Public–private partnerships in watershed management – evidence from the Himalayan foothills

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Abstract

Public–private partnerships have emerged in recent years as an important policy option to ensure service provision in the water resources sector. However, there is very little analysis of past experience of partnerships between the public sector and various arms of the private sector: water companies, NGOs or even farmer groups. Further, there is limited conceptualisation of what is meant by partnerships between the public and private sectors. This paper draws on a study of watershed management in Haryana to analyse the evolution of public–private partnerships in natural resource management. The paper finds that the public sector has an important role to play in facilitating design of an institutional contract that clarifies water rights and rules for benefit sharing and conflict resolution. Interestingly, the paper finds that when a proper institutional structure is in place, well-endowed individuals with sufficient interest in a common pool good (like an irrigation system) may emerge to provide irrigation services with positive equity and efficiency outcomes for the environment and rural communities. However, the paper argues that state parastatals have an important role to play in monitoring the impact of watershed management on traditionally marginalized groups like women and landless and coordinating inter-sectoral policy change to ensure that public–private partnerships can be sustained in the long term.

Keywords: Public–private partnerships; Irrigation management transfer; Collective action; Watershed management

1. Introduction

In recent years decentralised development approaches have gained wide acceptance in policy circles. In the agriculture sector in particular, irrigation management transfer (IMT) and joint forest management (JFM) policies have been promoted with a view to facilitate integrated management of natural resources

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in a watershed context. IMT and JFM policies typically refer to devolving management of previously publicly controlled forests or irrigation systems to farmer groups or other private-sector entities (International Water Management Institute (IWMI), 1995: 4). Donor supported JFM and IMT projects in particular have emphasised the need for community participation in undertaking tasks of catchment protection, water allocation, collection of irrigation service fees (ISFs) and routine maintenance of irrigation infrastructure, like water harvesting dams (ADB, 2001).

IMT as a strategy has gained wide acceptance in policy circles for a variety of reasons. First, it is has been demonstrated that IMT has the potential to reduce the budgetary burden of operating and maintaining irrigation systems on the user state. Second it is claimed that IMT policies have the potential to improve irrigation system performance and productivity. Third IMT has the potential to enhance sustainability and reduce the detrimental environmental impact of irrigation management. Among the driving forces that have influenced spread of IMT policies worldwide is the perception that public irrigation agencies lack the incentives to optimise management performance and that farmers have a direct interest in ensuring cost-effective irrigation management. It is assumed that a management system that is accountable to farmers will be more equitable and that equity considerations would be better addressed where beneficiaries bear the costs of service provision (IWMI, 1995: 2–3).

In recent years farmer managed irrigation (FMI) projects have experimented with transfer of management responsibility for groups of separate systems (intake, distribution and drainage) to management entities under farmer control. Saleth (1999: A87–A88) in discussing options for public–private partnerships in irrigation management in India highlights four configurations: build-own operate system (B-O-O), build-own sell system (B-O-S), build-own transfer system (B-O-T) and lease-own operate system (L-O-O). He concludes that the L-O-O system has the greatest potential in promoting “multiplayer-centred private participation” whereby the tasks of water distribution, fee collection and system maintenance are undertaken by private entities leasing an irrigation system. In Saleth’s view the key policy issues involved in the L-O-O system are determination of lease payment, the period of lease and an acceptable minimum maintenance requirement.

Notwithstanding the interest in farmer management of water resources, it has been pointed out that merely devolving responsibility to farmer groups does not necessarily guarantee efficient management (Kurian, 2003). This may be the case especially when farmer groups lack financial resources to participate effectively in irrigation management through payment of ISFs or by committing monetary resources towards routine maintenance of irrigation infrastructure. For example, a study on participatory natural resource management in Zimbabwe revealed that even when a community appears well-motivated, dynamic and organised, inadequacy of material resources may present severe limitations (Cleaver, 1999: 604). Resource constraints may also limit remote communities’ ability to lobby effectively with district authorities or donor agencies on issues related to management of natural resources.

The lack of financial resources within farmer groups should not be mistaken for a complete absence of resources, though. A number of recent studies emphasise that rural groups are internally differentiated on the basis of wealth and agricultural income (see Leach et al., 1999). Therefore, heterogeneous groups have the potential to produce local leaders that are capable of organising farmers, resolving conflicts and ensuring equity in distribution of benefits from a common pool resource (Vedeld, 2000; Poteete & Ostrom, 2003). Such perspectives tend to lend support to the growing interest in public–private

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1 A watershed refers to a geohydrological unit that drains at a common point (Brooks et al., 1992)
partnerships in management of water resources (ADB, 2000). The debate on public–private partnerships in water resources management highlights the potential role that well-endowed farmers can play in providing irrigation services (Dietz, 2000; Wang, 2002).

This paper attempts to enrich the debate on public–private partnerships through an analysis of a watershed management programme in the Shiwalik hills of Haryana. The Haryana watershed management programme is a particularly good choice for institutional analysis as it was one of the three programmes worldwide awarded the United Nations Environment Program’s Saving the Drylands prize in 1997 for successfully establishing public–private partnerships in natural resources management (http://www.unep.org/unep/envpolimp.techcoop/1.htm). The focus of the paper is on the evolution of state policies, natural resource management (NRM) strategies of state parastatals and collective action within farmer groups (Hill Resource Management Societies) vested with the responsibility of managing forest and water resources in the Shiwalik hills, Haryana. The research questions posed by this paper are:

- How does change in state policies over time, and spatial differences in implementation of natural resource management strategies by state parastatals, influence evolution of contractor-based provisioning of irrigation services under a watershed management programme?
- What are the micro-level institutional processes that mediate irrigation service provisioning by private contractors? For instance, how does access to groundwater through private tubewells influence potential for irrigation service provision by water contractors? Further, what role do social norms play in influencing compliance of water users with rules governing use of water from an irrigation system managed by a private contractor?
- What implication does operation of contractor-based irrigation service provisioning have for equity in benefit distribution and efficiency of water use? For instance, how are equity issues relating to head-end–tail-end water allocation, collection of user fees and farmer contribution towards routine maintenance of physical assets addressed? Further, what implication does contractor-based water provisioning have for environmental change?

The following sections of this paper are organised as follows. Section 2 outlines the research methods adopted for this study. Section 3 lays out the key features of public–private partnerships as they have evolved in the Shiwalik hills of Haryana. Section 4 discusses the role of contractors in water provisioning and discusses the role of peasant differentiation: trends in the regional economy, agricultural production strategies and non-farm employment engaged in by peasant households, the role of historically defined power and social exchange relations in influencing compliance with irrigation service rules and the implications of rule compliance for equity and efficiency of water use. Section 5 highlights the main conclusions of the paper.

2. Data and methods

2.1. Rapid survey of HRMS

Sixty two Hill Resource Management Societies (HRMS) were established in the Morni-Pinjore and Yamunanagar Forest Divisions during the watershed management project in Haryana. These 62 HRMS
were responsible for managing 96 earthen dams\(^2\). Our study focuses on the HRMS in the Morni-Pinjore division of Panchkula District for two reasons: (i) the watershed management project was initially started in the area and (ii) external intervention in the form of NGO visits was minimal between 1996 and 2000. This study covered 28 HRMS responsible for managing 45 earthen dams. Our survey of the 28 HRMS in the Morni-Pinjore Forest Division was undertaken over a period of one month in which information was collected on variables like group composition, access to alternative irrigation sources and participation in management of earthen dams. The highlights of the survey of 28 HRMS included:

- Human populations in Shiwalik villages rely on forest area to meet a substantial part of their subsistence needs for fuel wood and livestock fodder from forest areas.
- Agriculture is the predominant occupation of Shiwalik villages. However, in villages located near towns and cities non-agricultural employment usually takes the form of engagement in house construction activity and gatekeepers in factories. Closer to village settlements employment in stone quarrying and soil and water conservation activities sponsored by the Forest Department is available although it is, however, low payed and unpredictable.
- Access to irrigation offers the potential to double agricultural yields of wheat crop during the winter period. Irrigation from earthen dams typically benefits up 35 households in a micro-watershed. Water allocation is by hourly rotation starting with head-end water users and ending with those with plots at the tail end of an irrigation system. Water user fees are charged by the hour ranging from (Indian Rupees) Rs 10 per hour to Rs 25 per hour. Depending on the composition of the village there are usually multiple caste groups benefiting from irrigation from earthen dams.
- Only eight earthen dams from a total of 45 that were constructed in Morni-Pinjore Forest Division of Haryana were functioning when data for this study was collected in June 2000. The eight functioning dams were under the management of eight HRMS. A large number of dams had silted up or had been washed away much before their expected “shelf life” of about 10–15 years had been achieved. This failure was because of a number of technical failures relating to location of head works and quality of construction.

2.2. Case study

Two of the eight HRMS with functioning dams – Bharuali and Thadion – were selected for a comparative case study. Two rounds of household surveys were undertaken to cover all households in the study sites of the Bharauli and Thadion HRMS. The household surveys collected information on household demography, cropping patterns, asset ownership and participation in management of water harvesting dams. In addition to structured interviews, focused interviews and group discussions were undertaken. Data for the case study was collected over a 10-month period between March and December 2000.

Based on data collected during structured interviews, households were stratified on the basis of ownership of endowments into high, medium and low categories\(^3\). Analysis of irrigation management at both study sites also benefited from an examination of changes in household endowments over a

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\(^2\) It is important to note that a one to one correspondence between HRMS and dams does not exist. This is because some HRMS like Sukhomasiri had more than one dam under their management. Further, some dams were constructed in areas where no HRMS existed or HRMS were constituted were no dams were constructed.

\(^3\) The presentation of calculation of household endowment scores is shown in Appendix 1.
four-year period between 1996 and 2000. Household-level information on asset ownership was available from a survey undertaken in May 1996. Satellite imagery of land-use changes at the study sites was visually interpreted based on National Remote Sensing Agency (NRSA) photographs taken in April 1999 (NRSA, 1999). Land-use changes that took place in the Bharauli watershed between 1966 and 1999 were examined by overlaying 1999 satellite imagery onto Survey of India topography sheets of 1966. Map Info computer software was used to arrive at quantitative estimates of changes in land use.

3. Evolution of public–private partnerships in watershed management, Shiwalik Hills, Haryana

3.1. Sukhomajiri watershed model – institutionalising a link between forests and agriculture

Panchkula district has the largest proportion of land under forests in Haryana. As a result the district has been a particularly important focus of participatory forestry projects. Since the early 1980s a spate of community forestry initiatives have been undertaken: social forestry, joint forest management and the Haryana community forestry project. The Haryana Joint Forest Management Project was responsible for developing an integrated model of watershed management based on experiments that were undertaken in the village of Sukhomajiri between 1975 and 1985 (Arya & Samra, 1995). From the point of view of the Haryana Forest Department (HFD) the Sukhomajiri watershed management intervention was crucial to reduce silting of the Sukhna reservoir located further downstream in the state capital of Chandigarh. The Sukhomajiri model was premised on the idea that a linear relationship exists between the condition of forests located in the Shiwalik Hills and agricultural productivity in low lying plains (see Appendix 2). As a result fodder production on private fields was encouraged through provision of irrigation from earthen dams in the expectation that greater fodder and dung production from irrigated fields would obviate the need to use state-owned forests for fodder and fuel wood extraction. Between 1984 and 1989 an attempt was made to scale up or replicate the Sukhomajiri watershed model to about 65 micro-watersheds located in the Morni-Pinjore Forest Division of Panchkula District in Haryana. An important feature of the scaling up phase of the project was the creation of institutional mechanisms for sharing revenue from state forests with local communities. Seven features of the institutional contract that characterised joint management of watershed resources are worth highlighting (TERI, 1998):

- Water user associations were constituted as HRMS under the Registration of Societies Act. 1900. HRMS were given the opportunity to lease out rights to harvest fibre grass from state-owned areas. Similarly rights to harvest water from earthen dams located in state-owned forests were also leased out annually. The price of the lease is determined based on the average price of the product for the previous three years.
- Lease rights for fibre grass/water could be managed by a managing committee of a HRMS or management functions could be further devolved to a private contractor at annual auctions convened by the HRMS. In the case of fibre grass the private contractor had to ensure that at least two head

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4 Cattle dung is used extensively as a cooking fuel in the Shiwalik region. It was assumed that increased production of cattle dung would reduce pressure on state forests for supply of fuel wood for cooking purposes.

5 For administrative purposes the Morni-Pinjore Forest Division is further subdivided into three forest ranges – Pinjore, Panchkula and Raipur Rani.
loads of fibre grass were made available to each HRMS member household to meet subsistence requirements before they were sold to commercial enterprises like paper mills.

- Water private contractors had to ensure that landless households were given a share of water from dams provided they were members of the HRMS. Attempts were made to institute a system of tradable water shares so that landless households could sell their share of water to other households.

- An important principle that followed regarding use of HRMS funds was that a proportion of profits derived by the water contractor from the sale of water from dams (and fibre and fodder grasses) were to be deposited in the HRMS common fund. A proportion of these funds could then be used for community development activities such as construction of village roads, repair of school buildings or construction of rest areas for labourers.

- Membership issues were tackled, especially in cases where not all members in a village could benefit from water supply from dams. Further, where the HRMS comprised two or more villages, attention was paid to issues like how revenue raised from sale of water (and fibre and fodder grasses) could be spent.

- At least a third of positions on the managing committee of the HRMS are to be reserved for women. Every woman in a household was entitled to membership as distinct from membership of the male head of household in the general body of HRMS.

- The Haryana Forest Department (HFD) facilitates participation of community groups in watershed management by organising annual elections of managing committees of HRMS and monitoring annual auctions of fibre grass and water harvesting rights to forests under joint management.

3.2. Declining market in fibre grass and changes in fiscal regime – implications for farmer participation

Public–private partnerships in natural resource management are influenced by changes in external conditions. In the case of watershed management in Haryana, we note for example that changes in import policies of the central government had an impact on the extent of farmer participation in management of forest and water resources. Changes in policies of the central government also influenced the quantum of funds available with HRMS to undertake routine maintenance of earthen dams.

Fibre grass from the Morni-Pinjore Forest Division was traditionally supplied to the Ballarpur paper mills in Yamunanagar and the Pawmi paper mills in Barotiwala in Himachal Pradesh. The central government’s liberalisation of raw material imports in 1993 made it cheaper for paper mills to use imported softwood pulp rather than rely on traditional sources like forest departments. In the case of the Pawmi mill, for instance, prior to 1993 the mill relied on 1200 metric tonnes of imported softwood pulp from Sweden, the UK and Canada to meet half of its raw material requirements. The balance was met by procuring some 1500 metric tonnes of fibre grass annually from HRMS and purchasing some 500 metric tonnes of wheat stalk per month. But with cheaper imported raw materials becoming readily available, reliance on fibre grass and wheat stalk declined\. Transition to cheaper raw material imports also explains the decision of Ballarpur paper mill in 1998 to stop sourcing fibre grass from forests under management of HRMS. Another factor influencing paper mills’ decision to look for alternative raw materials was the 10% higher labour costs of using fibre grass.

As we observed above, HRMS gross profits were adversely affected by the decline in markets for

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\(^6\) For a general discussion of trends in international prices of paper and supply of raw materials by forest departments, see Kurian (1998).
fibre grass. As a result within a couple of years the HRMS showed little interest in leasing out fibre grass rights from the HFD. These trends were bound to affect severely gross profits of HRMS and subsequently revenues of the forest department (Table 1). So in 1998 the forest department brought out a set of rules that stipulated that the HRMS were to share a proportion of their profits from the sale of fibre grass with the HFD. Some argue that the forest department’s taxation regime impeded the HRMS from ploughing back profits into community development or resource conservation tasks (CSE, 1999).

3.3. Declining markets for fibre grass: implications for repair of earthen dams

The link between forests in catchment areas and agricultural fields is critical in conceptualising resource degradation in the Shiwalik hills. Two basic features characterise the link between forests and agriculture. First, soil erosion in forest areas leads to silting of earthen dams, which would consequently compromise agricultural productivity. Second, most HRMS funds derived from the sale of fibre grass are known to have been channelled towards the repair of the earthen dams. A study of HRMS investment patterns found the main share of HRMS funds had been invested in construction/repair of a village hall, followed by construction/repair of temples and earthen dams (Datta & Varalakshmi, 1999: 117). However, the ability of the HRMS to channel funds from the sale of fibre grass towards repair of earthen dams was severely curtailed by declining markets, owing to limited demand for fibre grass from paper mills.

Table 1. Gross profits of HRMS in Morni Pinjore Forest Division.

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<tbody>
<tr>
<td>Sukhomajiri</td>
<td>73,380</td>
<td>23,690</td>
<td>NA</td>
<td>Pinjore</td>
</tr>
<tr>
<td>Dhamala</td>
<td>112,015</td>
<td>27,690</td>
<td>NA</td>
<td>Pinjore</td>
</tr>
<tr>
<td>Lohgarh</td>
<td>273,890</td>
<td>111,890</td>
<td>NA</td>
<td>Pinjore</td>
</tr>
<tr>
<td>Jattamajiri</td>
<td>28,630</td>
<td>22,590</td>
<td>NA</td>
<td>Pinjore</td>
</tr>
<tr>
<td>Surajpur</td>
<td>43,450</td>
<td>NA</td>
<td>NA</td>
<td>Pinjore</td>
</tr>
<tr>
<td>Bharauli</td>
<td>42,000</td>
<td>29,500</td>
<td>Did not lease</td>
<td>Raipur Rani</td>
</tr>
<tr>
<td>Thadion</td>
<td>27,700</td>
<td>20,000</td>
<td>25,500</td>
<td>Raipur Rani</td>
</tr>
<tr>
<td>Rana</td>
<td>25,500</td>
<td>14,000</td>
<td>10,000</td>
<td>Raipur Rani</td>
</tr>
<tr>
<td>Mirpur</td>
<td>31,500</td>
<td>19,000</td>
<td>9000</td>
<td>Raipur Rani</td>
</tr>
<tr>
<td>Masoompur</td>
<td>102,000</td>
<td>70,000</td>
<td>42,600</td>
<td>Raipur Rani</td>
</tr>
<tr>
<td>Govindpur-Mandpa</td>
<td>28,500</td>
<td>16,000</td>
<td>20,000</td>
<td>Raipur Rani</td>
</tr>
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NA = Information not available.
* All values in Indian Rupees.

7 A sales tax (23.8%) and a HFD tax (25%) were imposed on gross profits from fibre grass sales. Subsequently, 30% of what remained after imposition of the HFD tax was deposited in a joint account operated by the Divisional Forest Officer and the president of the HRMS. Ten percent of what remained after imposition of the HFD tax was deposited in a common fund or kalyan kosh. Sixty percent of what was left after imposition of the HFD tax was deposited in the HRMS account. Our survey of HRMS in the Morni-Pinjore Forest Division shows that such taxation of proceeds dramatically reduced the net profits accrued by community organisations. For instance, in the case of Sukhomajiri HRMS barely 42% of gross profits from fibre grass sales remained with the local community.
3.4. Natural resource management strategies of state parastatals – importance of transparent and accountable procedures

In addition to changes in state policies, spatial differences in implementation of NRM strategies by state parastatals like irrigation or forest departments can have an influence on the trajectory of public–private partnerships. This fact is highlighted by varied success in ensuring compliance with the principle of catchment stabilisation during project implementation. The catchment stabilisation principle basically emphasises the need to form village forest management organisations prior to dam construction. Village-based organisations were to institute rules regulating access to state forests for fuel wood, fodder and fibre grass. In response to regulated use of forest areas, earthen dams could be built. The assumption was that the regulated forest use would have stabilised rates of soil erosion and, as a result, increased the lifespan of the dams. Our analysis of earthen dams in the post-project phase reinforces the importance of institutions for catchment protection (Table 2).

We note that approximately 31% of all dams in the Morni-Pinjore Forest Division silted up within five years of construction and 33% within 10 years of construction. Interestingly 20% of dams constructed functioned for less than a year! A range-wide analysis highlights the importance attached to watershed institutions during the different phases of the scaling up. We notice there are two clear periods of dam construction in which it is possible to discern a relationship between watershed institutions and the lifespan of dams. The first period that extended between 1984 and 1989 covered the Panchkula forest range. This was a period in which scant attention was paid to institutional issues related to setting up water user groups. Instead emphasis was purely on constructing earthen dams. As a result half of the dams silted up within five years of construction.

During the second phase of dam construction, which extended from 1990 to 1998, we note a gradual movement towards the Raipur Rani forest range. During this phase new dams were constructed and community-based organisations were also established. Major stakeholders of the watershed project – the Ford Foundation, Tata Energy Research Institute and the HFD closely monitored the process. As a result of closer monitoring and greater transparency, dams surviving beyond five years increased by 50%. Further, the proportion of dams silting up within five years of construction fell from 50% in the previous

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<tbody>
<tr>
<td>Number of dams silted within 5 yrs of construction</td>
<td>31.3%</td>
<td>4</td>
<td>18</td>
<td>22.2%</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Number of dams silted within 10 yrs of construction</td>
<td>33.3%</td>
<td>5</td>
<td>27.7%</td>
<td>3</td>
<td>21.4%</td>
<td>7</td>
</tr>
<tr>
<td>Number of dams functioning less than 1 year</td>
<td>20%</td>
<td>6</td>
<td>33.3%</td>
<td>1</td>
<td>7.1%</td>
<td>1</td>
</tr>
<tr>
<td>Number of dams functioning in 2000</td>
<td>17.7%</td>
<td>4</td>
<td>22.2%</td>
<td>2</td>
<td>14.2%</td>
<td>2</td>
</tr>
</tbody>
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Note: Number in bold refers to total number of dams in forest range.
phase to 21.4%. Nevertheless, we must emphasise that when compared to the Sukhomajiri pilot phase, dam performance had undergone a marked decline in Raipur Rani. This is evident from figures on numbers of dams surviving beyond 10 years from construction. This we argue is because of the failure to ensure catchment stabilisation before dam construction.

4. Contractor-based water-provisioning: unpacking the role of organisational entrepreneurs

4.1. Contractors as foot soldiers of public–private partnerships

The watershed management project in Haryana was originally conceptualised as a means of avoiding the use of private contractors. Instead HRMS were to serve as intermediate organisations to share the benefits of forest management with the HFD. In the case of fibre grass, the HRMS was expected to make an initial payment to the HFD to lease the right to harvest the product. However, discussions with forest guards revealed that forest communities were seldom able to raise the lease amount for fibre grass. So in most cases an individual from within the village paid the lease amount. In the case of some HRMS, especially those in the Pinjore forest range, HRMS held open auctions to award fibre grass harvesting rights. At these auctions sometimes the same individual who paid the initial lease amount of behalf of the HRMS again purchased the harvesting rights. Similarly in the case of earthen dam management too we found that individual farmers were responsible for purchasing rights to allocate water. We found that water contractors undertook considerable risk considering that in the event of failure of rainfall they stood to lose their initial deposit with the HRMS.

From the point of view of the discussion on public–private partnerships five points may be made with reference to management of earthen dams. First, collective action among farmers was evident in five out of eight HRMS. Four HRMS where collective action was prevalent were characterised by relative heterogeneity in distribution of endowments (arable, rainfall land, livestock and family labour). All three HRMS that failed to show evidence of collective action were characterised by relative homogeneity in distribution of household endowments. Second, water allocation from earthen dams tended to be relatively more equitable and efficient under a system of contractor-based management that tended to emerge in heterogeneous groups. By contrast water allocation under HRMS management that emerged in homogeneous groups was characterised by poor compliance with ISF collection rules.

Third, we also notice that contractors tended to engage in water provisioning when less than 50% of water users had access to private alternatives like tubewells. This fact was highlighted by the single HRMS group that despite being heterogeneous, failed to show evidence of collective action. Fourth, contractors tended to engage in water provisioning when more than 50% of water users relied on agriculture as a primary source of income with non-farm income making a negligible contribution. Finally, contractors tended to emerge in water provisioning when they felt assured that they could ensure...
farmer compliance with rules regulating water use, ISF collection and dam repairs owing to the presence of a repository of social norms. In the following sections we will examine each of the above issues in greater detail. However, prior to that it may be useful to situate the discussion within the wider context of trends in the regional economy.

4.2. Trends in the regional economy

The rise of contractor-based water provisioning may be rooted in trends in the wider regional economy. Haryana is one the green revolution states in India that has charted impressive gains in agricultural per-capita income. In this connection five factors merit attention in our analysis of regional economy trends. First, there appears to be a de-linking of agricultural performance from poverty reduction. This is apparent from the fact that between 1989–90 and 1993–94 the poverty level more than doubled despite impressive gains in per capita agricultural income (Bhalla, 1999). Second, owing to the increasing non-viability of farm operations, marginal landholding households have tended to take up non-farm jobs that were traditionally the preserve of landless households. Third, there has been a gradual shrinkage of seasonal employment offered by the HFD together with a simultaneous increase in jobs like stone quarrying that are unpredictable and low paid. Fourth, except for wheat and maize, the increases in harvest prices of crops (between 1995 and 1999) have not kept pace with increases in consumer prices of food (GoH, 2000). Finally, our case study data on changes in distribution of household endowments suggests that access to irrigation was leading to a process of peasant differentiation10. This is reflected in the over-time changes in distribution of household endowments among households using earthen dams in Bharauli and Thadion.

4.3. Access to irrigation as a driver of peasant differentiation

A process of peasant differentiation explains in great measure the underlying processes that influence emergence of contractor-based water provisioning in the Haryana Shiwaliks. Our analysis of trends in the movement of household endowment scores suggests that access to irrigation was a powerful driver of this process of peasant differentiation. However, the nature of the differentiation process was characteristically different in Bharauli and Thadion. Analysis of endowment scores in Bharauli and Thadion reveals that:

- Bharauli was a relatively more heterogeneous group when compared to Thadion at both points of time (1996 and 2000).
- Bharauli appears to be becoming more heterogeneous over time while Thadion is becoming more homogeneous (Table 3).

A useful way to understand the reason behind such trends in group heterogeneity is to examine each of the four variables that went into calculations of household endowment scores (Table 4). We examine the coefficient of variation for each of the following variables: average land irrigated, average size of land owned, average number of livestock and average family size. We also examine patterns of variance

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10 It may be relevant in this context to point out that sharecropping does not exist among water using households.
for each of these variables in Bharauli and Thadion. We find that patterns of variance are comparable for all variables except for average irrigated land. We therefore argue that the land area irrigated had the greatest explanatory power in explaining trends captured in the movement of endowment scores for both water user groups.

An important observation may be made in this context: the level of group heterogeneity in Bharauli was increasing because although a greater proportion of water users (compared to Thadion) was receiving water from the dam, not all their plots were being irrigated. In such a situation, factors like location of plots in relation to the earthen dam play a crucial role in determining what proportion of a farmer’s total plots may be irrigated. By contrast, in Thadion proliferation of tubewells offered water users an alternative source of irrigation. As a result water user’s plots situated at a distance from the dam distribution network could still receive irrigation from tubewells. This explains why with an expansion in tubewell irrigation, the level of group heterogeneity was declining over time in Thadion.

What implications does peasant differentiation induced by over time change in access to irrigation have for social and economic relations? Considering that contractor-based water provisioning emerged in Bharauli we stratified households there into high (3), medium (9) and low endowment (23) category households. We then analysed differences in the nature of on-farm operations, non-farm employment and dependence on common pool natural resources in the vicinity of the Bharauli micro-watershed. We find that households in the high endowment category achieved the highest per acre crop productivity. Further, high endowment category households also achieved the highest cropping intensity rates and per acre rates of fertiliser application. When compared to households in the medium and low categories, households in the high category benefited from higher levels of labour hiring and a larger area with access to water from earthen dams (Table 5). In addition it must be pointed out that households in the high endowment category achieved the highest mean farm-based incomes. Primarily owing to their greater access to irrigation such households tended to rely less on livestock rearing as a source of farm-based income.

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Table 3. Distribution of household endowments in water user groups, 1996 and 2000.

<table>
<thead>
<tr>
<th>Water user group</th>
<th>Distribution of household endowments 1996</th>
<th>Distribution of household endowments 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bharauli</td>
<td>61.4</td>
<td>69.1</td>
</tr>
<tr>
<td>Thadion</td>
<td>46.6</td>
<td>33.6</td>
</tr>
</tbody>
</table>

Table 4. Variance for variables of household endowment scores.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Bharauli</th>
<th>Thadion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average irrigated land</td>
<td>83.3</td>
<td>64.1</td>
</tr>
<tr>
<td>Average size of land owned</td>
<td>51</td>
<td>55.1</td>
</tr>
<tr>
<td>Average number of livestock</td>
<td>82.6</td>
<td>86.6</td>
</tr>
<tr>
<td>Average family size</td>
<td>40</td>
<td>45.7</td>
</tr>
</tbody>
</table>
4.4. Irrigation service provision – strategy of peasant accumulation

Our analysis indicates that an individual farmer drawn from the high endowment category has been responsible for leasing out water harvesting rights for the last three years in Bharuali (see Table 6). We argue that this is a strategy aimed at accumulation. The farmer who has purchased water harvesting rights has the largest land area in the command area of the earthen dam. Moreover, his farm plots are located at the end of each of the three distribution lines. Alternative irrigation from private tubewells in particular is unavailable owing the prohibitive costs involved in striking a tubewell. This makes it imperative for him to monitor closely the use of water by head-end water users to ensure that he receives his designated share of water with minimal conflict. By contrast in Thadion three of the wealthiest households using water from the dam had access to water from private tubewells. Therefore, their motivation to undertake risks of water provisioning was less.

The success of the water contractor in ensuring reliable supply of water from the dam in Bharuali has enabled him to derive surplus agricultural income that he has in recent years devoted in part towards purchase of fibre grass harvesting rights. Interestingly, the water contractor does not rely on non-farm employment as a source of household income. However, it must be noted here that the potential for the individual farmer to accumulate profits from purchase of water and fibre grass harvesting rights is influenced by factors like availability of markets for forest products and favourable agricultural terms of trade. For example, we find that the contractor in Bharauli has been less enthusiastic about purchasing fibre grass harvesting rights owing to decline in markets for the product. On the other hand, favourable terms of trade for wheat (that is grown in rabi (winter season) using water harvested in earthen dams) has meant that the contractor is assured of sufficient demand for water from other farmers using the dam.

Table 5. Intensity of farm operations by endowment cluster.

<table>
<thead>
<tr>
<th>Endowment cluster</th>
<th>Cropping intensity rate</th>
<th>Per acre fertilizer application (in kilos)</th>
<th>Percentage of households hiring in labour</th>
<th>Area irrigated by earthen dam (in acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>196.0</td>
<td>216.6</td>
<td>100</td>
<td>3.0</td>
</tr>
<tr>
<td>Medium</td>
<td>175.4</td>
<td>211.1</td>
<td>66.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Low</td>
<td>185.7</td>
<td>191.5</td>
<td>60.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 6. Contractor profits\(^a\) from water harvesting in Bharauli.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lease amount paid by contractor</td>
<td>N/A (under HRMS provision)</td>
<td>N/A (under HRMS provision)</td>
<td>3000</td>
<td>2500</td>
<td>5000</td>
</tr>
<tr>
<td>Amount deposited in HRMS account</td>
<td>Nil</td>
<td>3000</td>
<td>2500</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Hourly user charge</td>
<td>25/hr</td>
<td>25/hr</td>
<td>25/hr</td>
<td>25/hr</td>
<td></td>
</tr>
<tr>
<td>Profit from water leasing (i.e. difference between lease amount and total dues collected by contractor on hourly basis)</td>
<td>N/A(^b) (under HRMS provision)</td>
<td>N/A(^b) (under HRMS provision)</td>
<td>No profit due</td>
<td>7500</td>
<td>5000</td>
</tr>
</tbody>
</table>

\(^a\) All values in Indian Rupees.

\(^b\) N/A: not applicable.
4.5. Ensuring compliance with irrigation service rules – influence of non-farm employment and social norms

We noted in the preceding discussion that three factors; namely surplus agricultural income derived under irrigated conditions, absence of private tubewells and sufficient demand for water by other peasants had motivated the contractor in Bharuali to engage in water provisioning. However, water provisioning is only the first step towards sustaining a process of peasant accumulation. For the individual peasant to ensure that accumulation actually takes place, compliance of water using households with rules regulating use of earthen dams is of utmost significance. Here we find that a repository of social norms and degree of non-farm employment in Bharuali has influenced compliance with water allocation rules.

The relatively greater access of the water contractor to arable land and, more specifically, to irrigated land has accorded him a powerful place in the village power structure. Historically the water contractor has been a source of credit for landless households especially in times of droughts and floods. He has also been a source of employment for marginal land owning households. The contractor has played an important role in regional politics by being leader of Bharuali panchayat between 1995 and 2000. The contractor’s power within the village together with the fact that a substantial number of water users rely on irrigated agriculture as a primary source of income has influenced the level of compliance with water-use rules. First, the contractor has devised an intricate web of exchange relationships whereby payment of water dues is tied to services like agricultural labour that marginal landowners owe the water contractor. Second, owing to his predominant position in the power structure, the contractor has been able to prevent other peasants from bidding at water auctions.

Third, water users in Bharuali had evolved a wealth of expertise from managing a kuhl (traditional watercourse). Some 60% of water users in Bharuali have evolved a common set of norms from participating in management of a kuhl (water distribution channel) that is over 100 years old. In addition, norms operating at the level of extended families (gotras) influence bidding at water auctions. For instance, Singh Ram a nephew of the water contractor said that he abstained from bidding at water auctions since it went against ethics that specified he should not participate when a member of his family was involved already. Such norms may be predicated on the expectation of a family member receiving a favour in the future.

Fourth, we observe that approximately 65% of water using households in Bharuali derive 60% of their total annual income (in aggregate terms) from non-farm sources. This may appear to contradict our earlier contention that when 50% or more of water using households derive their primary income from non-farm sources the potential for collective action may diminish. However, we must remember in the context of our discussion on compliance with irrigation service rules that most of these households belong to the low endowment category and continue to be heavily reliant on smallholder agriculture to meet a substantial part of domestic food requirements.

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11 By primary source of income we mean total income derived by a household that exceeds 60% from one particular source.
12 In contrast to Bharuali where a repository of social norms and high levels of dependence on irrigated agriculture had combined to ensure rule compliance in dam management, we find an absence of hierarchical social norms and less dependence on irrigated agriculture in Thadion. In Thadion we find that close to 90% of water using households relied on non-agricultural jobs as a primary source of household income (see Kurian and Dietz, forthcoming).
13 We observe that low endowment category households derived the highest livestock-based incomes when compared to medium and high category households. Livestock-based incomes were facilitated by access to fodder from private fields under dam-assisted irrigation. As a matter of fact, low endowment category households had access to the highest area under dam-assisted irrigation as a proportion of total land owned.
4.6. Consequences of rule compliance: some efficiency and equity considerations

The emergence of contractor-based provisioning was influenced by the institutional structure—lease arrangements for public resources, secular trends in agricultural terms of trade for wheat in particular and distribution of irrigated land within a water user group. In order to assess the socio-economic consequences of contractor-based water provisioning we examine collective action rules in relation to management of earthen dams by focusing on two issues: water allocation and participation in repair and maintenance. In so doing, we examined efficiency and equity implications of collective action rules in Bharauli and Thadion.

Water allocation rules. We adapted Ostrom’s use of “water availability difference” to examine predictability of availability of water among peasants at the head-end and tail-end of the dam distribution network (Ostrom, 1994: 552). The difference in predictability of water supply between head-end and tail-end peasants was lower in Bharauli than in Thadion (Table 7). This we argue reflects the higher level of efficiency associated with lower level of conflict among peasants and greater clarity about water usage rules.

Another indication of the efficiency of the water distribution system is the difference between average water requirement and water availability. Based on rule of thumb calculations of water requirements during the rabi season and mean land sizes we arrived at the difference between water requirements and water availability. In Bharauli relatively efficient water management rules guaranteed a relatively large number of households access to water from the dam. In Thadion, by contrast, because a few households have a monopoly on use of water, the difference between water availability and requirement is double. Greater efficiency in use of the water-harvesting dam is also reflected in the expansion of the Bharauli distribution network.

In response to growing profits from water sales, the contractor expanded the distribution network in 1999/2000 to provide irrigation for 15 additional households. As a result, a total of 19.5 acres was brought under irrigation. We must emphasise here that within the constraints imposed by command area topography and availability of water in the dam, the dam contractor does attempt to balance the needs of a wide constituency of water users. For instance, 40% of the new beneficiaries were either his brothers or belonged to his extended family. Further, the contractor attempts to supply peasants from other caste

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14 In defining efficiency we adopt a multi-layered approach. We argue that efficiency would be enhanced by the presence of robust operational rules that minimise conflicts, elicit payment of irrigation service fees that facilitate routine maintenance of watershed resources. The presence of such robust operational rules we argue would greatly facilitate organisational sustainability of community-based natural resource management. In discussing equity we highlight three issues: 1. those who use water pay for its use, 2. those who use more water pay more and 3. those who bear a cost in facilitating provision of the collective good are compensated for the risks they bear (see Sen, 1999).

15 We allotted weights to qualitative assessments of how predictable was access to water from earthen dams for farmers in Bharauli and Thadion. The weights were allotted based on whether farmer’s access to water was high (2), medium (1) or low (0).

16 During a period of normal rainfall three waterings are required for a wheat crop. Four hours are required to water 1 acre of wheat crop from the dam. Mean land size among water users in Bharauli is 4.7 acres. Therefore, mean per capita water requirement for wheat for water users in Bharauli is 18.8 hr (4.7 × 4). But in 1999–2000 a total of 555 hr of water was supplied in Bharauli at a mean per capita rate of 16.1 hr. In Thadion mean land size is 5.8 acres. Therefore, mean per capita water requirement for water users is 23.2 hr (5.8 × 4). But in 1999–2000 a total of 479 hr of water was supplied in Thadion at a mean per capita rate of 32 hr.
groups and those with smaller land sizes as well. Finally, the interests of large landholders who can wield enormous political clout are accommodated in the expansion plan.

Water management in Thadion provides a contrasting picture. We find that that owing to relatively greater access to private tubewells water users had developed conflicting interests in water use. For instance, we find that approximately 46.6% of water users in Thadion compared to barely 9% in Bharauli were growing paddy in the dry season. Interestingly all households growing paddy in Thadion had their farm plots located in the head end of the distribution channel of the earthen dam. The relatively greater water intensity of paddy cultivation (when compared to wheat) has compromised access of tail-end water users to water from earthen dams. Such differences in cropping preferences among head- and tail-end water users in Thadion has resulted in conflicts and poor enforcement of water allocation rules.

Participation in repair and maintenance of earthen dams. We found that farmers in Bharauli were more keen to participate in routine maintenance of the earthen dam compared to their counterparts in Thadion. For instance, between 1995 and 2000 the mean number of labour days contributed towards maintenance of the distribution network was 3.7 compared to 2.3 in Thadion. Further, the mean monetary contribution towards maintaining the distribution network was Rs 377 compared to Rs 156 in Thadion. We also observe through regression analysis that large landholding households made the largest monetary contributions towards maintenance of the distribution network; peasants with smaller areas irrigated by the dam made more labour contributions towards maintenance activities.

Land use changes. Visual interpretation of satellite imagery acquired in April 1999 and its comparison with Survey of India Maps of 1965 reveals some interesting changes in land use in Bharauli (NRSA, 1999). First, as a result of the expansion of the dam distribution network the area under perennial agriculture has increased. Approximately 60 acres of agricultural land has been brought under perennial agriculture as a result of supply of water from the dam in Bharauli. Household surveys in Bharauli indicate that crops like radishes, onions and chillies are sown during the rabi period, between December and April. Second, expansion of the dam distribution network has resulted in reclamation of river bed areas for cultivation purposes. Satellite imagery indicates that approximately 30 acres of land was reclaimed and brought under cultivation.

4.7. Can public–private partnerships be sustained?

We observed in the preceding paragraphs that contractor-based water provisioning from earthen dams had resulted in relatively greater success with ensuring equity and efficiency of water use (Table 8). Equity and efficiency issues were reflected in conflict-free water allocation, greater fee collection,
success with routine maintenance and favourable land use changes\textsuperscript{17}. However, from the point of view of the debate on public–private partnerships we think it is pertinent to ask whether such patterns of micro-level institutional performance can be sustained. We highlight three areas where state parastatals and imaginative policy coordination can play an important role:

- ** Tradable water shares and the landless:** Our case study of earthen dam management in Bharauli shows that the system of tradable water shares – a feature of the watershed management project had failed. Contractor-based water provisioning had failed to ensure that the interests of the landless could be incorporated in watershed management. We argue that state parastatals, with participation of NGOs, could play an important role in designing institutional mechanisms that put the interests of landless households into the mainstream so as to avoid conflicts over water use (see Moench et al., 2003). Such interventions could range from micro-credit enterprises to expanding both options for non-farm employment and returns on such forms of engagement.

- **How gender matters:** Our study of contractor-based water provisioning in Bharauli HRMS shows that as a result of orderly water allocation, women’s work load in on-farm activity had increased. This was because access to irrigation from earthen dams has improved fodder grass production on agricultural fields. As a result women make more trips transporting fodder grass from the fields to their homes. Second, when decisions are made to increase cattle herd sizes to maximise returns from the sale of milk, women end up spending more time feeding and bathing cattle. Third, unlike grass from forest areas, fodder grass from agricultural fields has to be threshed in a machine before it is fed to livestock. Notwithstanding the increase in workload for women we found that avenues for their views to be heard in deliberations on watershed management were limited. This is because cultural norms that prevented women from speaking out in front of men effectively made their labour contribution in irrigated agriculture invisible. For example, our 8 HRMS survey indicated that a failure to consider women’s views resulted in HRMS funds being spent predominantly on male priorities (like construction of resting rooms for men and repair of temples) as against female preferences (like repair of school buildings and provision of drinking water taps in the village). We believe that functionaries of state parastatals could play an important role in ensuring that such entrenched forms of inequity in use of public resources is corrected. This may necessitate development of innovative methodologies to monitor distribution of benefits and costs of participating in watershed management (Kurian, forthcoming).

\textsuperscript{17} Our study revealed that proliferation of tubewells in Thadion resulted in head-end users of the earthen dam using water for paddy cultivation. As a result water storage during the monsoon season was compromised resulting in less water availability for wheat cultivation in the dry season with particularly adverse implications for tail-end water users who had no access to alternative irrigation from private tubewells (see Kurian and Dietz forthcoming a.).
• **Inter-sectoral policy coordination:** We pointed out earlier that in response to changes in the import policies of the central government, paper mills had reduced their demand for fibre grass supplied by HRMS. As a result, the gross profits of HRMS had shown a tendency to decline. In the case of Bharauli we find that in response to declining markets for fibre grass the HRMS had actually stopped leasing out fibre grass harvesting rights from the HFD. This was bound to affect the quantum of funds available to undertake routine maintenance of earthen dams. This issue could seriously undermine success with contractor-based water provisioning. We therefore argue that the state could play a constructive role in inter-sectoral policy coordination with a view to sustaining micro-level institutional change to do with natural resource management (see Alsop *et al.*, 2000; Kurian and Dietz, forthcoming b.).

5. Conclusions

There has been a growing interest in decentralised development approaches. Our analysis of public–private partnerships in the context of watershed management in Haryana underscores the importance of public sector initiative in natural resources management. We pointed out how the HFD initiated a dialogue with community groups in the watershed area of Sukhna Lake. The dialogue resulted in the Sukhomajiri model of participatory watershed management that facilitated positive socio-economic and environmental change for all stakeholders – the HFD as well as farmers. We also highlighted the important role that the HFD played in institutionalising a system of water rights and organisational rules for management of water from earthen dams.

Public–private partnerships by their very nature are dynamic. We demonstrated how access to irrigation in the context of skewed distribution of household endowments in Bharauli was leading to increasing group heterogeneity when compared to Thadion. Further, we highlighted the fact that changes in state import policies and fiscal regime affected gross profits of HRMS. Declining profits of HRMS had adverse implications for investment of HRMS in repair of earthen dams. This example highlighted the importance of inter-sectoral policy coordination as an instrument of sustaining public–private partnerships. Further, we also pointed out that lack of transparent and accountable procedures of the HFD resulted in poor success in dam construction. A large number of dams silted up and were destroyed owing to poor technical design and faults in construction.

Our analysis of collective action within peasant groups revealed that contractor-based water provisioning tended to be relatively more successful in ensuring compliance with water management rules. Interestingly, we observed that contractor-based water provisioning tended to emerge in groups that were relatively more heterogeneous in distribution of household endowments. However, we pointed out that for contractors actually to engage in water provisioning there must be sufficient interest among other water using households in use of water. We pointed out that this was a function of factors like agricultural terms of trade for particular crops like wheat. Further, we pointed out that water contractors emerged when private alternatives like tubewells did not exist and when agriculture provided a significant source of household income.

This paper has also demonstrated that apart from provisioning, contractors play an important role in ensuring compliance with water management rules. Ensuring compliance with water management rules is facilitated by presence of social norms within community groups. Historically defined power and social exchange relations may go a long way in facilitating compliance with water management rules,
with implications for equity and efficiency of resource use. We noted for instance that favourable land use changes had taken place as a result of operation of robust water management rules in Bharuali. Similarly water allocation was orderly, user fee collection met with greater success and community participation in maintenance activity was forthcoming. However, the outcomes for women and the landless of robust water management institutions were disappointing. We pointed out in this context that women had to shoulder more tasks because of improvement in agricultural productivity arising from improved access to irrigation from earthen dams. But despite their increased workload women remained outside the pale of decision making in HRMS. It was in this context we argued that functionaries of state parastatals could play an important role in addressing inequities in benefit distribution that are embedded in wider rural social structures.

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References


Appendix 1

Methodology for computation of household endowment scores

Crop agriculture and animal husbandry are important sources of rural livelihoods in the Morni-Pinjore Forest Range, Haryana. Off-farm employment as casual labour in stone quarrying and forest department afforestation activities are important because they supplement income from agriculture-based activity. This is particularly the case with land-owning households. It must be emphasised that landless households derive a significant part of their income from off-farm and non-farm sources. Considering that landless households do not constitute more than 15–25% of households in Shiwalik villages, we can safely assume that most households derive their livelihoods from farm-based activity. This is why we chose to construct household endowment scores based on agriculture and animal husbandry.

1. Variables. In the process of constructing household endowment scores we considered four variables: (i) total rainfed land owned, (ii) total irrigated land owned, (iii) type of livestock owned and (iv) size of household. Total irrigated land owned refers to land irrigated by tubewells, earthen dams and kuhls (seasonal water channels). The principal livestock types considered in constructing the endowment scores are adult cows, buffaloes, bullocks, goats and camels. Household size refers to total number of members in a household.

2. Weights. In constructing household endowment scores we devised weights for each of the assets outlined above. The weights were decided based on food productivity assessments undertaken in Shiwalik villages. Four criteria guided the allocation of weights for variables:

- per-acre productivity of corn/rice and wheat under non-irrigated conditions
- per-acre productivity of corn/rice and wheat under irrigated conditions
- average milk production by buffaloes in summer, monsoon and winter months
- average milk production by cows in summer, monsoon and winter months

3. Assumptions. In devising weights for caloric value of cereal crops and average milk production we made five assumptions:

- Each adult requires a minimum of 2300 kcal per day.
- The annual average kilocalorie requirement for an individual would therefore be some 850,000 kcal.
- A kilogram of a cereal like corn, wheat or rice contains on average 3500 kcal.
- Cow’s milk contains 700 kcal per litre.
- Buffalo milk contains 900 kcal per litre.

4. Cereal crops caloric equivalent. Household-level assessments of crop and milk production were undertaken for which the following measures based on production under irrigated and non-irrigated conditions were used:

- One acre of rice or corn in kharif season under non-irrigated conditions yields 1200 kg per acre on average.
• One acre of wheat in *rabi* season under non-irrigated conditions yields 500 kg per acre.

Therefore, under non-irrigated conditions annual average yields per acre are approximately 1700 kg (i.e. 1200 + 500).

• A yield of 1700 kg per acre under non-irrigated conditions is equivalent to some six million kcal per acre per year (i.e. 1700 × 3500 kcal per kg).

Following from our earlier assumption regarding a minimum calorie requirement per individual of 850,000 kcal per year, 6 million kcal would sustain seven members of a family.

• Under irrigated conditions one acre of corn in *kharif* season yields 1800 kg per acre.
• Under irrigated conditions one acre of wheat in *rabi* season yields 1600 kg per acre.

Therefore, under irrigated conditions total yield per acre is approximately 3,400 kilos (i.e. 1,800 + 1,600).

• A yield of 3400 kg per acre under irrigated conditions yields a caloric equivalent of 11,900,000 kcal per year (i.e. 3500 × 3400).
• Assuming a minimum annual calorie requirement of 850,000 per individual, 11,900,000 kcal would sustain 14 members of a family.

5. **Milk production and caloric equivalent.** Milk production in Shiwalik villages varies by season. In the summer months between March and May an adult buffalo produces about 5 litres of milk per day. During the monsoon period between June and October, milk production peaks at about 10 litres per day. In the winter, between November and February, average milk production per day is about 4 litres. However, as no milk is produced for a few weeks in a year we assume that average annual milk production is approximately 2000 litres. Two thousand litres of milk produced by an adult buffalo translates into a caloric equivalent of 1.8 million kcal annually; thus the 1.8 million kcal contained in buffalo milk can sustain 2.5 persons annually.

On the other hand during the monsoon season, a cow produces some 750 litres of milk. During the summer season, milk production falls to approximately 450 litres. Therefore, total annual milk production by a cow would be in the range of 1200 litres. This 1200 litres of cows milk translates into a caloric equivalent of 840,000 kcal. This 840,000 kcal contained in cows milk could sustain one family member annually.

Based on average food productivity assessments for cereal crops and milk we calculated household endowment scores as follows:

\[
(7L_r + 14L_i + 2.5B + 1C + 0.5Ca = 0.1G)/HH\ size
\]

where *Lr* = acres of rainfed land, *Li* = acres of irrigated land, *B* = number of adult buffaloes, *C* = number of adult cows, *Ca* = number of camels, *G* = number of goats, *HH size* = number of members in a household.
Appendix 2

The Sukhomajiri watershed model