: assessing option for improvement and its impacts on environmental sustainability.

Haileslassie, A., Blümmel, M., Clement, F., Samad, M. Food-feed crops water partitioning approaches to calculate Livestock Water Productivity: exploring options and limitations for sustainability indicator

Ishaq, S., Clement, F., Samad, M., Acharya N. S., Dey A., Radha, A.V., Blümmel, M., Haileslassie, A., and Khan M. A. Triple burden, dual responsibility and single returns: Assessing roadblocks in dairy livestock improvement of landless and land poor livestock keepers from a gender perspective

Radha, A.V., Acharya N. S., Clement, F., Samad, M., Haileslassie, A., Ishaq, S., Estimation of livestock feed availability using vegetation reflectance in the Ganges river basin, India

10.4 Conference presentations

Haileslassie, A., 2010, Livestock water productivity in Indo-Ganga Basin: Assessing impacts of selected interventions on sustainable water use, National Workshop on Water Conservation and Quality Challenges: Towards Adaptive Strategies, March 22, 2010, New Delhi, The Energy and Resources Institute (TERI), UNICEF, Hindustan Unilever Ltd

10.5 Training material

PRADAN is developing the following materials in local language to disseminate the research findings and to enhance understanding of communities through improved package of practices.

- Wall posters and hand bill on different kinds of diseases of livestock and their remedial measures
- Hand bills on maintaining hygienic cattle shed
- Wall poster for sensitizing people on the grazing management (poster showing degraded land because of continuous free grazing and fodder land where stall feeding is going on)
- Leaflets for growing of less water consuming fodder and storing of green and dry fodder
- Flex on the integrated approach of improving the crop- livestock and water productivity. The flex would include the photographs, slogans, etc.

PROJECT PARTICIPANTS

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Mr Pawan Kumar, executive producer cum director, local resource person in Basra village, Hisar District

Appendix A

INSTITUTIONS RELATED TO WATER (FOR CROPS AND LIVESTOCK) – SAWAL PROJECT

<table>
<tr><th></th><th>State</th><th>Market</th><th>Community</th><th>Individual</th></tr>
<tr><td rowspan="2">BANKURA

(ACCESS DOMINATED BY INFORMAL ARRANGEMENTS AMONG FARMERS AND PUMP RENTAL MARKETS)</td><td rowspan="2"><u>Provision</u>: ponds and dug wells in private fields, pumps

<u>Regulation</u>:
Pump electrification strictly controlled by the State Water Investigation Directorate (SWID) regulations

Groundwater extraction regulated by the West Bengal Groundwater Resources (Management Control and Regulation) Act 2005

Electricity rates (kept high)

<u>Subsidies</u>:
For digging ponds and wells: Watershed Development Programme in 2006, NREGA and direct subsidies to farmers from Gram Panchayat and Panchayat Samiti</td><td rowspan="2"><u>Among villagers and with neighbouring village:</u> Marketed pump irrigation services</td><td colspan="2"><u>Ownership and management of</u>: water harvesting structures and pumps

<u>Access to water depend on</u>: land ownership, size of land holding, type of land, social capital, financial capital – the forms of capital required vary among villages of the same area, depending on the biophysical and socio-cultural local context</td></tr>
<tr><td><u>Collective action</u> to control water, e.g. build small or large dams on the river, store water in unused fields</td><td></td></tr>
<tr><td>ETAWAH

(ACCESS DEPENDENT PRIMARILY ON GVT SUPPLY THROUGH CANAL AND TO A LESS EXTENT ON PRIVATE RENTAL MARKETS OF</td><td><u>Provision and maintenance:</u>
o Canal water for irrigation and for fillings ponds for livestock against irrigation fees, by the Irrigation Department – canal maintenance by the Irrigation Dpt
o Electricity for irrigation pumps by the Electricity Dpt</td><td><u>Among villagers:</u> tubewell rental markets

<u>By local entrepreneurs</u>: tubewell digging</td><td>Agreements between groups of farmers for deciding the timing to share tubewell access: either on mutual understanding on a daily basis or by a system of time slot allocation through numbering</td><td>Ownership of tubewells</td></tr>
</table>

	State	Market	Community	Individual
TUBEWELLS)	o Tubewells (gvt ownership) o *Regulation*: Control of water supply to individual farmers upon the size of the cultivated area and crop cultivated Electricity rates Subsidies: no direct subsidies to farmers Digging of ponds and check dams by Soil Conservation Department, NREGA			
HISAR **(ACCESS DEPENDENT PRIMARILY ON GVT SUPPLY THROUGH CANAL AND TO A LESS EXTENT ON PRIVATE RENTAL MARKETS OF TUBEWELLS)**	*Provision and maintenance*: Canal water by the Irrigation Department against irrigation fees, big damages repaired by the Irrigation Dpt Maintenance of ponds for livestock by the Irrigation Department *Regulation*: Control of water supply to different areas on political grounds, to individual farmers upon the size of the cultivated area and crop cultivated *Subsidies*: For digging ponds: Horticulture Department (direct subsidies to farmers), NREGA, Watershed Development Programme (2006)	*Among villagers*: Tubewell rental markets *By local entrepreneurs*: tubewell digging	*Ownership of* ponds for livestock bathing and drinking water Informal agreement between farmers for small repairs of the canal *Collective action,* e.g. clean the pond for bathing and drinking water of livestock (all villagers participate), collection of funds to dig a borewell for drinking water supply during summer Informal agreements between groups of farmers	Ownership of tubewells

	State	Market	Community	Individual
	For the purchase of pipes: Watershed Development Programme (2006) (direct subsidies to farmers)		for deciding the timing to share tubewell access	

INSTITUTIONS RELATED TO LIVESTOCK – SAWAL PROJECT

	State	Market	Community	Individual
BANKURA **TERTIARY ACTIVITY: kept for traction, rituals and as financial assets** **DOMINATED BY GRAZING** **INFORMAL ARRANGEMENTS**	*Regulation*: Access to forest land for grazing regulated under the Indian Forest Act, 1927 and Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006) *Extension and services:* Free vaccination, advices from the veterinary officer	*Among villagers:* Rental of ox ploughing services, sale and purchase of straw, *With neighbouring villagers*: sale and purchase of straw *With merchants who come to the village*: Exchange, sale and purchase of animals, milk, straw *Local markets:* Exchange, sale and purchase of animals – one market only for crossbred species (Bolpur, 80 km from Saltora) – dung market not developed Veterinary services by government employees or private doctors	Joint ownership of animals Exchange, share and gifts of animals, e.g.: farmers exchange old animals + financial compensation against young animals; two farmers share the purchase of two animals, etc Exchange of dung between farmers Arrangements to take cattle for grazing between several households Arrangements to protect vegetables from grazing animals. Shared use of chickens (and sometimes goats) for rituals: every household contributes	Private ownership of animals
ETAWAH **SECONDARY ACTIVITY: Sale of milk and animals** **MARKET-ORIENTED**	*Extension and services:* Trainings and information through ATMA, vaccination for reduced cost (2 Rs), advices from the veterinary officer *Subsidies*: loans and subsidies to buy buffaloes for ST/SC, subsidies for AI, free provision of chicks and feed to	*Among villagers:* sale and purchase of feed: straw, dung, green fodder, crop residues, collected grass, concentrates, etc *With neighbouring villagers*: sale and purchase of straw, dung, manure, concentrates, green fodder	Exchange of buffalo caring and feeding against dung Gift of animals for marriages	Private ownership of animals

	State	Market	Community	Individual
DOMINATED BY STALL-FEEDING	start poultry farm, loans to groups of 10 BPL farmers to purchase pigs and goats	<u>*To private, NGO-led and State dairy cooperatives directly or through milkmen from the village:*</u> Sale of milk <u>*To merchants*</u>: purchase of salt, straw, Sale and purchase of animals <u>*Local and regional markets:*</u> Exchange, sale and purchase of animals, straw, – many markets available State and private veterinary services		
HISAR **SECONDARY ACTIVITY: Sale of milk and animals** **MARKET-ORIENTED** **DOMINATED BY STALL-FEEDING**	<u>*Extension and services:*</u> free vaccination, advices and trainings from the veterinary officer, insurance for cattle <u>*Subsidies:*</u> subsidies to buy bulls and keep murrah breed buffaloes, loans for sheep breeding, poultry rearing, pig, buffaloes and cows calf rearing	<u>*With villagers:*</u> sale and purchase of feed: straw, dung, crop residues, concentrates, green fodder. Sale of ghee <u>*With neighbouring or far-off villagers*</u>: Sale and purchase of wheat straw (up to 80 km), crop residues, <u>*To dairy cooperatives through milkmen*</u>: Sale of milk, ghee <u>*To merchants:*</u> purchase of wheat straw, cotton seeds, oil cakes, salt, etc - Sale of wool, animals, milk	Exchange and lending of camel services for ploughing and transportation (cart) Gift of animals for marriages Gift of ghee and milk to the priest of the village	Private ownership of animals

	State	**Market**	**Community**	**Individual**
		Local markets: Sale and purchase of animals State and private veterinary services		

INSTITUTIONS RELATED TO LAND – SAWAL PROJECT

	State	Market	Community	Individual
BANKURA **SMALL LANDHOLDIND, DOMINATED BY SUBSISTENCE CULTIVATION** **PRIMARY ACTIVITY**	*Provision/Regulation*: Hereditary land property rights given under the form of land certificates to landowners and quasi property rights to sharecroppers (*bargadars*) – (registration initiated under Operation Barga, 1980) Land redistribution to landless Sharecropping rules fixed by the State: 75% of the production for the sharecropper if he bears all production costs and 50% if the landlord bears 50% of the costs (Operation Barga, 1980) *Extension and services: Krishak Sabha* = farmer organisation associated with the CPIM who provides information, trainings, the GP delivers farm inputs provided by government schemes, ADO organises trainings and provides advices *Subsidies*: depending on central scheme: mini-kits of farm inputs, loans with the Krisan Credit Card	*Among villagers:* sale, purchase and rental of land, sharecropping agreements, agricultural labour, sale of vegetables and rice, *With neighbouring villagers*: Sale of vegetables *With merchants who come to the village*: Sale of vegetables *In private shops*: purchase of inputs *Local markets:* Sale of vegetables and rice Veterinary services by government employees or private doctors	Informal arrangements to cultivate land between brothers	Private ownership of land, land inherited from father to sons, equally divided between sons
ETAWAH **PRIMARY ACTIVITY**	*Provision/Regulation*: Hereditary land property rights given under the form of land certificates to landowners	*Among villagers:* sale, purchase and rental of land, sharecropping agreements, agricultural labour organised in	Informal arrangements to cultivate land between brothers	Private ownership of land, land inherited from father to sons, equally divided

	State	Market	Community	Individual
MARKET-ORIENTED IN 2 VILLAGES, SUBSISTENCE FARMING IN ONE VILLAGE	Land redistribution to landless *Extension and services:* Trainings and information by farmers through ATMA and by ADO, information through GP, quality check of seeds by Ag Dpt *Subsidies*: subsidies for seeds of rice, wheat, pulses in government cooperatives (under the Registrar Cooperative Society) and agricultural stalls (one per block), loans for buying fertilisers in government cooperatives with the Krisan Credit card (restricted to farmers with land>5acres) Schemes for land levelling by Soil and Conservation Department	groups with a leader (paid extra for his leading role) specially for potato harvesting or individually (wage rate higher than in group), tractor hire, sale and purchase of straw, dung, *With neighbouring villagers*: Rental of land, sale and purchase of straw, dung, oil cakes *With merchants who come to the village*: Sale and purchase of animals, milk *In government cooperatives / private shops*: purchase of inputs *Local and regional markets:* Exchange, sale and purchase of vegetables and grains – many markets available	Groups of labourers headed by a leader Landowner buys fertilisers at subsidised prices for the sharecropper Groups of farmers organise trolleys to buy fertilisers and seeds collectively at the gvt cooperative Villagers cooperate to defend the access of their fields to herders from other villages	between sons
HISAR **PRIMARY ACTIVITY** **MARKET-ORIENTED AND SUBSISTENCE FARMING**	*Provision/Regulation*: Hereditary land property rights given under the form of land certificates to landowners *Extension and services:* Training and information by ADO *Subsidies*: subsidies for cotton and pulse	*Among villagers:* sale, purchase and rental of land, sharecropping agreements, agricultural labour, tractor hire *To merchants who come to the village*: Sale of agricultural products *In private shops*: purchase of inputs	Informal arrangements to cultivate land between brothers	Private ownership of land, land inherited from father to sons, equally divided between sons

	State	Market	Community	Individual
	seeds (restricted to farmers with land>5acres) Land levelling under the WSD programme (led by DRDA with GP)	*Local markets:* Sale of agricultural products		

APPENDIX B – Abstracts of publications

Journal papers

1. Clement, F., Haileslassie, A., Murty, MVR, Blümmel, M, Ishaq, S., Samad, M. Dey, S, Das, H., *(under revision)* Livelihood and Institutional Prerequisites to Alleviating Poverty through Water Productivity Increase. Insights from the Ganga Basin, *accepted in Experimental Agriculture*

Abstract: The concept of water productivity (WP) or "more crops per drop" has been revived recently in international water debates. Its application has notably been extended from single crops to mixed farming systems, integrating both crops and livestock, with the wider objective to reduce poverty. Using evidence from the Ganga Basin, we discuss the current relevance of this concept as a tool to guide recommendations for livelihood improvement and poverty alleviation. We argue that WP studies would benefit from a greater attention to the role of capitals, inequities and institutions. Firstly, recommendations would be more effective if they are tailored to the heterogeneity of capitals and capabilities of farmers among and within communities. Secondly, because poor farmers often face lack of access and control over water use, it is crucial to understand the policies and customary rules that determine water access to reduce inequities. Interventions could, thus, provide more benefits to the poorest members of communities if institutions are analysed at the outset of the study. Lastly, we have highlighted the importance of considering collective action, which has hitherto been often neglected in WP analyses.

Keywords: institutions; water access; livelihood; capitals; capabilities; India

2. Haileslassie A., Blümmel M., Murthy M. V. R., Samad M., Clement F., Anandan S., Sreeedar N. A. Radha A. V. and Ishaq, S. Understanding livestock feed and water nexus across mixed crop livestock system's intensification gradient: an example from the Indio-Ganga Basin, *accepted in Experimental Agriculture*

Abstract: The per capita water availability in the Indo-Gangetic basin is projected to be reduced to a level typical for water-stressed areas. Producing more products of crop and livestock, per unit of agricultural water invested, is advocated as one of the key strategies for future food production and environmental security. The objectives of this study were to understand the spatio-temporal dynamics of water requirements for livestock feed production, attendant Livestock Water Productivity (LWP) and implications for sustainable use of water resources. We focused on three districts representing typical crop-livestock mixed systems at different degrees of intensification: grouped as *intensive* and *semi-intensive* systems. LWP, like its counterpart Crop Water Productivity (CWP), is based on principles of water accounting and is defined as the ratio of livestock beneficial outputs and services to the water depleted and degraded in producing these. In calculating LWP and CWP, four major data sets were required: livestock, land use, land productivity, and climatic data. These data sets were obtained from secondary data sources in the representative districts. To triangulate the information, field observations were made and discussions were held with key informants. Our results showed a higher LWP value for *intensiv*e systems. The LWP value tended to decrease with time. This can be accounted for by the shift to a feeding regime that depletes more water despite its positive impacts on milk productivity. This practice deviates from the popular myth of producing more agricultural products using the same or lower quantity of water input and thus urges policy makers to optimize increasing products per unit of area and water

Keywords: South Asia; water productivity; feed quality; crop residues; sustainability

3. Haileslassie, A., Blummel, M., Samad, M, Clement, F., Ishaq, S., Adapting livestock water productivity to climate change, *accepted by the Journal of Climate Change and Management*

Abstract: Adapting livestock water demand to climate change helps to save water for ecosystems services. The main purposes of this paper were to explore effects of smallholder access to resources on Livestock Water Productivity (LWP) and to assess the impacts of selected interventions in reducing water demand per unit of livestock output. We selected 203 sample farm households representing intensive and semi-intensive systems. Household survey was undertaken to capture data on land, water and livestock management. For the analysis, sample farms were clustered: poor, medium, better-off. LWP was estimated as a ratio of livestock beneficial-outputs to depleted-water in producing livestock' feed. Impacts of selected interventions, on LWP, were analyzed using a scenario approach. Our result showed different LWP values among farm-clusters and production systems. The intensive system showed higher LWP than the semi-intensive. Dairy water consumption to produce a liter of milk was higher than the world average: ranging between 100-1,000 L. Among the farm-clusters, variation of LWP was system specific and affected by farmers' access to virtual water trading (i.e. milk and feed market). Improving milk productivity, feed quality and feed water productivity reduced livestock water demand and thus helps to mitigate the impacts of climate change. This paper reveals that LWP, in the business as usual scenario, is low. But by improving animal productivity, quality feed supply and water conservation, livestock water demand can be adapted to climate change.

Keywords: Livestock, Sustainability, Interventions, Climate change, Water saving

Papers in preparation

1. Clement, F., Venot J-P., Assessing the environmental justice of water projects and reforms in the rural south: A co-exploration of institutions and myths (*to be presented at the workshop "Global Environmental Justice: Towards a new agenda", University of East Anglia, Norwich, UK, 2-3 July 2010, to be published in a journal special issue with other workshop papers*).

Abstract: Water development projects punctuate the landscapes of the rural South where water sector reforms are endlessly pursued. On the one hand, these new projects and reforms emerge on the ground that they enhance rural livelihoods and are central for food production and sound use of natural resources. On the other hand, the social and environmental inequalities they can induce are often not properly anticipated or recognized. When acknowledged, these effects are attributed to shortcomings in implementation; the remedy is said to be further reforms and projects. In this way, water projects have locked themselves into a 'business as usual' approach, which we argue is unlikely to succeed in delivering equitable water access and control. We do so by investigating the links between procedural (which say do water users have in water development projects?) and distributive justice (how are the benefits distributed?), based on case studies of water development projects –watershed programs in Eastern India and small reservoirs in West Africa. We draw from the fields of political ecology, development and governance studies and combine institutional and discourse analysis to understand the realities of water projects and their environmental justice dimension. We defend that water projects are grounded in environmental and development narratives that are co-produced by science and policy. Those narratives wield notions of sustainability and justice as universal, hence 'black-boxing" the realities of water resources management. Crucially, and in contrast with the new vocabulary of development, they continue to regard intended beneficiaries as 'recipients' rather than actors with agency. Water projects induce new and multiple claims over resources thus influencing the distribution of goods and bads and related perceptions of justice. Global environmental justice discourses need to recognize that the fairness of any intervention is shaped by, and depends on, the vantage point considered to effectively address current issues of inequality.

2. Clement, F., Haileslassie, A., Ishaq, S., Samad, M., Institutions for equitable and sustainable improved water productivity: The case study of crop-livestock systems in the Ganga Basin (*to be presented at the International Conference of the International Association of the Commons (IASC) "Sustaining Commons: Sustaining our Future", Hyderabad, India, 10-14 January 2011*)

Abstract: In the Ganga basin in North India, water shortages are a common issue faced by farmers, even in irrigated areas. Most households in the region rely on farming systems combining crop cultivation and livestock activities. Access to and control over water supply is thus critical not only for agricultural productivity and food security but also for the production of sufficient and high quality feed for animals. Because the water requirements of animals have often been neglected or largely underestimated, scientists have recently explored the scope for increasing the water use efficiency of livestock through improved feed, animal and water management. However, there has been little research on the institutional framework required for these interventions to result not only in enhanced productivity but also in poverty alleviation and reduced inequalities. This paper addresses this gap by investigating the multi-scale and multi-sectoral institutional challenges linked with livestock water productivity interventions in North India. Three major issues are discussed: equitable access and control over water, democratic decentralisation for locally-grounded interventions, and a coordinated and integrated frame for government action. Based on observations and findings from nine case study villages across three districts of the Ganga Basin, a series of recommendations are proposed for policy-makers at district and national level.

Keywords: Livestock water productivity; access; decentralisation; cross-sectoral; Ganga Basin

3. Haileslassie, A., Blümmel, M., Clement, F., Acharya, N. S., Radha, A.V., Ishaq, S., Samad, M., 2009. Micro scale livestock water productivity: assessing option for improvement and its impacts on environmental sustainability.

Abstract: Analysis of variations of Livestock Water Productivity (LWP) across farm typology is a key element to understand intersystem variability and sets of interventions that help to addresses livelihood demands and environmental sustainability. This study was a continuation of district level study: where we suggested LWP variation across agricultural intensification gradients of crop livestock mixed systems in the Indo-Gangetic basin of India. Here, the overarching objectives were to explore effects of smallholder access to key livelihood capital on the magnitude of LWP and to assess impacts of selected interventions on sustainable water use. Intensive (i.e. higher fertilizer and water inputs e.g. Hisar, Etawah) and semi-intensive systems (i.e. limited management inputs, e.g. Bankura) were selected for this study. We used the different subsystems in intensive (*wheat-cotton*, *wheat-rice*, *millet-mustard*, *millet-pulses*) and semi-intensive (*paddy-rice*) crop-livestock systems as a sampling frame. We selected 203 sample farm households: representing the sample frame. A detail household survey was undertaken during 2009 production season to capture data on livestock, land and water management. For the analysis, the sample farms were clustered based on size of land, livestock and their access to irrigation water: described as *poor*, *medium* and *better off*. Our result showed apparently different LWP values among sample farms in different systems and farm typology. The highest LWP value was observed for wheat-cotton, wheat-rice, millet-mustard and millet-pulses systems. Among the livelihood typology, variation of LWP was system specific and affected by access to virtual water trading (e.g. milk, feed). In wheat-cotton, wheat-rice, millet-mustard and millet-pulses systems all farm clusters had better access to feed and livestock product marketing. This was the major incentive for the poor to buy feed and invest on high milking breeds and thus maintain LWP values that was comparable with the better–off farms. Contrastingly, LWP values in paddy-rice system showed a contrasting variation among the livelihood groups: with the better-off farmers showing higher LWP values compare to the poor. The

differences were accounted for by land holding size, whereby the better-off farm cluster gains more income from draught power uses. Interventions focusing on improved milk productivity, feed energy density and energy water productivity showed a promising impact: impact that demonstrated achieving livelihood demand and environmental sustainability through an integrated approach.

Keywords: livelihood capital, water, mixed systems, sustainability**,** metabolizable energy, energy water productivity, energy density, Indo-gangetic basin

4. Haileslassie, A., Blümmel, M., Clement, F., Samad, 2009. Food-feed crops water partitioning approaches to calculate Livestock Water Productivity: exploring options and limitations for sustainability indicator

Abstract: The global agricultural sector is challenged by increasing water scarcity and simultaneously growing demands for food. To contribute to the improvement of agricultural water productivity, Livestock Water Productivity (LWP) Framework was developed by earlier studies. Despite a significant achievement made in practical applications of this framework, methodological complexity deters from an easy use and better understanding of the results in terms of sustainability. For example the approaches to partitioning agricultural water (e.g. between grain and residues) and the units of expression Water Productivity (WP) are inconsistent across number of studies that were published following the framework development. The over arching objectives of this paper is to explore how the values of Livestock Water Productivity (LWP) is affected by water partitioning approaches and how the different units of expressions of LWP (e.g. USD M^{-3}; Kg M^{-3}) hid the water use efficiencies of livestock. We revisited some earlier data on livestock products and water invested to produce these products, in the Indian state of Gujarat. The total agricultural water presented in these from secondary data was subjected to different partitioning methods: harvest index; ratio of metabolizable Energy (ME) in grain and to ME in residues; ratio of financial values of grains to financial values of residue. Additionally we compared the financial (USD M^{-3}) and physical water productivity (Kg M^{-3}) units. Our results showed stronger estimates of LWP values for economic partitioning approaches while the lower LWP value was estimated for harvest index (biomass) partitioning approach. The ME partitioning approaches showed an intermediate values and thus can be proposed as a potential method of agricultural water partitioning as it evades the extremes values and also has stronger logical relation with the volume of water used by the different part of the crop. Expression of LWP using financial unit hid the higest amount of water investment per unit of product (e.g. in high price areas) thus give wrong impression on sustainable water use.

Keywords: Metabolizable Energy; South Asia; Agricultural Water; Water Productivity Framework

5. Ishaq, S., Clement, F., Samad, M., Acharya N. S., Dey A., Radha, A.V., Blümmel, M., Haileslassie, A., and Khan M. A. Triple burden, dual responsibility and single returns: Assessing roadblocks in dairy livestock improvement of landless and land poor livestock keepers from a gender perspective

Abstract: Livestock keeping is an important activity among rural households and the role of women in livestock care has also been well documented. In landless and land-poor households, women usually perform more tasks related to livestock than among large landholders (water-rich farmers). However their benefits from livestock activities are much lower and generated income only meet subsistence needs. In this paper, we assess the constraints that women from landless and land poor households face while undertaking livestock based occupations. The argumentation is based on two case study villages in Hisar and Bankura district in the Ganga Basin. Results indicate that

constraints are not only rooted in poor access to resource base and lack of organizational support but also catalyzed by the "men" factor.

Keywords**:** livestock; gender; poverty

6. Radha, A.V., Acharya N. S., Clement, F., Samad, M., Haileslassie, A., Ishaq, S., Estimation of livestock feed availability using vegetation reflectance in the Ganges river basin, India

Abstract: In the context of an increasing need for information on livestock feed resources availability and a lack of reliable data, there is scope to use remote sensing techniques to fill this knowledge gap. This study focused on using satellite images to estimate the livestock feed availability in three different agro ecological zones of the Ganges basin. The use of Landsat ETM+ data with advanced analytical methods such as vegetation index techniques are particularly pertinent to evaluate livestock feed availability and land use patterns, as demonstrated in this study. The latter has great applications for many planning and management activities. The term land cover relates to the type of feature present on the surface of the earth and the term land use relates to the human activities associated with a specific piece of land. Land use and land cover maps were combined with other secondary data viz., Standard Livestock Unit and Livestock Unit Per capita, in order to map feed surplus and deficit in three different districts. The results have been validated with secondary data collected from different sources. These techniques will help the planners and researchers in understanding feed availability and requirement at different scales and support decision-making in agriculture and livestock interventions.

Keywords: Feed Resource, Livestock Census, Vegetation reflectance, Landsat ETM+, Remote sensing, Ganges Basin, India

Conference proceedings

1. Haileslassie A., Blümmel M., Murthy M. V. R., Samad M., Clement F., Anandan S., Sreeedar N. A. Radha A. V. and Ishaq, S. 2009. Understanding livestock feed and water nexus across mixed crop livestock system's intensification gradient: an example from the Indio-Ganga Basin p. 98. In Chandrasekharaiah M., Thulasi A., Suganthi U. and Pal D. T. (Eds) 2009. Diversification of Animal Nutrition Research in the Changing Scenario, Volume I , 17-19 December 2009, Bangalore, India

Abstract: The per capita water availability in the Indo-Gangetic basin is projected to be reduced to a level typical for water-stressed areas. Producing more products of crop and livestock, per unit of agricultural water invested, is advocated as one of the key strategies for future food production and environmental security. The objectives of this study were to understand the spatio-temporal dynamics of water requirements for livestock feed production, attendant Livestock Water Productivity (LWP) and implications for sustainable use of water resources. We focused on three districts representing typical crop-livestock mixed systems at different degrees of intensification: grouped as *intensive* and *semi-intensive* systems. LWP, like its counterpart Crop Water Productivity (CWP), is based on principles of water accounting and is defined as the ratio of livestock beneficial outputs and services to the water depleted and degraded in producing these. In calculating LWP and CWP, four major data sets were required: livestock, land use, land productivity, and climatic data. These data sets were obtained from secondary data sources in the representative districts. To triangulate the information, field observations were made and discussions were held with key informants. Our results showed a higher LWP value for *intensive* systems. The LWP value tended to decrease with time. This can be accounted for by the shift to a feeding regime that depletes more water despite its positive impacts on milk productivity. This practice deviates from the popular myth of

producing more agricultural products using the same or lower quantity of water input and thus urges policy makers to optimize increasing products per unit of area and water

Keywords: South Asia; water productivity; feed quality; crop residues; sustainability

2. Haileslassie, A., Blummel, M., Clement, F., Descheemaeker, K., and Samireddypalle, A., (2010). Building resilience of rain fed production systems to climate change: livestock water productivity perspectives. Proceedings of the National Symposium of Climate Change and Rain fed Agriculture held at CRIDA, 2010, Volume II 398-400. Hyderabad, India

Abstract: The per capita water availability in the Indo-Gangetic basin is projected to be reduced to a level typical for water-stressed areas. This increases the vulnerability of agricultural systems to climate change induced shock. The objectives of this study were to understand the spatial dynamics of water requirements for livestock feed production, resulting Livestock Water Productivity (LWP) and their implications for systems and vulnerable community groups' adoption to climate change. LWP is defined as the as a ratio of livestock's beneficial outputs (e.g. in physical, financial or energy terms) and services to the water depleted in producing feed for livestock. We compared two districts representing typical crop-livestock mixed systems of irrigated (Hisar) and rain fed agriculture (Bankura). Data on livestock, land use and climate were collected from the study districts (1992-2003). Detailed household survey was conducted in 2009 to have better insight on variability of LWP across farm typology and the most vulnerable group. Our results showed a lower LWP value for rain fed systems compared with the irrigated system. This can be accounted for by lower productivity of livestock and their feed, whereby the latter induced higher water requirements per unit of livestock products. Unlike the irrigated system, in rain fed systems there is less access to virtual water trading (e.g. marketing for animal products and feed) and thus farmers are not enthusiastic to invest in livestock development. This is particularly important for the poor farmers who are more dependent on communal grazing areas for their livestock feed. Therefore improvement in feed productivity, feed quality, livestock management and access to market will help to build rain fed systems' resilience to climate change.

Keywords: South Asia; feed productivity; feed quality; crop residues; sustainability

APPENDIX C – List of participants to the district and national workshops

BANKURA DISTRICT
District level workshop, 8th March 2010, Circuit House, Bankura.

Sl No.	Name	Designation	Organisation
1	P.P. Majumdar	Sabhadhipati	Zilla Parishad, Bankura
2	M.G. Ali Ansari	District Magistrate	Govt of West Bengal
3	Swarup Singha	Karmadhakhya, Krishi O Sech	Zilla Parishad, Bankura
4	Ajay Kumar Ghosh	Additional District Magistrate (Development)	Govt of West Bengal
5	Ashis Kumar Sinha	PD	District Rural Development Cell, Govt of West Bengal
6	Floriane Clement	Post Doctoral Fellow	IWMI, Hyderabad
7	Amare Haileslassie	Post Doctoral Scientist	ILRI, Hyderabad
8	Venkata Radha A	Scientific Officer	IWMI, Hyderabad
9	Madar Samad	Director, South Asia	IWMI
10	N. Sreedhar Acharya	Senior Officer	IWMI
11	Saba Ishaq	Senior Scientific Officer	IWMI
12	K P Karmakar	Asst. Divisional Forest Officer	Govt of West Bengal
13	Madhab Kisku	Farmer, Jhagradihi	Saltora
14	Durgadas Hansdah	Farmer, Udaypur	Saltora
15	Sunil Soren	Farmer, Lakhipur	Saltora
16	Sumitra Hansdah	Farmer, Udaypur	Saltora
17	Laboni Soren	Farmer, Lakhipur	Saltora
18	Achala Kora	Farmer, Chatinbaid	Saltora
19	Badani Kisku	Farmer, Jhagradihi	Saltora
20	Nikhilesh Mondal	District Nodal Officer,	NREGS cell, Bankura, Govt of West Bengal
21	Arindam Roy	District Panchayat & Rural Development Officer, Bankura	Govt of West Bengal
22	Dr S W Kole	Dy. Director of textile (Sericulture)	Govt of West Bengal
23	B K Layek	Asst. Director of textile (Sericulture)	Govt of West Bengal
24	B. G. Holkar	Manager (SIP)	Damodar Valley Corporation, Bankura
25	Ashoke Kumar Sar	Asst. D. Agri. (Admin)	Soil Conservation, Bankura, Govt of West Bengal
26	Sandip Layek	Asst Engr. (AM), Bankura I	Water Resources Investigation and Development, Govt of West

			Bengal
27	Dr Swarup De	Asst. Director ARD (MI)	Govt of West Bengal
28	Sri N Panda	Asst. Divisional Forest Officer, Panchet Division	Panchet forest Office, Bishnupur, Govt of West Bengal
29	Jayanta Das	EE(AI) Bankura	Water Resources Development Directorate (WRDD)
30	Shyamal Kr Mondal	District Planning Officer, Bankura	Govt of West Bengal
31	Angshuman Mandal	Manager, Panchet	Damodar Valley Corporation
32	Biswajit Barat	Center in Charge	Natural Resource Data Management System cell, Bankura, Govt of West Bengal
33	Arnab Chakraborty	Programme Director	PRADAN
34	Himangshu Das	Executive (Project)	PRADAN
35	Rajsekhar Bandyopadhyay	Executive (Project)	PRADAN
36	Suman Mitra	Sr Asst (FAA)	PRADAN
37	Soumik Kar	Executive (Project)	PRADAN
38	Biswajyoti Basu	Development Apprentice	PRADAN
39	Pintu Das	Executive (Project)	PRADAN
40	Rajesh Mit	Team Leader	PRADAN
41	Rammoy Patra	Deputy Director of Agriculture, Bankura	Govt of West Bengal
42	Arnab Bose	Executive (Project)	PRADAN
43	Madhumita Nath	Executive (Project)	PRADAN
44	Anjana Ghosh	Executive (Project)	PRADAN
45	Sudip Ghosh	Executive (Project)	PRADAN
46	Prasenjit Maondal	Executive (Project)	PRADAN

HISAR DISTRICT
District level workshop, 12th March 2010, Central Institute of Research on Buffaloes (CIRB), Hisar

S. No	Name of the Participant	Designation	Organization
1.	Parveen Kumar	Sub-Divisional Agriculture Officer	Agriculture Department Hisar, Govt of Haryana
2	Om Prakash	Farmer	Basra
3.	Dharam Singh	Sarpanch	Gram Panchayat, Basra
4.	Bir Singh	Farmer	Basra
5.	Sohan Lal	Farmer	Basra
6.	Satyawan	Sarpanch (and local village resource person)	Gram Panchayat, Mugalpura
7.	V.B. Dixit	Principal Scientist	CIRB
8.	Hardeep Kmar	Agricultural Development Officer, Uklana Block	Agriculture Department Hisar, Govt of Haryana
9.	Sunil Kumar	Farmer (and local village resource person)	Mugalpura
10.	P.K. Jena	Lecturer	Guru Jambeshwar University, Hisar
11	Shilap Gulia	Student	
12.	Neelam Sharma	Student	
13.	Poonam Devi	Student	
14.	Shakoor Khan	Student	
15.	Rachna Rani	Student	
16.	Satish Sharma	District Youth Club Leader	Nehru Yuva Kendra -Hisar
17.	R.P. Narwal	Director -Research,	CCSHAU- Choudhary Charan Singh Agriculture University-Hisar
18.	D. Lal	Principal Scientist	CIRB
19.	A. S. Kumar	Veterinary Specialist Group	Animal Husbandry Department, Hisar, Govt of Haryana
20.	Raj Kumar	Local resource person	Hisar
21.	Amare Haileslassie	Post Doctoral Fellow	ILRI
22.	Saba Ishaq	Senior Scientific Officer	IWMI
23.	Floriane Clement	Post Doctoral Fellow	
24.	Venkata Radha	Scientific Officer	
25.	Sreedhar Acharaya	Senior Scientific Officer	
26.	Satyawan	Chairman	BS, Hansi II
27.	P.C. Lamba	Senior Scientist	CIRB
28.	A. Bhardawaj	Principal Scientist	CIRB
29.	Brij Lal	President Zilla Parishad, Hisar	Govt of Haryana
30.	Amitav Dey	Senior Scientist	ICAR
31.	Vijay Sagnwan	Deputy Director	CIRB
32.	Indrajeet	Principal Scientist	CIRB
33.	A.P. Nehra	Senior Extension Specialist	Chaudhary Charan Singh Agricultural University, Hisar

34.	Ramgopal	Member	Gram Panchayat, Mugalpura
35.	Lal Chand	Member	
36.	Pratap Singh	Member	
37.	Ram bahagat	Member	
38	Sunil	Member	
39	Jaybeer	Member	
40	Sandeep Kumar	Member	
41.	Jitendra Kumar	Subject Matter Specialist (T&I)	Agriculture Department Hisar, Govt of Haryana
42	Rajkumar	AAO	CIRB
43.	Jai Kumar	Assistant	CIRB
44.	Pawan Kumar	Local resource person	Basra

ETAWAH DISTRICT
District level workshop, 18th March 2010, Krishi Vigyan Kendra , Etawah

S. No	Name	Designation	Organisation
1	Prem chand Dwedi	Project Director	Rural Development and Planning, Gvt of Uttar Pradesh
2	Mahindra singh	Deputy Director (Agri)	Agriculture Dept. , Gvt of Uttar Pradesh
3	J.P Shrivastawa	Chief Veterinary Officer	Animal Husbandry Dept., Gvt of Uttar Pradesh.
4	R.K.Sharma	Veterinary Officer	
5	Yogendar Singh	Veterinary Officer	
6	R. B.Lal	Veterinary Officer	
7	Lamba	Veterinary Officer	
8	G.S.Bhaskar	Executive Engineer	Canal Irrigation Dept., Gvt of Uttar Pradesh
9	G.R Shakya	Executive Engineer	
10	Munshilal	Junior Engineer	Tubewell Irrigation Dept
11	Mahesh Chandra	Nazir	District Rural Development Agency (DRDA)
12	Rajendra Singh	Accountant	DRDA
13	Shankar Singh	Programme Coordinator	Krishi.Vigyan.Kendra (KVK) Etawah
14	M.N. Tripathi	Subject Matter Specialist, Plant.Protection	
15	Vinod Prakash	Subject Matter Specialist, Extension	
16	Sunita Mishra	Subject Matter Specialist, Science	
17	A. Warsi	S.M.S (Agronomy)	
18	Rajeev Chauhan	General Secretary	SCAN Etawah
19	L.N. Shukla	Manager	Global Dairy Farmers
20	R.B Upadhya	Chairman	ATMA
21	Anil Mishra	Farmer	Chandanpur
22	Hari Tewari	Farmer	Dadra
23	Survesh Tiwari	Farmer	Pachdeora
24	Shanker Tiwari	Farmer	Pachdeora
25	R.K.Tiwari	News Correspondent	A.C.N.Etawah
26	Ram Ji	News Correspondent	A.C.N.Etawah
27	Rajendra Singh	Block Development Officer, Barhoura block	Govt of Uttar Pradesh
28	Awadhesh Yadav	Agriculture Development Officer Saifai block	Agriculture Department, Govt of Uttar Pradesh
29	Badam Singh	P.E.O	Animal Husbandry Dept., Govt of Uttar Pradesh
30	Pradeep Yadav	Veterinary Officer	
31	Venkata Radha	Scientific Officer	IWMI
32	Floriane Clement	Post Doctoral Fellow	
33	Saba Ishaq	Senior Scientific Officer	
34	Amare Hailesslassie	Post Doctoral Fellow	ILRI
35	D.N.Shindey	Vice President	BAIF

NATIONAL WORKSHOP, NEW DELHI,
27th March 2010, NASC Complex, Training hall

S. No	Name	Designation	Organisation
1	Madar Samad	Regional Director South Asia	IWMI
2	D.N. Shindey	Vice President	BAIF
3	M.A. Khan	Director, and Benchmark Basin Coordinator for Challenge Programme.	ICAR Research Complex for Eastern Region, Patna
4	Bharat Sharma	Senior Agricultural Water Management Specialist/ Head Delhi Office	IWMI
5	Rajesh Mit	Team Leader of Bankura District	PRADAN
6	R.K. Batta	Principal Scientist	ICAR HQ, Natural Resource Management Division
7	Amitav Dey	Senior Scientist	ICAR Research Complex for Eastern Region, Patna
8	R.N. Singh	Joint Director	Animal Husbandry Department, Hisar, Govt of Haryana
9	A.S. Nanda	Director of Research	Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab
10	A. K. Dhawan	General Manager	Milkfed, Chandigarh, Punjab
11	Sangeeta Agarwal	Programme Manager	WWF
12	D.B.V. Ramana	Senior Scientist	Livestock Production Management, Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad
13	Suparna Katyaini	Research Associate	Water Resources Division, The Energy and Resources Institute (TERI), New Delhi
14	Md. Faisal	Scientist	Centre for Environmental Management of Degraded Ecosystems (CEMDE) University of Delhi
15	Floriane Clement	Post Doctoral Fellow	IWMI
16	A. Venkata Radha	Scientific Officer	
17	N. Sreedhar Acharya	Senior Scientific Officer	
18	Saba Ishaq	Senior Scientific Officer	
19	Amare Haileslassie	Post Doctoral Fellow	ILRI
20	B.K. Mishra	Region In Charge	BAIF
21	Baldev Singh	Joint Director (Feed and Fodder)	Animal Husbandry Department, Govt of Punjab
22	D.K. Mehta	In charge of irrigation projects in northern regions & Industrial Issues in Indus Ganga Basin	Central Water Commission
23	Pragati Maity	Senior Scientist	Central Soil Salinity Research Institute, Division

			of Irrigation & Drainage Engineering, Karnal
24	Subir Mitra	Senior Manager	National Dairy Development Board, Anand
25	Upali Amarasinghe	Senior Researcher	IWMI
26	Arnab Chakraborty	Programme Director	PRADAN

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