The Economic Impact of Forest Hydrological Services on Local Communities: A Case Study from the Western Ghats of India

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

The conventional wisdom that 'more forest is always better' has dominated policy making in the management of forested watersheds. In the context of the supposed hydrological regulation service provided by forest ecosystems, however, hydrologists have debated this assumption for more than two decades. Unfortunately, detailed studies of the relationship between forest cover, hydrology and the economic use of water have been relatively scarce, especially in the tropical forests of South Asia. Building upon a larger research project at four sites in the Western Ghats of peninsular India, this study examines the link between stream flow, agricultural water use and economic returns to agriculture. The study attempts to simulate the likely impacts of regeneration of a degraded forest catchment on stream flow and the consequent impact on irrigation tank-based agriculture in a downstream village. The authors find that regeneration of forests would reduce the ratio of runoff to rainfall in the forested catchment thereby significantly reducing the probability of filling the well-used irrigation tank. This in turn reduces the probability of the command area farmers being able to cultivate an irrigated paddy crop, particularly in the summer season, thereby reducing expected farm income as well as wage income for landless and marginal landowning households. The study results seem counter intuitive to conventional wisdom. This result is, however, not because the hydrological relationships in this region are peculiar, but because the community immediately downstream of the forest is using water in a particular manner, viz., through irrigation tanks for growing water-intensive crops. The main implication is that policy-makers must move away from simplistic notions of forests being good for everything and everybody under all circumstances, and facilitate context-specific, ecologically and economically informed forest governance.

Key words: Hydrological services, ecosystem services valuation, economic impact assessment, forest hydrology

The Economic Impact of Forest Hydrological Services on Local Communities: A Case Study from the Western Ghats of India

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1. Introduction

Tropical forest ecosystems generate multiple benefits to society, among which are goods such as fuelwood, fodder, timber, leaf manure, food and medicines, and services such as carbon sequestration, habitat for wildlife, and biodiversity. One important set of benefits from forest ecosystems is watershed services, which include hydrological regulation (groundwater recharge, low-flow augmentation, and flood control) and soil conservation. Thus, changes in forest conditions are likely to have profound implications for society. This is particularly true in the case of river basins in South Asia, where forests as well as water resources are being used intensively by a large population, often under a highly seasonal rainfall regime.

In spite of their importance, the watershed service benefits of tropical forests and associated ecosystems are perhaps the least well understood and the most contentious of all forest-related benefits. Neither are the physical relationships between forest cover and watershed services adequately understood, nor (partly as a consequence) are the socio-economic impacts accurately assessed. As a result, when it comes to the management of forested watersheds, policy making is dominated by conventional wisdom that assumes that ‘more forest’ of any kind at any location and in place of anything else is ‘better’ for all watershed services for all communities downstream. Such oversimplifications are no longer scientifically tenable.

As a modest yet empirically grounded contribution aimed at filling this knowledge gap, we launched a four-year research project on the impacts of forest cover change on watershed services in four sites spread over two eco-climatically distinct regions of the Western Ghats of peninsular India, in collaboration with the National Institute of Hydrology, the Ashoka Trust for Research in Ecology and the Environment, and UNESCO’s International Hydrological Programme. The economic assessment reported here is from one site in the lower rainfall region (Bandipur in southern Karnataka). We attempt to predict in economic terms the consequences for agriculture of hydrological change that might be result if the forests in a currently heavily used catchment were to regenerate fully. The study, one of the first studies of its kind in South Asia, is also distinctive in its use of detailed hydrological data, in its contextualisation of the community-water relationship in the local techno-institutional arrangements, and its willingness to go beyond ‘marginal change’ analysis.

We begin with a review of the literature on forest-hydrology-society relationships and an identification of some of the gaps that need to be filled in Section 2. We then present the overall conceptual framework of our study in Section 3 and describe in Section 4 the ecological, social and agro-hydrological context in which this framework is applied. The quantitative relationship between rainfall and water availability as derived from the larger study is summarised in Section 5. We then describe the methodology of socio-economic data collection in Section 6. The analysis of incomes and employment under different cropping patterns is presented in Section 7, and the estimated impacts of hydrological change in Section 8. The main conclusions and their implications are highlighted in Section 9.

2. Forest Ecosystems, Watershed Services and Social Well-being: The Existing Literature

2.1 Forests Cover Change and Hydrological Services: The Complex and Contentious Linkages

Popular belief is that forests perform extremely critical watershed functions, as they enhance rainfall, act as "sponges" that prevent floods during the monsoon and release water during the dry season, and prevent soil erosion. But debates generated by clear-cutting experiments in temperate watersheds have triggered much rethinking amongst forest hydrologists of this reigning orthodoxy over the past few decades. It has been observed that trees actually consume more water (through transpiration) compared to other vegetation, that trees may prevent sheet erosion but not gully erosion, that flood control effects of forests may be significant only in small or medium-sized catchments, that sediment loads in rivers emerging from geologically unstable mountain systems such as the Himalayas may be hardly influenced by the extent of forest cover in the catchments, and that the soil erosion and water infiltration rates of different 'non-forest' land-uses vary quite dramatically. It is therefore now accepted that the effects of forest degradation, loss, or afforestation on watershed functioning will vary with climate, spatial scale, precipitation characteristics (such as rainfall intensity), pedology, soils and, most importantly, with the type of change that actually takes place in the vegetation, whether classified as forest or otherwise (Bruijnzeel, 1993; Bonell, 1993; Bruijnzeel, 2004).

In the Western Ghats region, natural forests have been extensively transformed by state agencies and local communities into various forms such as monocultural forest plantations of Teak, Eucalyptus and Acacia, heavily used but well-managed forests that are more in the form of tree savannas or even grasslands, heavily used open-access forests that have often degraded to scrub, and coffee/tea/rubber plantations. Hydrological studies of these land-cover changes are few and potentially divergent. Findings include significant declines in water yields when grasslands are planted with eucalyptus in the Nilgiris (Sikka *et al.*, 2003), possible increases in overland flow due to planting up of grasslands with *Acacia auriculiformis* in the Western Ghats (Putty and Prasad, 2000), but rapid recovery of soil hydraulic properties when *Acacia auriculiformis* is planted on the highly degraded (laterized) soils of the coastal Western Ghats (Purandara *et al.*, 2001). The hydrology of deciduous forests is poorly understood since most studies are in the evergreen forests.

2.2 Links Between Forest Hydrology and Human Well-being

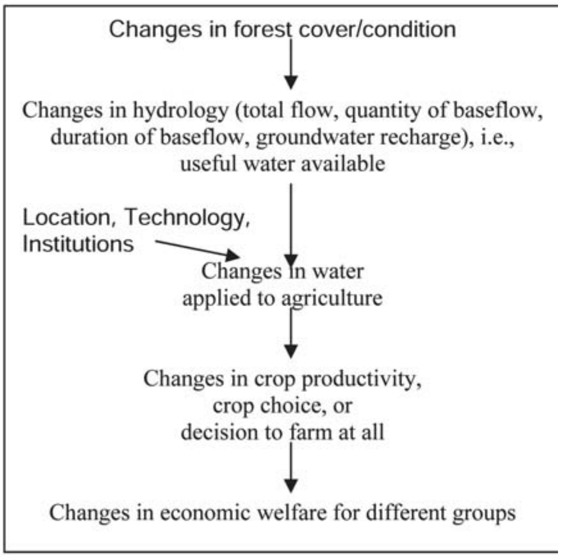
A detailed review of the literature on economic assessments of the impacts on watershed services of forest conversion is beyond the scope of this paper (see Lélé and Venkatachalam, 2006). In brief, the patterns and trends are as follows. In the first place, the hydrological impacts began to receive the attention of economists only relatively recently, as the earlier literature focused largely on soil erosion impacts of forest conversion. The studies therefore are few in number. Second, many of these studies are not grounded in empirically validated hydrological models, the exceptions being those led by Vincent et al. (1995), Kramer et al. (1997) Pattanayak and Kramer (2001) and Aylward and Echeverria (2001). Others either assume some simple relationships or seek to bypass the problem by adopting a contingent valuation approach in which (implicitly) the consumer is assumed to have full knowledge of the biophysical relationship between forest cover change, hydrology and economic activity (e.g., Chopra and Kadekodi, 1997)[1] Third, in terms of the nature of forest cover change studied, few studies have looked at the impact of forest degradation, the main focus being on either complete deforestation or forest conversion. Fourth, the regional coverage of the studies, especially of the hydrologically grounded ones, is limited, with studies in South Asia being particularly scarce. We are not aware of any environmental economic assessments of forest-driven hydrological change in the Western Ghats region. Finally, economic analyses tend to focus on aggregate changes in agricultural profits or consumer surplus, but do not include changes in employment generated or wage incomes.

In spite of these limitations, the literature has significantly illuminated the complex relationship between forest cover change, hydrology and local communities. For instance, the impacts can be in different directions. Vincent et al., show that replacement of natural forests by dense pine plantation can reduce water flows whereas Pattanayak et al. analyse a situation where loss of forest cover leads to reduced baseflow. The magnitude of the economic impact also varies considerably from study to study. This contextual nature of the impact requires one to better understand the role played by eco-climatic conditions and the techno-institutional variables mediating between the hydrological system and the water use sectors.

Our study contributes to this literature in three ways. First, it is located in a region—the Western Ghats—that is of considerable significance in terms of watershed services but has received limited attention so far. Second, it draws upon real hydrological data that have been made available to the researchers because this study is part of a larger interdisciplinary effort. Third, it includes estimates of wage income changes to the marginal or landless households from changes in agriculture.

3. Framework and Objective

We use a modified version of the framework given by Pattanayak (2004) that outlines the links between forest cover change and economic welfare (see the conceptual framework). We include an explicit step for highlighting changes in water applied to agriculture even though, as we shall see, it is not always possible to measure this change directly. We also indicate that location, technology and institutions can influence how ‘available water’ gets translated into ‘applied water’.



Conceptual Framework

We should clarify that agriculture is not really the only sector in which water is used.

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[1] This study also highlights the difficulty of separating out, in a contingent valuation approach, the economic value of different elements of the forest ecosystem service ‘bundle’.

Obviously, water is also essential for domestic activities and the livestock sector. In the particular context of our study, however, our observations suggest that a combination of government drinking water supply schemes and precautionary practices followed by the communities ensure that water availability for the domestic and livestock sectors will not be significantly affected by changes in hydrology. Focusing on the impacts on agriculture therefore seems reasonable for this study.

The objectives of this economic assessment then are to understand how changes in hydrology translate into changes in water applied to agriculture and thereby to changes in productivity and crop choice and eventually to the economic welfare of different groups in the village. Note that this is not a complete benefit-cost analysis of forest cover change impacts across different stakes and stakeholders (see Lélé *et al.*, 2001 for an example of this type of study). We are interested here in understanding the direction and magnitude of impacts caused by changes in hydrological services alone.

4. Study Site: Ecological, Social and Agro-hydrological Characteristics

4.1 Western Ghats Region

The Western Ghats region—a forested region straddling a range of hills running parallel to the western coast of India (see dark areas in Figure 1)—is in many ways an ideal region for exploring the links between forest cover, hydrology and local economies. First, virtually all the major rivers in southern India originate in the Western Ghats. Changes in land-use and land-cover in the Ghats are potentially of critical importance to the millions of people depending on these streams and rivers, especially in the drier eastern portion of the Deccan plateau. These changes are also of importance to the communities residing in the Western Ghats themselves, because even in this generally high rainfall region seasonal scarcity of water is ubiquitous. Second, the reg-ion has a long history of forest dependence by local communities, so forest degradation has significant implications locally. Third, the region is considered a global biodiversity hotspot, so forest cover change has much wider significance.

4.2 The Biophysical Context

The hills and forests of Bandipur (11°572 023 N, 76°122 173 E to 11°352 343 N, 76°512 323 E) are part of the hilly southern fringe that separates the Mysore region of Karnataka state from the Nilgiris in Tamil Nadu and the Wynaad region in Kerala. The ridges range up to 1400m a.s.l. and the streams emerging from these hills and ridges drain into flat terrain to the north at about 800m a.s.l. The geology is dominated by Gneissic rocks and the soils are dominated by weathered alfisols, acidic and porous, with clay increasing from about 20-30 % in the upper 20 cm to over 50 % at 50 cm. The surface layers are sandy clay loam with coarse sand and pockets of clay-rich “black soils”. The region is characterised by a climate classified by Indian Meteorological Department as ‘Tropical Savanna, hot, seasonally dry’. Annual rainfall varies spatially from less than 700 mm in the eastern fringes to over 1200 mm in the south-west. The rain comes both from the south-west monsoon (June-Sept) and the north-east monsoon (Oct-Dec). Pre-monsoon showers in March-May can also periodically cause major rainfall events in the dry-season. The forests are tropical dry deciduous of the *Terminalia alata* (Roxb.)-*Anogeissus latifolia* (DC.)-*Tectona grandis* (L.f.) series (Pascal, 1986). The main forested area was declared a National Park in the 1970s. There is significant human use and associated forest cover changes along the entire northern fringe of the National Park. The main occupation in the villages surrounding the

National Park is agriculture, with *jowar* (*Sorghum bicolour*), *ragi* (*Eleusine coracana*), maize and, more recently, cotton and tobacco being the main (rainfed) crops while paddy and sugarcane cultivation occurs in the irrigated patches. Animal husbandry, agricultural wage labour and forest product collection are important secondary occupations. Village communities are heterogeneous, with hamlets of tribal groups such as *Soligas* located right on the park fringe and more mixed caste hamlets elsewhere.

In a region of 800mm rainfall, rainfed cultivation is the norm. However, over the centuries, farmers in this area as well as in other parts of peninsular India have devised irrigation tank technology as a solution to the problems of water scarcity (Vaidyanathan, 2001). The plains around the Bandipur forest are dotted with such structures. The tanks, created by earthen embankments, impound the streamflow and, if they are adequately filled, the water is let out through sluices into channels that provide gravity-based irrigation to the lands downhill from the channels. Since the rainfall in this area is somewhat bimodal, occasionally the tanks may fill up twice a year and enable the irrigation of two crops. Although groundwater-based irrigation, mainly through borewells, has begun to spread in this region, most irrigation in villages close to the National Park still comes from irrigation tanks. Surface flows in streams emerging from the National Park are therefore crucial to agriculture, but their use is mediated by the tank systems.

The larger research project of which this study is a part involved the selection and monitoring of ‘control’ (i.e., relatively undisturbed forest) catchments within the core area of the National Park and of ‘heavily used’ or ‘degraded’ catchments on the fringe. One of the degraded catchments so chosen was of the Baragi stream, which emerges from the Marigudi ridge and flows eastwards through Baragi village before turning northwards and joining other streams (see Figure 2). The Baragi irrigation tank (see photographs in Figure 3) was constructed in the 19th century across this stream and then renovated and expanded to its present size in 1982. The tank now has a full reservoir level (FRL) of 31.84 m (104.43 feet) giving a live storage level variation of 6.19 m (20.43 feet) and a corresponding live storage volume of 1.32 M.cu.m, a waterspread area of 106.65 acres (43ha) and an irrigated command of 135 acres (source: Minor Irrigation Department). The catchment area of the tank is ~29 sq.km., including 20 sq.km. of heavily used forest, with the rest being agriculture and barren land (see Figure 2).[2]

4.3 The Agrarian Context

To understand the manner in which the availability of water in the irrigation tank influences agriculture and incomes in Baragi village, it is necessary to arrive at a picture of the overall agrarian context of the village. Baragi revenue village is a large village, whose boundary includes a significant portion of the forests on the eastern slopes of the Hekkon ridge (see Figure 4). The total geographical area of the revenue village is recorded as 2795 ha, including 1403 ha that are designated as forest land, mostly subsumed under the National Park.

Baragi revenue village contains several hamlets, of which the one relevant to this study is the main settlement of Baragi itself that is located downstream of the Baragi irrigation tank (see Figure 4). Baragi is a large hamlet, with 392 households drawn from various castes and landholding categories. There is of course a correlation between caste and landholding, with the upper caste households owning the bigger landholdings. The total percentage of landless households is quite

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[2] The map was generated using IRS-1C satellite imagery provided by ATREE and our GIS database.

significant (19%), but the bulk of the households (59%) are in the small-holder[3] category. It should be noted that the labourers working on agricultural lands in the tank command area are drawn not only from the Baragi hamlet but also from neighbouring hamlets.

Agriculture is the main occupations in Baragi. The important irrigated crops are paddy (in the tank irrigated area) and sugarcane, turmeric and onion in the borewell irrigated areas. The main dry crops are jowar, ragi, cotton and marigold. Livestock rearing (both cattle and goats) and collection of forest produce are important secondary occupations. Some persons in Baragi hamlet are engaged in non-agricultural jobs. A significant fraction of adults in the landless and marginal landholding households migrate seasonally in search of wage labour, usually to the coffee growing areas in neighbouring Wynaad and Kodagu districts.

In areal terms, most of the agriculture in Baragi village and surrounding areas is rainfed. But the extent of irrigated land is not insignificant, comprising ~15% of cultivated area in 2003.[4] This includes a tank command area of 54.7 ha (135 acres) and a well irrigated area of 19 ha (47 acres). Moreover, the productivity of irrigated lands is several times higher than that of rainfed lands, making the irrigated land in general and the tank command land in particular a major asset in the local economy. With landholdings in the tank command being well distributed, the tank irrigation system is of direct concern to a significant fraction of households in Baragi hamlet (144 out of 392), and also of indirect concern to many households among the landless and small landholding classes who engage in wage labour.

Water is important not just for agriculture; households also depend on tank, stream and ground water for domestic use and for use by livestock. However, our observation was that these uses are relatively insulated from changes in tank inflow patterns for two reasons. First, the villagers have followed a tank management system wherein some minimum storage for livestock-related and domestic use is guaranteed. Second, state agencies have implemented drinking water supply schemes that draw upon deep borewells which are not at this point in time sensitive to the catchment hydrological changes that we have examined. Thus, our investigation focused on agriculture and within that on the impact of changes in catchment hydrology on economic benefits from tank irrigated agriculture.[5]

4.4 Link Between Tank Filling, Cropping Patterns and Agriculture, and Implications for the Study Design

The traditional irrigation tanks in peninsular India in general and the Baragi tank in particular are not meant for ‘protective’ or supplementary irrigation of rainfed crops. They are designed to supply water to cultivate water-intensive crops, typically paddy (Shah, 2003). If there is adequate water to irrigate the entire command area during the growing season for an irrigated crop, the command area farmers cultivate that crop. Otherwise, they do not release water at all and instead cultivate a non-irrigated crop.

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[3] Landholding classes are defined as per the Government of Karnataka benchmarks: small= <5 acres, medium = 5-10 acres, large>10 acres. Landholding is calculated in terms of equivalent dry acres using the ratio 1 acre of irrigated land = 3 acres of dry land.

[4] This fraction was ~6% in 1970, but increased substantially when the irrigation tank was renovated in 1982. Additional increases have taken place due to the spread of open well and borewell-based irrigation.

[5] We investigated the possible impact of changes in groundwater recharge in the catchment on groundwater levels in the area upstream of the tank, and found that the groundwater was currently abundant enough to not feel the impact of forest cover change.

The dependence of cropping decisions in Baragi on the level and timing of inflows into the tank is shown schematically in Figure 5. Farmers have to decide by the end of June as to whether there is enough water in the tank to irrigate a 4-month paddy crop during the kharif (June-Nov) season. If not, they opt to cultivate jowar (a non-irrigated crop). Similarly, if the tank is adequately filled by early December, the farmers opt for a 6-month long rabi/summer[6] (Dec-June) paddy crop; otherwise they leave the command area largely fallow.[7]

This irrigated tank agricultural system has several implications for the analysis of impacts of hydrological change. First, the irrigation tank system is an almost 'binary' or 'threshold-based' system—there are no partially irrigated crops with productivity that is mid-way between *jowar* and paddy (in the *kharif* season) or between almost nothing and paddy (in the summer). The impacts of changes in the pattern and quantum of inflows would not be felt in any simple proportionate manner but rather in terms of changes in the probabilities of different crops being taken up. The relevant economic variable then becomes the *expected value of annual agricultural incomes*. And the impact of hydrological change has to be in terms of the change in expected value of agricultural income. Further, estimating this requires estimating not just changes in crop production or income, but also changes in crop probabilities, induced by changes in the probabilities of tank fillings.

Second, the management of the irrigation tank is a collective one. This means that the irrigation decision applies to the entire command area. For instance, even if there is enough water to irrigate half the command area for a paddy crop, such partial irrigation will not be carried out—either all farmers in the command get the benefit or nobody gets the benefit of the inflows into the tank. In such a situation, the farm-level agricultural production function approach cannot be used to determine the contribution of irrigation to incomes, because the quantity of water applied is not a farm-level decision variable. Consequently, we had to estimate the impacts of the big switches in cropping pattern: from an irrigated to an unirrigated one or vice-versa for the whole command area.

Third, the significant degree of economic class difference within the community means that agricultural wage labour is an important dimension of the economy. With adults from many landless and small holder households working as wage labourers in the irrigated lands, changes in cropping patterns affect the demand for agricultural wage labour. Economic impact therefore needs to be measured in terms of changes in both farmer incomes and agricultural wage incomes.

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[6] *Rabi* typically refers to the crop immediately after the monsoon (say Nov-Feb), and summer refers to the third crop (Feb-June). Since the irrigated paddy crop taken if the tank is full in December straddles these two seasons, we call it the *rabi*/summer crop.

[7] The actual linkages are somewhat more complicated. First, there is some inter-seasonal dependency. The summer paddy crop invariably extends till end of June, by which time they have missed the sowing window for the *kharif* unirrigated *jowar* crop. They then end up cultivating a smattering of short-duration crops in a few of the agricultural plots that have adequate moisture. Second, not cultivating an irrigated summer paddy crop means the tank remains partially filled till April, increasing the probability of the tank getting filled by the pre-monsoon rains in April-May. Third, occasionally, even if the tank is not full, the farmers immediately below the tank embankment get enough seepage water to be able to cultivate an irrigated crop while others cultivate a rainfed crop. Fourth, the decision about whether or not an irrigated crop should be taken up and water should be released from the tank is not the command area farmers' alone. It requires the approval of the Minor Irrigation Department. This can sometimes be delayed, resulting in missing the season. These complications are not easy to factor into the quantitative analysis, but would have to be kept in mind during policy discussions.

5 Relationship Between Rainfall, Catchment Response and Tank Filling[8]

Before we proceed to the economic analysis, we present in brief the understanding of the relationship between rainfall, tank inflows and irrigation events that emerged from the larger research project (Lélé *et al.*, 2007). We first present the analysis of the relationship between rainfall and irrigation events under present catchment vegetation. We then predict the impact of forest regeneration on this relationship.

5.1 Rainfall and Tank Filling

Discussions with the farmers indicated that the tank fills more frequently in the post-monsoon (Oct-Dec) period than in the pre-monsoon or monsoon period. This is because a) more rainfall tends to occur in the Sept-Nov period than in the April-June period (see graph in Figure 6), and b) the rains during the monsoon wet the catchment and so there is likely to be higher runoff (per unit rain) in the post-monsoon period.

Historical data on tank water levels, obtained from the Karnataka Minor Irrigation Department for the period 1994-2005, were plotted along with rainfall and compared with farmer recall of irrigation events (see Figure 7). In this graph, sharp rises in the tank water levels refer to events of tank filling which are followed by steady declines in tank water levels corresponding to irrigation releases, in addition to evaporation and seepage losses. It can be seen that, during this 10 year period, there were a total of nine irrigation events resulting from eight full tank fillings and one partial filling in the Baragi tank. Of these, seven irrigation events occurred during the summer (corresponding to December tank filling events), and two irrigations events occurred during kharif (corresponding to June tank filling events). During the irrigation event of summer 2003, the tank was partially full and water release catered only to a sub-set of farmers in the command area. As indicated by the farmers, December tank filling events are far more common. Analysis of seasonal rainfall patterns preceding tank filling events suggests that the net rainfall occurring between September and November is the primary determinant of a tank filling by December. A probabilistic analysis of historical rainfall and actual irrigation events suggests that the probability of a 3-monthly rainfall event during this period such that the tank fills by early December is 57%, or once in two years, whereas the probability of a similar (tank filling) rainfall happening in the March-June period is 23%.

5.2 Rainfall-runoff and Vegetation

From the December tank filling events for the years 2002, 2004 and 2005 (the years for which the tank water level data were more reliable), we found that the average amount of Sep-Nov rainfall required for the tank level to rise from dead storage to FRL period was 314 mm. Using the reservoir level-capacity relationship for this particular tank (as given in Minor Irrigation Department documents), the daily changes in tank levels, and estimated values of evaporation and seepage losses, we estimated that the tank catchment had a gross runoff coefficient[9] of 0.15.

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[8] This section draws heavily upon the larger hydrological study carried out with support from the Ford Foundation and UNESCO, in collaboration with Ashoka Trust for Research in Ecology and the Environment and the National Institute of Hydrology.

[9] Ratio of runoff to rainfall. Here ‘runoff’ is equated to tank inflows although some of these inflows may be subsurface.

This tank catchment includes 22.12 sq.km. (75% of the total area) of open and degraded forests and 7.26 sq.km. (25%) of cultivated, fallow and grassland area. We applied a 1D soil-water balance model that combines the SCS-Curve number method to estimate the runoff from the agricultural part of the catchment, which came to a runoff coefficient of 10%. Therefore, the runoff coefficient of the forested catchment works out to 18%. This matched broadly with the results of the streamflow monitoring upstream of the Baragi tank during 2004 and 2005, which gave a Sept-Nov runoff coefficient of 23%.

The runoff coefficient for the same period in the control catchments monitored inside Bandipur National Park was around 12-14%. We therefore concluded that regeneration of the forest in the Baragi tank catchment to the levels in the control catchment would lead to a decline in the runoff coefficient from at least 18% to 12%. This means that more rainfall than the current average of 314 mm would be required for the tank to fill by early December. The amount of rainfall required for the tank to fill would increase gradually between 325 mm to 614 mm as the runoff coefficient decreases to make up for the same volumetric contributions from the forest catchment. Since rainfall is an exogenous stochastic variable, this means the probability that there is enough or more than enough rainfall in a particular year to fill the tank (the ‘probability of exceedance’) would decline as the runoff coefficient declines, or alternatively the ‘return period’ of tank filling rainfall will increase. This relationship is plotted in Figure 8. As the figure shows, the relationship between return period and runoff coefficient is highly non-linear. The return period increases from approximately two years (57% probability) to approximately six years (18% probability) when the runoff coefficient declines from the current 18% to 12%. Any further reduction, even by 1 or 2 percent points, results in a sharp increase in the return period to ten years. Further analysis suggests that, for the June tank filling, the current probability is 20% and this would decline to ~7% if the catchment vegetation improved to the level of the control. These are the changes in tank filling probability (and hence probability of irrigated crop cultivation) that we shall apply in section 8 after estimating the economic returns under tank filling and no tank filling scenarios in the next two sections.

6 Socio-economic Data Collection and Sampling

The socio-economic data collection focused on the estimation of agricultural productivity of, incomes from, and wage employment in farms located within the tank command under different cropping scenarios. To reduce errors involved in oral recall, we tried as far as possible to collect data through actual monitoring. We were able to do this during two growing seasons: *kharif* (June-Nov) 2004 when unirrigated *jowar* was cultivated, and *rabi*/summer (Jan-June) 2005 when an irrigated paddy crop was cultivated. We obtained the data for these crops through actual monitoring of crop cultivation practices and production for a sample of farmers. We had to collect the data for the alternate crops (that would have been grown if the tank had filled differently) using oral recall.

A total of 144 farmers own land in the tank command, most of them from Baragi hamlet of Baragi village, and a few from the neighbouring hamlets/villages of Hongahalli and Tenkalahundi. The details of this population of farmers are given in Table 11. Note that landholdings in the tank command are typically quite small, averaging 1.0 acres for the entire population of 144 farmers. We aimed at a sample of 25% for our monitoring effort, and so ended up with 34 (out of 138) farmers during *kharif* 2004. During the irrigated summer crop of 2005, we added six farmers to this sample who were getting water from the waste weir. We used a stratified random sampling approach. Based on the existing literature and our preliminary discussions with the farmers, we anticipated that productivity might vary depending upon landholding size, soil type, as well as soil moisture. Since direct measurements of the last variable were not possible, we used two proxy location variables: location along the reach (head-end, middle and tail-end, the assumption being that head-enders get more seepage water) and elevation within the command (upland, mid-land, lowland, the observation being that lowland plots get more soil moisture from seepage).

We carried out the data collection at two levels. We collected basic socio-economic data on household demographics, education, occupation, and landholdings inside and outside the tank command for the household as a whole. We gathered data on actual labour, other inputs, costs and production only for land held within the tank command. We collected the data through a combination of the 'diary' method (where farmers maintained daily notes on farming activities and inputs) and verification by us or our field assistant on a weekly basis. On the other hand, we gathered the harvest data through direct observations in the fields.[10] For the cropping scenarios that we were not able to cover (mainly irrigated paddy during the *kharif*) we used productivity information based on group discussions with the farmers, and cost data from the summer paddy crop that we monitored. We used SPSS to analyse quantitative data.

7. Estimating Agricultural Incomes and Wage Employment Under Alternative Hydrological Scenarios

For each season/crop that we monitored, we analysed the sample data to identify the main determinants of crop productivity, net income, and labour hired. We then extrapolated the results to the entire tank command. We present the analyses first for the possible cropping scenarios during *kharif* season and then for the *rabi*/summer season.

7.1 Average Incomes under Alternative Scenarios for the Kharif Season

As explained in section 4.3, the two alternative scenarios for the kharif season are cultivation of jowar under unirrigated conditions or cultivation of paddy under irrigated conditions. We present the analysis for unirrigated jowar first and in more detail because the data are based on actual monitoring that we carried out.

7.1.1 Determinants of Productivity, Net Income and Wage Labour Demand in *kharif jowar* Cultivation

We first assessed whether the physical yield of *jowar* is significantly influenced by reach, location, soil type and inputs applied. After eliminating 4 plots where a different type of *jowar* was cultivated (fodder *jowar*, not hybrid *jowar*), we first tested each independent variable separately for its influence on physical productivity in this sample of 30 plots. The average productivity across these plots is 34 kg/gunta (with std.dev.= 10), where gunta is a traditional unit equal to 1/

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[10] In most cases, the land was owned as a single parcel or plot and so the data collected pertain to the farmer's entire tank-irrigated landholding. In the few (3) cases where the farmer (typically a big land-holder) held multiple parcels within the command, we focused all the data collection on only one parcel for practical reasons. Thus the fraction of plots sampled was somewhat lower (22%) than the fraction of households sampled.

40th of an acre. Given the small sample size, we first tested for the influence of each variable separately rather than test simultaneously with 5 independent variables (elevation, reach, soil type, farm size, manure applied) and any interaction terms. We found that elevation was significantly correlated with productivity. Lowland *jowar* plots were more productive than upland plots, a finding that fits the farmers' information that lowland plots get more soil moisture, a crucial factor in an unirrigated situation. Soil type also made a difference: the blacker soil was more productive, probably because it holds more moisture as a result of higher clay content. Interestingly, landholding size and manure applied were not significantly correlated with productivity. We then used a multi-variate general linear model with only three independent variables: elevation, soil type (recoded into a binary variable), and an interaction term. We found (see Table 2) that the significance of soil type drops when elevation and soil type are simultaneously present, with soil type showing up significant only in the interaction term. We therefore used elevation as the only relevant variable in the extrapolation of hybrid *jowar* productivity from the sample plots to the entire tank command.

The variation in economic returns from hybrid *jowar* cultivation is a more complex phenomenon to both estimate and explain. The key question was how to assign prices/shadow prices for the variety of outputs and inputs that are part of the integrated agriculture-livestock-domestic system for which markets are generally thin. On the output side, the main product (hybrid *jowar*) has a well developed local market, and farmers were able to quote a price that they could sell their product at quite easily. This price did not vary significantly from farmer to farmer. So although the bulk of the *jowar* output was retained by the farmers for self-consumption, we feel confident about using the local market price of hybrid *jowar*. However, the market for the by-product (straw) is much thinner: no farmer in our sample reported selling the straw. Similarly, animal husbandry is integrated into the farming system: dung and draught power are inputs to agriculture, with milk being used largely for consumption in the household. The other main input is labour, of which a significant fraction is contributed by the household. There is an active labour market in the area, but the fraction of hired labour of the total labour employed in cultivation varies from 13% to 100% across farms. To treat the shadow price of self-labour as equal to the market wage rate is to assume that the return to household labour is guaranteed at that rate even if all of it has to be hired out. However, while this may be true on the margin for one household, it may not be true if all households were to stop using self-labour in their farms. Another way to look at the problem is to assume that household returns from the cultivation of own land include returns to self-labour plus the profit that remains, the division of which is not so important. So we do not assign a shadow price to own labour used in cultivation. Similarly, the products of the livestock sector are treated as intermediate inputs to agriculture, produced by household labour applied to livestock management.

In other words, we defined

Net income = Gross income (=price*production) – paid out costs only.

One could refine the cost calculations by assigning value to land and other forms of capital invested in agriculture, but presumably this would cancel out anyway when we estimate the *change* in agricultural incomes between two different hydrological scenarios.

Given that markets for inputs into cultivation are thin, we sought to explain the variations in net income of tank command cultivators (from tank command cultivation) in terms of their fixed endowments, primarily landholdings (inside and outside the tank command), household adult labour, livestock holding, and fixed factors such as the elevation variable that was significant for *jowar* productivity. We used a multiple linear regression model, and included the square of landholding inside the tank command to test for non-linear effects. We expected net income to increase with landholding in command, decrease with the square of this landholding, increase/ decrease with other landholding, increase with household labour and livestock, and be higher for lowland plots.

The results of the multiple regression analysis of net income from *kharif jowar* are given in Table 14. The results are broadly consistent with our expectations. In particular, apart from the effect of elevation on productivity that influences net income, landholding size has a major influence on net income. Net income is positively and strongly influenced by landholding in the command for obvious reasons, but it also declines with the square of landholding. This is primarily because larger landholders have to hire more labour as their family labour is not enough.[11] Using the statistically significant coefficients in the regression, we constructed an equation for estimating the net income of all tank command farmers from *kharif jowar*:

Net income from kharif hybrid jowar =

– 1677 + 210(holding in tank command in guntas) – 0.975*(square of landholding in tank command in guntas) – 2793*Elevation dummy (coded as 0=low ormid, 1=upland)..(1)*

Similarly, the wage employment generated per unit area of *kharif* hybrid *jowar* cultivation also varied with landholding size, with the average hired labour cost for small farmers being 19 Rs/ gunta and that for medium and large farmers being 26.5 Rs/gunta (significant at 0.90 for N=29).

7.1.2 Estimating Income and Employment from *kharif jowar* for Entire Tank Command

In extrapolating the results for the sample farmers to farmers in the entire command, certain modifications are required because not all farmers in the command cultivated *hybrid jowar*. First, eight farmers cultivated fodder *jowar* in a total of 10 acres, of which 4 happened to be in our sample. This sample was too small for us to detect any relationship between location or other variables and productivity. We simply extrapolated their average productivity and returns (obtained from the monitoring of 4 sample plots) to the population of fodder *jowar* cultivators. So we used average values obtained from our monitoring. We also found that not all farmers were able to cultivate *jowar*. Second, several plots close to the tank embankment received so much seepage that *jowar* cultivation was not possible. Farmers cultivated either marigolds (11.5 acres) or beans (0.5 acres). We estimated the economic returns for these minor crops based on discussions with the farmers. The estimated production, gross income, net income and wage employment generated during the unirrigated *kharif* season of 2004 from all crops are given in Table 15. Note that the wage employment generated is slightly underestimated because we do not have data for wage labour used in the few farms cultivating marigold, beans and fodder *jowar*.

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[11] A separate regression of the fraction of self-labour in total labour used in *kharif jowar* cultivation showed significant positive influence of the total number of working age adults in the household and a negative influence of the number of adults engaged in salaried jobs or business. Increased landholding should also increase the demand for manure, but in the case of *kharif jowar*, it appears that farmers are not willing to purchase additional manure, possibly because *kharif jowar* is not a very lucrative crop.

7.1.3 Estimating Returns under Irrigated *kharif* Paddy Scenario and the Difference

During the period of our data collection, there was no irrigated *kharif* crop. Hence, for the alternative scenario of irrigated paddy cultivation during the *kharif* season, we drew upon discussions with farmers on productivity and the cost data from our summer paddy survey (adjusted to the shorter duration of the *kharif* crop). The estimates of production, income and employment generation are given in Table 13.

The differences between the irrigated and unirrigated *kharif* scenarios, resulting from whether the tank fills up in June or not, are given in Table 16. The main results are:

a) An increase in net income of the tank command farmers by Rs.345,800, which amounts to an average increase of Rs. 2,400 per farmer, and

b) An increase in the wage employment generated by Rs.164,100, which is shared by landless labourers and small landholders who do not own irrigated land.[12]

7.2 Average Incomes under Different Crops in Rabi/Summer Season

The estimation for the summer cropping scenarios is simpler, because cultivation takes place in the tank command only if there is irrigation, in which case the cultivated crop is paddy. We used the data from monitoring sample farmers during irrigated rabi/summer crop during the summer of Jan-June 2005 (see Table 11, last column) to analyze the pattern of variations in productivity, net income, and the wage employment generated. We then used these regressions to estimate returns for the entire tank command. In the case of no irrigation, there is virtually no crop, so the only income is from wage labour, the extent of which has to be estimated approximately.

7.2.1 Determinants of Productivity, Net Income and Wage Labour Demand in Summer Paddy Cultivation

We began as before with an analysis of the physical productivity of paddy. The average productivity across all sample plots was 65 kg/gunta (with std.dev.=9). This showed no significant variation across elevation, nor did it show significant variation with respect to any other variables such as paddy variety, fertilizer or manure use, soil type, or horizontal location, whether tested singly or in a multiple linear regression. Essentially, the heavy irrigation and the limited variation in farming practices seem to limit the variation in paddy productivity. The reported sale price of paddy was also very similar across respondents.

Since we considered ourselves to have higher quality data on the inputs into summer paddy cultivation,[13] we carried out a more detailed analysis of the economics of summer paddy cultivation in order to identify the determinants of the main components of paid costs, viz., hired labour (~50%) and expenditure on chemical fertilizers (32%). As in the case of *kharif jowar*, we sought to understand farmer expenditure on these factors in terms of the endowments of the

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[12] Estimating this per household or per capita is difficult as the number of households from which the tank command wage labour was drawn could not be estimated.

[13] We separated self-labour (including labour used in mutual exchange) from hired labour was done after the *kharif* data had been collected, and hence this separation and also that of male and female labour is somewhat approximate.

household, including landholding in tank command, other landholding, household labour available, labour occupied in salaried jobs or business, and large ruminant holding.

The results the multiple regression analysis of total paid out costs are given in Table 17, and are along expected lines. Costs are positively correlated with landholding and square of landholding in tank command, suggesting that the largest farmers incur higher costs per unit area. When more adults are available in the household, paid out costs decrease as more self-labour can be utilised. But when more adults are engaged in non-agricultural activities, the paid out costs of agriculture are higher because more labour has to be hired in. Owning higher large ruminant units means less paid out costs to hire bullocks for ploughing and other operations.[14]

A separate analysis of hired labour costs alone corroborated these relationships (see Table 8), highlighting the importance of household labour and the absence of a perfect market for this labour. The separate analysis was also used to generate the equation for estimating employment generated by summer paddy. A separate analysis of expenditure on chemical fertilizers showed that the expenditure was very well correlated with landholding in the command, thus indicating that there was high homogeneity among the farmers when it comes to the method of application of fertilizer for paddy cultivation.

7.2.2 Estimating Incomes and Employment from Summer Paddy for Entire Tank Command

On the basis of the above regression analysis, we constructed the following equation:

Paid out costs for summer paddy =

52(land in tank command in guntas) + 0.55*(land in tank command ^ 2) + 1312*(no. of adults engaged in non-agri jobs) – 170*(Number of large ruminant units).. (2)*

We used this equation to estimate the net income from summer paddy cultivation to the tank command farmers.

Similarly, the regression for wage labour cost gave us the equation to estimate the employment generated from summer paddy, viz.,

Expenditure on hired labour =

38.0(landholding in tank command in guntas) + 0.230*(square of landholding in tank command) + 970*(Number of adults engaged in non-agricultural jobs)..(3)*

The estimates so generated are given in Table 19. Since virtually no cultivation takes place when there is no irrigation during *rabi*/summer, the totals in the last row of Table 19 represent the differences between the irrigation and no irrigation scenarios, at least as far as net income is concerned. Thus, when a summer paddy crop is possible, net income per farmer increases on an average by approx. Rs.9,900.

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[14] It is not related to paid out costs for manure since manure purchase is low.

The effect on wage employment is not as high as suggested by Table 19. Most of those who obtain wage employment in summer paddy cultivation do not sit idle if there is no summer paddy crop. But our discussions with these agricultural labourers suggest that they would get less than half the Rs.281,000 of employment that is generated by summer paddy. In addition, this employment is available elsewhere (typically in the neighbouring districts of Wynaad and Kodagu), requiring seasonal migration on the part of the labourers. This imposes significant non-monetisable hardships on these households.

8. Likely Impacts of Changes in Catchment Response on Agricultural Income and its Distribution

We are now in a position to use the estimates of changes in tank fillings due to changes in vegetation derived in Section 5 with the estimates of differences in net incomes and wage employment generated by different crops in order to predict the likely economic changes due to changes in forest vegetation. The hydrological analysis showed that regeneration of forests would lead to declines in June and December tank filling frequencies, which would translate in turn into less frequent cultivation of irrigated crops. The economic analysis showed that per farmer differences in income from irrigated versus unirrigated crops was quite substantial. Table 10 gives the changes in the expected values of income and employment if the changes in forest cover result in the predicted decline of the probability of tank filling. It appears that the impacts of such catchment forest regeneration will be significantly negative, resulting in a 49% decline in average (expected) net incomes from command area agriculture for the command area farmers and a 33% decline in the average wage employment generated in the command area.

9. Conclusions and Implications

We have attempted to simulate the likely impacts of regeneration of a degraded forest catchment on streamflow and the consequent impact on irrigation tank-based agriculture in a downstream village. We find that regeneration of the forest will reduce the runoff coefficient of the forested catchment and thereby significantly reduce the probability of the irrigation tank filling in either season. This in turn reduces the probability of the command area farmers being able to cultivate an irrigated paddy crop in either season. Less frequent paddy crop cultivation results in significant reductions in net income from command area agriculture and in the wage employment generated in the command area.

This result, that is, that increases in or regeneration of forest cover in the hilly catchment will actually significantly reduce the economic benefits accruing to the community downstream, is perhaps counter-intuitive and certainly contrary to some of the findings in the watershed services literature such as that of Pattanayak and Kramer (2001). This is not because the hydrological relationships in the Western Ghats are topsy-turvy. It is a consequence of the particular way in which streamflows are being managed and utilized by the local community, viz., by impounding wet season flows and using the water in the dry season, and that too for a water-intensive crop which can be cultivated only if the tank fills up completely during the rainy season. This kind of agriculture depends on quick runoff from the tank catchment so that the tank fills more easily and in time for the farmers to start cultivating an irrigated crop. Reduced forest vegetation and soil compaction in the tank catchment due to grazing will ensure early runoff and thus favour this kind of agriculture.

Note that under somewhat different agricultural water use systems, the impacts may be different. For instance, the decline in streamflow because of regenerating forest vegetation does not mean that this portion of the rainfall is entirely lost to evapotranspiration by the forest. It is possible that a significant portion of this water would end up in the form of an increased contribution to the groundwater aquifer (a partitioning that we were unable to estimate). Agriculture based on open well or bore well cultivation might then stand to gain (although such agriculture is currently not very prevalent in this village). One could also visualise a scenario where the irrigation tank was managed to provide protective irrigation to a much larger area of dry crops (such as *jowar* or *ragi*). Under these circumstances, the farmers would feel the impacts of declining inflows less sharply (although it would still be negative).

A couple of caveats are in order. First, hydrological changes cannot be restricted to a micro scale. Increased use of irrigation water in the tank command usually means reduced availability downstream. But it is not possible to trace these wider scale effects easily. One can also say that further downstream the catchment size is much larger, and so forest cover changes in one small catchment upstream are not going to dramatically affect the users that far downstream. Second, the prediction of decline in benefits is based only on declines in flows. However, improvement in forest condition will also result in declines in upstream soil erosion and consequently reduce the siltation rate of the tank, thereby extending its useful life. That there is substantial sediment entering the tank is obvious to anybody visiting the tank. However, from discussions with local farmers, it seemed that there was enough dead storage capacity in the tank to absorb the current silt load (corresponding to a degraded catchment) for a couple of decades. Thus, the effects of changes in siltation due to changes in forest condition have been deferred in time and are perhaps small in any case. The irrigation tank-dependent community or communities immediately downstream of the Bandipur forests still stand to lose economically in their agricultural incomes and agricultural wage employment if the forests regenerate.

Empirically, our results highlight the point that, under certain circumstances, farmers immediately downstream of a forested catchment may have an incentive to degrade the forest (or to let it degrade) in order to ‘harvest’ greater streamflows. In other words, the watershed ‘service’ of forests is a highly contextual phenomenon, and simplistic assumptions about its direction and magnitude should not be made. Methodologically, this study also makes a strong case for a more rigorous and interdisciplinary approach to understanding the phenomenon of watershed services. In addition to the obvious need for substantial analysis of catchment hydrology, our study highlights the importance of understanding the crucial ‘agro-hydrological’ linkage between standard aggregate hydrological variables such as runoff or recharge and the water applied in the field—a linkage that is both technological and social in nature. Farmers who do not have access to certain technologies do not have a direct linkage with the runoff from the catchment. The functioning of a technology like an irrigation tank is also dependent on social arrangements around it. In this case, since all the tank command farmers agree to a system that is “all or none” (irrigated water-intensive crop for all or no irrigation at all), the technology generates certain kinds of outcomes. The other modest methodological contribution we offer is the illustration of how one may address ‘non-marginal’ change situations and ones in which relationships are probabilistic. Finally, the study also draws attention to the need to look at impacts in terms of both agricultural profits or incomes and also wage employment generated, and to be sensitive to the nature of local markets for labour and other inputs.

We are certainly not claiming that forest regeneration reduces all benefits from forests. We did not try to estimate the value(s) of all other forest ecosystem benefits and how they would change if the forest regenerated (see Lélé *et al.*, 2001 for such an attempt). We did collect, as a part of the larger research project, some qualitative and quantitative data regarding the use of forest product by local communities. Preliminary analysis indicates that the set of households collecting forest produce for consumption or sale is entirely different from the set of households cultivating land in the tank command. The forest-dependent households live in and cultivate lands upstream of or outside the command area of the tank, and they would certainly stand to gain from a denser forest. This underlines the fact that even within the so-called 'local community' there can be major divergences in the nature of the stakes of different groups in the forest. Policy-makers must therefore move away from simplistic notions of forests being good for everything and everybody in all circumstances, and facilitate context-specific, ecologically and economically informed forest governance mechanisms.

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TABLES

Table 1: Landholding Classes among Tank Command Farmers

Hamlet to which farmer belongs	Land holding category [acres][a]				Total farmers	Plots[c] monitored: unirrigated *jowar*	Plots monitored: summer paddy
	0-1	>1 - 2	>2 - 4	>4			
Baragi	85	23	6	3	117	28	34
Hongahalli	18	4	0	0	22	5	5
Tenkalahundi	1	4	0	0	5	1	1
All hamlets	104	31	6	3	144[b]	34	40

[a] Refers only to the land held by the farmers within the tank command.

[b] Includes those who got seepage water from waste weir during summer of 2005.

[c] Almost all farmers own only one plot in the command, so plot and farm are equivalent. In the three cases where the farmer owned multiple plots in the command, we focused on a single plot for practical reasons.

Table 2: Results of General Linear Model Analysis of Physical Productivity of *kharif jowar* Crop (kg/gunta)

R Squared = .533 (Adjusted R Squared = .458).

Source	df	Mean Square	F	Sig.
Corrected Model	4	352.1	7.132	.001
Intercept	1	25710.2	520.764	.000
ELEVATION[a]	2	582.8	11.804	.000
SOILRECO[b]	1	50.8	1.029	.320
ELEVATION * SOILRECO	1	173.5	3.515	.073
Error	25	49.4		
Total	30			
Corrected Total	29			

[a] ELEVATION is coded as 1=lowland, 2=midland and 3=upland. Although These are ranks, they are treated as cardinal values for the regression.

[b] SOILRECO is a variable constructed by recoding the multiple soil types into two major categories: clayey-black and non-black.

Table 3: Estimated Aggregate Production and Income in Entire Tank Command: Irrigated *kharif*

Crop	Elevation	Area (acres)	Yield (kg/acre)	Gross income (Rs)	Net income (Rs)	Employment generated (Rs)
Paddy	Upland	29	2,850	768,075	148,809	274,655
	Midland	53	2,625	707,438	271,962	
	Lowland	55	2,400	514,800	282,225	
Paddy	Fed by waste weir	3	2,625	7,875	15,394	6,998
Total				1,998,188	718,391	281,653

Table 4: Results of Multiple Regression Analysis of Net Income from *kharif jowar* crop

Adjusted R-square = 0.720, N=30; degrees of freedom = 27

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-1677.553	1275.392		-1.315	.203
Land holding in tank command (gunta)	210.448	37.791	2.176	5.569	.000***
Square of landholding in tank command (gunta^2)	-.975	.222	-1.674	-4.382	.000***
Total other land holding (equiv. dry acres)	31.732	38.632	.108	.821	.421
Total livestock units owned by household	55.582	159.137	.055	.349	.731
Total number of adults of working age	-28.954	213.093	-.016	-.136	.893
Number of working age adults engaged in non-agri. occupations	-353.765	928.399	-.049	-.381	.707
Elevation=Upland (yes/no)	-2793.696	983.269	-.332	-2.841	.010*

Table 5: Estimated Production and Income in Entire Tank Command: Unirrigated *kharif*

Crop	Elevation	Area (acres)	Yield (kg/acre)	Gross income (Rs)	Net income (Rs)	Wage employment generated (Rs.)
Hybrid	Upland	40	720	160,290	64,775	117,537
Jowar	Midland/Lowland	70	1460	535,090	317,385	
Hybrid *Jowar*	Midland/Upland	10	600	35,600	-13,480	n.a.
Marigold	Midland/Lowland	11.5	1500	45,000	3000	n.a.
Beans	Midland/lowland	3	6000	5,400	900	n.a.
Fallow	Inside command	0.5	0	0	0	0
	Fed by waste weir	3	0	0	0	0
Total		135+3		781.380	372,580	117,537

Note: Net income from fodder *jowar* is negative because we are using the market price for fodder *jowar*, which was very low. Presumably, the shadow price of self-consumed fodder *jowar* is higher

Table 6: Impact of *kharif* Irrigation on Gross and Net Income and Employment Generated

Scenario	Crop	Gross income (Rs)	Net income (Rs)	Employment generated (Rs)
No irrigation	Hybrid jowar+ misc.	781.380	372,580	117,537
Irrigation	Paddy	1,998,188	718,391	281,653
Difference (absolute)		1,997,407	345,811	164,116
Difference per tank command farmer		8,450	2,401	1,140

Table 7: Multiple Linear Regression Analysis of Total Paid Out Costs[a] for Summer Paddy Cultivation

R-square=0.92; Adjusted R-square = 0.91, N = 39; degrees of freedom=33

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	2077	972		2.138	.040
Landholding in tank command (gunta)	52	22.5	.336	2.316	.027
Square of tank command landholding (gunta^2)	.55	0.15	.556	3.796	.001
Adults engaged in nonagricultural occupations (jobs, business)	1312	664	.114	1.975	.057
Total working age adults in household	-49	137	-.021	-.358	.722
Total large animal units (excl. sheep goats)	-170	87	-.114	-1.963	.058

[a] Total paid out costs include costs of bullock hiring, hired labour, purchased manure and its transport cost, and chemical fertilizer costs.

Table 8: Results of Multiple Linear Regression Analysis of Total Hired Labour Costs for Summer Paddy

R-square=0.92; Adjusted R-square = 0.85, N = 39; degrees of freedom=33

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	224	475		.471	.641
Landholding in tank command (gunta)	38.0	15.6	.463	2.432	.020
Square of tank command landholding (gunta^2)	.230	.102	.436	2.255	.031
Adults engaged in nonagricultural occupations	971	411	.160	2.359	.024
Total working age adults in household	-87.1	81.4	-.070	-1.070	.292
All other land in dry land equiv acres	-6.5	17.4	-.025	-.375	.710

Table 9: Estimated Aggregate Production, Income and Employment Generated in Entire Tank Command: Summer Paddy

Crop	Elevation	Area (acres)	Yield (kg/acre)	Gross income	Net income	Employment generated
Paddy	Tank command	135	2,584	2,075,598	1,366,860	269,298
Paddy	Fed by waste weir	6	2,584	91,861	63,366	11,664
Total		141	2,584	2,167,459	1,430,226	280,963
Total per tank command farmer				15,052	9,932	1,951

Table 10: Possible Impacts of Catchment Forest Regeneration on the Baragi Agricultural Economy

Scenario	Season	Probability of tank filling	Expected value of net income	Expected value of employment generated
Degraded forest in catchment (Current)	*Kharif*	20%	459,761	150,087
	Rabi/summer	57%	815,229	80,074
	Total for year		1,274,990	230,161
Degraded forest in catchment (Current)	*Kharif*	7%	403,093	128,929
	Rabi/summer	18%	257,441	25,287
	Total for year		660,534	154,216
DIFFERENCE in expected values	Change in total annual income/ employment		-614,456	-75,945
	Change in annual income / employment per farmer in command		-4,267	-527
	% change in annual income / employment		-48%	-33%

Note: In US$, the change in expected value of total annual income in the command is ~$15,360, while that in income per farmer is $107. But these absolute values are less important than the relative values of the change.

FIGURES

Figure 1: Location of Karnataka State (with district boundaries), Western Ghats region and Bandipur study site

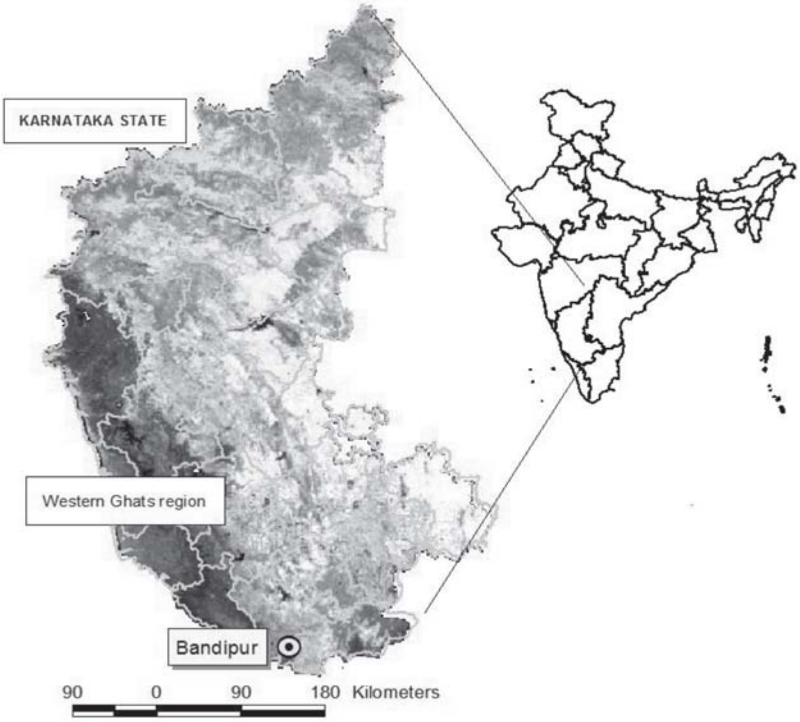


Figure 2: Baragi: Tank Catchment, Streams, Tank Command Area, and Revenue Village Boundaries (the left half of the map falls inside Bandipur National Park)

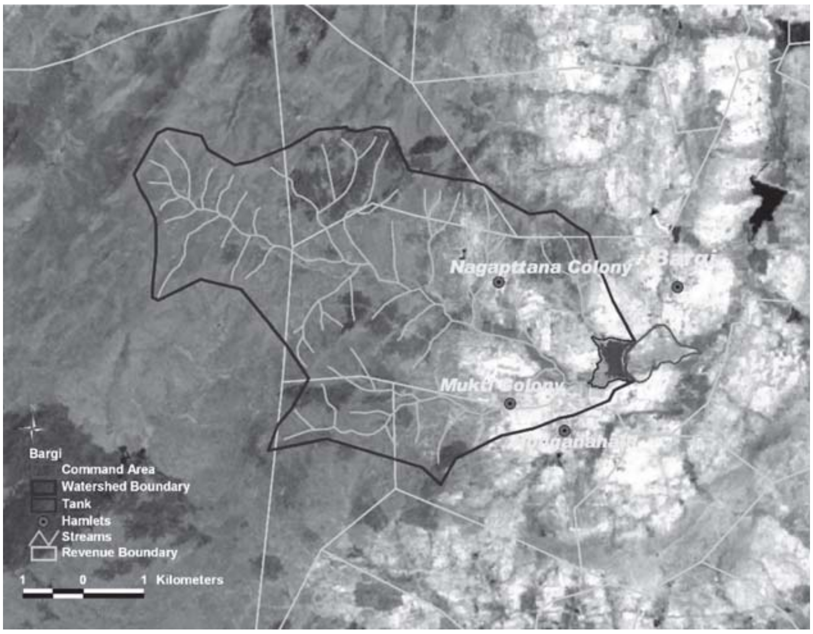


Figure 3: Baragi Tank Embankment (L) and Irrigated Paddy in the Command Area (R)

Figure 4: Revenue Villages and Hamlets around Baragi Tank (revenue village boundaries are in red, the tank command area is shown in sky blue)

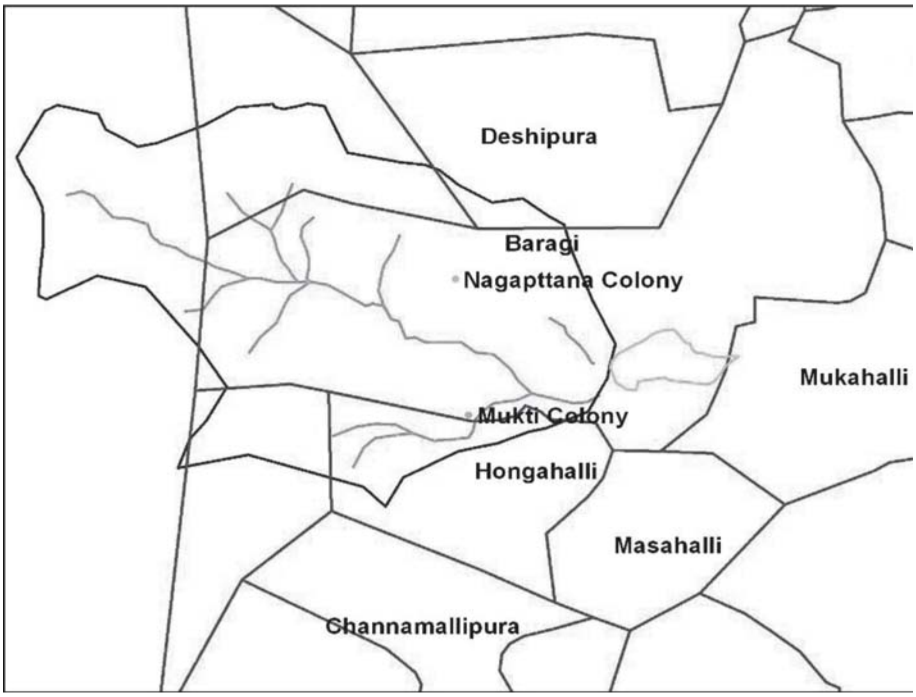


Figure 5: Cropping Decisions in Baragi command (A slightly simplified schema)

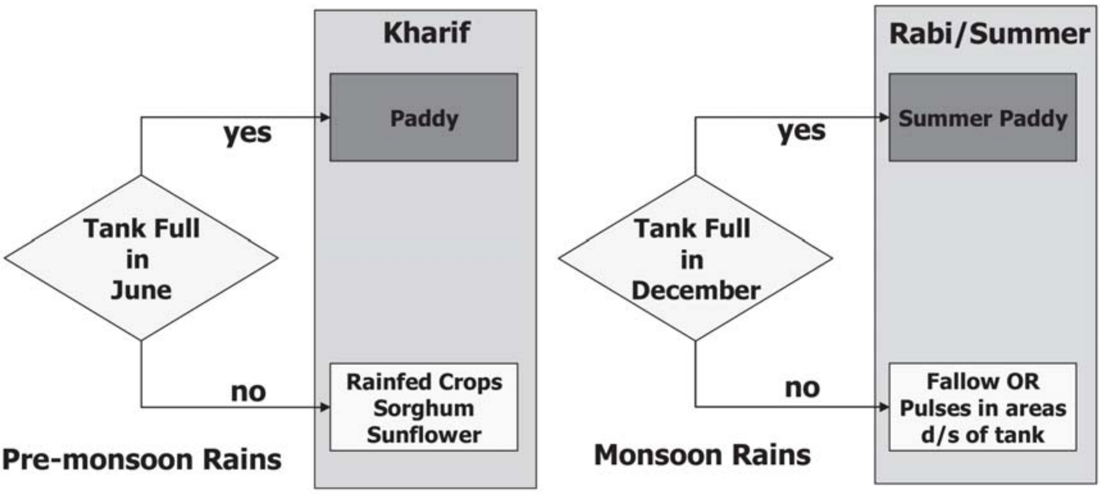
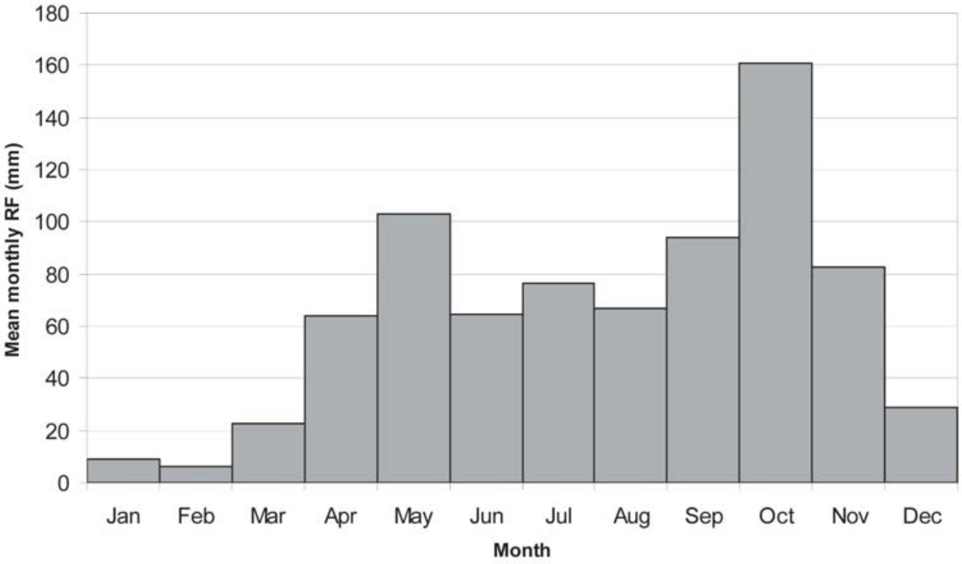


Figure 6: Monthly Average Rainfall near Baragi Village



(Source: 20 years daily rainfall data from Mookahalli raingauge)

Figure 7: Monthly Rainfall and Tank Level of Baragi Irrigation Tank for 1994-2005

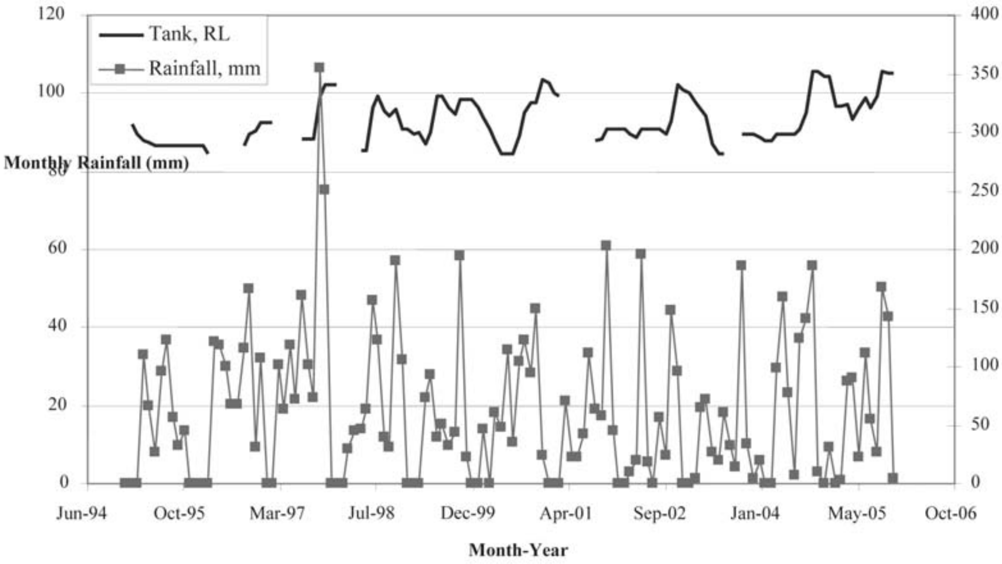


Figure 8: Variation in 'Probability of Exceedance' of Rainfall Required to Fill Tank for a Certain Runoff Coefficient during the Northeast Monsoon (Sep-Dec) Period.

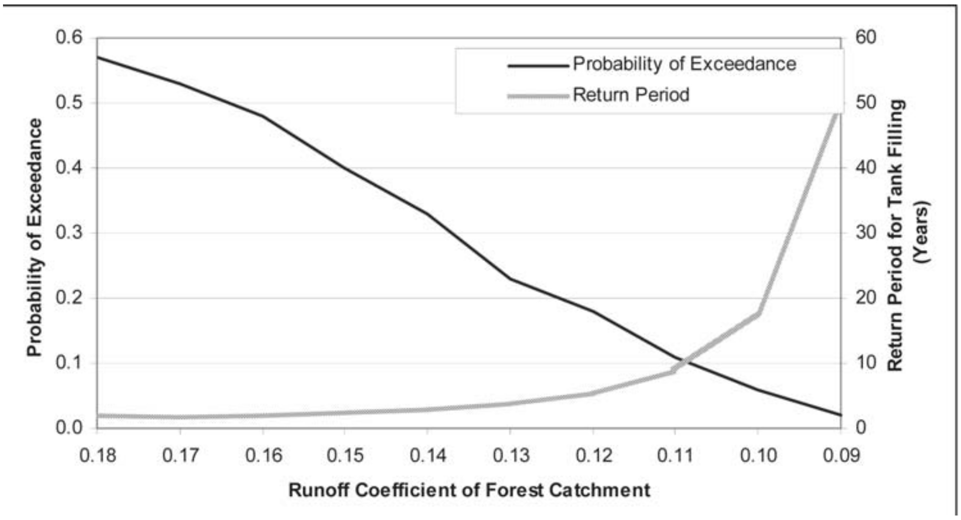


Figure 9: Hybrid *jowar C*rop Ripening in Baragi Tank Command in September 2004 (L); Summer Paddy Crop Harvested in Baragi Tank Command during July 2005 (R).