Forest Cover Change,

Hydrological Services,

and Economic Impact

Insights from the Western Ghats of India

Centre for Interdisciplinary Studies in Environment & Development

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MEMBERS OF THE STUDY TEAM

Sharachchandra Lélé (CISED)
(Technical Coordinator)

Jagdish Krishnaswamy (ATREE)

B Venkatesh (NIH)

Shrinivas Badiger (CISED)

B K Purandara (ATREE)

Ajit Menon (CISED)

along with

CISED
Iswar Gouda Patil
A K Kirankumar
Rajeev Kumar
Santosh Hegde
Sowjanya Peddi
Lakshmikanth

NIH
Veerabasantha Reddy
Pramod Mulangi
Yuvraj

ATREE
Pradeep Joshi
R Rakesh
Suparsh
M C Kiran

UNESCO SUPPORT TEAM

Mike Bonell (UNESCO)
(Technical Advisor)

R Jayakumar and Bhanu Neupane (UNESCO)
(Administrative Coordinators)

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Chapter 1. Introduction

1.1 Forests, hydrology and socio-economic impact: complex linkages

Tropical forest ecosystems generate multiple benefits to society, including goods_such as fuelwood, fodder, timber, leaf manure, food and medicines, and services such as carbon sequestration, habitat for wildlife and biodiversity. Watershed services, which include hydrological regulation (groundwater recharge, low-flow augmentation, flood control) and soil conservation, are considered to be one of the important benefits from forests. Thus, changes in forest condition are likely to have profound implications for society. This is particularly likely in densely populated, historically used river basins of South Asia, where forest cover is changing rapidly in quantity and quality, and where river flows are being increasingly harnessed for supplying scarce irrigation and drinking water.

In many ways, the hydrological service benefits of forests and associated ecosystems (such as grasslands) are perhaps the most poorly understood and contentious of all forest ecosystem benefits.[1] Firstly, there are few rigorous studies of hydrological impact—even in physical terms—of different forest covers. Existing studies are limited to a few regions, and the insights that may have emerged from these studies cannot be safely extrapolated to other regions in the tropics. Secondly, the studies that exist do not provide a consistent picture of the link between forests and hydrological regulation. What seems to emerge is that not all types of "forests" have equal or even unidirectional influence on hydrology, and neither are all "non-forest" land-uses deleterious to all these services. Thirdly, we understand even less about how physical changes in hydrological parameters might translate into social impact. In this section, we summarise briefly the current understanding and debates about the influence of tropical forest/land-cover on hydrological services and about the social significance of these services.

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 after almost eighty years of watershed experiments (in mostly temperate regions), hydrologists had, by the mid-1980s, become rather sceptical of these popular "myths" (Hamilton, 1987; Hamilton, 1983). The growing knowledge of the higher consumption of water by trees compared to other vegetation such as grass was even used to question and reverse the traditional policy of afforesting non-forested catchments upstream of water-storage reservoirs in some temperate locations (Calder, 1979; Scott and Lesch, 1997; Finlayson, 1998). Strong evidence that flooding and sediment transport in flood plains downstream of young, geologically unstable mountain systems such as the Himalayas is often unrelated to "deforestation" upstream contributed to this process of myth deconstruction (Ives and Messerli, 1989).

Subsequent research, however, showed that conclusions drawn from clearcutting experiments in temperate ecosystems cannot be casually extrapolated to tropical ecosystems and the "clean" manipulations in the experiments bear little resemblance to the actual process of deforestation[2] (Bruinjzeel, 1991;1993). In the tropics, controlled experiments are few and far between, not covering the diversity of geomorphological

[1] In contrast, there has been a fair amount of research on the impacts of forest cover change or land cover change in general on soil erosion (see Dixon, 1997).

[2] Deforestation caused by grazing, fuelwood extraction and fire would dramatically alter soil properties, as would conversion of forest to plough-based agriculture.

conditions. Furthermore, they often are of short duration and/or do not accurately mimic the actual land-use that prevails after conversion of forests (Bonell, 1998). It is now accepted that the effects of tropical forest degradation, loss, or afforestation on watershed functioning will vary with spatial scale, precipitation characteristics (such as rainfall intensity), pedology, soils and of course the type of land-use that prevails after forest conversion (Calder, 1992; Bonell, 1993). In other words, simplistic statements that forests have positive (or negative) watershed benefits are no longer tenable; the relationship is likely to be highly contextual.

In the particular context of south Asia, research therefore needs to focus on two different 'forest' use systems. On the one hand, the use of forests by local communities has generated a complex mosaic of dense stands of secondary growth, tree savannahs, seasonally protected grasslands, stunted scattered trees and shrubs, heavily grazed grasslands with exposed soils, or even closed canopy tree cover with no understorey or leaflitter. It has already been shown that from a productivity or diversity point of view, the tendency to characterise all such forests as 'degraded' is without an adequate empirical basis (see, e.g., Lélé, 1993; Lélé, 1994, for the Western Ghats). The hydrological impacts of such heavy use, however, remain largely unknown (Bruijnzeel, 1989).

On the other hand, state forest agencies have followed the practice of converting natural forests or historically used grazing lands into monocultural plantations, earlier for production forestry and more recently for their supposed local and environmental benefits. But it is not clear that these strategies are indeed always beneficial from a watershed perspective. Recent evidence on this question is mixed. Firstly, soil erosion depends more on the ground cover than on tree canopy cover. Thus, high erosivities have been recorded in teak plantations, where the canopy is high, leaves are large, trees are deciduous and undergrowth is poor (Kusumandari and Mitchell, 1997). Rainfall erosivity under plantations of *Acacia auriculiformis*, mature oil palms, and bamboo in Java increased significantly after the canopy was established (Young, 1991). Secondly, hydrological changes are equally dependent upon earlier land-use, nature of plantation and pedological properties. Planting of eucalyptus on natural montane grasslands in the Nilgiris has been found to reduce water yield from catchments by up to 23%, with implications for downstream hydropower projects (Sikka *et al.*, 2003). A reduction in water yield was also observed in a study of the hydrological effects of replacing natural forest with pine plantations in Chiang Mai, Thailand (Vincent *et al.*, 1995). Research on the impacts of monocultural afforestation is therefore also called for.

The social impacts of changes in hydrology due to forest cover changes are even less well understood or studied.[3] From the few studies that are based on empirically established models of the forest-water relationship at that site,[4] one finds that the impacts are highly context-dependent. While Vincent's study related to water availability for agriculture and urban areas, Aylward *et al.* looked at the impacts of converting forest to pasture on total flows and sediment load (Aylward *et al.*, 1998), Pattanayak's various papers analysed the impacts of deforestation on baseflow used in agriculture in eastern Indonesia (Pattanayak, 2004; Pattanayak and Kramer, 2001b;a) and Kramer *et al.* (1997) examined the flood control benefits of forests. Not surprisingly, the 'economic value' of impacts ranged from 3 cents/yr/ha of forest for flood control to about \$8/yr/ha for increased agricultural production in eastern Indonesia. Secondly, the beneficiaries of increased hydrological services may be quite different from those who bear the costs of forest conservation (see, e.g., Xiaogang, 2001)—a point that tends to get glossed over in the economic valuation literature but which is of crucial importance in devising policies for forest and water management. This is

[3] This section is based on the review in Lélé and Venkatachalam (2006).

[4] Most other studies are based on either overly simple models that are not calibrated or validated for the study site, such as the Universal Soil Loss Equation, or on contingent valuation approaches that assume that local resource users are completely knowledgeable about the forest-water relationship—a highly questionable assumption in most cases.

particularly true in the south Asian context, where natural resources are used intensively by diverse groups. Thirdly, the impacts would clearly depend upon the technological and institutional context governing water use—something that has again received little attention so far.

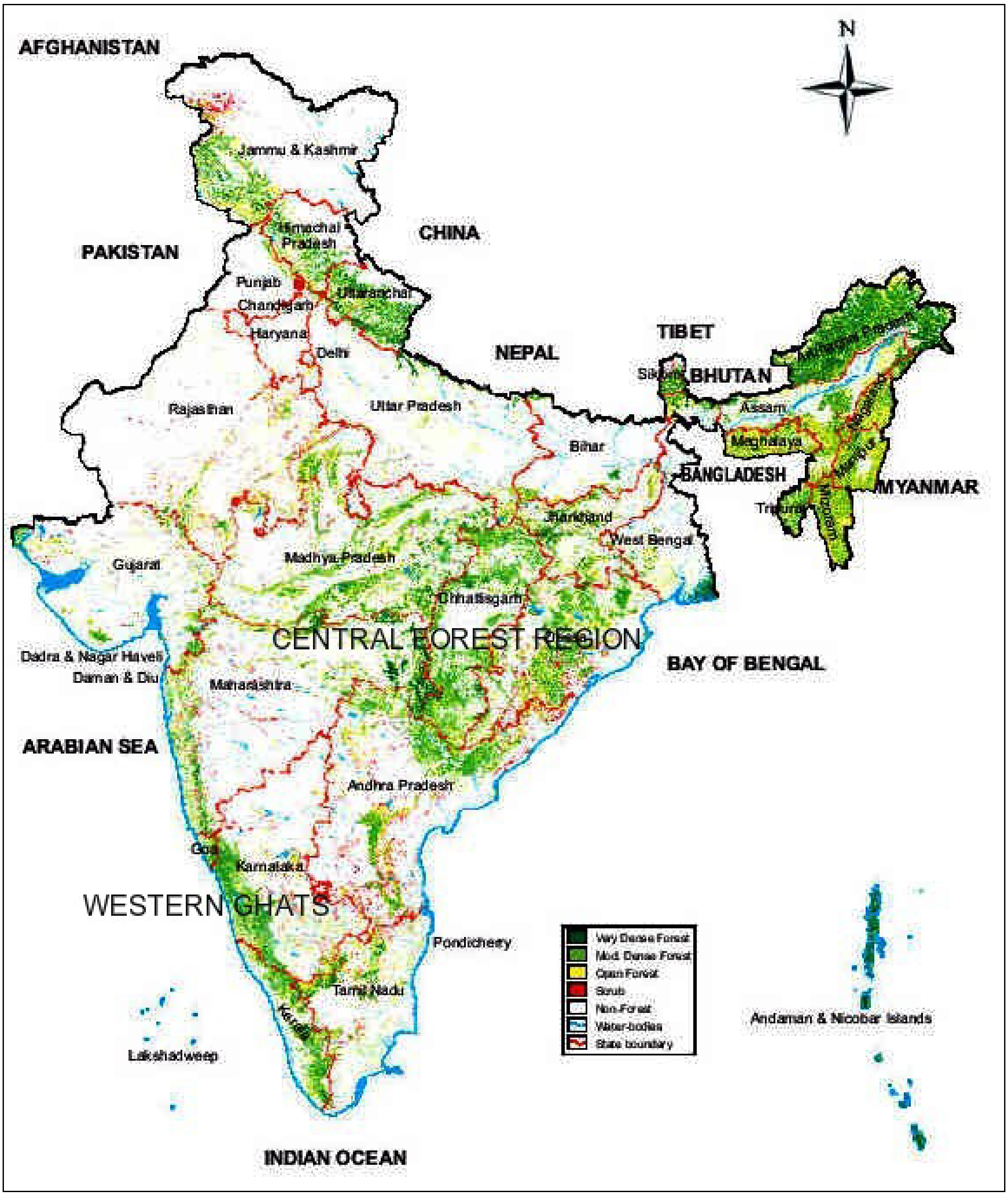

Figure 1-1 Location of Western Ghats region and Karnataka state in India

The Western Ghats region of peninsular India is one of the most important regions from the point of view of understanding hydrological service impacts of forest cover change and also represents the complexities of the social use of forests. On the one hand, the heavily forested Ghats region is the site of historically intense use of forests by local communities for meeting their needs of fuelwood, fodder, grazing, leaf manure, etc., as well as felling by the state forest department for meeting regional needs of timber. This has resulted in a complex mosaic of relatively undisturbed forest, savannah, grassland and barren lands, interspersed with monocultural plantations established by the forest department. It is also the site of major shifts in land-use from "forest" to "non-forest", including agriculture or plantation crops. State forestry activities have also significantly affected the composition of these forests. On the other hand, virtually all the major rivers (particularly the important east-flowing rivers) in southern India originate in the Western Ghats. The changes in land-use and land-cover in the upstream catchments of these rivers are therefore of critical importance to the millions of farmers on the eastern portion of the Deccan plateau, especially the increasing numbers depending upon river flows (direct or dammed) for irrigation. They are also likely to be of importance to the communities local to the Western Ghats themselves, because even in this high rainfall region, seasonal scarcity of water is ubiquitous, and fertile soil is at a premium.

This study is an attempt to contribute to an improved understanding of the forest-water-community linkage through field investigations in the Western Ghats that lie within Karnataka state (see Figure 1-1). The study is distinctive in its attempt to integrate the biophysical investigation of forest-hydrological changes with the socio-economic investigation of impacts of such changes. We describe below the questions investigated, the framework within which they are answered, the analytical approach, methods used for site selection and for the hydrological and socio-economic studies.

1.2 The framework and the research questions

Based on the above review of literature, we identified the following research questions as the focus of our investigations:

a) How are changes in forest condition resulting from intensive use and afforestation likely to affect hydrological variables?
b) What might be the magnitude and distribution of the impacts of such changes in hydrological variables on the local communities that use this water for various purposes?
c) What are the benefits and costs imposed by changes in forest condition resulting in direct changes in forest product availability?
d) What factors influence the magnitude and distribution of benefits and costs that result to local communities from hydrological and other changes?

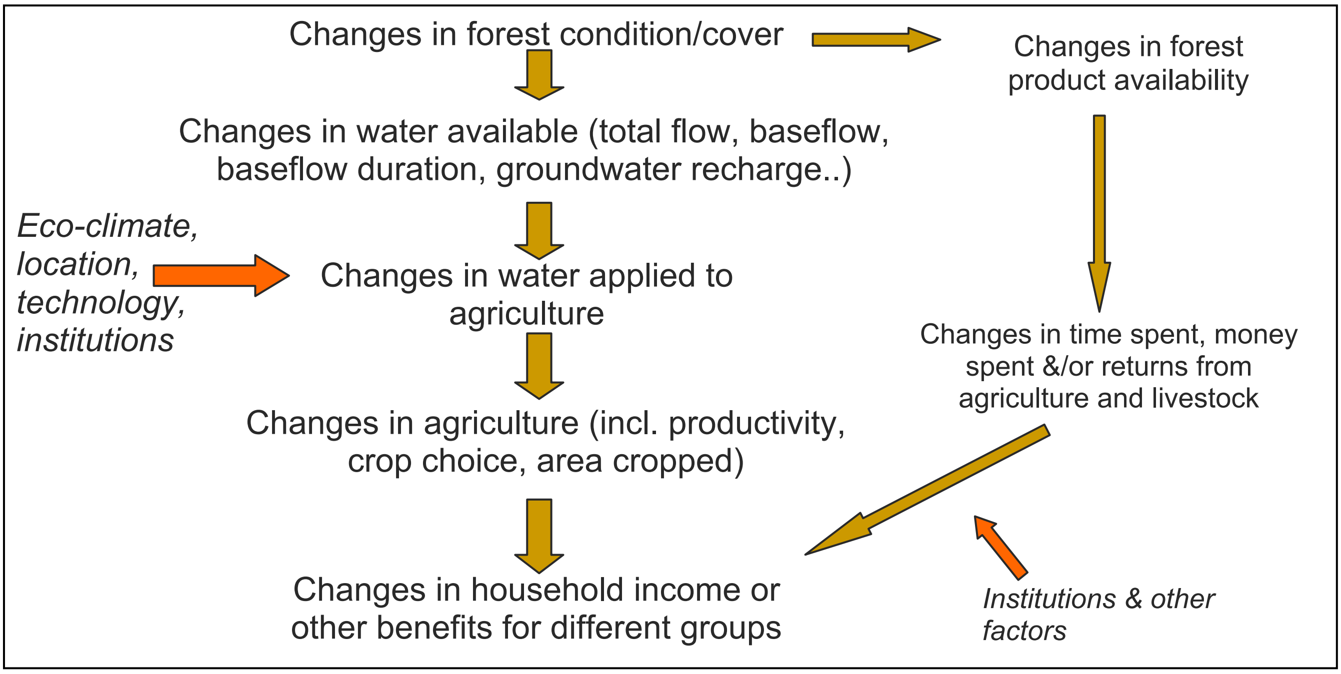

Figure 1-2. Conceptual framework for the study

The manner in which these questions are linked to each other and the investigation and analysis are therefore structured is best understood through the framework depicted in Figure 1-2. This is essentially a modified version of the framework outlined by Pattanayak (2004) that outlines the links between forest cover change and economic welfare. We include an explicit step for highlighting changes in water applied to agriculture, although as we shall see it is not always possible to measure this change. We also introduce the role of location, technology and institutions to understand how changes in hydrology translate into changes in water applied to agriculture.

1.3 Study regions

it was not practically possible to cover the entire Karnataka Western Ghats in one study, we decided to limit ourselves to two regions: the Uttara Kannada-Shimoga region and the Mysore plateau region. This provided us with an eco-climatic gradient and also facilitated access for the hydrologist teams that were located in Belgaum (NIH) and Bangalore (ATREE) respectively.

The Uttara Kannada-Shimoga region can be broadly categorised into 3 eco-climatic zones: coastal, malnaad (hilly) and transition.[5] However, further variations are introduced by changes in soil type. We limited the variation in soil conditions by excluding the northern portion of the district, which has black cotton soils, from our 'region of interest'. The three zones in this region of interest are indicated broadly in Figure 1-3. Small portions of Shimoga district are also included in the malnaad and transition zones.[6] The total size of this "region of interest" is about 7,500sq.km. The major differences between the three eco-climatic zones within this region of interest are enumerated in Table 1-1.

The Mysore region falls in the southern limits of the Southern (or Mysore or South Deccan) plateau, flanked in the south by the high-elevation Nilgiri hills (see Figure 1-4). While the plateau region typically has elevations of 600-900m, the ridges encompassing BRT and Bandipur rise above 1400m. The region is characterised by a climate classified by IMD as 'Tropical Savanna, hot, seasonally dry'. The rainfall ranges from 500mm to 1500mm, thus representing a drier regime as compared to the Uttara Kannada region.7 Further, unlike the Uttara Kannada region which receives virtually all its rainfall from the south-west monsoon, this region receives only 40% of this annual rainfall from the Southwest monsoon (June-September). A significant fraction of the annual rainfall is contributed by the north-east monsoon during the October-January period. The geology of the region is characterised by gneisses, granites and charnockites. Soils in BR Hills and Bandipur are generally rocky, gravely-clay varying from moderately shallow to moderately deep. Stream channels often are extremely rocky with rock outcrops in the upper slopes, and sandy in the lower slopes. Differences within the Mysore plateau region and more details of each sub-region are given in Table 1-2

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[5] The boundaries between these zones are not sharp, since the crestline is not very sharply defined as in other parts of W.Ghats, and even otherwise the coastal belt also has hills which slowly rise towards the crestline.

[6] The western part of Sagar taluka is considered part of the malnaad zone and the eastern part of Sagar taluka as well as the talukas of Sorab and Shikaripur are included in the transition zone.

[7] Most of the raingauge stations are located at lower elevations. Given sharp changes in altitude along the edges of the region, orographic features are likely to influence rainfall significantly. We are attempting to use sophisiticated using co-krigging methods (that incorporate elevation information) to better characterize the rainfall distribution in the area.

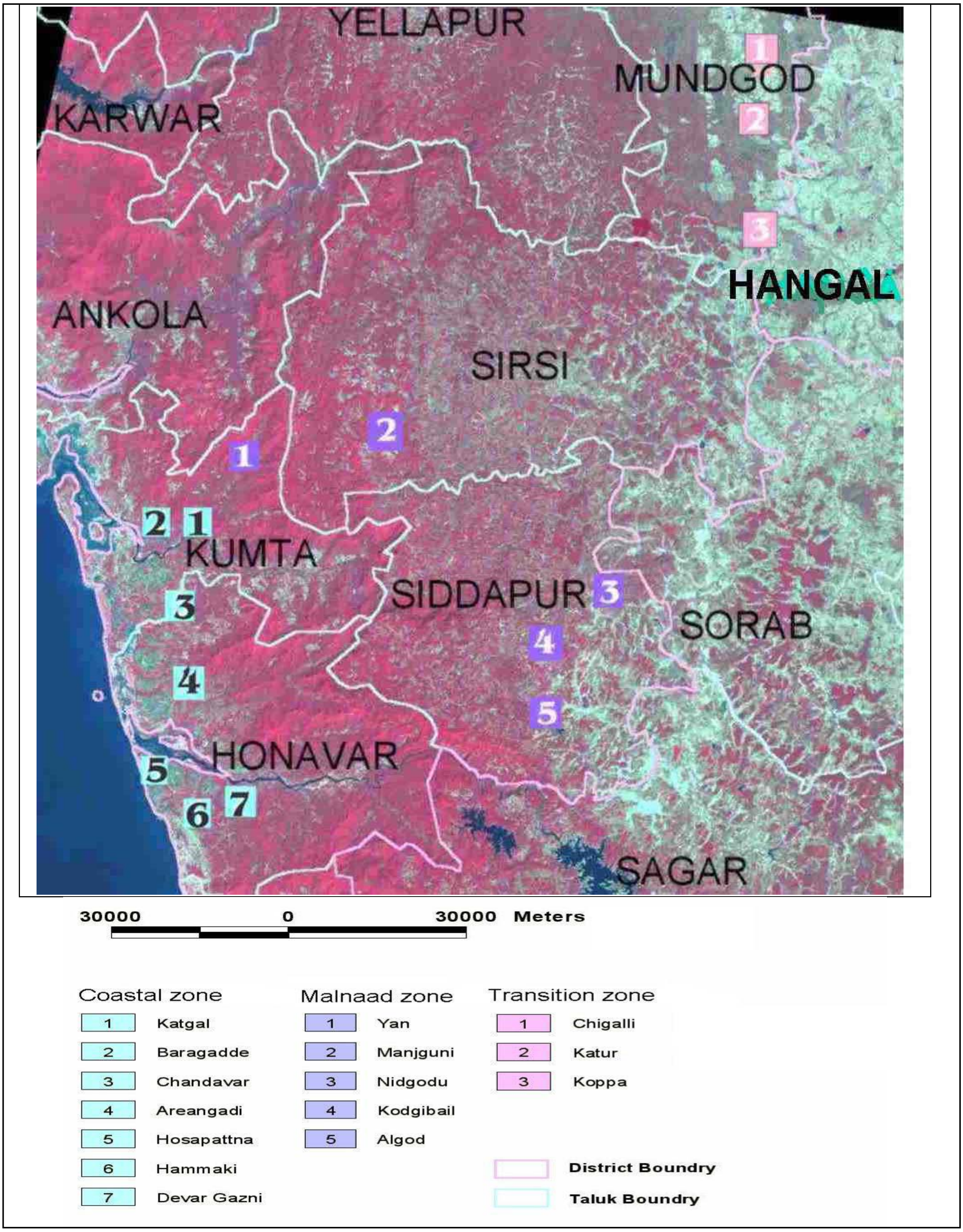

Figure 1-3. Overview of Uttara Kannada region broadly indicating the eco-climatic zones and sites that were considered for the study.

Table 1-1. Characteristics of eco-climatic zones or 'blocks' within the Uttara Kannada-Shimoga region

Variables	Coastal	Upghat	Transition
Talukas	Kumta, Honnavar, Ankola, Karwar and Bhatkal	Sirsi, Siddapur, western Yellapur, western Sagar	Mundgod, eastern Yellapur, eastern Sagar, Shikaripur and Sorab
Rainfall (west-east)	3000-6000 mm	8000mm-2500mm	2500-1500 mm
Terrain	Narrow coastal plain quickly merging with foothills of the Ghats	Highly undulating terrain; dense stream network	Relatively flat with a few ridges
Soil type	Red lateritic with lateritic outcrops near the coast	Deep red lateritic with variation in clay content	Partly red lateritic with very high clayey loamy content
Vegetation type	Predominantly semi-evergreen, with patches of evergreen, mangrove, and moist-deciduous types	Semi-evergreen and moist deciduous, with some evergreen *kans*	Predominantly dry deciduous, with moist deciduous patches on the west and some evergreen *kans*
Forest plantation types	Widespread planting of *Acacia auriculiformis* on most of the degraded lands in the last 10 years	Teak and eucalyptus replaced natural forest till the 1980s; subsequently widespread planting of *A. auriculiformis in open lands*	Early plantations mainly of teak and bamboo. Scattered *Acacia* plantations in the last few years
Major crops	Coconut, paddy, arecanut, cashew,	Arecanut+spice horticulture, paddy	Paddy and pulses
Irrigation system	Rain and stream fed, but also significant pumping	Mainly rainfed and baseflow dependent	Mainly rainfed and minor irrigation tanks
Settlement pattern	Dense, continuous settlements along the coast, scattered settlements in the interior	Scattered hamlets, often consisting of very few households each	Much more concentrated settlements
Tenure regimes	Large areas under 'Minor Forest' (*de facto* open access)	Soppinabetta and Minor Forests, with small RF patches	Reserve Forests are the predominant tenure regime
Major forest cover change since 1980	Acacia plantations on lateritic outcrops. Dense forests converted to tree savannas/ grassland/ degraded scrub in some locations	Acacia plantations replacing grasslands. Some patches of dense forest converted to grassland/ degraded scrub	Dense forests converted to tree savannas/ grassland/ degraded scrub, and also to cultivation

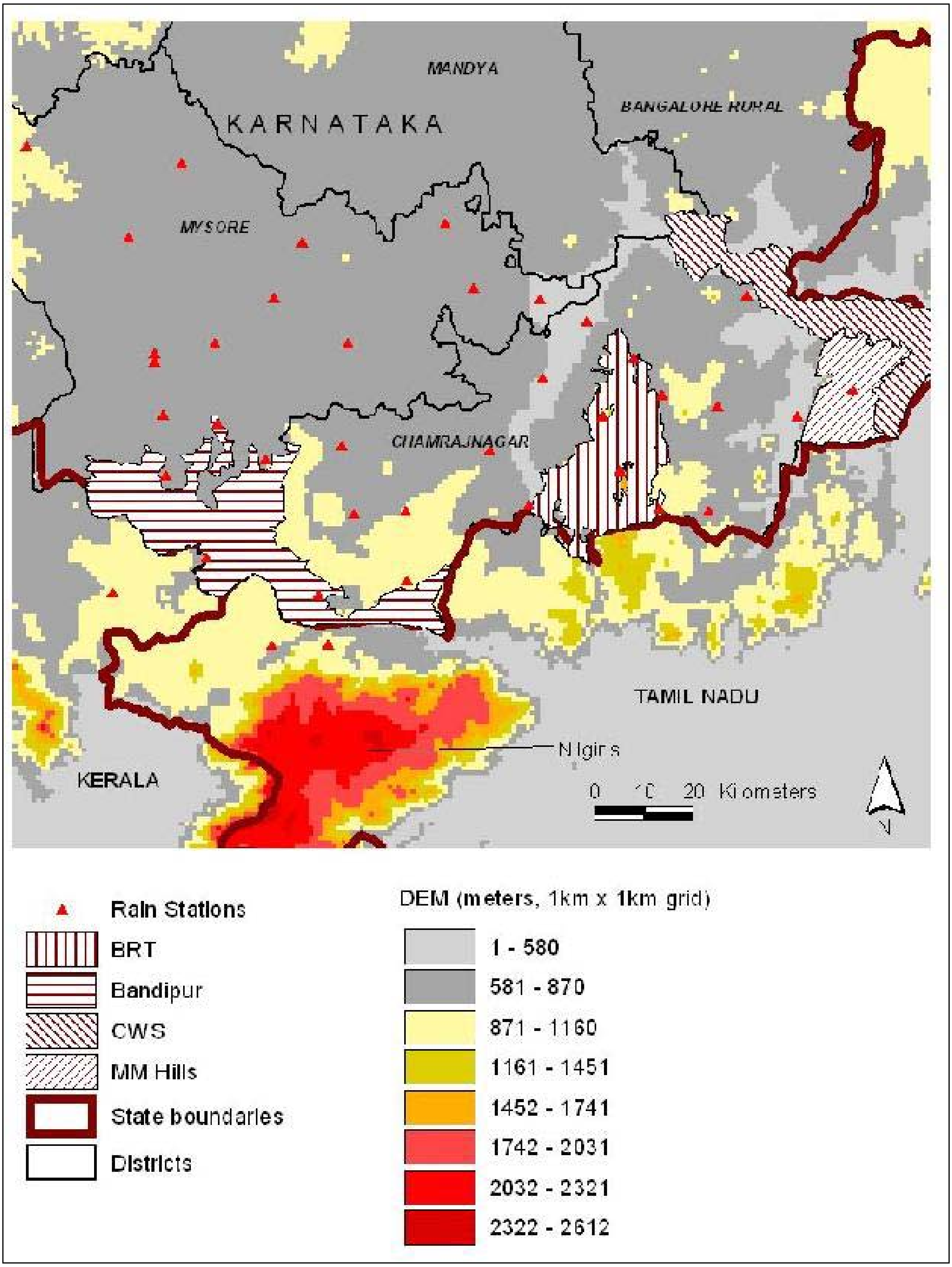

Figure 1-4. Overview of Mysore plateau region and the different forest blocks within it.

Table 1-2. Characteristics of eco-climatic zones or 'blocks' within the Mysore region

VARI-ABLES	BR HILLS Block	BANDIPUR Block	MM HILLS Block	MUTHATI (CWS) Block
Talukas	Yalandur, Chamarajnagar, Kollegal	Gundlupet, H.D.Kote,	Kollegal	Kollegal, Kanakapura
Rainfall (mm)	900-1400	700-1000	~1200	~900
Terrain	Highly undulating and deeply dissecting topography	Highly undulating and deeply dissecting topography	Highly undulating and deeply dissected topography	Highly undulating and deeply dissected topography
Elevation Range	700-1600	700-1400	300-1400	400-1150
Soil Type	Moderate shallow, deep gravely clay to sandy clay loam	Moderate deep gravely clay to clay	Gravely clay varying from moderately shallow	Gravely Loam to moderate clay
Vegetation Type	Evergreen, Moist deciduous to dry deciduous scrub	Evergreen, Moist deciduous, dry deciduous scrub bamboo	Moist deciduous to dry deciduous scrub bamboo	Evergreen, Moist deciduous to dry deciduous scrub
Forest Plantation types	Scattered silver oak plantations at mid-elevations, and coffee plantations at high elevation	Scattered teak plantations, some large eucalyptus plantations on Park fringes	None	No Info
Major Crops in downstream areas	Ragi, Paddy, Sugarcane,	Jowar, Ragi, Cotton, Avare (Green beans), Cabbage, Paddy below irrigation tanks	Ragi, Paddy,	Ragi, Avare, Hurali, Thogare
Irrigation System	Combination of rainfed, tank-fed and groundwater (open and bore wells)	Rain and stream fed and some minor irrigation tank	Rain and stream fed and some minor irrigation tank	Rain and stream fed and some minor irrigation tank
Demo-graphic Pattern	Dense population along foothills and sanctuary fringes, dependent on forests for fuelwood and grazing	Densely populated along the boundary, dependent on park forests for fuelwood and grazing	Sparse population in the hills, dense along foothills, dependent on forests for fuelwood and grazing	Dependency on forest for fodder and fuel in highlands, and collection of fuel and fodder in lowlands.
Settlement Pattern	Settlement only in the foothills, none within the watershed area	No settlements within the boundaries, densely populated along the fringes	Large settlements both in highlands and foothills	No settlements in the highland area, settlements are only in the foothills
Tenure Regime in forest lands	Wildlife sanctuary, some gomaal in fringe villages	National Park, Reserve Forests, some gomaal	Reserve Forests, some gomaal	Wildlife Sanctuary
Major forest cover change since 1973	Decline in forest cover at northern end, regeneration in interior parts	Degradation of forest cover along fringes, some increase in eucalyptus plantations	Significant declines in forest cover in patches	Not showing up appreciable differences since 1973

1.4 Methodology

1.4.1 Approach to site selection

Originally, we planned to chose a set of 'blocks' that spans the range of eco-climatic and socio-hydrological conditions within each region, and within each block to adopt a 'paired catchment' approach. The idea of the paired catchment approach is to use catchments that are proximate (and hence experiencing similar rainfall) and similar to each other in terms of shape, size and geology to control for these confounding factors in the hydrological studies. Similarly, if we can find communities that are 'otherwise similar' but living downstream of catchments with distinctly different land-cover, we would be able to estimate the likely socio-economic impacts of changes in land-cover in a reasonably accurate manner.

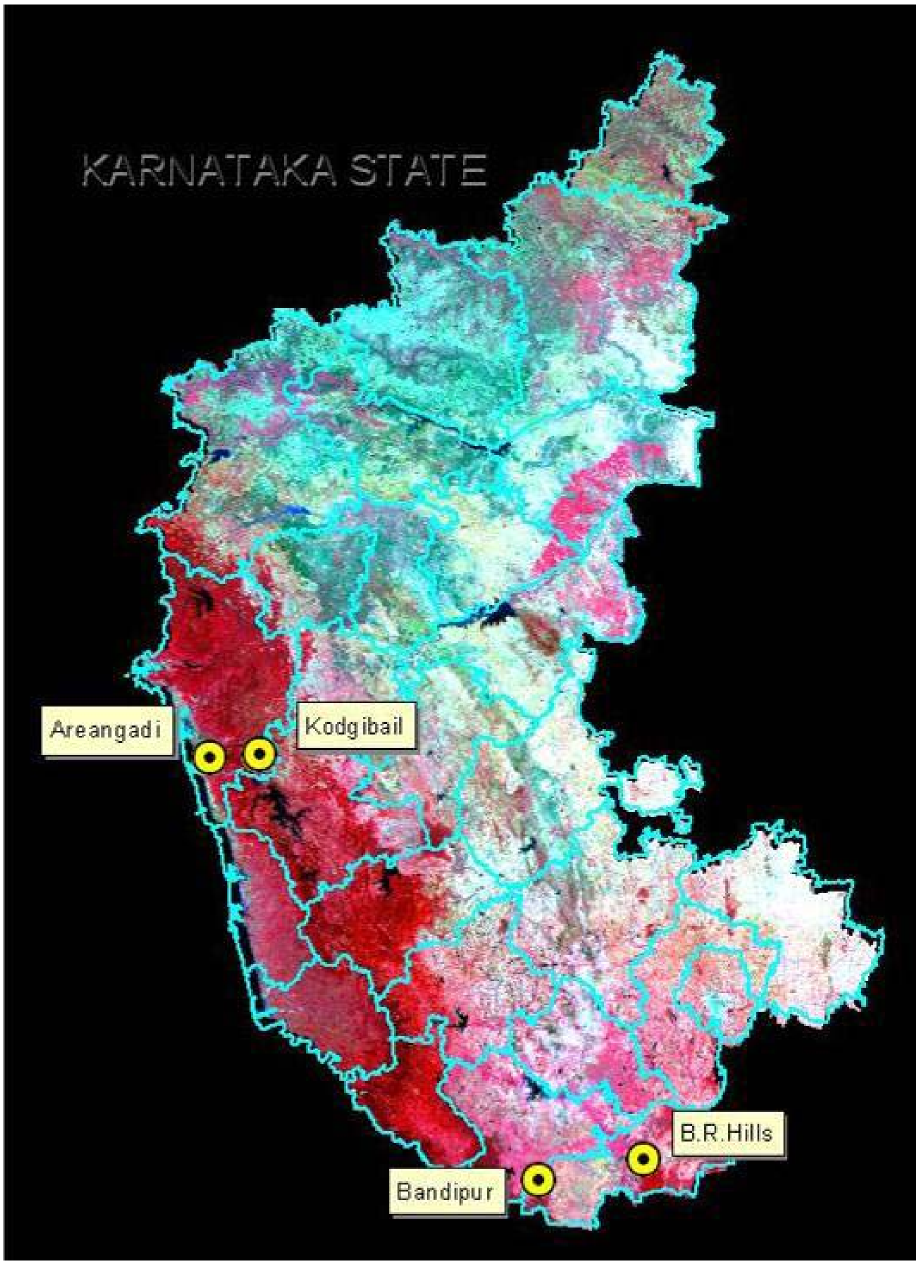

Figure 1-5. Locations of selected blocks

We used Remote Sensing and GIS techniques to generate layers information of land cover, stream network, slope/contour information, forest legal boundaries, settlement locations and village boundaries (linked to census information). These layers were used to review large portions of the two regions (Uttara Kannada-Shimoga, and Mysore plateau) and identify potential 'blocks', i.e., sites where one might find triplets of catchments of similar size and slope, with similar communities downstream of the catchment, but with distinct land covers, viz., dense forest, degraded forest and plantations. We shortlisted more than a 100 potential catchments and conducted extensive field visits during February-May 2003 and beyond to verify their appropriateness and feasibility for the hydrological and socio-economic investigations.

In the process of these extensive field investigations, we discovered that this approach was easier visualized than actualized. First, the land cover tends to be highly heterogeneous and fragmented, with fragments of even a few hectares (especially in the wetter region). It was particularly difficult to find catchments fully or predominantly covered with plantations, since the plantation boundaries always followed a different logic. Plantation species also varied from region to region. Eventually, we dropped the search for plantation-covered catchments in the Mysore plateau as they were sparsely distributed in this region. Second, variation in geology and soils further reduced the choice in terms of 'intrinsically similar' catchments, and interventions in natural streamflows in the form of water conservation works, minor irrigation systems and other flow interruptions were widely prevalent.

Third, and perhaps most important, there is a strong correlation between forest condition and human presence. This means that it is difficult to find a 'relatively undisturbed' forest in areas densely inhabited by people, and conversely, it is difficult to find catchments with heavily used forest vegetation in an area that is sparsely inhabited. The remaining dense forests are mostly on steep slopes whereas the heavily used forests and the plantations are in more accessible areas.

Table 1-3 Suitability of paired catchments for socio-economic assessment

Region	Block	Catchment	Is a community present immediately downstream?
Uttara Kannada	Upghat/Malnaad (Kodgibail)	Control (2)	No (or very small)
		Degraded (1)	Other catchments also contribute to community's water availability
		Plantation (Acacia: 2)	Other catchments also contribute to community's water availability
	Coastal (Areangadi)	Control	Yes, but other catchments also contribute
		Degraded	Very small
		Acacia (3)	Very small
Mysore	Bandipur	Control	No
		Degraded-Hediyala	Yes, but other catchments also contribute
		Degraded-Baragi	Yes
	BR Hills	Control	No
		Degraded (Arepalya)	Yes, but other catchments also contribute, and community depends significantly on groundwater
		Degraded (C_doddi)	Yes, but community is largely dependent upon deep groundwater

As a result, we eventually dropped the criterion that the catchments should be suitable for both hydrological and socio-economic comparisons, and focused on meeting the former criterion alone. Even in doing this, we had to make several compromises. In particular, in the higher rainfall region, forest cover was so heterogeneous, that to get homogeneous land cover we had to reduce the catchment size to few hectares or tens of hectares, thereby ending up in first-order streams. The final set of catchments selected is depicted spatially in Figure 1-5 and listed in Table 1-3. As can be seen from the last column of this table, the catchments were generally not suitable for doing 'paired' comparisons or even direct inferences of socio-economic impact.

First, as Table 1-3 shows, there is no significant community downstream of the control (dense forest) catchment in 3 of the 5 blocks. Second, even where there are significant communities, the problem is complicated because the communities receive streamflow from several catchments other than the one chosen for monitoring. Third, in the BR Hills block of Mysore region, the communities are significantly dependent upon deep groundwater that comes from a regional recharge zone, and not much on surface flows in the streams that come from the catchment. Only the Shimoga-Shikaripur block (highlighted in bold) has significant and distinct communities that are immediately downstream of both the control and degraded catchments and are not significantly dependent on deep groundwater, but largely on surface flows.

In light of the above, we decided to largely abandon the paired-catchment approach for the socio-economic impact assessment. We would instead adopt a 'simulation' approach within each block. That is, we would generally attempt to estimate changes in flows (resulting from changes in land cover) through the paired catchment approach, but try to estimate the impact of changed flows by comparing 'good rainfall years' with 'bad rainfall years' within a particular catchment that has a significant-sized community. This will tell us (within limits) how communities are affected by changes in streamflows or recharge. This information will then be used to predict the effects of similar changes in flows or recharge that might actually be caused by land-cover change. In the case of the upghat Kodgibail block, given that both the control and the degraded catchments were too small to make significant contributions to the communities, we had to adopt a multi-scale or 'nested' approach, wherein measurements of the homogeneous first-order catchments were nested within flow measurements for heterogeneous second- and third-order catchments.

In the selected catchments we proposed to carry out detailed hydrological and socio-economic studies. However, as we became more familiar with the field situation, we realized that limitations of funds and humanpower would not allow us to carry out intensive studies in all sites or blocks. We therefore decided to carry out intensive investigations in two blocks (Kodgibail in the north and Bandipur in the south) and relatively 'coarse' investigations in the other two blocks.

Table 1-4. Variables monitored in the 3 coarse-monitoring blocks

Block	Catchment type & name	Rainfall		Streamflow		Evapo-ration	Soil hydraulic conductivity	Overland flow detection/ Low flow detection	In-stream sub-surface water level	Ground-water level
		Ordinary rain gauge	SRRG or TBRG	Stage (Staff gauge/AWLR)	Discharge (Current meter)	Evaporimeter, Wet/Dry Thermometer	Disc Permeameter	Detector/Low flow flume	Piezometer	Observation Well
Coastal (Areangadi)	Dense Forest: Tottalagundi	1 ORG for all catchments: Sept 03 onwards	1 SRRG for all catchments: Sep 03 onwards	Daily: None in 03, daily Apr04-Apr05, AWLR May05 onwards	20 current meter readings during June-Dec04	1 Evapori-meter along with wet & dry bulb temperature readings: Sep 03 onwards	15 readings over 5 depths during Apr-May05	Not installed	Not installed	1 well daily from Jun04 onwards
	Degraded 1: Ulligere			None in 03, Daily Apr04-Apr05, AWLR May05 onwards	14 current meter readings in June-Dec04		15 readings over 5 depths during Apr-May05	Not installed	Not installed	1 well daily from Jun04 onwards
	Degraded 2: G G Kamat			None in 03, Daily Apr04-Apr05	Only few readings obtained		15 readings over 5 depths during Apr-May05	Not installed	Not installed	1 well daily from Jun04 onwards
	Acacia1: Bhat			None in 03, Daily Apr04-Apr05	Not yet obtained		15 readings over 5 depths during Apr-May05	Not installed	Not installed	Nil
	Acacia2: Middle			None in 03, Daily Apr04-Apr05	Not yet obtained		15 readings over 5 depths during Apr-May05	Not installed	Not installed	Nil
	Acacia3: Manju			None in 03, Daily Apr04-Apr05, AWLR May05 onwards	8 current meter readings in Jun-Dec04		15 readings over 5 depths during Apr-May05	Not installed	Not installed	1 well daily from Jun04 onwards
BR Hills	Dense Forest: Budipadaga	1 ORG since Aug 03	SRRG for Oct03-Jul04, TBRG Sep04-Mar05	Staff Gauge Daily Oct 03 to Mar05, AWLR: Sep04 to Mar05	No current meter readings obtained yet	Not installed	2 samples collected 2004	Detector not installed; flume not installed	Not installed	Nil
	Degraded 1: C_Doddi	Not installed	SRRG for Dec 03; TBRG since Jul04 onward	AWLR 21 Sep 2004 to 31 March 2005;	No current meter readings obtained yet	Nov03 to Mar05	2 samples collected 2004	Flume operational Sep04-Mar05	Oct04-Mar05	Nil
	Degraded 2: Arepalya	Not installed	SRRG Dec03 onwards	Daily staff gauge Sep03 to Mar05	No current meter readings obtained yet	Nov03 to Mar05	No samples collected	Detector not installed; flume not installed	Not installed	1 Well from Nov03 to Mar05

Table 1-5 Variables monitored in intensively studied blocks (Kodgibail and Bandipur)

Block	Catchment type & name	Rainfall		Streamflow		Evapo-ration	Soil hydraulic conductivity	Runoff detection/ Low flow measure-ment	In-stream sub-surface water level	Ground-water level
		Ordinary rain gauge	SRRG or TBRG	Stage (Staff gauge/AWLR)	Discharge (Current meter)	Evaporimeter, Wet/Dry Thermometer	Disc Permeameter	Detector/Low flow flume	Piezometer	Observation Well
Upghat (Kodgibail)	Dense Forest 1: Hulimane	1 ORG for all catchments: June 03 onwards	1 SRRG for all catchments: June 03 onwards	Rectangular notch: 4 times during daytime Current meter not reqd		1 Evapori-meter along with wet & dry bulb temperature readings: Sep 03 onwards	15 readings over 5 depths during Dec04	Not installed	Not installed	One well daily from Jan04
	Degraded 1: Mavinahalli			Rectangular notch: 4 times during daytime, Current meter not reqd			15 readings over 5 depths during Dec04	Not installed	Not installed	Two wells daily Jan04 onwards
	Acacia 1:			Rectangular notch: 4 times during daytime, Current meter not reqd			15 readings over 5 depths during Dec04	Not installed	Not installed	One well daily Jan04 onwards
	Acacia 2:			Rectangular notch: 4 times during daytime, Current meter not reqd			15 readings over 5 depths during Dec04	Not installed	Not installed	One well daily Jan04 onwards
	Acacia 3:			Rectangular notch: 4 times during daytime, Current meter not reqd			15 readings over 5 depths during Dec04	Not installed	Not installed	One well daily Jan04 onwards
	Dense Forest 2: Vajgar	1 ORG for all catchments: June 03 onwards	1 SRRG for all catchments: June 03 onwards	Rectangular notch: 4 times during daytime, Current meter not reqd		1 Evapori-meter along with wet & dry bulb temperature readings: Sep 03 onwards	15 readings over 5 depths during Dec04	Not installed	Not installed	One well daily Jan04 onwards
	Degraded 2: Vajgar			Rectangular notch: 4 times during daytime, Current meter not reqd			15 readings over 5 depths during Dec04	Not installed	Not installed	Two wells daily Jan04 onwards
	Entire 3000 ha at Bilgi bridge	From above	From above	Daily July03 onwards	More than 10 events	From above	From above	Not applicable	Not applicable	Not monitored
Bandipur	Dense Forest 1: Soredahalla II	Not installed	2 TBRGs: May04-Aug05 and Jul04-Aug05	Staff gauge & AWLR working My04-May05	2 events during 2004	IISc Mulehole station data Oct04-May05 Not installed	2 readings during 2004	Detector not installed, flume working	working/ reinstalled	Not available
	Dense Forest 2: Hebbehalla	1 stolen July04	1 SRRG Jun04 onwards + 1 TBRG in GG Betta Sep04-May05	Staff gauge & AWLR working from Jun04-May05	7 events during 2004		3 readings during 04/05	Detectors destroyed—reinstalled, flume working	Working/ reinstalled	Not available
	Dense Forest 3: Chemenahalla	Not installed	1 TBRG Jun04-Jul05	Installed but damaged	No events recorded		No readings	No installed	Working	Not available

Block	Catchment type & name	Rainfall		Streamflow		Evapo-ration	Soil hydraulic conductivity	Runoff detection/ Low flow measure-ment	In-stream sub-surface water level	Ground-water level
		Ordinary rain gauge	SRRG or TBRG	Stage (Staff gauge/AWLR)	Discharge (Current meter)	Evaporimeter, Wet/Dry Thermometer	Disc Permeameter	Detector/Low flow flume	Piezometer	Observation Well
	Degraded 1: Hediyala	1 working from 14 August 2004 to 21 June 2005	Hediyala TBRG Aug04 onwards, upstream TBRG vandalised, reinstalled: Nov04-Aug05	Staff gauge stolen and damaged: 3 events recorded in ALWR	No events recorded	Working from Jun04 to May 05	5 readings during 04/05	Detector installed but stolen; flume not installed	Working	1 well Jun04 onwards
	Degraded 2: Baragi	1 ORG Oct04 onwards	1 SRRG working Oct04 onwards	Staff & AWLR installed: 2 events recorded in AWLR	No events recorded	Jun04-onwards	No readings taken yet	Not installed	Working	Not monitored

Note: In the Bandipur block, attempts were made to monitor two more sub-catchments of the main catchments identified above. However, the heavy damages inflicted by elephants, flash floods and vandalism on the instrumentation required us to abandon the monitoring of most variables in these sub-catchments in order to ensure basic data for the main catchments. Similarly, several instruments in the above-mentioned catchments were damaged at various points in time and were repaired or replaced.

1.4.2 Broad methodology of hydrological studies

The broad approach followed for the hydrological studies was to measure rainfall, evaporation and runoff, and, in the intensively studied sites, to couple this basic information with investigations of hydrological processes, such as soil hydraulic conductivity and soil moisture depletion rates. Details of the parameters observed, spatial and temporal sampling, and instruments are given in Table 1-4 and Table 1-5.

1.4.3 Broad methodology for understanding socio-economic impact

In theory, the effects of land-cover changes and resulting hydrological and sedimentation-related changes in a particular catchment will be felt all the way down the river. However, as one proceeds downstream from the catchment, the stream merges with other streams and eventually joins a river. The effects of land-cover change in a particular catchment then get 'diluted' as one goes downstream. Simultaneously, the size of the 'community' that gets affected goes on increasing. We have therefore decided that the 'affected community' in our study will be the community living between the streamgauging point chosen for our hydrological monitoring (which is typically at the point at which the stream exits the forest) and the point at which the stream then joins another distinct stream *downstream of the settlement*, [8] or till the point that water from other sources becomes dominant.[9] Note that the 'affected community' chosen in this manner is only relevant for the hydrological analysis; the people who use the forest in the catchment may come from both within and outside this community and will have to be sampled in some manner.

In all the blocks, basic information on demography, community structure, landholding and cropping patterns, livestock holding and a qualitative understanding of the dependence of households and agricultural systems on water was built up.In the less intensively studied blocks (Areangadi and BR Hills), subsequent investigations were focused on one or two aspects that seemed most sensitive to hydrological change. In the intensively studied blocks (Kodgibail and Bandipur), we carried out detailed agro-hydrological monitoring to establish the link between catchment hydrology and local agricultural economies, and also monitored agricultural activities for a whole year for a sample of households in order to generate detailed and reliable data on their practices, production and income.

In the next four chapters, we shall present the main findings from our studies. In order to present to the reader the complete story (from hydrology to social use of water to its impacts), each chapter corresponds to one block. Within each chapter, we begin by describing the context and indicate the most relevant form that the research questions take in that context. We then describe the findings of the hydrological investigations in the catchments, the agro-hydrological linkages, and the results of the socio-economic studies. We then try to synthesize the findings across the blocks in the last chapter and discuss the broad findings that emerge from this study.

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[8] Note that between these two points, some water does flow into the stream from the intermediate catchment area. Moreover, as mentioned in Table 6, other streams may merge with the monitored stream before it reaches any settlement.

[9] E.g., in Hediyala, downstream of Chilakahalli hamlet, the agricultural fields get irrigation from the canals emanating from Nugu reservoir, and are therefore not dependent on the flows in the Hediyala stream.

Chapter 2. Forests, baseflow and agriculture in a high rainfall zone: The case of Kodgibail

The question of forest-water-community linkages is often debated in the context of the densely forested regions of the Western Ghats, such as Uttara Kannada district of Karnataka. Within this district, the Malnaad region represents the semi-evergreen forest belt, corresponding to the high rainfall along the crest line. In such a context, one might speculate that the hydrological impacts of forest cover change are significant only for downstream communities. But, as we shall see, water management continues to be an important issue in the Malnaad region.

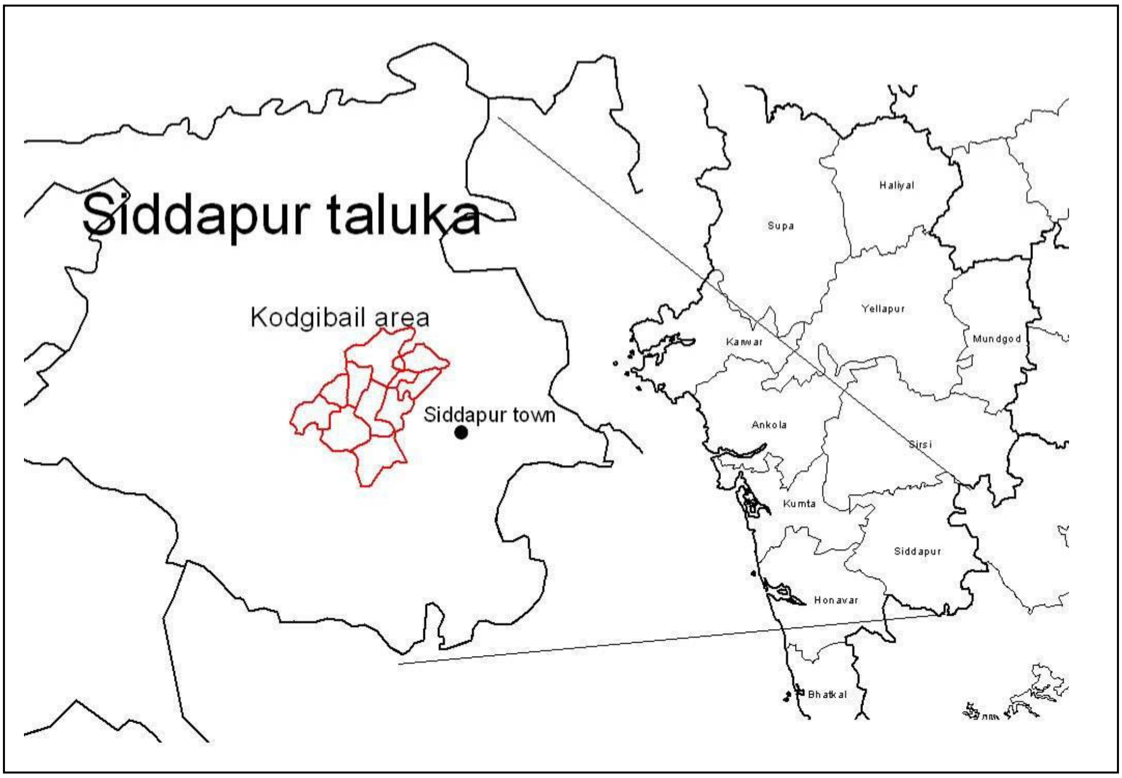

Figure 2-1. Location of Kodgibail village and Bilgi hole catchment in Uttara Kannada district.

2.1 *Description of the study area*

2.1.1 <u>Location, topography and climate</u>

Siddapur is one of the 11 talukas in Uttara Kannada district, and along with Sirsi and Yellapur to its north, constitutes the heartland of the 'Malnaad' (hilly) portion of this district, characterized by mixed areca and spice orchards and paddy cultivation. The village of Kodgibail is located about 7.5 km northwest of Siddapur town (see Figure 2-1). The area is characterized by a dense stream network in an undulating terrain, although hills seldom rise more than a 100m. The long-term rainfall average is around 2900mm, although in good years it may go above 3500mm. The rain comes from the south-west monsoon, and therefore has a unimodal distribution within the year, being concentrated in the May-November period, with the bulk falling during June-September.

Geologically, the Malnaad region consists of pre-Cambrian formations with gneiss and intrusive granites concentrated mostly along the coastal tracts and adjoining areas towards east. The major soil type found in the study area is red or yellowish-red lateritic soil, with gravely-clay texture. Forest soils are deep to moderately drained, dark brown to dark yellowish brown with sandy-clay to sandy-clayey-loam texture. They are rich in humus, acidic and usually deep.

The main stream running through Kodgibail village is one of the many that join the Bilgi *holé* (major stream) that runs south of the village. The bridge on Bilgi holé located about 3 km southwest of Kodgibail forms a convenient gauging point, at which point the catchment of about 27 sq.km. includes not just Kodgibail but several other villages or parts of villages as well.[10] The locations of Kodgibail village and the Bilgi hole catchment are indicated in the map in Figure 2-1. The villages in and around the catchment and the main stream flowing within the catchment are indicated in Figure 2-2.

The forest vegetation of this area is a mixture of semi-evergreen and moist deciduous associations (Pascal, 1986). The latter vegetation type is often the product of intensive human use, and therefore may take the form of a tree savanna, heavily pruned trees and grass in the understorey. Pure grasslands, again the result of human interventions, occur in small patches, and are dominated by *Themeda* sp (Lélé and Hegde, 1997). As can be seen from the satellite image and land cover map in Figure 2-3, the distribution of forest is quite patchy, for reasons we shall discuss in section 2.1.3.

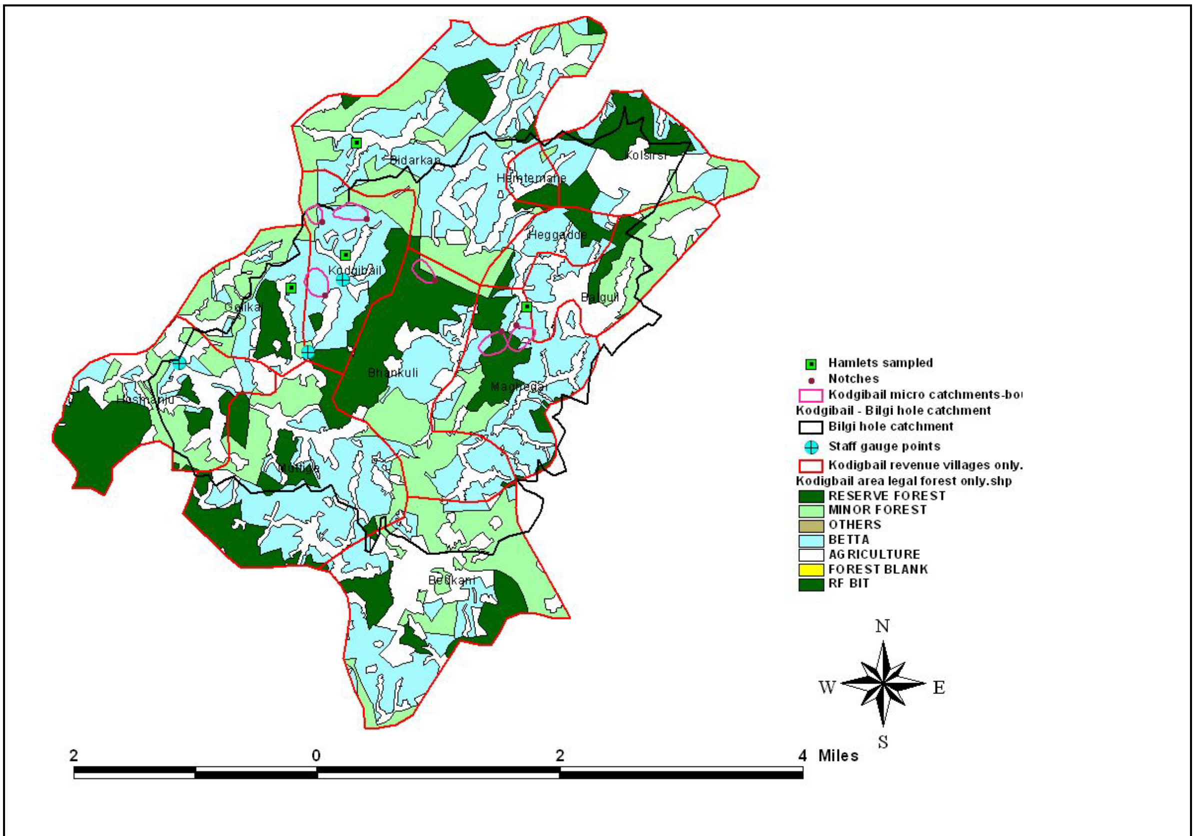

Figure 2-2. Catchment boundary at Bilgi Hole bridge and revenue villages intersecting with it.

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[10] The villages that are largely within the Bilgi hole catchment are Kodgibail, Golikai, Hosmanju, Muttige, Bhankuli, Maghegar, Tyarshi, Balguli, Heggadde, Kolsiri and Hemtemane. By ‘ village’ we mean the revenue village, which may vary in size from tens of hectares to even a few thousand hectares and may contain several hamlets or scattered settlements.

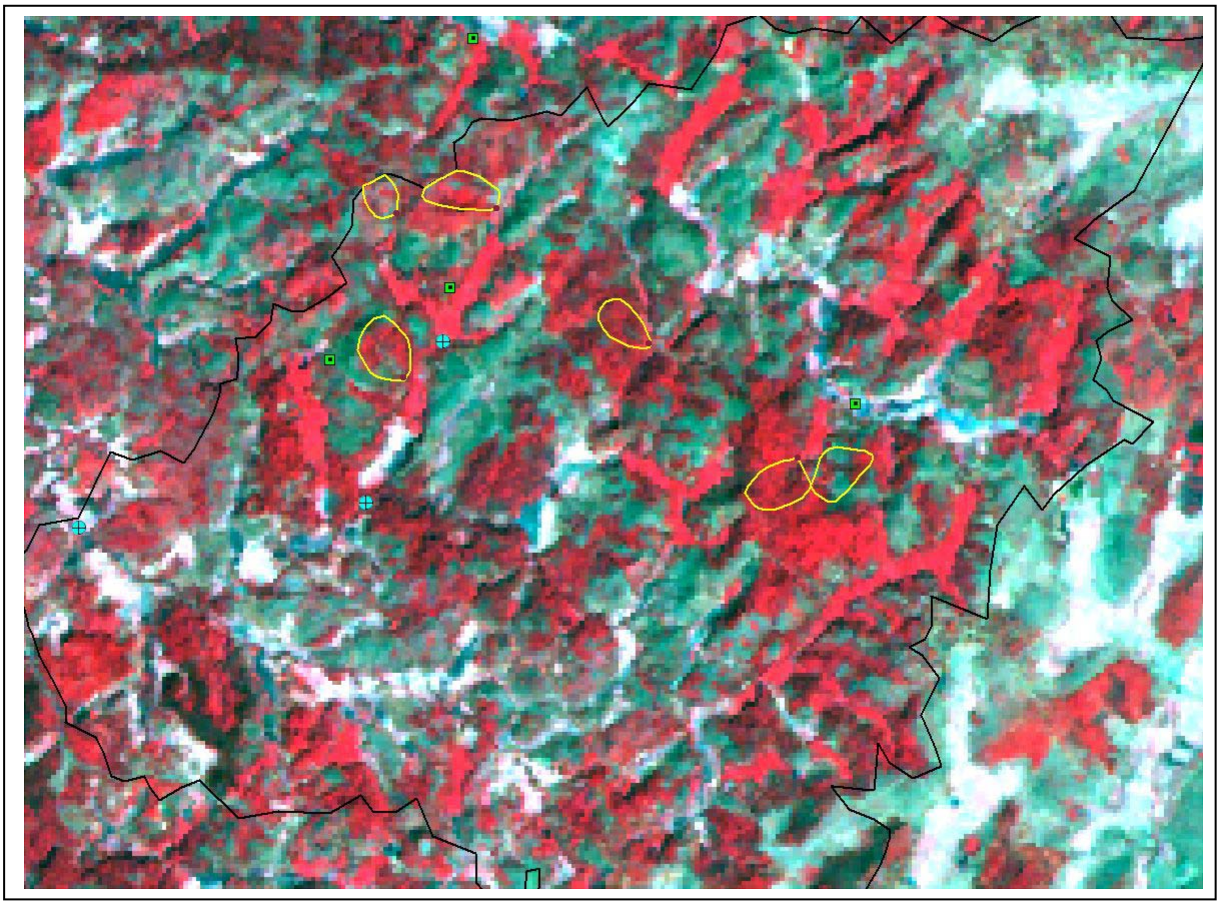

Figure 2-3. Land cover in Bilgi-hole catchment: False colour composite of IRS-LISS 3 imagery. (Bright reds are mostly areca orchards or acacia plantations, dark reds are dense forest, whites are paddy lands, greenish areas are tree savannas, degraded scrub or pure grassland. Yellow lines delineate first-order catchments that were monitored.)

2.1.2 Social composition and livelihood systems

The social composition in this area is typical of the southern Malnaad region of Uttara Kannada district. Households from the Havyak Brahmin, Naik and Vokkaliga castes comprise the vast majority of the landed households, while the Adikarnataka caste comprises the landless households. The pattern of landholding is often quite skewed and caste hierarchies play a significant role in determining social position, although the extent of economic and social differentiation is much lower than that in the eastern plains of Karnataka.

Typical of this region, the settlements are scattered across many hamlets, sometimes consisting of just a few households who cultivate land in that particular valley. Sometimes smaller villages may be entirely single-caste, but larger villages tend to be heterogeneous. Rural population density in Siddapur taluka is ~100 persons/sq.km.

The primary occupation in this area is agriculture and horticulture. Arecanut-spice[11] orchards (*thota*) have a long history in this region, and this horticultural system generates substantial

[11] The spices being cardamom shrubs in the understorey, pepper vines and more recently vanilla vines on the areca palms.

cash returns. Paddy cultivation is, on the other hand, carried out mainly for subsistence. Paddy is cultivated mainly during the rainy season (*kharif* or *mungaru*: June-Nov), but a smaller area is also cultivated during the summer (*hingaru*: Jan-April). Other crops include small patches of sugarcane in well watered locations, and a few lentils, beans and vegetables cultivated in small plots. In the Bilgi holé catchment, about 20% of the land is cultivated, of which 12% of the land is under paddy cultivation and 8% under arecanut-spice orchards. As can be seen from the map in Figure 2-3, the arecanut orchards are located in upper (narrower) portion of the valleys, whereas paddy fields are typically located in the lower (wider) portion or in shallow valleys. Each contiguous strip of arecanut cultivation typically consists of a large number of individually owned pieces within it. It may be noted that the Havyak Brahmin households are the major owners of arecanut-spice orchards whereas the Naiks own some orchards but they along with other castes cultivate most of the paddy lands. Livestock (cows and buffaloes) are maintained mainly as a source of dung and milk, and a few bullocks are maintained to provide draught power in the paddy fields.

2.1.3 Role of forests and typical patterns of forest use/cover

Forest lands play crucial but mostly indirect roles in the livelihood systems of the local communities.[12] A few household do collect and sell non-timber forest products, but as a secondary occupation. Some also derive occasional wage labour income through work on forest plantations owned by the Forest Department. But hunting is banned and timber extraction very limited; forests therefore do not provide much direct income. But households collect or harvest large quantities of firewood for domestic and agricultural use (arecanut boiling) from the forest and also some amount of small timber. Forest lands are also important sources of fodder and grazing for the livestock. Perhaps most important, forests are the source of leaf manure and mulch that are applied in large quantities to the arecanut orchards and manure in smaller quantities to the paddy lands.

Legally speaking, although all forest lands are ostensibly state property, access to forest products is controlled by a complicated system of property rights. Forests are divided into three categories: Reserve Forests, Minor Forests and *Soppinabettas*.[13] The first refers to state-controlled forests in which harvesting rights for local communities are very limited. The second refers to areas that have been assigned to villages for common use, but over which there is no formal regulatory mechanism, making them almost open-access. They were also in most cases the historical grazing lands of the villages. The third category[14] refers to parcels of forest land to which exclusive and substantial rights over fuelwood, fodder, grazing, and leafy matter have been granted. These parcels have been assigned to (owners of) specific arecanut orchard plots—sometimes on a one-on-one basis and sometimes to groups.

In order to investigate the possible impacts of changes in forest cover on hydrology and thereby on local communities, we had to characterise the common forest cover conditions that exist in the region today and the likely changes that might take place. Forest vegetation today is a mosaic of patches of varying floristic, architectural and disturbance conditions. These include relatively intact semi-evergreen forest, other dense but intensively used secondary vegetation, tree savannas, some pure grassland, and some completely barren

[12] Much of this broad summary is based on a combination of data collected in the village and earlier work carried out by us in this region (Lélé, 1993;2001)

[13] Strictly speaking, the nomenclature is RF (Proper), RF (Minor), and Protected Forest (Soppinabetta) respectively. But since the restrictions that apply in RF (Minor) are much fewer than those that apply in RF (Proper)—the latter being similar to other Reserve Forests—we use the more common and sensible nomenclature.

[14] *Soppinabetta* means 'hill for leafy matter' in Kannada, which highlights the importance of leafy matter for cattle bedding, mulch and manure in the local livelihood system.

patches. At the same time, dotting the landscape are many patches of monocultural plantations, mostly of *Acacia auriculiformis.*

In this complex and shifting mosaic of forest cover types, one may identify three distinct 'ideal types' where the forest cover might have remained constant as a result of certain stable patterns of use and management: a) dense forest, resulting from a limited extraction regime, typically obtains in certain Reserve Forest patches, b) tree savannas that result from intense but controlled harvest of fuelwood, leafy matter and grass that typically obtains in the well-managed soppinabettas, and c) Acacia plantations that are the results of departments afforestation programmes, typically replacing grazing or barren land, where initial survival has been ensured through fencing and guarding. These types may also represent the extremes that might result from taking different extreme policy approaches—one that is conservation oriented, one that prioritises people's use and control, and one that priorities commercial timber production. We therefore chose to study the effects of switching between these three forest cover types.

2.1.4 Role of water in livelihood systems and the critical hydrological variables

Given an agriculture-based livelihood system, the role of water is obviously significant in local livelihoods. Being a high rainfall region, water is not really scarce. But the unimodal distribution of rainfall means that there is a lengthy dry season, thereby imposing certain constraints within which agriculture has to function. These need to be understood in order to identify those aspects that are likely to be sensitive to changes in hydrology induced by changes in forest cover.

The main paddy crop is grown in the rainy season using rainwater and part of the runoff from neighbouring lands. Since the runoff during the monsoon is plentiful (whatever the land cover), it seems that the extent and productivity of the kharif paddy crop is not likely to be affected by changes in streamflow that might be induced by forest cover changes, at least in the medium term. However, the cultivation of a second (summer) crop of paddy depends entirely on the availability of streamflow that can be impounded, diverted or, more recently, pumped into the paddy fields. This limits the second crop to just about 10% of the kharif area, and to certain low-lying or spring-fed portions of the valleys. Our discussions with the farmers indicated that the extent and productivity of this summer crop is very sensitive to the magnitude and duration of the post-monsoon flows in these locations, which in turn might be influenced significantly by the nature of the forest cover on the slopes of the catchments.

The arecanut-spice orchard is a sophisticated perennial multi-cropping system that mimics the evergreen riparian forest that it has replaced centuries ago. However, unlike the forest vegetation, the arecanut palms (and the understorey spice crops) have shallow roots. Maintaining the productivity of the arecanut orchard therefore requires careful control of soil moisture and ambient temperature and moisture conditions in the orchard. While the focus of water management during the monsoon is on diverting excess inflows away from the orchards so as to avoid flood damage, the focus during the dry season is on ensuring that there is adequate (but not too much) soil moisture. This is achieved by a combination of appropriate site selection for the orchard (narrow well-drained valleys), maintenance of shade trees around the orchards, mulching of the arecanut orchards, and water management. Starting December, farmers start constructing temporary bunds on the streams flowing through their orchards so as to divert the post-monsoon baseflow through the channels between the rows of arecanut palms.[15] The amount and duration of post-

[15] In some valleys, farmers have also constructed small farm ponds inside or at the upstream end of their orchards, the water from which seeps into the soil slowly and ensures moist soils. Recently, forays into vanilla as a high-value understorey crop has led to some farmers using pumpsets to lift this water (or water from shallow dug-wells inside their orchards) and apply it using sprinklers.

monsoon baseflow would therefore seem to be the most important hydrological variable from the point of view of arecanut orchard productivity.

Water is also of course important to domestic and livestock-related activities. Given the high rainfall, water availability is not a major issue for most of the year. However, households mentioned that they do face shortages during summers that follow a poor monsoon. The manner and extent to which this shortage is felt by a household seems to vary across hamlets and even across households, as some have access to wells and others don't.

2.2 Focus of the investigation and research design

In light of the above, the focus of our investigations in this block was on

- understanding broadly how the annual runoff might differ across micro-catchments of three different forest cover types, but also specifically how differences in forest cover might lead to changes in post-monsoon flows that is of greatest relevance to agricultural production,
- understanding specifically how arecanut orchard productivity and the extent of summer paddy might be affected by these hydrological changes, and
- understanding simultaneously how forest land cover types differ in their contributions of forest products to the village economy, and finally
- to attempt to simulate the effects of large-scale shifts in forest cover on the local communities using the above analysis.

To address the first question, we needed catchments with largely homogeneous land-cover within them. Given the highly heterogeneous landscape, we could find such catchments only on first-order streams, whereas the cultivation takes place along second- and third-order streams. We therefore had to adopt a multi-scale or nested approach. We chose six micro-catchments (two each in the dense forest, tree savanna and plantation category) and monitored runoff, sampled soil hydraulic conductivity and monitored soil moisture in them. To address the second question, we also monitored flow along second- and third-order streams, and attempted to estimate the differential contribution of different types of first-order catchments to the post-monsoon flow observed at the higher scales.

The water availability-productivity linkage was sought to be understood in different ways. In the case of arecanut orchard productivity, we monitored post-monsoon flows and soil moisture within 5 different orchard valleys, and estimated the productivity of (as well as agricultural practices used in) the individual orchards through both oral recall and actual monitoring on a weekly basis. In the case of summery paddy, we sampled farmers cultivating this crop over the entire 2700 ha Bilgi holé catchment.

The use of forests by households and the differential contribution of different forest cover types were studied at two levels. Household use was assessed through household questionnaires, and within these questionnaires, we separated the collection from different sources/patches, and then put together the data for each patch.

2.3 *Findings in the first-order stream catchments*

2.3.1 Basic characteristics of studied micro-catchments

The locations of the 6 micro-catchments as well as the gauging points on the second- and third-order streams are shown in Figure 2-4.

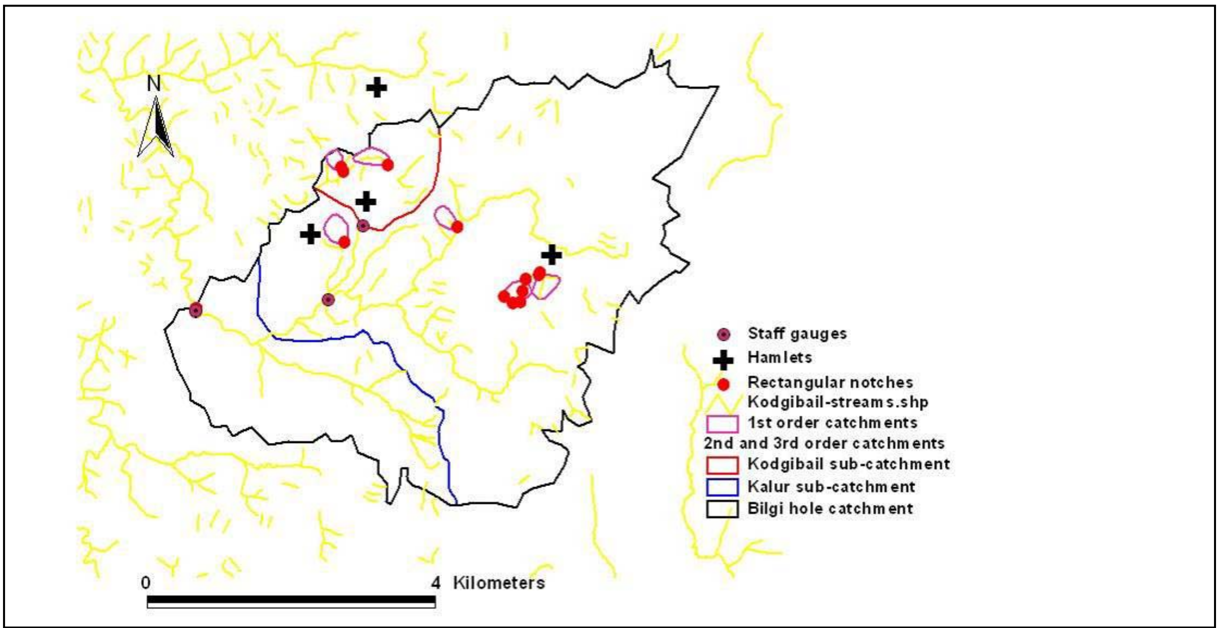

Figure 2-4. Location of micro-catchments of different forest covers and higher order catchments.

Figure 2-5. Soil profile of a hillock adjoining areca cultivation in Kodgibail. Soil thickness is very high and variations in wetting can be seen. Weathered rock is visible in the right bottom corner.

Geology and soils

The first-order catchments we monitored ranged in size from 4 to 10 ha, with slopes varying from XXX to XXX. The soils in the catchments are generally deep, often going below 2 m, as can be seen from Figure 2-5. The soil texture at different depth in the selected catchments is shown in Figure 2-6. Note that there is limited variation in soil texture across depth, but that there is significant variation across the sample watersheds, in particular that the degraded site has high clay content in its surface layer. This feature is relevant in explaining some of the differences in soil moisture depletion discussed later.

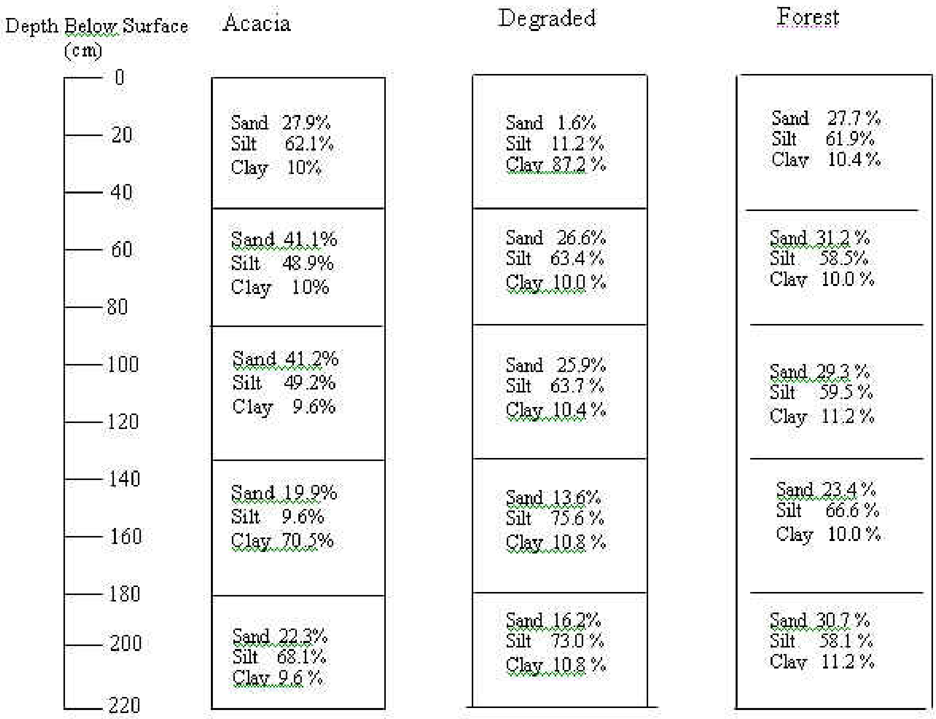

Figure 2-6. Average soil texture at different depths in Kodgibail sample watersheds

Forest cover and composition

The natural forest vegetation in the Kodgibail area is semi-evergreen, but with human use over centuries, the vegetation today is a mosaic of dense semi-evergreen patches, moist deciduous tree savannas, scrub thickets and grasslands, interspersed with Acacia auriculiformis plantations. The first-order catchments were chosen to have relatively homogeneous vegetation, but this was not always possible. We carried out a detailed field sampling of the forest vegetation, laying 100 m x 20m transects in each first-order catchment and enumerating tree species, tree girth, tree height and disturbance level. We then used the results of this sampling to visually interpret Google Earth imagery and generate forest cover maps for the first order catchments and for the entire Bilgi hole catchment. Details of the methods and results of the vegetation sampling are given in the Appendix. A brief summary of the estimated tree densities, basal area and observed dominant species is given in Table 2-1.

Table 2-1. Summary of vegetation parameters for 1st order catchments

Catchment	Estimated average tree density for entire catchment (per ha)	Estimated average basal area for entire catchment (sq.m./ha)	Dominant species
Hulimane NF	615	2632	Gymnonthra conariea, Sagereaea listari, Ixora barcheata, Holigarna aronottiana
Vajgar NF	485	3536	Lophopetalum wightianum, Alseodaphne semicarpifolia, Gymnonthra conariea, Sagereaea listari, Holigarna aronottiana
Vajgar SB	615	1896	Alseodaphne semicarpifolia, Lophopetalum wightianum, Ixora barcheata, Aporosa lindleyana
Mavinahalli SB	352	2099	Hopea wightiana, Terminalia panniculata, Aporosa lindleyana, Terminalia alata
Acacia 1	132	1068	Acacia auriculiformis, Anacardium occidentale, Garcinia indica, Syzigium cumini
Acacia 2	345	2053	Acacia auriculiformis, Buchanania lanzan, Holigarna aronottiana, Alseodaphne semicarpifolia, Syzigium cumini

The vegetation sampling and mapping exercise indicated that

1. While Acacia plantations were least diverse, some natural tree species are mixed within the plantation.

2. Both so-called ‘degraded’ catchments contained significant areas of dense tree vegetation. There was also significant difference in the species composition and tree density of the Mavinahalli degraded catchment vis-à-vis the Vajgar degraded catchment, with the latter being denser and containing more semi-evergreen species compared to the former.

3. There were also significant differences in the species composition between the two natural forest catchments. However, both clearly had high tree densities and basal area compared to all other categories.

2.3.2 Comparison of soil hydraulic conductivity

In order to predict the hydrological effects of land cover change, it is important to understand what the treatment involves: whether it is a change in land cover or are there associated changes to soil properties as well. Saturated and unsaturated hydraulic conductivity are both related to the degree of resistance from soil particles when water flows in pores. These resistances are affected markedly by the form sizes, branchings, jointings and tortuosities of pores as well as by the viscosity of the water.

The present investigations were carried out by using disc and Guelph permeameters in the Malnaad block region of Uttara Kannada district in Karnataka. Table 2-2illustrates the variation of hydraulic conductivity values measured under varied land cover changes. It is noticed that the field saturated hydraulic conductivity (Ks^*) varies between 3.59 mm/day and 0.35 mm/day in a natural forest followed by plantation of acacia auriculiformis (1.38 mm/day to 0.13 mm/day) and in degraded land it was minimum varying from 0.94 mm/day to 0.05 mm/day.

Table 2-2. Saturated Hydraulic Conductivity values under different land-use types in Malnaad block

Site Number	Soil Type / *Land use*	Layer	No of Samples	K* mmh^{-1}			Antilog SI
				Arith. Mean	Log Mean	Range	
1	Acacia	0.00 m	18	61.80	57.32	31.59 to 109.88	0.406
		0.10 m	18	38.23	35.64	19.93 to 74.11	0.371
		0.45 m	13	19.93	16.16	8.55 to 68.4	0.613
		0.60 m	13	16.88	15.88	9.12 to 36.00	0.352
		0.90 m	13	21.22	19.17	10.6 to 43.20	0.455
		1.20 m	13	13.47	12.18	7.03 to 31.80	0.442
		1.50 m	13	7.06	5.35	2.18 to19.45	0.639
2	Degraded	0.00 m	18	42.30	39.31	14.41 to 75.95	0.409
		0.10 m	18	40.19	29.47	2.26 to 106.52	0.910
		0.45 m	13	25.83	25.40	17.56 to 36.00	0.190
		0.60 m	13	8.16	5.63	1.8 to 21.6	0.909
		0.90 m	13	3.84	2.85	0.72 to21.6	0.846
		1.20 m	13	2.51	2.15	0.91 to 6.7	0.564
		1.50 m	13	2.73	2.19	1.05 to6.9	0.683
3	Natural Forest	0.00 m	18	180.62	149.66	51.15 to 384.18	0.647
		0.10 m	18	76.98	57.45	11.89 to 171.56	0.870
		0.45 m	13	17.35	16.07	11.44 to 36.00	0.384
		0.60 m	13	16.44	15.23	11.8 to 42	0.359
		0.90 m	13	16.20	15.19	10.08 to 36	0.346
		1.20 m	13	16.20	14.50	4.35 to 37.11	0.518
		1.50 m	13	18.39	17.36	9.61 to 37.55	0.347

In all the three cases, the Ks* is maximum in surface layers and showed a sudden decrease with depth. In box plots in Figure 2-24-Figure 2-26, it is found that a maximum of 384 mm/hr is observed in surface soil of natural forest (range is from 51.15 mm/hr to 384.18 mm/hr) with a sharp decline at 0.1 m depth (maximum observed is 171.56 mm/hr). Logarithmic mean is 149.66 mm/hr and 57.45 mm/hr at the surface and 0.1 m depth respectively. Beyond this depth there is a gradual decline up to a depth of 1.2m and then showed an increase at a depth of 1.5 m.

The observation made in the acacia auriculiformis, showed a similar trend in surface and at 0.1 m depth. However, it is noticed that the maximum Ks* is 109.88 mm/hr with a logarithmic mean of 57.32 mm/hr where as at a depth of 0.1 m it reduced to 74.11 mm/hr with a log mean of 35.64 mm/hr.

Investigations carried out on degraded land showed that the field saturated hydraulic conductivity vary between 14.41 mm/hr and 75.95 mm/hr in the surface layer where as at a depth of 0.1m, more wider range (2.26 mm/hr to 106.52 mm/hr) is observed. This clearly indicates that such variation could be the result of soil compaction due to trampling cattle and anthropogenic disturbances. It is interesting to note that the Ks* decreases significantly with depth in comparison to acacia plantation. In spite of having similar soil and geologic condition there is a considerable decrease in field saturated hydraulic conductivity. The higher hydraulic conductivity observed in acacia plantation could be attributed to the improved soil conditions resulting from plant growth and root development. However, in natural forest the entire hydrological process varies significantly due to the biomass and density of root, interception, stem flow and canopy cover (Fleming and Smiles, 1975). In general, vegetation cover reduces the impact energy of droplets, so reducing surface slaking and crusting. Removal of water by transpiration results in a more uniform reduction of soil moisture with depth, enhancing infiltration and hydraulic conductivity, whilst the accumulation of organic matter provides a suitable substrate for soil micro-organisms as well as conferring a degree of structural stability to the soil mantle and impeding overland flow.

Our analysis of rainfall intensity in Kodgibail (not shown here) indicated that the maximum intensity of 54 mm/hr occurred only once in 3 years, and an intensity of 50 mm/hr occurred twice2 in 3 years and the 44 mm/hr repeated 12 times in 3 years (intensities were summed with reference to 15 minute rainfall). A comparison of these intensities with saturated hydraulic conductivity at different depths in different catchments is given in the Appendix. It shows that that all the higher intensity rainfall are much lesser than the field saturated hydraulic conductivity at the surface and 0.1 m depth, particularly in forest and acacia plantation. However, due to the sharp decrease in hydraulic conductivity at depth, all the concentrated water will flow as delayed flow or interflow. The case is similar in acacia in the surface layer but at a depth of 0.1 m, there is a sharp decrease in hydraulic conductivity leading to saturation excess overland flow.

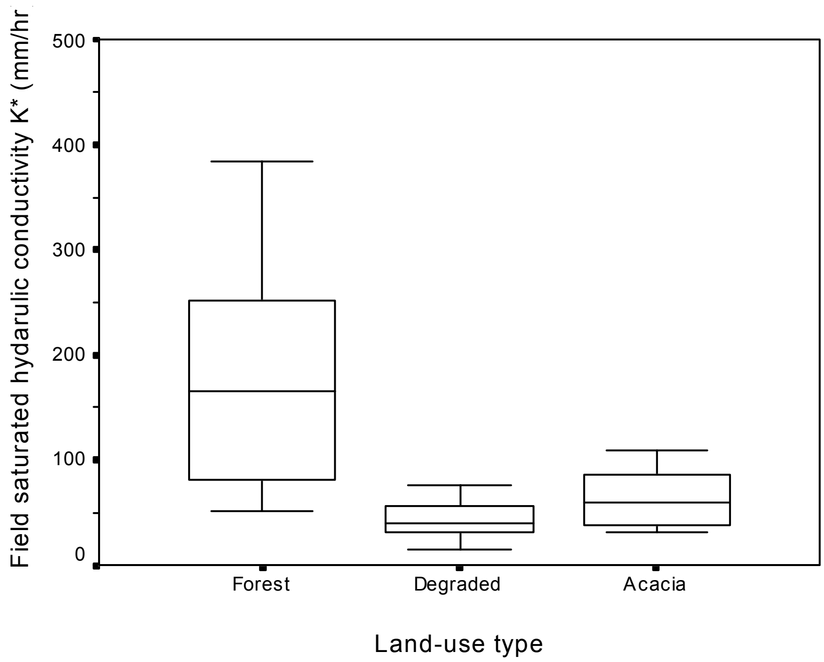

Figure 2-7. Field saturated hydraulic conductivity, K*, as a function of land-use at surface

We compared the log mean of the field saturated hydraulic conductivity across land cover types, for different depths. The box plot for the surface layer values is given in Figure 2-7. This plot indicates that the surface conductivity values are higher in dense forest than in the other two land cover types. Dense forest also has a higher value at the next depth, but here the conductivity of degraded forest is (surprisingly) higher than that under acacia. Similar box plots for other depths, given in the Appendix, indicate similar inconsistencies across depth. In the lower layers (from 0.6m to 1.5m), dense forest and acacia have higher values of Ksat in most, but not all cases. In general, one may still say that there is a) a decreasing trend of the hydraulic conductivity with the depth, and b) that the conductivity is often higher for dense forest than under the other two land cover types.

2.3.3 Comparison of spatial variation in soil moisture within the selected watersheds

In order to evaluate the soil moisture phenomenon at different spatial location in each of the identified land-use type, a One-way analysis of variance (ANOVA) was performed with the observed data, followed by multiple-comparison test (LSD). The test indicates that the observed soil moisture values are significantly different at least at 0.01 level

Table 2-3. Result of ANOVA test between pairs of spatial points with the selected watershed

Land-use type	Spatial Location	Top	Middle	Bottom
Acacia	Top		0.01	0.01
	Middle	0.01		0.001
	Bottom	0.01	0.01	
Degraded	Top		0.01	0.01
	Middle	0.01		0.001
	Bottom	0.01	0.01	
Forest	Top		0.01	0.01
	Middle	0.01		0.001
	Bottom	0.01	0.01	

Note: 0.01 value represents the significance level for that particular comparison

In Figure 2-8 various trends in log mean K* with depth are presented and can be used to describe differences in K-sat in different land covers, in conjunction with Table 2-2. The forested watershed shows a decreasing trend in the Ksat values with the depth. However, the forest is more pervious in the upper soil layers and further show steady Ksat values. Whereas the other land cover have much lower values at the surface compared to the forest, and the Ksat values in degraded watershed kept decreasing till 1.50 m depth. At the same time, the acacia watershed shows an increasing Ksat values at middle layers (between 0.45m to 1.05 m) and converge to the value of degrade at the bottom most layer. Also it is noticed that the log mean value of Ksat is little higher in the same layer. This indicates that the root density of the trees may be grouped around this layer and may be the reason for the increase in the Ksat values. The roots in the forest (where there is mix of young and old trees in the watershed) might have spread across all the depth starting from 0.6m and down till the measured range.

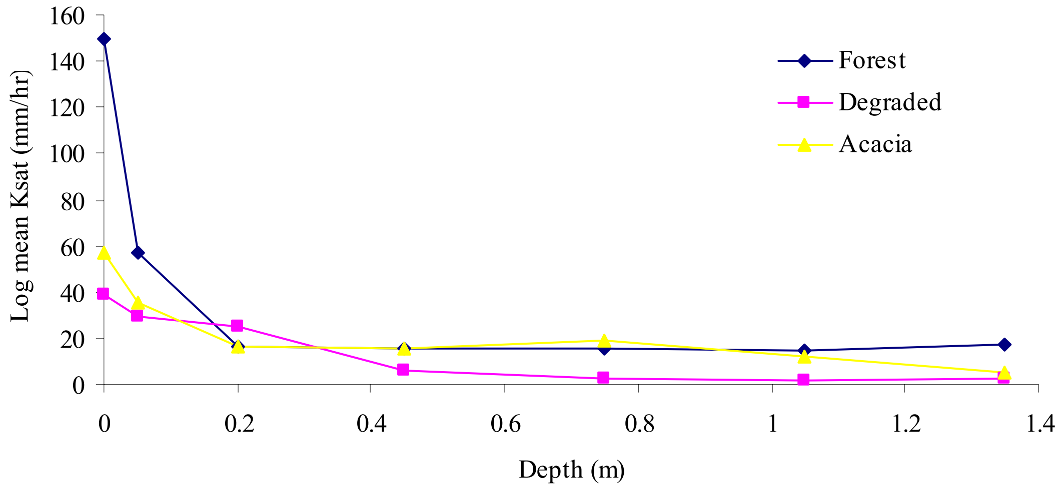

Figure 2-8. Log mean field saturated hydraulic conductivity values (K*) for each of the samples at various depths (K* values plotted against the mid-point of the sampled soil layers).

The scatter plots of field saturated hydraulic conductivity (see Figure 2-9) drawn between surface versus 0.1m depth shows that all the three land covers does not show significant groupings. Two important groups are observed: one is a mixture of all the three land covers natural forest, acacia auriculiformis and degraded lands and another group having a portion of natural forest with high hydraulic conductivity.

The variation in hydraulic conductivity in forest is the result of human disturbance and grazing of cattle in the closed forests. The scatter plots drawn between 1.2 m and 1.5 m depth (Figure 2-9) show a clear-cut grouping of three land covers. This indicate that the surface soils are much disturbed in all the three land covers whereas at the bottom there is a distinct differentiation in hydraulic conductivity which is not disturbed at all.

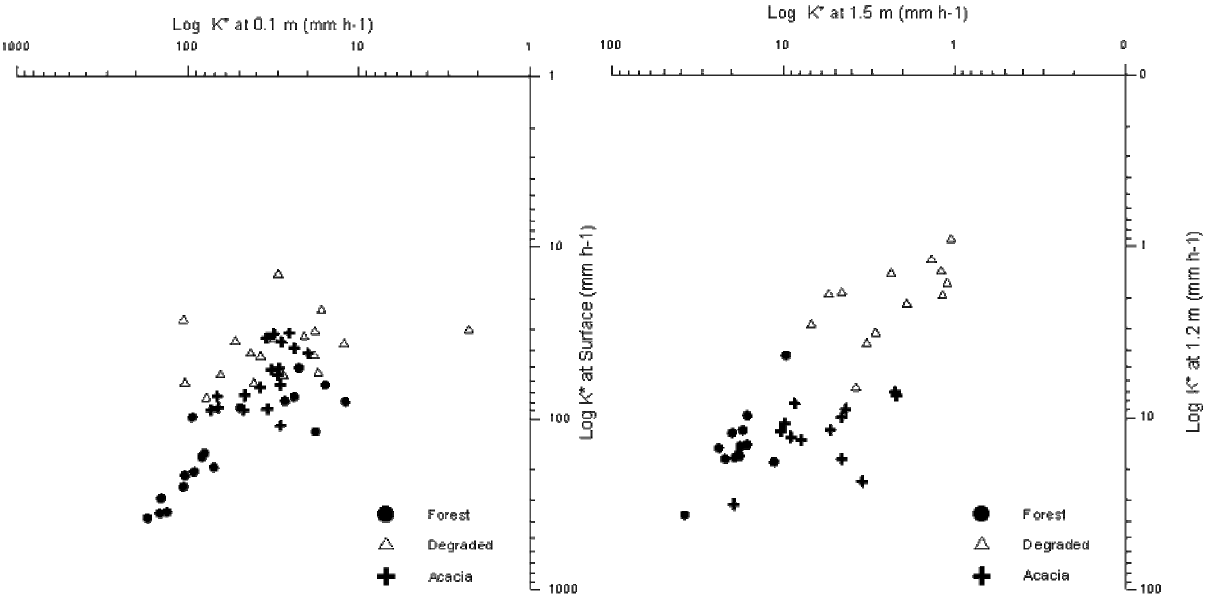

Figure 2-9. Scatter plots of Log K surface vs. 0.1m and 1.5m depth.

2.3.4 Annual rainfall-runoff

The salient feature of the observed flow from these three land-use types are shown Table 2-4, Table 2-5 and Table 2-6 respectively for year 2003, 2004 and 2005. These tables depict the overall runoff characteristics of the selected watersheds. In order to understand the influence of land cover on runoff generation, parameters such as specific discharge and specific peak discharge were computed for selected watersheds.

Table 2-4. Annual rainfall-runoff and peak discharges in monitored first-order catchments: 2003

Sl No	Land use type	Area (ha)	Rainfall (mm)	Runoff (mm)	Specific Discharge (cumec/ha)	Specific Peak Discharge (cumec/ha)	% Runoff
1	Acacia1	8.728		439.49	0.0031	0.1952	19.52
2	Acacia2	4.481		638.60	0.0072	0.2836	28.36
4	Degraded1	10.083		708.48	0.0073	0.3146	31.46
5	Natural Forest 1	6.545	2252	339.89	0.0030	0.1509	15.09
6	Degraded3	8.655		970.89	0.0049	0.4309	43.09
7	Natural Forest 2	9.131	2253.3	547.87	0.0028	0.2431	24.31

Table 2-5. Annual rainfall-runoff and peak discharges in monitored first-order catchments: 2004

Sl No	Land use type	Area (ha)	Rainfall (mm)	Runoff (mm)	Specific Discharge (cumec/ha)	Specific Peak Discharge (cumec/ha)	% Runoff
1	Acacia1	8.728	2846.30	696.90	0.081	0.005	24.48
2	Acacia2	4.481		1096.02	0.247	0.008	38.51
4	Degraded1	10.083		916.56	0.092	0.009	32.20
5	Natural Forest 1	6.545		410.50	0.063	0.002	14.42
6	Degraded3	8.655	2726.82	1232.53	0.144	0.007	45.20
7	Natural Forest 2	9.131		729.10	0.081	0.004	26.74

Table 2-6. Annual rainfall-runoff and peak discharges in monitored first-order catchments: 2005

Sl No	Land use type	Area (ha)	Rainfall (mm)	Runoff (mm)	Specific Discharge (cumec/ha)	Specific Peak Discharge (cumec/ha)	% Runoff
1	Acacia1	8.728	3662.44	1287.91	0.1491	0.0078	35.17
2	Acacia2	4.481		1587.57	0.3576	0.0141	43.35
4	Degraded1	10.083		1743.77	0.1745	0.0099	47.61
5	Natural Forest 1	6.545		725.70	0.1119	0.0116	19.81
6	Degraded3	8.655	3602.95	1732.74	0.2021	0.0159	48.09
7	Natural Forest 2	9.131		1029.99	0.1138	0.0107	28.59

It can also be seen from these tables that the % of runoff is lowest in forest and followed by the acacia and degraded yielded the highest. Similar observations are reported for some of the New Zealand catchment Rowe (2003) and for Coweeta watersheds in USA (Hewlett. et. al., 1979). Also, it can be seen from the table that the specific peak discharge is also quite high for the degraded watersheds than other two watersheds with Acacia and Forest. This implies that, the acacia watersheds over a period of time may restore the land to behave as that of the forested watersheds.

2.3.5 <u>Peak flow analysis</u>

The peak discharges of 0.00382 m3/sec, 0.00624 m3/sec and 0.00209 m3/sec or greater (assuming these values as threshold) respectively for Acacia, degraded and forested watersheds are compared during the study period. The so obtained values were than divided by the respective areas of these watersheds to get the specific peak discharges. This partial duration data for each year was derived. The total number of flow events and their respective rainfall events are also grouped and tabulated in Table 2-6. These derived partial duration series was subjected to probability analysis (Figure 2-10).

The results presented in Table 2-7 indicate that there is an increase in the peak flow of the order of 14 time in degraded to a lowest of 0.21 in Acacia watershed in comparison with that of the forested watershed, which is considered as the control.

Table 2-7. Peak flow(cumec/ha) for selected rainfall events under different land-uses for (a) year 2003, (b) year 2004 and (c) year 2005 in Malnaad block region

(a) year 2003

Date	Rainfall (mm)	Acacia 1	Acacia 2	Degraded 1	Degraded 2	Natural forest 1
23-Jun-03	149.80	0.38	0.537	0.82	0.44	0.26
22-Jun-03	113.40	0.33	0.473	0.71	0.35	0.23
5-Jul-03	92.60	0.24	0.287	0.50	0.26	0.33
24-Jul-03	77.10	0.12	0.206	0.32	0.22	0.25
21-Jun-03	71.10	0.09	0.137	0.35	0.24	0.18
4-Oct-03	68.90	0.13	0.117	0.19	0.19	0.07
21-Aug-03	66.00	0.28	0.255	0.18	0.30	0.17
28-Jul-03	65.00	0.33	0.129	0.36	0.17	0.20
6-Jul-03	56.20	0.08	0.141	0.29	0.13	0.15
26-july-03	55.70	0.14	0.113	0.28	0.14	0.13
	81.58	**0.21**	**0.24**	**0.40**	**0.24**	**0.20**
Percentage Increase of Runoff over forested watershed		6.71	21.13	102.23	23.68	

(b) year 2004

Date	Rainfall (mm)	Acacia 1	Acacia 2	Degraded 1	Degraded 2	Natural forest 1
4-Aug-04	154.20	0.462	0.418	0.679	0.586	0.233
16-Jun-04	108.40	0.596	0.573	0.988	0.467	0.254
15-Jun-04	96.99	0.439	0.409	0.826	0.409	0.210
3-Aug-04	96.33	0.295	0.331	0.554	0.342	0.150
13-Aug-04	94.54	0.280	0.271	0.496	0.405	0.113
30-May-04	86.39	0.177	0.266	0.331	0.378	0.168
10-Jun-04	79.87	0.338	0.269	0.865	0.303	0.191
6-Aug-04	79.06	0.257	0.252	0.411	0.343	0.190
5-Aug-04	75.80	0.241	0.224	0.357	0.261	0.165
29-July 04	73.35	0.240	0.256	0.641	0.322	0.134
	94.49	**0.33**	**0.33**	**0.61**	**0.38**	**0.18**
Percentage Increase of Runoff over forested watershed		83.87	80.84	240.18	111.11	

(c) year 2005

Date	Rainfall (mm)	Acacia 1	Acacia 2	Degraded 1	Degraded 2	Natural forest 1
25-Jul-05	160.07	0.80	1.05	1.11	1.15	1.27
2-Aug-05	135.45	0.80	0.80	0.76	0.77	0.39
24-Jul-05	125.67	0.69	0.53	0.89	0.93	0.51
30-Jun-05	118.34	0.71	0.64	0.98	1.04	0.48
3-Aug-05	117.69	0.98	0.78	0.91	0.92	0.41
28-Jul-05	115.73	0.31	0.52	0.34	0.37	0.66
29-Jun-05	113.45	0.49	0.66	0.32	0.36	0.15
26-Jul-05	108.88	0.61	0.67	0.82	0.84	0.87
5-Jul-05	105.46	0.41	0.29	1.07	1.11	0.45
28-Jun-05	103.99	0.62	0.58	0.08	0.10	0.09
	120.47	**0.64**	**0.65**	**0.73**	**0.76**	**0.53**
Percentage Increase of Runoff over forested watershed		21.74	23.67	37.93	43.80	

However, there is a high temporal variability of the increment within each of the watersheds. Since the peak flows is function of intensity and duration of rainfall in addition to land use. Lesser rainfall amounts with high intensity and small duration gives higher peaks than higher rainfall amount and vice versa. Irrespective of rainfall amount, comparison among the peak flows from all three watersheds shows that a moderation in peak flow from 0.061 m3/sec for degraded watershed to 0.014 m3/sec for forested watershed for the event with 154 mm of rainfall during the year 2004. However during 2005, the forested watershed yielded the highest peak than Acacia watershed for the same event (160mm) with the highest of 0.10 m3/sec for degraded watershed. This could be a possible phenomenon, in case if this higher rainfall event was preceded by number of smaller rainfall event, which will saturate the soils. Subsequent higher rainfall event might have caused the higher peak. The above comparison is between the catchment of the same order i.e., between 7 to 9 ha watersheds. Further, it is observed that, the ratio of the peak flow of forested watershed with other watershed show a variation during the study period (Figure 2-10). The figure shows that, as the storm size increases, the % increment of peak flow increases. The degraded watershed has shown the higher ratio of increment even at the lower storm size.

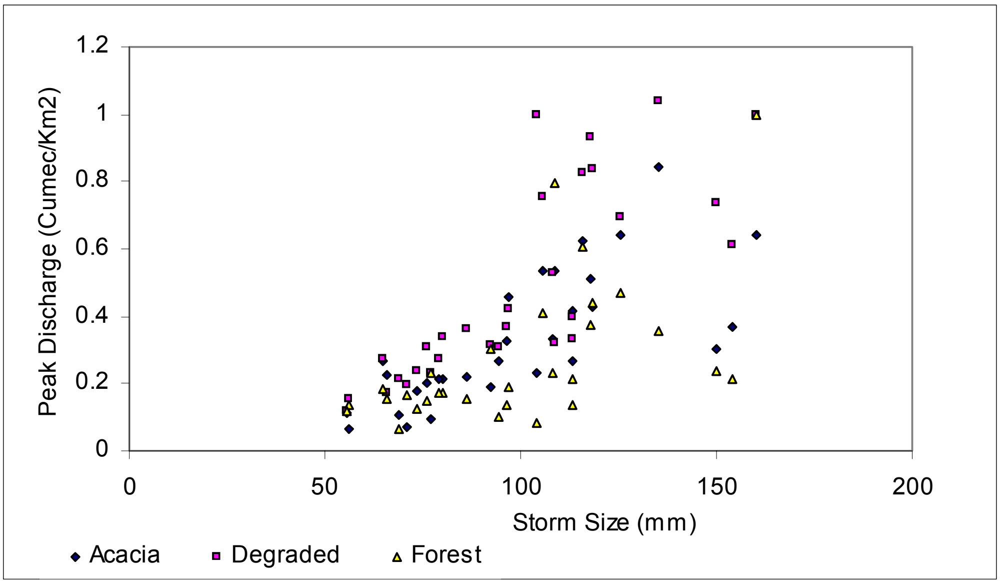

Figure 2-10. Percent Increase of peak flow for different storm size under Acacia and Degraded watershed in comparison with forested watershed.

The frequency plot of the peak flow (Figure 2-11) under different land-uses confirms that the forest have lower magnitude of flows in comparison with that of the other two land-uses. However, the degraded yielded the higher magnitude of the peak flow. The highest peak discharge observed in all these watersheds is of the same magnitude. This invoke that, under the extreme rainfall and the soil wetness condition, even the forested watershed may generate higher flows. This phenomenon is quite evident from these observations in the Malnaad block region. The same has been reported from the experimental basin from humid and temperate regions (Hewlett, 1982; Hamilton and King, 1983; Bonell, 2005)

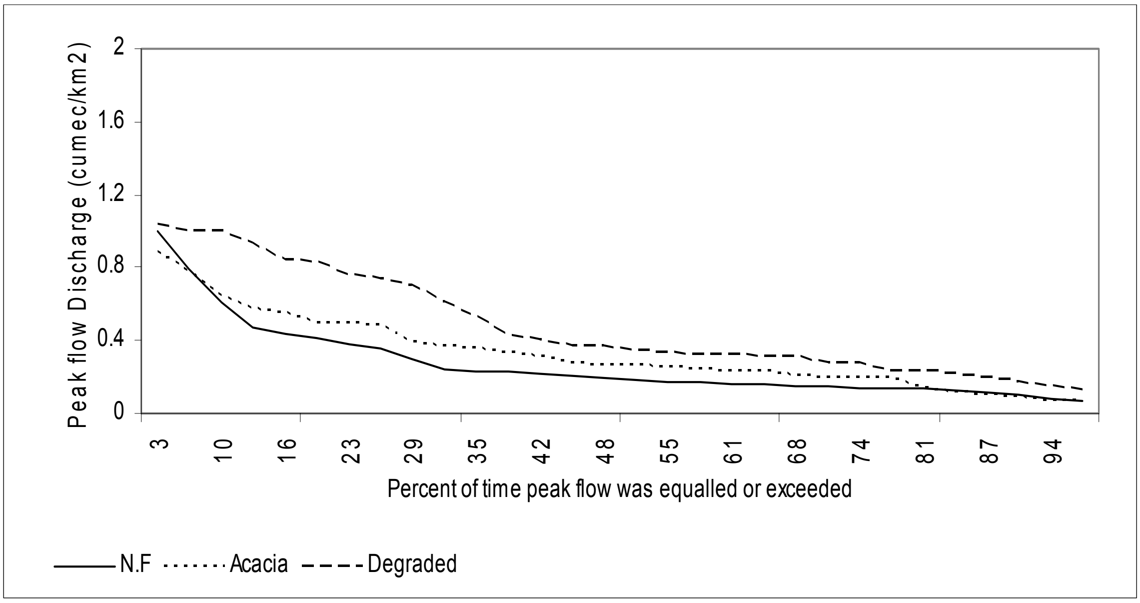

Figure 2-11. Frequency plot of peak discharge under different land-use

2.3.6 Moisture recession across catchments, depths and time

Soil moisture is an important variable for understanding and predicting a range of hydrological processes including flooding, erosion, solute transport and land-atmosphere interactions. Soil moisture exhibits a high degree of spatial and temporal variability. Both surface soil moisture and subsoil moisture have profound effects on the above processes. While, many researchers have studied the horizontal variation and temporal changes of soil moisture, but little attention has been paid to the profile features of the soil moisture. There have been a number of recent papers indicating that land use (Fu et al., 2000), slope gradient (Moore et al., 1988), aspect and curvature (Western et al., 1999), slope position and relative elevation (Crave and Gascuel-odux, 1997), precipitation (Famiglietti et al., 1998) and mean soil moisture (Bell et al., 1980) have influence of the distribution of soil moisture. However, in the present study, in order to gain a better understanding of soil moisture variations in relations to land use is analysed. The results are presented below;

The temporal variation of profile soil moisture for three land-uses is shown in Table 2-8. The results indicate that standard deviation of soil moisture within upper layers is more variable than in the lower soil layers. This is nature of variation in the upper layer has been observed in some of the watersheds under different land covers in China (Fu, et al., 2003; Wang et al., 2001). The deeper layer in the forest soil shows a stable variation. But the soil moisture under degraded watershed shows a higher variation below150 cm depth. However, a greater variation of soil moisture is observed below 120cm depth in watershed covered with Acacia plantation. These variations indicate that the moisture is influenced by the land-use and land cover of the watersheds and also the texture of the soil at different depth with increase in the clay content with the depth It is also observed from the table.8, is that, the gradient of moisture under degraded and forest have a negative value compared to that of the acacia watershed. A higher moisture variability is observed in the Acacia watershed followed by the forested watershed

Table 2-8. Statistics of profile features from time averaged soil moisture content (gravimetric content, in %) at different soil layer on different plots

Sl. no	Layers	Land use / Land cover type			Standard Deviation		
		Acacia	Degraded	Forest	Acacia	Degraded	Forest
1	0-15 cm	14.93	23.54	22.53	7.26	10.64	11.40
2	15-30 cm	16.92	21.05	18.36	6.43	9.74	6.82
3	30-45 cm	17.60	18.70	17.70	8.45	7.93	3.98
4	45-60 cm	13.59	17.86	17.96	5.37	7.46	3.92
5	60-75 cm	15.20	19.67	16.30	4.38	5.83	3.55
6	75-90 cm	15.24	20.92	17.29	2.58	4.73	5.68
7	90-105 cm	18.16	22.72	16.39	4.54	7.23	3.57
8	105-120 cm	19.34	20.72	15.26	4.81	6.68	3.17
9	120-135 cm	22.94	22.60	14.64	5.05	5.18	3.93
10	135-150 cm	23.94	21.91	14.98	6.76	6.28	3.69
11	150-165 cm	15.15	18.34	14.86	6.90	7.31	3.20
12	165-180 cm	24.19	19.88	14.21	4.21	5.54	3.60
13	180-195 cm	26.23	24.00	15.34	6.46	9.07	3.96
14	195-210 cm	20.96	20.18	12.85	3.17	4.27	3.09
15	Profile variability (VP)	4.20	1.92	2.37			
16	Profile gradient (Gi)	2.87	-1.60	-4.60			
17	Temporal Variability (VT)	3.54	3.66	3.24			
18	Mean Moisture (M)	19.24	20.93	16.60			

This is quite obvious as the plants use more moisture in their root zone in these watersheds. The table also depicts that the moisture content increases below the depth of 150cm. This sudden increase may be attributed to change in the soil type (may be the composition of soil with respect to percentage of sand, clay and silt). However, these watersheds show a higher temporal variability in the moisture.

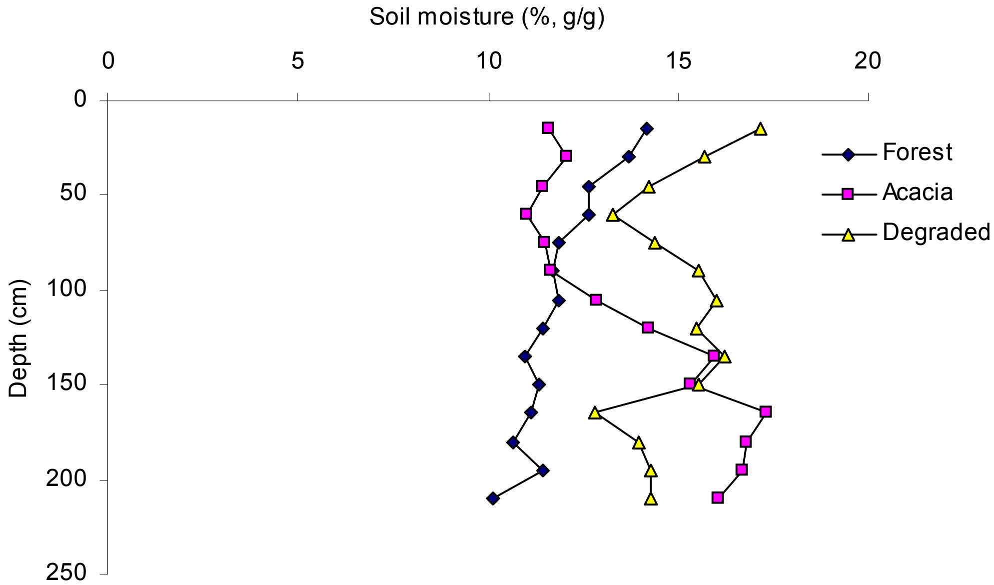

Figure 2-12. Depth-wise variation of the Soil moisture at the top point across the land-use types

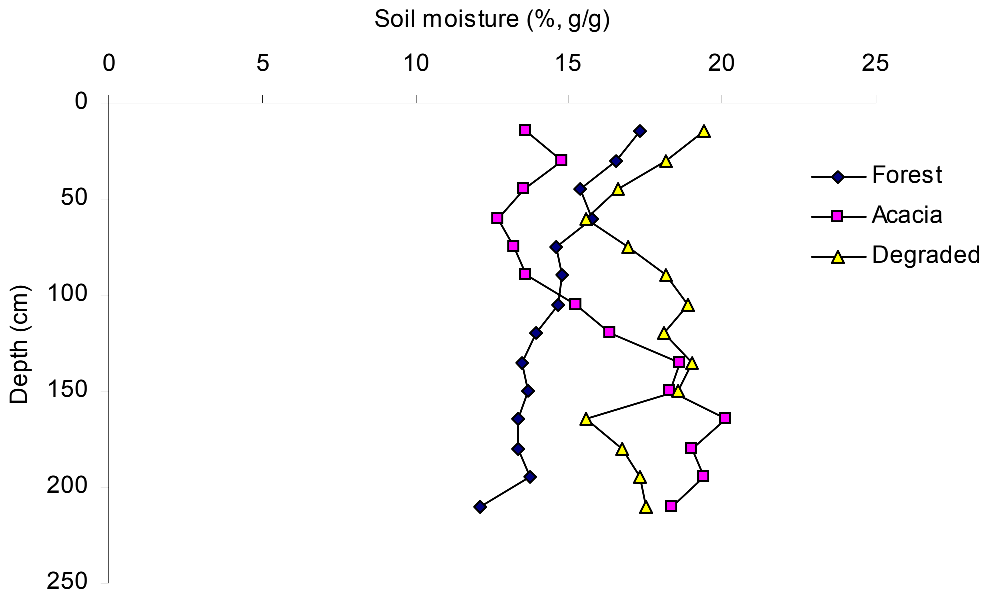

Figure 2-13. Depth-wise variation of the Soil moisture at the middle point across land-use types.

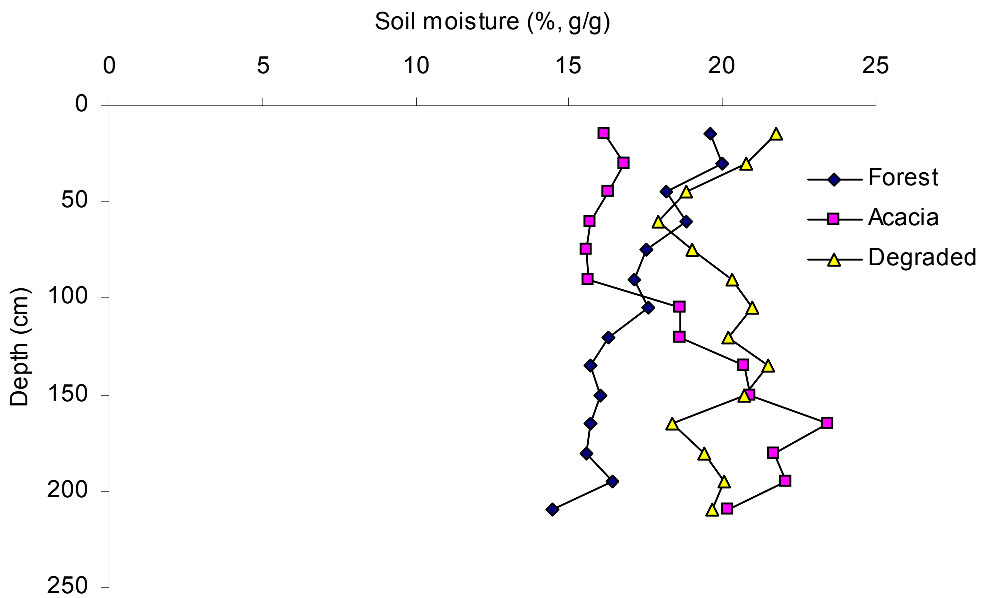

Figure 2-14. Depth-wise variation of the Soil moisture at the lower point across the land-use types.

Figure 2-12 to Figure 2-14 show the variation of the soil moisture in the vertical profile for the three land-uses. It is noticed from these figures that two profiles are increasing and waving type whereas one profile is decreasing type. The increasing and waving type profile includes the Acacia and degraded watersheds. The decreasing type of profile corresponds to the forested watersheds.

In the acacia plantation, the soil moisture fluctuation with depth is observed. This could be due to the fact that the major portion of the watershed covers with the 12 year old acacia plantation and the height of the plants vary between 12-15 m, while some regenerated younger plants are also present in the watershed. The roots of the older trees may have a reached at the greater depth for extracting the moisture. The younger trees may be extracting water at the surface and sub-surface layer. But below 150 cm, the moisture content is increasing; this indicates that, the roots have mostly concentrated within 100 to 150 cm depth from ground surface. The same pattern has been observed in the degraded watershed. The degraded watershed is mainly covered with the grass during the post rainy season along with old trees. Therefore, the moisture is low down to about 60-70cm and thereafter the moisture is increasing till 210cms.

With regard to that of the forested watershed, this covered by the old trees with root length down to a few meters. Therefore, the moisture at the upper soil layers are not used much and mostly conserved. However, at the deeper depths, the moisture is being extracted by roots hence the decreasing moisture content. Also, it can be noticed from the Figure.11, is that, at 200 cm depth, the moisture in all the land-use types have shown a decreasing trend. This implies that, either the moisture is contributing towards the deeper percolation, hence to the ground water recharge, or there may be a change in the geology of the area at this depth, which is dominating the moisture content. However, a detailed geological survey is required to explain these processes in detail.

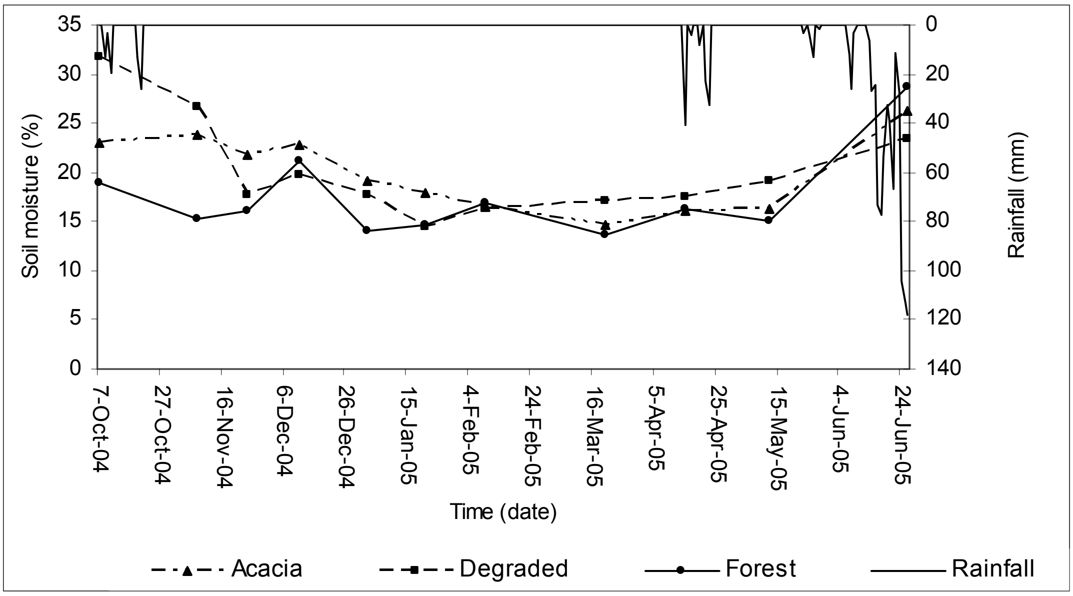

Figure 2-15. Temporal variation in soil moisture in the three land-cover types

The temporal variation of mean soil moisture content within 0 to 210 cm in three land-uses is shown in Figure 2-15. Also shown are the daily rainfall and the variation of the same time. The seasonal changes in the mean soil moisture were apparent. First as expected, an increase and decrease in soil moisture corresponding to the high and low rainfall, and it exhibited two peaks and four troughs. Also, the moisture content reached the peak following the heavy rainfall during the later part of the June 2005. It can even be seen, an intermittent rainfall in the early October 2004 has given rise the increase in the soil moisture and subsequently the moisture has decreased continuously. The dry trend has continued in spite of a rainfall event in April 2005.

From Figure 2-12 to Figure 2-14 above, it is seen that the soil moisture under the selected watersheds has similar trend across all the point within the watersheds. This behaviour suggests that there may be lateral flow occurring within the soil strata and may be contributing to the soil moisture. This phenomenon is further supported by the observed field saturated hydraulic conductivities across the all the layers. The differing values across different depth will enhance the possibility of lateral flows. This is clearly observed in the soil moisture content.

The available soil moisture in the forested watershed is being used by the trees for transpiration. This is quite evident from the soil moisture pattern observed, wherein the soil moisture is decreasing all through the depth down to 2.10 m (observation were done down to 2.10 m). Whereas in other two watersheds, the trends are quite different than that of the forested watershed. The soil moisture in these watersheds is being used by the trees down to 1.0 m and 0.6 m respectively in acacia and degraded. Thereafter an increasing trend in soil moisture is observed. The same trend is observed at other points also. However, below 1.50m depth, both acacia and degraded watersheds have registered a decreasing trend in the soil moisture. This could be due to the change in the soil properties. These changes can be attributed to the changes in the soil type observed in the field. (A soil profiling was done in these watersheds, two distinct soil layers were observed as seen in Figure 2-16). The root density of the trees may even cause these variations at different depths across the points in each of the watersheds. It is noticed that, the roots in acacia plantation have penetrated down to 1.m and above. The density of these roots does vary at different depth with the soil moisture. It is observed that, the soil moisture is quite high even at 2 m depth in acacia in comparison of that of the forested watershed. The higher root density has been in the forested watershed with higher soil moisture content in the soil (see Figure 2-17). Whereas in the degraded watersheds, the density is quite low, therefore the soil moisture is higher.

While studying the horizontal and profile variation of soil moisture, they have identified the effect of topography on the soil moisture and its distribution both spatially and vertical variation (Famiglietti, et al., 1998; Western et al., 1998). The previous studies carried out elsewhere, e.g., Fu et al., 2001; Fu and Chen, 2000; have identified parameters such as slope, relative elevation and aspect that are the main factors controlling the soil moisture. The study area is of undulating type, which may play an important role in distribution of soil moisture.

Figure 2-16. Soil Profile at Acacia Plantation (Kodgibail)

Figure 2-17. Soil Profile in a Forested Watershed at Kodgibail with high root density

The effect of undulation can be seen in the distribution of the soil moisture across the point within each of the watersheds. The lower point has more soil moisture than that of the top point. This indicates that the lower points are situated more or less on a flat terrain than that of the other two points. Some of these variations in soil moisture can be due to the variation of the topography itself. However, quantification of these effects is not in the framework of the present analysis.

2.3.7 Summary of findings

The findings from the above analyses may be summarised as follows:

1. Under the saturated conditions, the forest can generate higher amount of runoff as that of the other land-use types.
2. The observed runoff analysis for different land-use show that, the highest peak flow magnitude was observed in degraded watershed followed by Acacia in comparison with the forested watershed.
3. The specific discharge is highest in degraded watershed (24% higher than forest) and lowest in forested watershed
4. The influence of land-use on the soil moisture variation and its dynamics is observed and statistical analysis indicates the root density is concentrated within 30 to 90 cm and down to 200 cm in Acacia plants and in natural forest respectively
5. The soil moisture deficit index is appeared to be having an influence on the runoff generation in the watersheds.
6. The Ksat values in Acacia are more or less comparable with that of the forest, hence the possibility of more water movement down the soil strata.
7. Comparatively higher groundwater recharge is observed in the acacia plantation.

2.4 Linkage between baseflow, areca productivity and incomes

We sampled arecanut orchards in 5 valleys or stretches of areca cultivation having differences in the post-monsoon flows. The idea was that these differences would simulate the differences that might result from land-cover changes in the catchments. The areca cultivation in each valley was largely owned by households in the settlement in that valley and so the households in that valley were the population from which the sample was primarily drawn.

2.4.1 Socio-economic profile of the sample settlements/hamlets

The basic profile of these settlements is given in units that were sampled. The basic profile of the communities in each settlement is given in Table 2-9, Table 2-10 and Table 2-11.

Table 2-9. Household details for study village/hamlets

Revenue Village Name	Hamlet Name	Total Number of Households (Population)	Brahmin HH	Vokkaliga HH	Naik HH	SC HH	Landless HH
Kodgibail	Kodgibail	62 (390)	8	54	0	0	3*
	Mavinahalli	10 (32)	2	8	0	0	0
Golikai	Golikai	20 (100)	7	13	0	0	0
	Kalur	40 (240)	0	0	40	0	0
Magegar	Vajgar	9 (49)	3	0	6	0	0
Bidrakan	Narmundigai	28 (140)	2	0	26	0	0
	Sannamane	11 (37)	0	0	0	11	11
Total		180	22	75	72	11	14

Note: * Kodgibail landless households belong to Vokkaliga community.
Source: Census of India 2001 and our own surveys

Table 2-10 Livestock Details in the study hamlets

Village Name	Hamlet Name	Cows	Buffalos	Drought Animals	Total
Kodgibail	Kodgibail	124	33	13	170
	Mavinahalli	16	4	0	20
Golikai	Golikai	54	7	8	69
	Kalur	26	20	10	56
Magegar	Vajgar	18	17	2	37
Bidrakan	Narmundigai	33	21	18	72
	Sannamane	7	2	0	9
Total		278	104	51	433

Table 2-11. Cropping pattern in the study hamlets

Village Name	Paddy in Acres	Areca in Acres	% of Areca in total
Kodgibail	38	75	66%
Golikai	25	20	44%
Kalur	40	15	27%
Narmundigai	21	15	42%
Vajgar	15	20	57%

Note: These are the agricultural lands owned by the households in each hamlet. The lands themselves may be in the same valley or in neighbouring valleys.

As can be seen from the last table, areca orchards constitute a very significant fraction of the total cultivated land owned by the households, and if one were to factor in the much higher economic returns per acre of areca, one can conclude that areca (with associated intercrops) is in fact the predominant land use. An arecanut orchard is located in the narrow valley typically created by second order streams and consists of arecanut in the canopy and cardamom and pepper intercrops (see Figure 2-18). Arecanut orchards are not irrigated, but their moisture levels are controlled by diverting excess water during the monsoon away from the orchards and conversely bunding and diverting post-monsoon flows from streams that flow along the orchards into the channels along rows of arecanut palms. Recently, farmers have attempted to grow vanilla as an intercrop. While this boom lasted only a few years, the farmers installed sprinkler irrigation systems for the vanilla intercrop, which were then also used for summertime areca irrigation. We purposefully excluded these farmers from our sample, since it seemed that the traditional approach of irrigation through small bunds and streamflow diversion was still the predominant practice in the region.

Figure 2-18. Canopy in arecanut orchard showing arecanut bunches.

The sample farmers we selected for detailed survey and monitoring therefore consisted of non-sprinkler farmers spread across 5 valleys (6 farmers per valley). For basic socio-economic information, the household was our unit of data collection. Given that these farmers tended to have multiple plots of land at different points in the valley, we covered multiple plots per farmer (but not necessarily their entire landholding) spread in upstream, mid-stream and downstream locations for the detailed monitoring of agricultural practices and inputs.

2.4.2 Areca production, economic returns and post-monsoon flows

We adopted a three-stage approach to making the linkage between post-monsoon flows and the arecanut economy. We first demonstrate and quantify the variation in post-monsoon flows across valleys and the relationship between flow levels and soil moisture in arecanut orchards. We then demonstrate a correlation between flows and arecanut productivity. Finally, we analyse the differences in productivity along with those in household endowments to translate the differences into economic terms.

Post-monsoon flows and soil moisture in sample valleys

We established V-notches for measuring post-monsoon flows in all 5 valleys (see appendix for details) and flow levels in these notches were measured daily. The estimated flows in the streams immediately downstream of the orchards are shown in Figure 2-19. The observations serve to confirm and quantify the statements by the farmers regarding the duration of the flow, viz., that flows in Golikai valley (which includes Kalur) cease the earliest, followed by Narmundigai and Vajgar, while the flows in the Kodgibail valley last the longest (sometimes do not cease at all till the beginning of the monsoon. Correspondingly the post-monsoon soil moisture levels are consistently highest in Kodgibail, followed by Narmundigai, and the lowest in Golikai and Vajgar, generally across all soil depths (Figure 2-20).

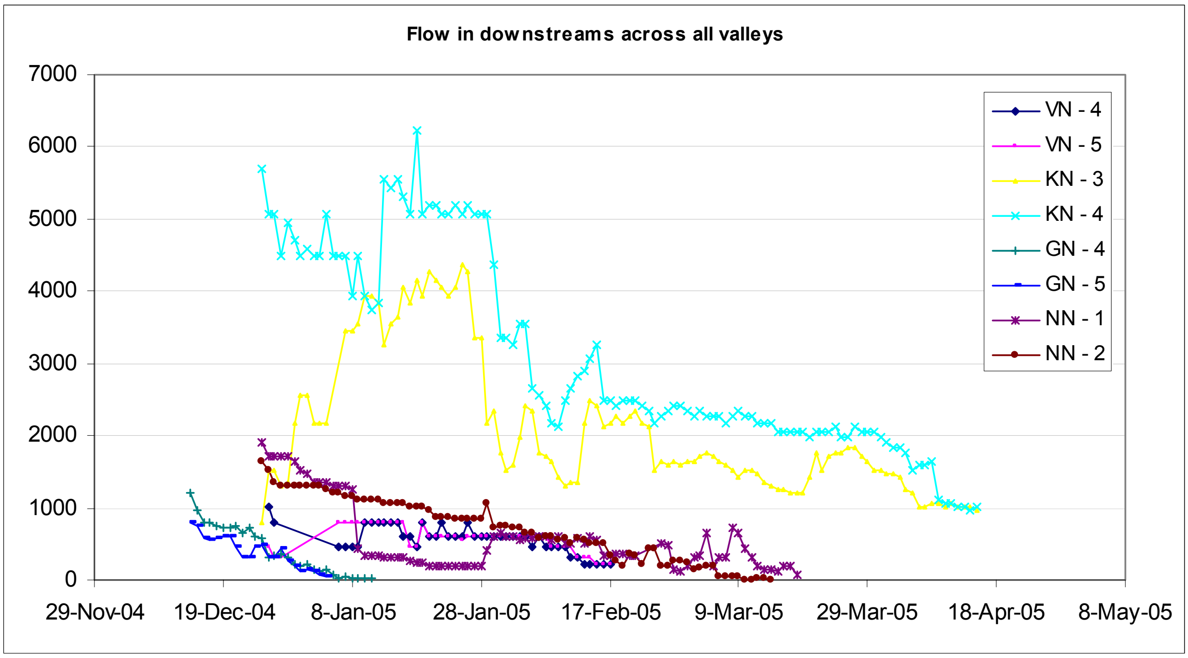

Figure 2-19. Post-monsoon flow magnitudes in the sample valleys at locations above and below the arecanut orchards

Soil moisture was sampled at multiple depths and multiple points in each orchard plot. Moisture content of composite samples for each depth was estimated using gravimetric method. Moisture sampling was carried out in 3 months of the post-monsoon period. The results are presented in Figure 2-20.

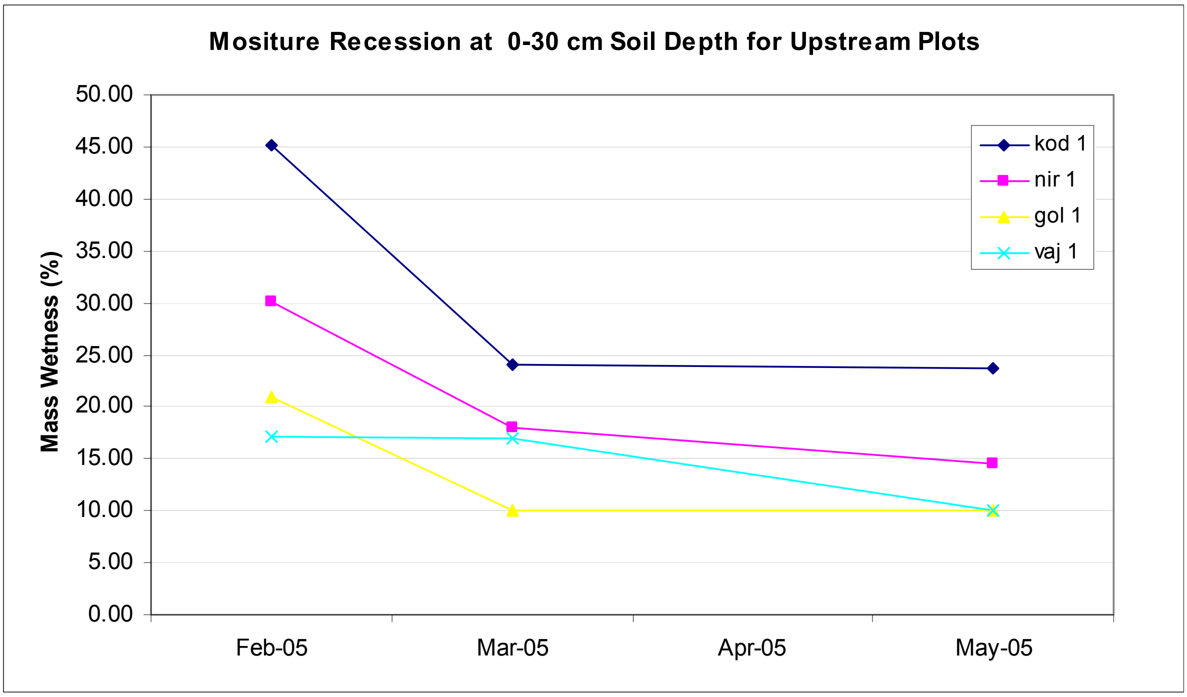

Figure 2-20. Soil moisture levels and rate of recession of soil moisture across the sample valleys.

It should be noted that there may not always be a direct relationship between flows and soil moisture levels for several reasons. First, soil textural characteristics would also influence soil moisture. Second, flows may or may not be diverted by farmers throughout the orchards in their attempt to maintain moisture levels constant. Third, farmers may use other techniques, such as mulching, to maintain soil moisture levels. While it was not possible to quantitatively monitor and factor in the influence of these variables, we have discussed their impact qualitatively below.

Flows and arecanut productivity

Data on arecanut productivity in each farmer's orchard are available from two sources at two slightly different scales: oral recall survey data for harvest of 2004-05 season for the entire areca landholding of the farmer, and actually measured harvests for 2005-06 season for the specific monitored plot. The results from both sources are presented below in Table 2-12 and Figure 2-21.

Table 2-12. Results of oral recall survey of areca productivity across valleys/hamlets

Hamlet (post-monsoon flow situation)	Areca Productivity (qtls per acre)	
	Average	Std.Dev.
Golikai (dry)	6.2	2.5
Kalur (dry)	5.7	1.1
Narmundigai (intermediate)	8.1	3.6
Vajgar (wet)	9.3	4.8
Kodgibail (wet)	11.8	3.2
OVERALL	8.2	3.8

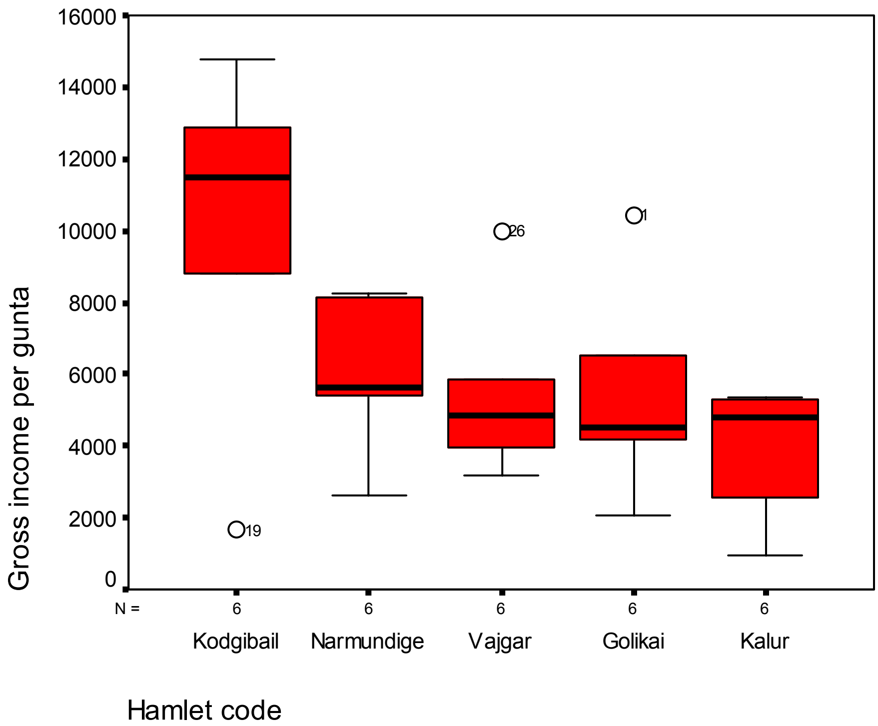

Figure 2-21. Comparison of median incomes from monitored arecanut plots across valleys (Kodgibail significantly different from Kalur at p<0.05 in non-parametric tests)

Both datasets show similar trends in areca productivity: Kodgibail valley, which has the longest-lasting post-monsoon flows, has the highest productivity, Narmundigai and Vajgar, with intermediate levels of flows, have intermediate levels of productivity, and Golikai and Kalur, where flows stop the earliest, have the lowest levels of productivity. The differences between the highest and lowest mean productivity valleys are statistically significant, but the intermediate differences are not always so.[16] Nevertheless, this substantiates our hypothesis that longer post-monsoon flows have a significant positive impact on arecanut productivity.

Arecanut productivity, inputs, household endowments and incomes

A multiple regression analysis of the net income from areca cultivation (defined as gross income minus paid out costs only) gives us an equation for relating net income to basic household parameters:

Net income per gunta = -193(areca holding in gunta) + 4669*(Kodgibail dummy)*, (coefficients significant at p<0.10 or better)

This indicates that, in addition to positive relationship with duration of baseflow (Kodgibail being proxy for locations with longest baseflow), income per unit area is negatively related to landholding. The latter indicates that for larger landholders paid out costs increase faster than the gains from larger holdings.

[16] Note that the boxplots show median values, and in the median value calculation excludes outliers. In this case, exclusion of one outlier exaggerates the difference between Kodgibail and other valleys. But the non-parametric tests include all datapoints and so the results are robust to the inclusion of outliers.

2.5 Conclusion

Forest cover in the villages of the high rainfall Malnaad region is currently often a mosaic of a few patches of high density natural forests, heavily used soppinabetta tree savannas, and monocultural Acacia plantations. Our studies in first-order catchments dominated by these land cover types clearly show that, in absolute terms, there is substantial groundwater recharge occurring under all three land cover types. Relatively speaking, tree savannas have poorer surface infiltration properties than the other two land cover types, and that even after allowing for savings in evapotranspiration losses, there are likely to be some reductions infiltration and contribution to groundwater under this land cover type, as there is greater surface runoff. Whether these reductions are significant enough to reduce the post-monsoon flows in the second and third order streams substantially remains to be understood. But if post-monsoon flows do get shortened by a month or two, they would have significant impacts on horticultural (areca) productivity and incomes. We must, however, keep in mind that the productivity of areca is also very significantly dependent upon the application of large quantities of leaf mulch and organic manure, which is obtained primarily from the pruning of trees and cutting of/grazing on grass in these tree savannas (which is what keeps them as tree savannas). It is therefore possible that the net trade-off (if any) is still favourable to the farmers.

APPENDIX 1: Forest Vegetation sampling and mapping

Methods

For sampling the forest vegetation, we laid 2 or more rectangular transects along the slopes of the catchments, each of 100m x 20m. Each transect was divided into 5 quadrats of 20m x 20m. Where the catchment shape prevented laying of a 100m long transect, as in Hulimane, we laid several shorter transects. The details of transects laid are given in the table below.

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Table 2-13. Distribution of vegetation sampling across catchments

Type of catchments/treatment	Catchments name	No of transects (20*100)
Acacia plantation	Acacia -1	2
	Acacia -2	2
Degraded (Soppinabetta)	Mavinahalli	2
	Vajgar	2
Natural forest	Hulimane	4*
	Vajgar	2

*Hulimane transect number one is 20*50 meters

In each transect, we enumerated all trees (defined as single-stemmed individuals of girth at breast height (GBH) greater than 10cm) in terms of their species, girth (using tape) and height (visual estimate). Disturbance levels were estimated by counting the number of cut tree stumps in each quadrat. Species identification was done using our own knowledge, local names and inputs from experts in Sirsi Forestry College and Bangalore. Simple listing of shrub species encountered (not frequencies) was also done. We also took canopy cover estimates using simple counts, but this method did not yield reliable results.

Figure 2-22. Forest cover in Hulimane NF and Vajgar NF & SB catchments: Google earth image and transect locations

For mapping the entire catchment vegetation, we overlaid the transects (geo-referenced using Garmin hand-held GPS) on Google Earth imagery, and carried out visual interpretation of the entire catchment vegetation. The images and overlaid transect locations are shown in Figure 2-22 and Figure 2-23. To simplify matters for interpretation, we divided the observed tree densities into 3-4 classes, assigned each quadrat to a particular density category and then developed training sets using these quadrats to identify and map these densities in the rest of the 1st order catchments. For the larger 27 sq.km. Bilgi Hole catchment, we reduced the number of categories and used substantial qualitative information from field visits (where

GPS readings were taken) to interpret agricultural and other land-covers that did not obtain in the first-order catchments.

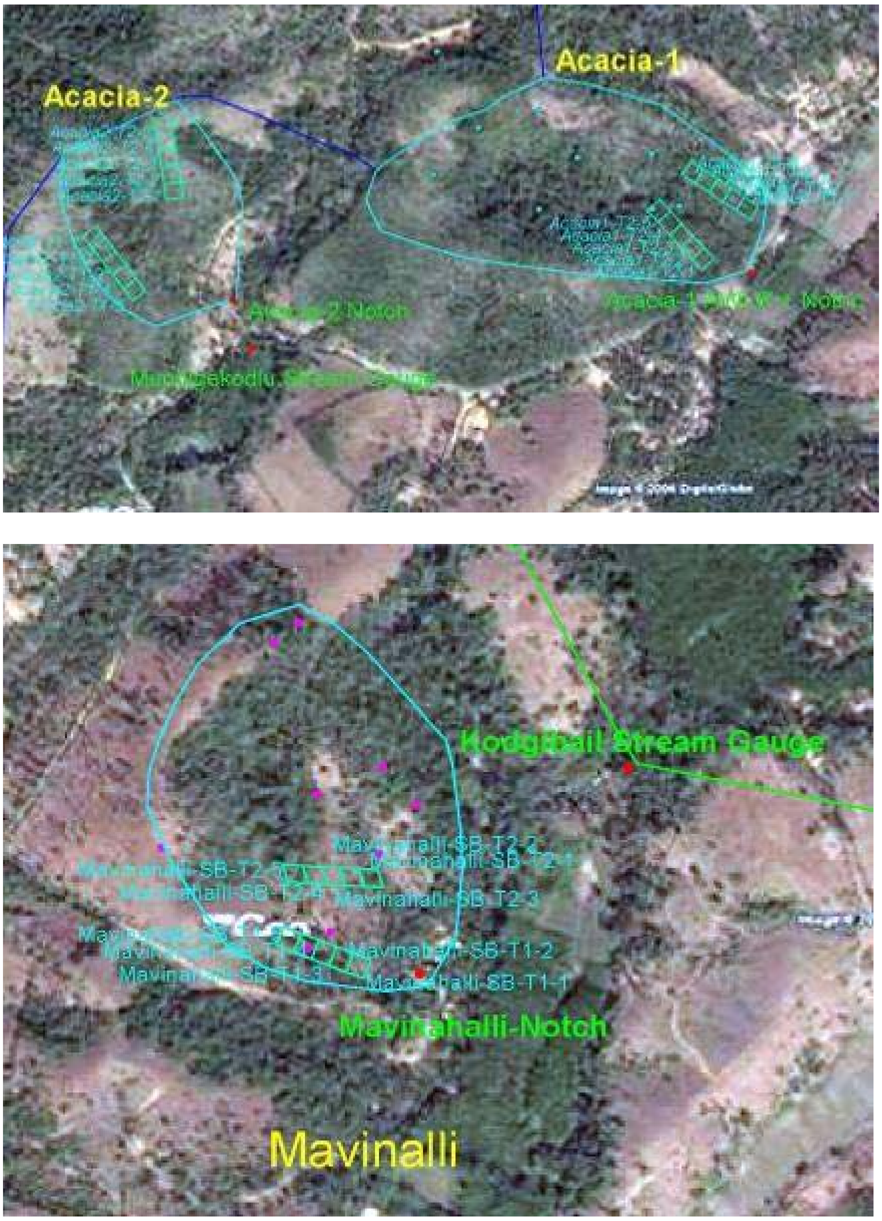

Figure 2-23. Forest cover in Acacia 1 & 2 and Mavinahalli SB catchments: Google earth image and transect locations

Results of vegetation sampling

The results of vegetation sampling are given in various tables below. The catchments are grouped into categories (natural forest (NF), soppinabetta/degraded (SB), and Acacia plantations).

Table 2-14. Species composition of 1st order catchments: Top 10 species encountered in vegetation transects

Natural Forest		Soppinabetta/Degraded		Acacia plantation	
Hulimane NF		**Vajgar SB**		**Acacia 1**	
Gymnonthra conariea	324	Alseodaphne semicarpifolia	178	Acacia auriculiformis	224
Sagereaea listari	260	Lophopetalum wightianum	159	Anacardium occidentale	19
Ixora barcheata	201	Ixora barcheata	83	Garcinia indica	6
Holigarna aronottiana	171	Aporosa lindleyana	80	Syzigium cumini	4
Hopea wightiana	156	Olea dioica	52	Olea dioica	3
Nerthe-unknown-2	120	Holigarna aronottiana	40	Tabernaemontana heyneana	3
Olea dioica	62	Gymnonthra conariea	24	Artocarpus integrifolia	2
Macaranga peltata	151	Sagereaea listari	24	Lophopetalum wightianum	2
Aporosa lindleyana	57	Mimusops elengi	20	Petrocarpus marsupium	2
Mimusops elengi	54	Garcinia indica	19	Randia spinosa	2
				Holigarna aronottiana	2
		Mavinahalli SB		Xanthoxylum retusa	2
Vajgar NF		Hopea wightiana	122		
Lophopetalum wightianum	130	Terminalia panniculata	49	**Acacia 2**	
Alseodaphne semicarpifolia	75	Aporosa lindleyana	48	Acacia auriculiformis	504
Gymnonthra conariea	75	Terminalia alata	48	Buchanania lanzan	11
Sagereaea listari	72	Syzigium cumini	25	Holigarna aronottiana	7
Holigarna aronottiana	50	Petrocarpus marsupium	19	Alseodaphne semicarpifolia	6
Ixora barcheata	44	Buchanania lanzan	15	Syzigium cumini	5
Aporosa lindleyana	39	Careya arborea	15	Randia spinosa	5
Macaranga peltata	32	Olea dioica	15	Plectronia didyma	5
Caryota urens	32	Alseodaphne semicarpifolia	12	Aporosa lindleyana	4
Hopea wightiana	31	Holigarna aronottiana	12	Carallia integerrima	3
Olea dioica	31			Ixora barcheata	3

Table 2-15. Vegetation structure of transects

Catchment name	Trees/ha	Basal area (sq.m./ha)
Hulimane NF	622.61	2866.52
Vajgar NF	1477.18	10761.13
Mavinahalli SB	440.40	2628.59
Vajgar SB	315.31	1823.30
Acacia-1	229.77	1862.22
Acacia-2	257.23	1528.59

<u>Variation in field saturated hydraulic conductivity across depths, for different land uses</u>

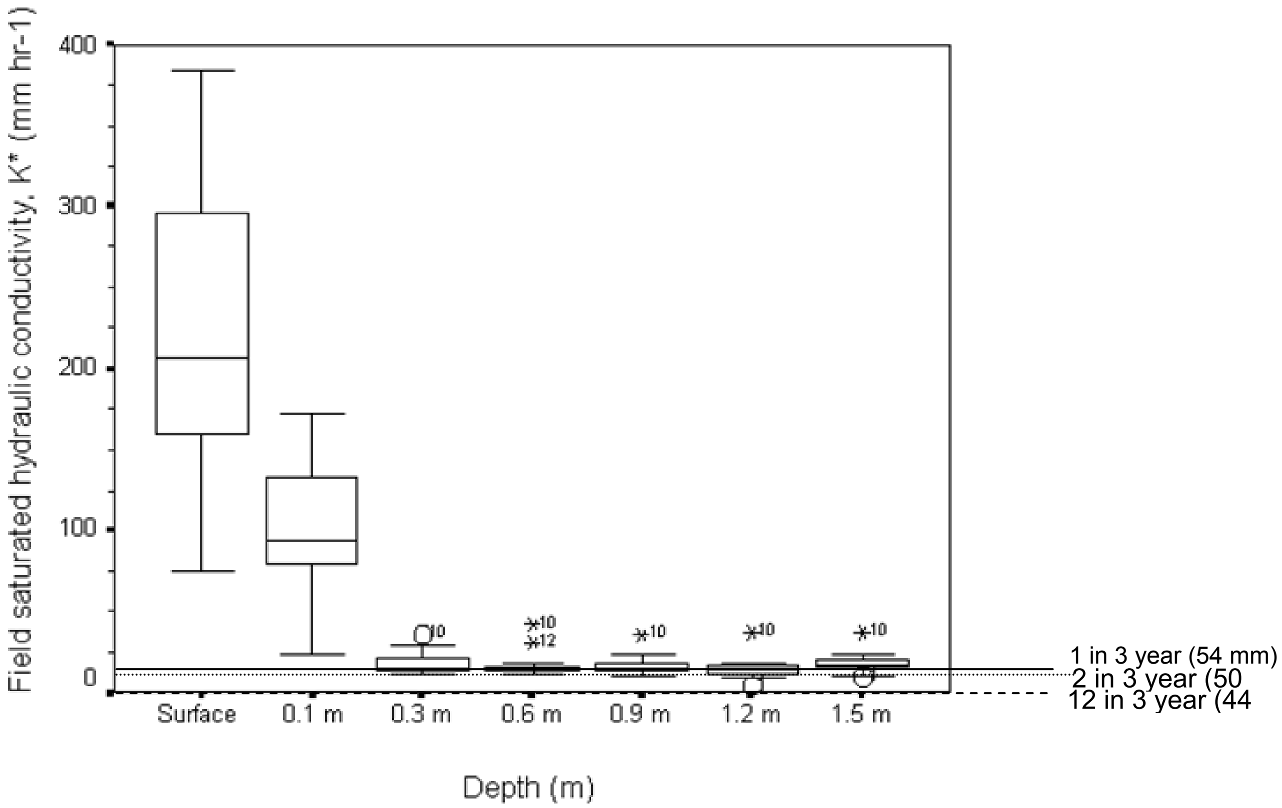

Figure 2-24. Saturated hydraulic conductivity as a function of depth in Dense Forest watershed

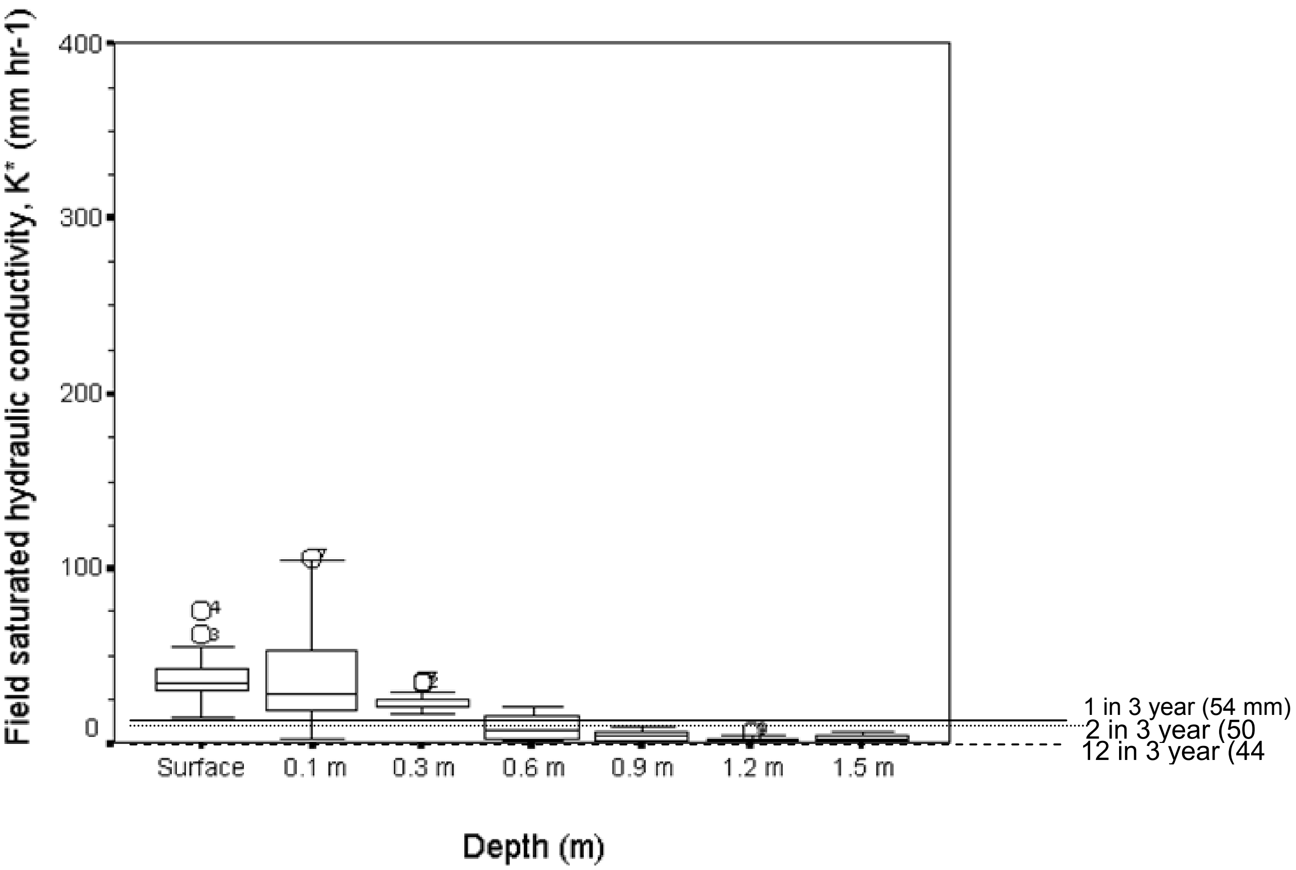

Figure 2-25. Saturated hydraulic conductivity as a function of depth in degraded watershed

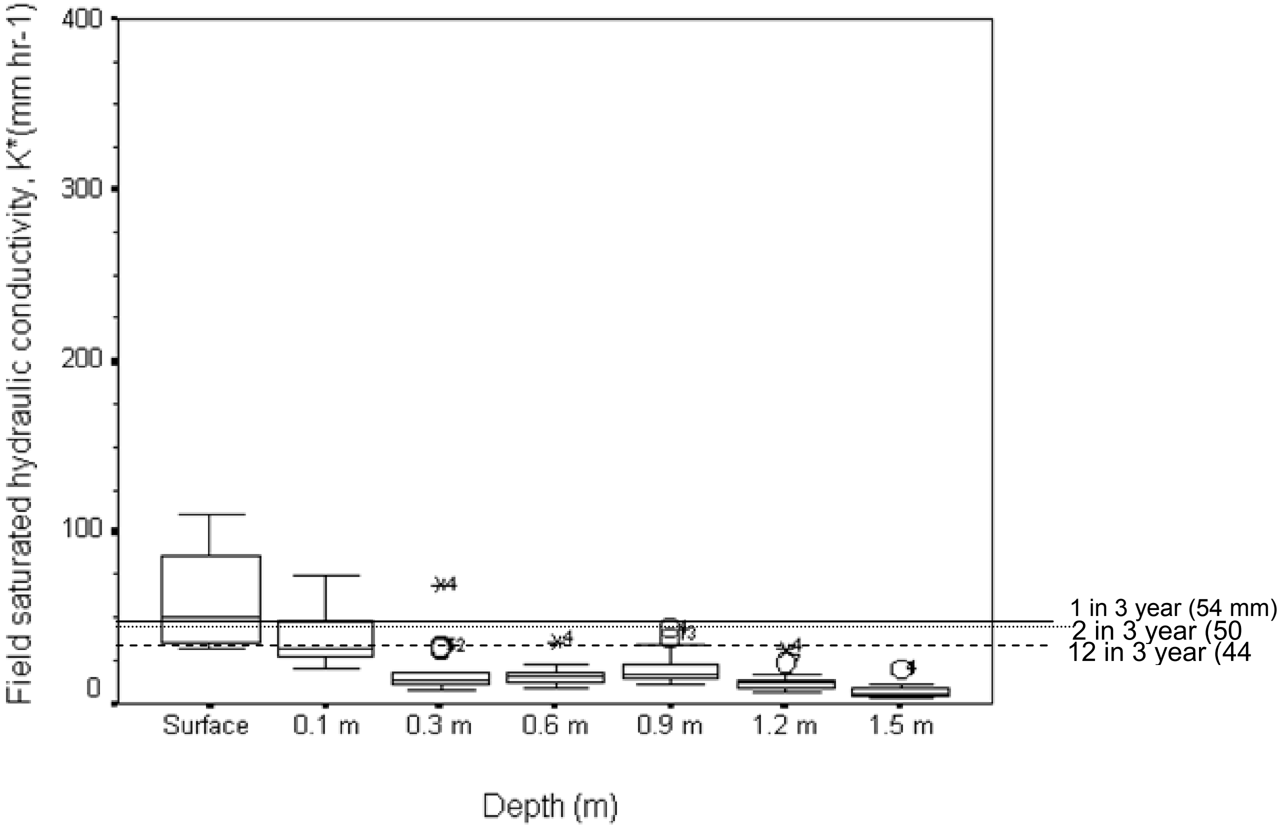

Figure 2-26. Saturated hydraulic conductivity as a function of depth in Acacia watershed

Variation in field saturated hydraulic conductivity across land use types at different depths

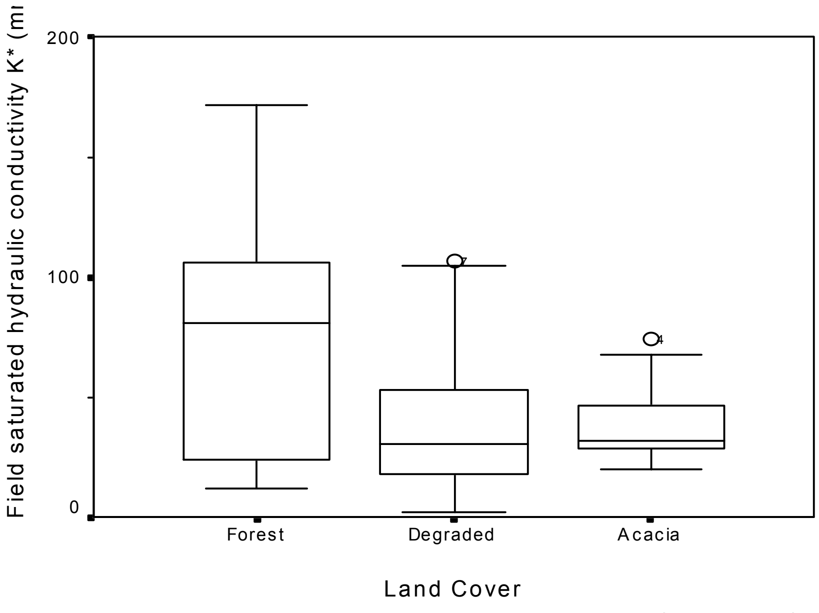

Figure 2-27. Field saturated hydraulic conductivity as a function of land use, at 0.10m depth

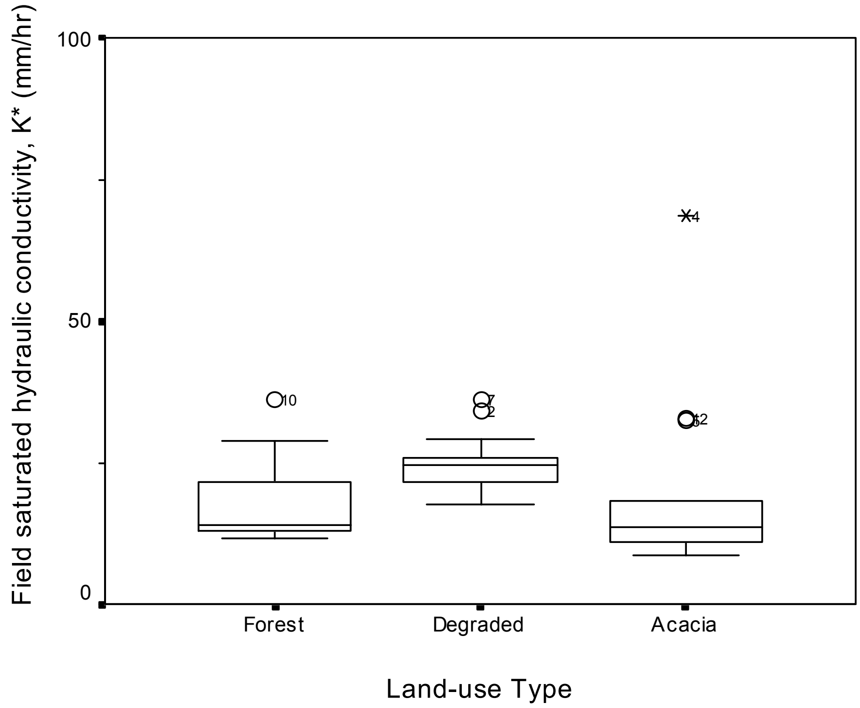

Figure 2-28. Field saturated hydraulic conductivity as a function of land use, at 0.30m

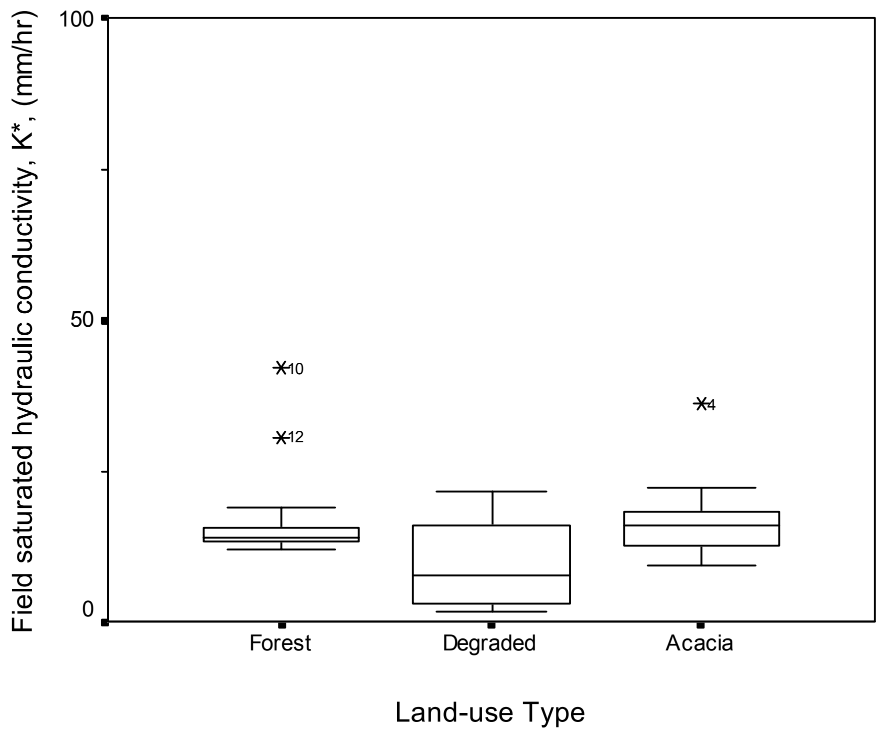

Figure 2-29. Field saturated hydraulic conductivity as a function of land use, at 0.60m

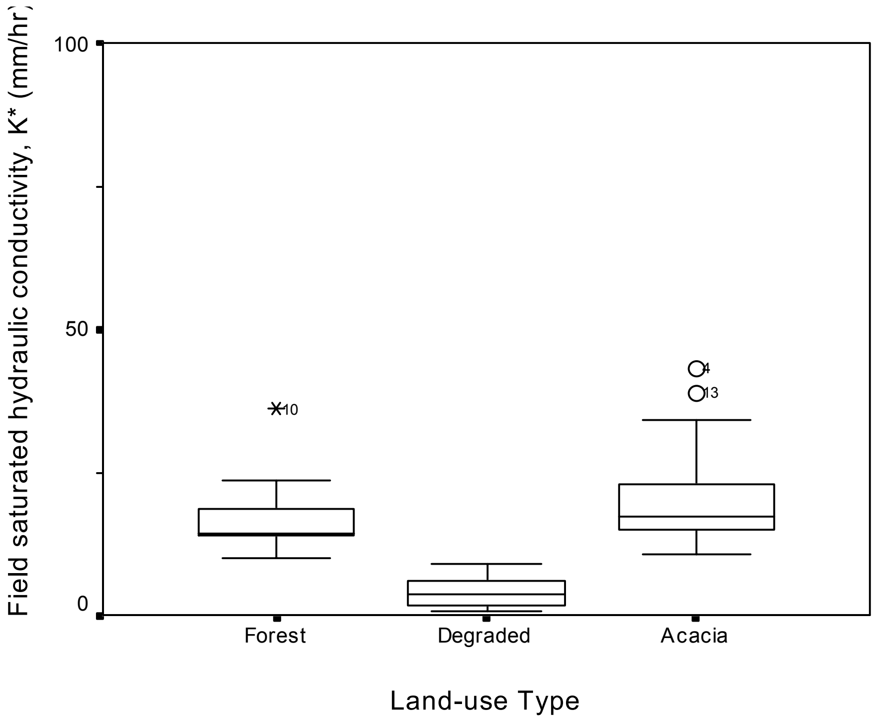

Figure 2-30. Field saturated hydraulic conductivity, K* as a function of land-use at 0. 90 m

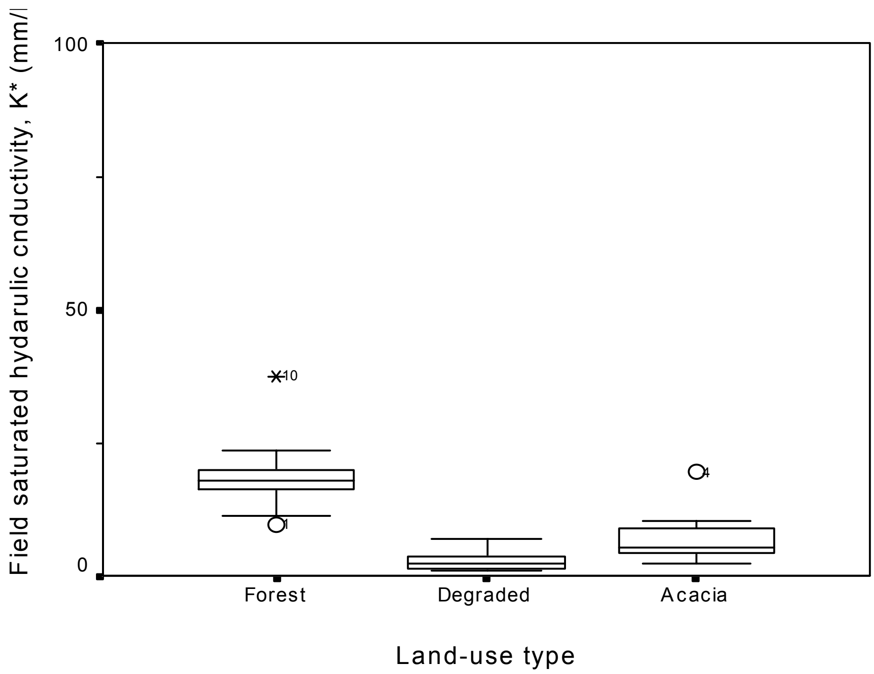

Figure 2-31. Field saturated hydraulic conductivity, K* as a function of land-use at 1.20m

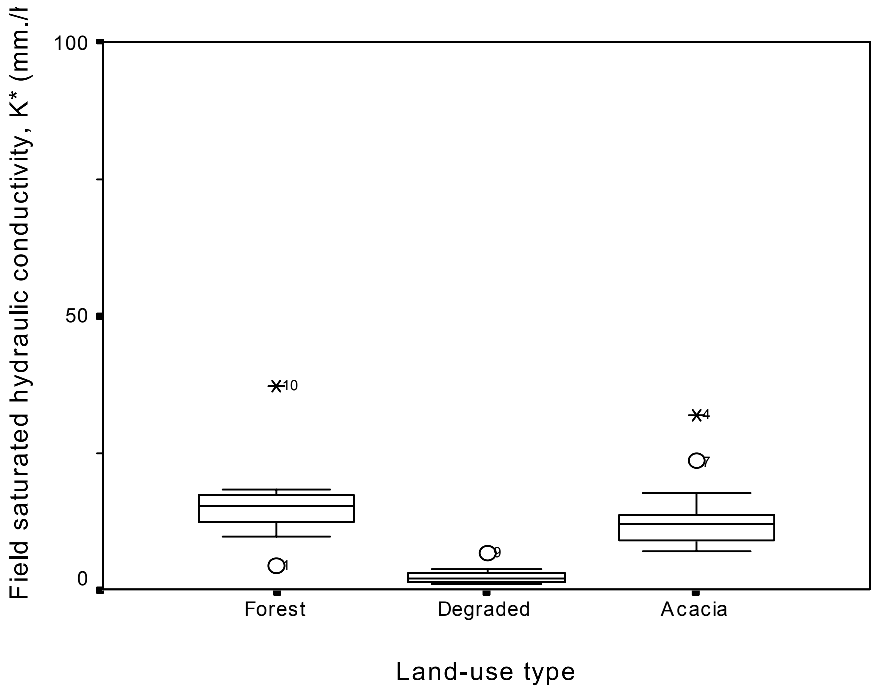

Figure 2-32. Field saturated hydraulic conductivity, K* as a function of land-use at 1.50m

Monitoring of post-monsoon flows in arecanut orchards

V-notches were locally fabricated and installed along various points in the streams that flow through the arecanut orchards in the 5 sample valleys. Photos below show the manner of installation and the flow observed.

Chapter 3. Forests, irrigation tanks and agriculture: The case of Bandipur

In contrast with the high rainfall, evergreen forest and undulating terrain of Kodgibail, the case of Bandipur block represents a situation of low rainfall, dry deciduous forest and clearer separation between forested hills and agricultural plains. It also represents a case where technology mediates much more strongly between the streamflow and the agriculture, in the form of irrigation tanks that collect and distribute the streamflow. This requires that the study of the forest-streamflow relationship be complemented by an analysis of the tank system and its links with agriculture. Simultaneously, one confronts a more heterogeneous social structure that creates differential dependence on forests.

3.1 Description of the study area

3.1.1 Location, topography and climate

The hills and forests of Bandipur (11°57′02″N, 76°12′17″E −11°35′34″N, 76°51′32″E) are part of the hilly southern fringe that separates Mysore region of Karnataka state from the Nilgiris in Tamil Nadu and Wynaad region in Kerala. The terrain is significantly hilly in the south, with ridges ranging up to 1400m a.s.l. The streams emerging from these hills and ridges drain into flat terrain to the north at about 800m a.s.l., with Nugu on the western side and Gundal on the eastern side being the main rivers.[17] The geology is dominated by Gneissic and the soils are dominated by weathered alfisols, acidic, 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 with 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.

Most of the Bandipur region forests were declared as state reserve forests in the early part of the 20th century. While most of the reserve forests were worked for timber, a small part (90 sq.km.) was declared a sanctuary in 1931. This was eventually expanded, and today the Bandipur National Park is 880 sq.km. in extent, mostly covered with dry deciduous forest of the *Terminalia alata* (Roxb.)-*Anogeissus latifolia* (DC.)-*Tectona grandis* (L.f.) series (Pascal, 1986), though the composition and density varies depending upon climatic, edaphic and human use regimes. The National Park is home to a large population of mammals and birds, including elephants, deer, and tiger. Although human settlements are no longer present in the park, there is a very significant human and cattle presence for firewood collection and grazing, particularly along the northern boundary of the park. There are about 156 villages along this northern boundary and their human population of more than 126,000 and livestock population of more than 116,000 depends significantly on the vegetation in the park. Consequently, the forest vegetation along the Park fringes is heavily ‘disturbed’. Forest fires occur annually, and the forest has also been invaded by invasive species such as Lantana and Eupatorium in recent decades. There are also many patches of state-owned teak and eucalyptus plantations, both inside and outside the National Park (including some abandoned ones in one of the catchments we studied).

[17] Bandipur is also the origin of the Moyar river, the narrow valley of which runs eastwards along the southern edge of the region.

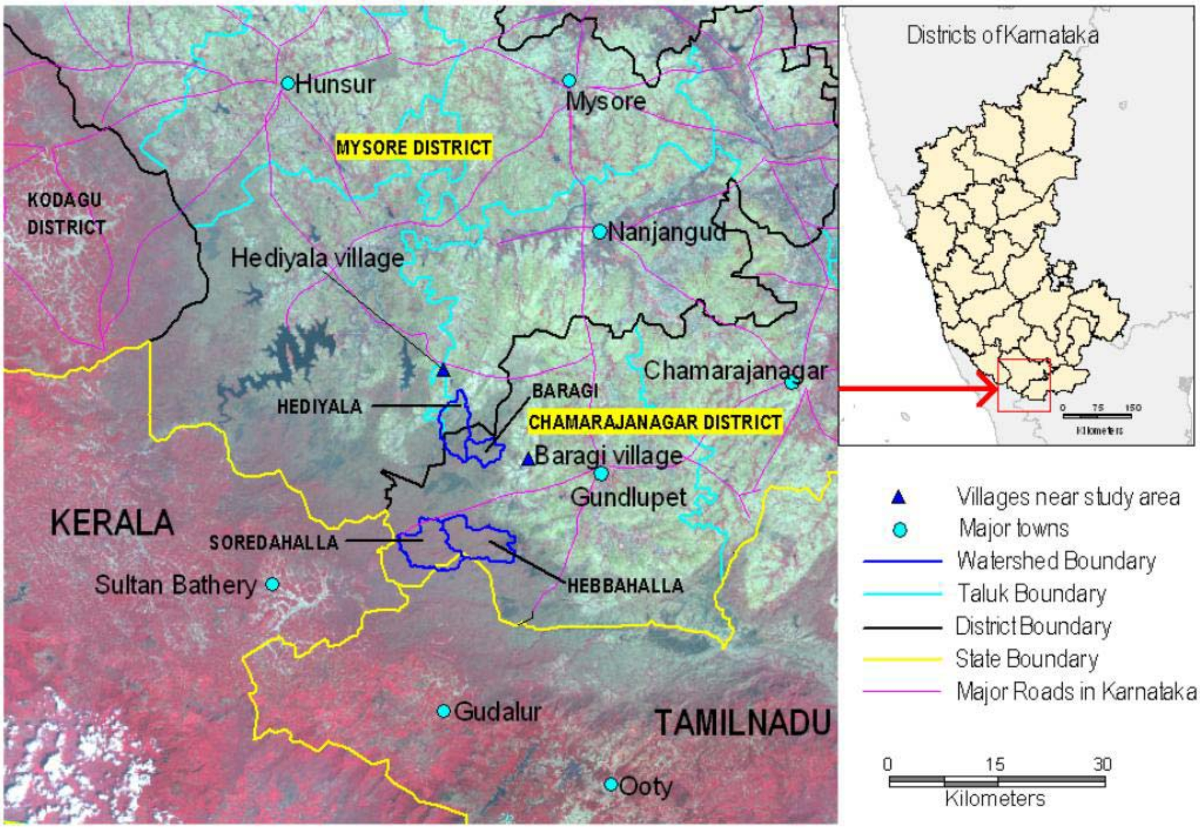

Figure 3-1. Location of Bandipur National Park and study catchments and villages in the southern Mysore region.

3.1.2 <u>Social composition and livelihood systems</u>

The park and the villages around it fall within HD Kote and Nanjangud talukas of Mysore district and Gundlupet talukas of Chamarajnagar district. The villages, settled a long time ago along the streams emerging from the hills, are characterised by relatively flat terrain of sedimentary soils, with some rocky outcrops and patches of common lands.

The social composition of these forest fringe villages is highly heterogeneous. Right next to the forest boundary there often are found settlements of ‘tribal’ groups—in this case Soligas—that lived in the forest as shifting cultivators and hunter-gatherers till a few decades ago.[18] The other settlements comprise of the predominant cultivator castes of Karnataka, viz., Vokkaligas and Lingayats, a scattering of Brahmins, Muslims, Shettys, and scheduled castes such as Adikarnatakas.

The main occupation for the landed households has historically been agriculture, with some households or castes specialising in artisanal activity. The majority of the cultivated area was historically under rainfed farming, with the traditional crops being ragi and jowar, along with maize.[19] Over the past few decades, tobacco and then cotton cultivation became quite common in the region. Irrigated areas are cultivated for paddy, sugarcane or more recently floriculture. Dairying is an activity that is picking up recently in the region, but many

[18] The settlements one sees today are often labelled as ‘colonies’, indicating that they were created by the state authorities when they forcibly settled the tribal groups on the Park fringe.

[19] Thus, the forest fringe villages of Bandipur, the fraction of net cultivated area that is irrigated was ~5% as per Census 1991 landuse data.

households maintain livestock mainly for the purpose of obtaining and selling dung manure. And in many households that do not own irrigated land, or when irrigation does not extend into the dry season, migration to the coffee and tea gardens of neighbouring Kodagu and Wynaad districts during the rabi and summer season is the only option.

3.1.3 Role of water in livelihood systems

In a region of 800mm rainfall, water may be thought of as scarce. However, preliminary investigations revealed that the perceived importance of water varies significantly across communities and the nature of water use has changed over time. Domestic water requirements are increasingly being met through state-supported drinking water schemes, which include provision of hand pumps, community bore wells, and piped water supply schemes that draw on water from irrigation tanks or bore wells. As such, villagers reported an easing of the domestic water scarcity situation. Livestock needs are met from irrigation and smaller tanks, some also located inside the forest. The most important (and occasionally contentious) use of water is for irrigation. While the irrigated areas appear to be small in comparison to the rainfed area, their higher productivity and the scope for double cropping gives these lands a disproportionately high economic significance. Maintaining and expanding irrigation facilities is therefore a major focus for the farmers.

Historically, farmers in different parts of peninsular India 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 (see the blue patches in Figure 3-2). The tanks impound the streamflow and if 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 bore wells, has begun to spread in this region, most of the irrigation in the villages close to the National park still comes from irrigation tanks. Surface flows in streams are therefore crucial to agriculture, but are mediated by the tank systems.

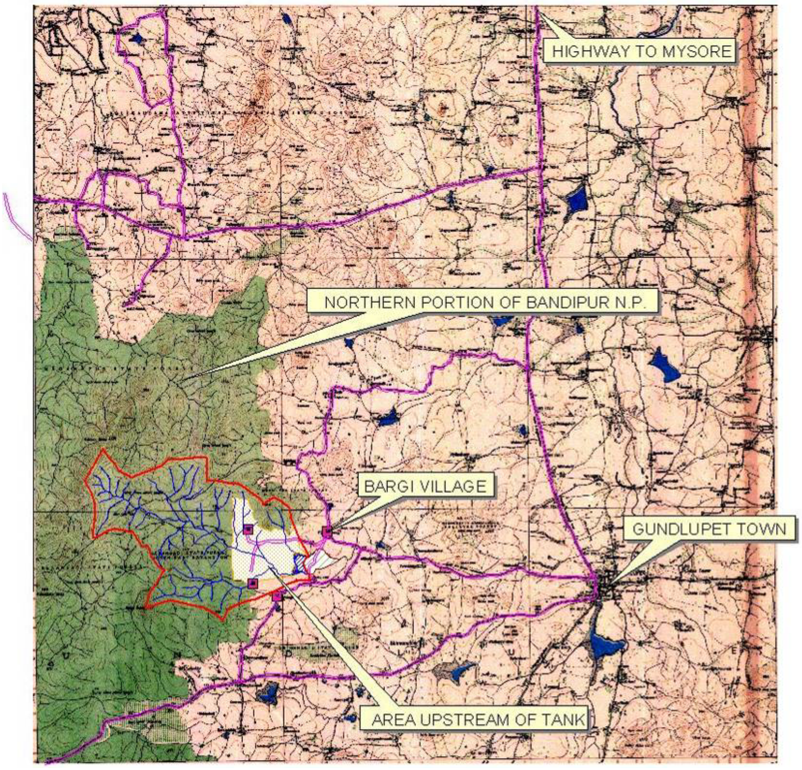

Figure 3-2. Northern fringe of Bandipur NP and locations of irrigation tanks.

3.1.4 Role of forests in local livelihoods

In comparison to the Malnaad region of Kodgibail, forest use is somewhat less intensive and also more patchy. Dependence on biomass for fuel and the need for grazing is still high, but these needs are not always met from the forest. Given that the forests that remain are within the National Park boundary,[20] people in hamlets closer to the Park go much more frequently than those further away. Grazing seems, however, to be ubiquitous and large herds seem to come from villages not immediately neighbouring the forest also. On the other hand, many of the larger landowning households probably do not depend much on forest biomass, preferring to meet their needs from agricultural waste and to stall-feed their livestock on similar waste or green fodder. On the other hand, the Soligas also collect non-timber forest products such as amla, honey and shikekai from the forest, and several groups fell timber for agricultural or house construction purposes.

Compared to the Malnaad region, the legal status of forests is somewhat simpler. *A*ll forest lands are in the state controlled category, being either Reserve Forest or (mostly) National Park. Other common lands have over the past three decades, been mostly converted to agriculture—legally or illegally. Physically speaking, only the National Park forests and some plantations on the Reserve Forests are still standing. *De jure*, not harvesting of firewood or grazing of livestock is supposed to be permitted in National Parks. But *de facto*, the Karnataka Forest Department (KFD) generally does not (or is not able to) prevent forest fringe villages from accessing the forests within the National Park boundary for firewood and grazing to any significant extent. The forests in the fringe areas are in effect almost open-access for these activities; felling of trees and bamboos has been largely curtailed. Since local communities have no control or role in forest management, such extraction has generally led to a secular decline in forest condition, particularly in the 1970s-1990s. Thus,

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[20] Replanting efforts outside the boundary under the Social Forestry project in the 1980s were patchy, eucalyptus-oriented and met with limited success.

unlike the Kodgibail case, heavy use here is equivalent to 'degradation'. As mentioned above, plantations of eucalyptus and teak do dot the landscape. But it was not possible and perhaps necessary to focus on them because a) they are located on much flatter lands as compared to the natural forests, b) they are too small in size to form more than first order catchments, and c) their role in the local economy is not very significant, given their limited size and patchy distribution.

3.2 Focus of the investigation and broad methodology

The main forest scenarios prevailing in this block are the relatively undisturbed forest in the core of the park and the relatively degraded forests on the fringes of the park. The main hydrological link between the forested catchments and the local communities is through their impounding of streamflow in the irrigation tanks and its subsequent use. We therefore focused our investigation on the following questions:

- How would forest cover changing between the two typical forms in this region—the relatively undisturbed core and the relatively degraded fringe—affect the quantum and timing of streamflow and possibly groundwater?

- How would changes in timing and quantum of streamflow[21] affect the storage levels and hence the operations of the irrigation tanks—specifically the probability of tank filling—and how might the impact of forest-cover-induced hydrological change be separated from changes induced simply due to rainfall variability?

- How would changes in storage in the tanks or the timing of their filling affect cropping patterns and hence agricultural incomes in tank commands as well as in other forms of agriculture that might be dependent on the tanks?

- How would changes in forest cover directly affect different forest using communities in the vicinity, what their overlap with the tank using community, and therefore what are the likely tradeoffs and synergies between direct forest use and tank catchment management?

To answer the first question, we followed our paired-catchment approach. We chose two 'control' (relatively undisturbed forest) catchments deeper within the National Park—on two streams Hebbahalla and Soredahalla—and two 'degraded' catchments at the northern end on two sides of the Hekkon ridge—Baragi and Hediyala. The locations of these catchments are indicated in Figure 3-1. We then sought to monitor and analyse the rainfall, streamflow and soil hydraulic properties of these catchments to understand how a change in forest vegetation might influence hydrological response. Operationalising the 'paired-catchment' approach was actually harder than anticipated. The catchments differed in terms of rainfall (1000-1100mm in the more southern control catchments and around 850mm in more northern disturbed catchments) and also size (the control catchments were larger).These differences were unavoidable, because human settlements are more towards the north (the fringe of the park) and because stream-gauging was much more convenient where bridges crossed the streams. We have tried to factor in these inherent differences in the catchments when comparing their hydrologic response.

[21] Soil erosion from the catchments is also an important parameter, since such sediment could reduce the storage in the downstream tanks. However, due to resource constraints, we were unable to investigate this dimension.

To answer the second question, we focused on the communities downstream of the degraded catchment of Baragi. The monitored ('hydrologic') catchments are only part of the area from which water flowed into the communities and their irrigation tanks, so we had to scale up the inferences of the paired 'hydrologic' catchment study to the 'community catchment' that fed the irrigation tanks. We did this by carrying out additional monitoring of streamflows at points closer to the tank as well as monitoring of tank levels and outflows. We then combined this with historical data on the tank water system to estimate changes in tank filling probability.

To answer the third question, we held detailed discussions with the tank users to obtain the broad shifts that take place due to changes in tank inflows, and then used a combination of oral recall surveys for a sample of households and detailed field monitoring of their farms in the tank command to determine differences in productivity and incomes under different crops. To understand variations in forest dependence, we carried out broad social mapping exercises to identify the forest users, and then used a combination of household surveys and focus group discussions to understand their patterns of forest use.

3.3 Understanding the catchment hydrology

Our analysis of the catchment hydrology has the specific aim of understanding how changes in forest cover might affect the quantum and timing of streamflows and any subsurface contributions to the tank downstream. We first describe the basic catchment characteristics such as topography, soils and vegetation. We then specifically investigate the differences in soil hydraulic properties across the catchments, to anticipate what the likelihood of infiltration-excess overland flow is under different forest cover and use scenarios. We then examine and compare the streamflow response to rainfall, first for individual rainfall events and then aggregating across seasons and the entire year.

It should be noted that the task of continuous and consistent hydrological monitoring in the study catchments proved to be an extremely difficult one, because we had repeated instrument failures due to extraneous causes. Wild elephants damaging instruments was the main cause, but we also had several instances of floods washing away instruments and a couple of cases of theft. As a result, the rainfall-cum-streamflow record that we have for the two hydrological years (2003-04 and 2004-05) is somewhat patchy. This has constrained some of the analysis that we present in this section.

3.3.1 Basic characteristics of studied micro-catchments

The size, slope and elevational features of the four study catchments are summarised in Table 3-1. The catchments differ in size, with the control catchments being significantly bigger than the degraded catchments. The mean slopes and elevational range is somewhat similar in three of the catchments as compared to Hebbahalla catchment, which is steeper than the others. An analysis of secondary data from rain gauges in the region suggests that there are some differences in the rainfall regimes between the control and the degraded catchments, with the long-term rainfall average being 1000-1100mm in the control catchments and around 850mm in the disturbed catchments.

Table 3-1. Size, slope and elevation of study catchments

Watershed	Type	Area (km^2)	Elevation (m)		Slope (deg)		Estimated Mean Annual Rainfall (mm)
			Mean	*Range*	*Mean*	*Range*	
Hebbahalla	Control	41.95	1025	560	9	34	1009
Soredahalla	Control	41.56	918	285	5	25	1161
Hediyala	Degraded	27.86	858	372	5	30	852
Baragi	Degraded	14.30	960	195	5	17	859

Source: Elevation and slope were calculated from Shuttle Radar Topographic Mission (SRTM) Digital Elevation Models.
Mean annual rainfall for the catchments is estimated using data for 1960-1997 from about 4-5 government rain gauges located in the area, krigged at 5 km resolution; the estimates should therefore be taken as indicative.

The geology of both control and degraded catchments are characterized by similar Gneissic complexes on which the reference soil types are dark greyish brown Typic Kandic Rhodustalf with sandy clay loam with coarse sand in the surface for the wettest Soreda catchment sites to dark reddish brown Typic Haplustalf for the drier sites, with sandy loam with coarse sand in the surface, especially in the degraded catchments (Bourgeon, 1989). These reference soil profiles as well as the data from the pits dug for this study, indicate that % clay could increase at some sites from 20-30 % in the surface horizons to nearly 60 % at 20-60 cm depth. At some sites, this clayey layer is located directly above the saprolite at 80-100 cm. However, at other sites, this increase in % clay is not so pronounced. However, as is to be expected, there is considerable heterogeneity in soil properties within and across catchments. The most distinctive difference is that the Hediyala catchment which has areas with more than 70 % sand in surface horizons, and less than 20% clay content, whereas the control catchments tend to have sites with the highest clay content and also have patches of black soils. These features are discussed later.

Table 3-2. Forest cover in the study catchments (%)

Forest Type	Hediyala	Baragi	Hebbahalla	Soreda
Scrub Forest	10	1	0	0
Scrub Woodland to Dense Thickets	21	23	0	0
Degraded Dry Deciduous Forest	8	2	8	2
Open Dry Deciduous Forest	41	48	30	28
Dense Dry Deciduous Forest	11	10	29	55
Moist Deciduous Forest	7	16	22	15
Semi-evergreen Forest	0	0	8	0
Grasslands	0	0	3	0

The forest cover in the study catchments was mapped using Indian Remote Sensing satellite WiFs sensor (pixel resolution 188 m), acquired for three dates between December 2000 and March 2003. The dates were chosen to capture seasonal variability, from the end of the wet season to the middle of the dry season. Images were geocoded using 1:250,000 scale Survey of India topographic maps. The French Institute vegetation maps (Pascal, 1992) and ground surveys were used as the reference data for the vegetation classification. Forest cover classification was done using IDRISI Kilimanjaro (Clark Labs, 2003). Multi-date Normalized Difference Vegetation Index (NDVI) was used to classify forest and habitat types through a classification and regression tree approach (Krishnaswamy et al., 2004; Das et al., 2006).

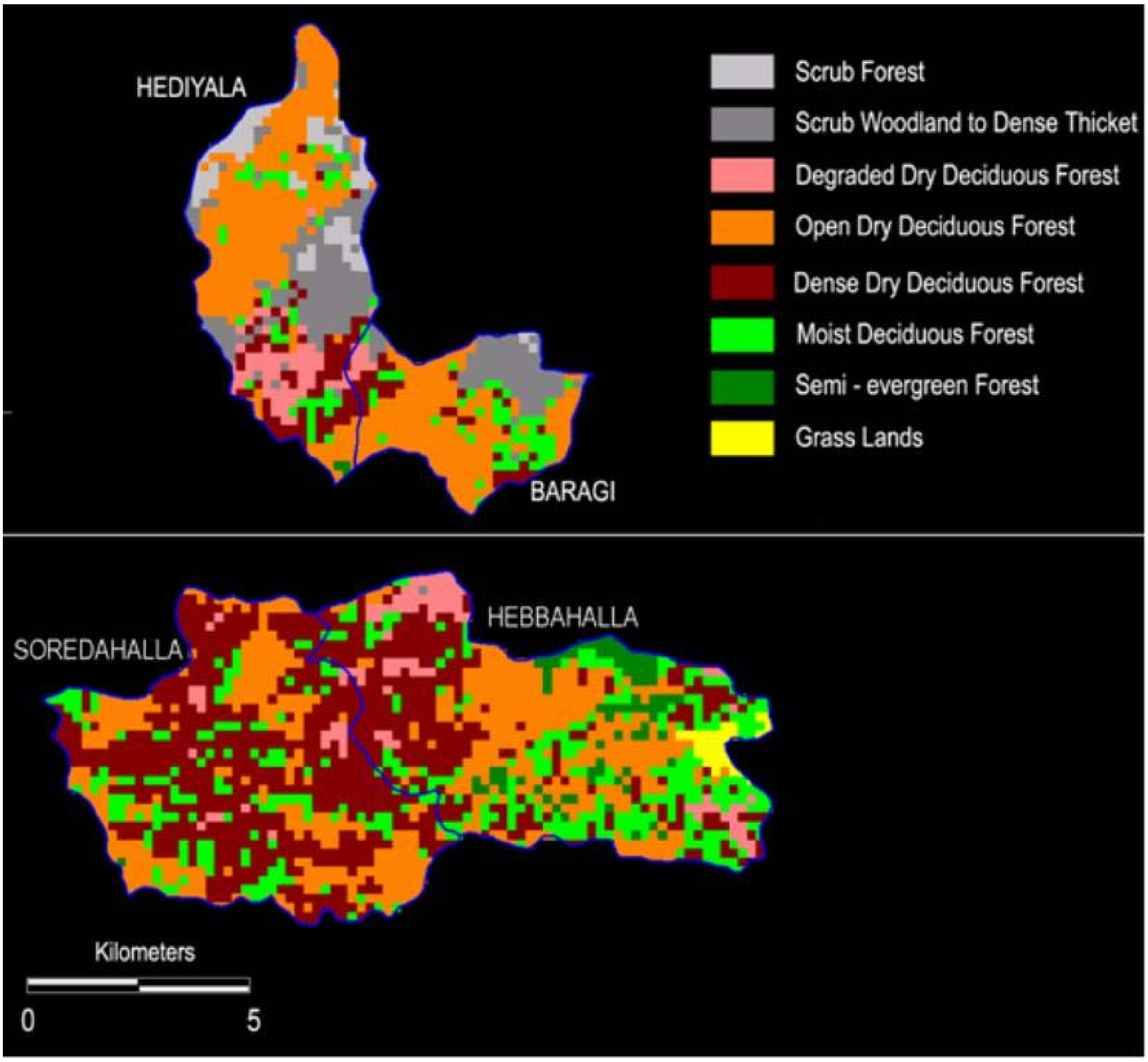

Figure 3-3. Land cover in the monitored catchments.

The forest cover maps are given in Figure 3-1, and the percentage area under each vegetation type is given in Table 3-2. At the outset, it should be noted that there is significant variation in the vegetation within each catchment. Nevertheless, there are systematic differences between the catchments that relate to the influence of two factors. On the one hand, the greater extent of moister forest types (semi-evergreen, moist deciduous) in the control catchments reflects the moister climatic regime in those catchments as mentioned above—something we will have to bear in mind while making the hydrological comparisons between the control and the degraded catchments. On the other hand, the presence of extensive areas of degraded scrub vegetation in both Hediyala and Baragi catchments substantiates their choice as degraded catchments. It should also be noted that Hediyala catchment is more degraded compared to Baragi. These differences in vegetation condition are further substantiated by a comparison of the vegetation structure as given in Figure 3-6 and Table 3-1, which is based on field measurements. And the simultaneously measured disturbance indices support the assumption that the differences are a result of higher level of use of the degraded catchments (and Hediyala in particular) by people and their livestock. Methods by which these variables were constructed and sampled are given in the Appendix. While the sampling for vegetation structure and disturbance was not uniformly distributed across the catchments (due to their large size), the differences are sufficiently large to validate the inference.

Figure 3-4. View of control (Soredahalla) and degraded (Hediyala) catchments

Figure 3-5. Dense dry deciduous forest and degraded forest with bamboo thickets.

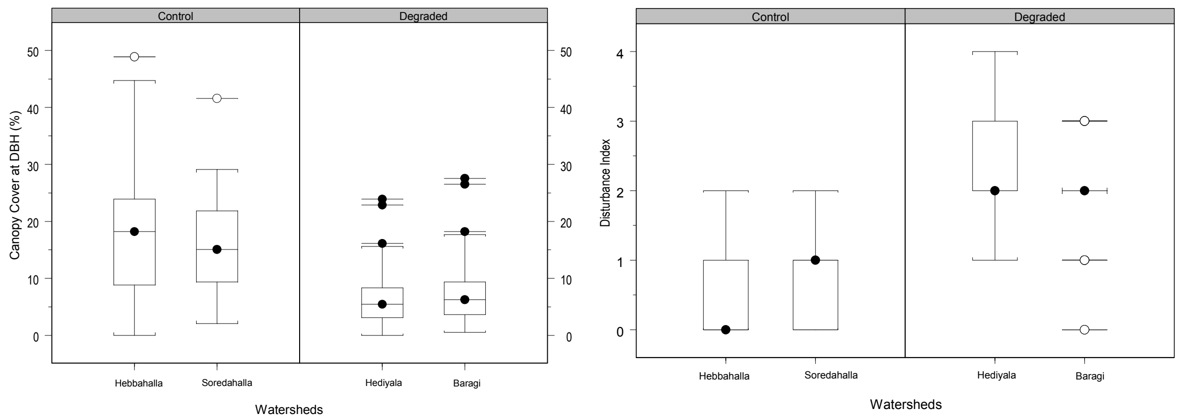

Figure 3-6. Canopy cover (left) and disturbance index (right) at select sites in the catchments[22]

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[22] Throughout this chapter, when box and whiskers plots are presented, the box shows median (line inside box) and 75th and 25th percentiles, while whiskers represent the max and min values excluding outliers, which are defined shown separately as points,

Table 3-3. Differences in vegetation structure in control and degraded catchments

Vegetation parameter	Control	Degraded
Median Ground canopy cover %	21.84	9.88
Median DBH canopy cover %	16.64	5.72
Median Shrub height in metres	1.500	1.800
Median Tree height in metres	12.00	6.000

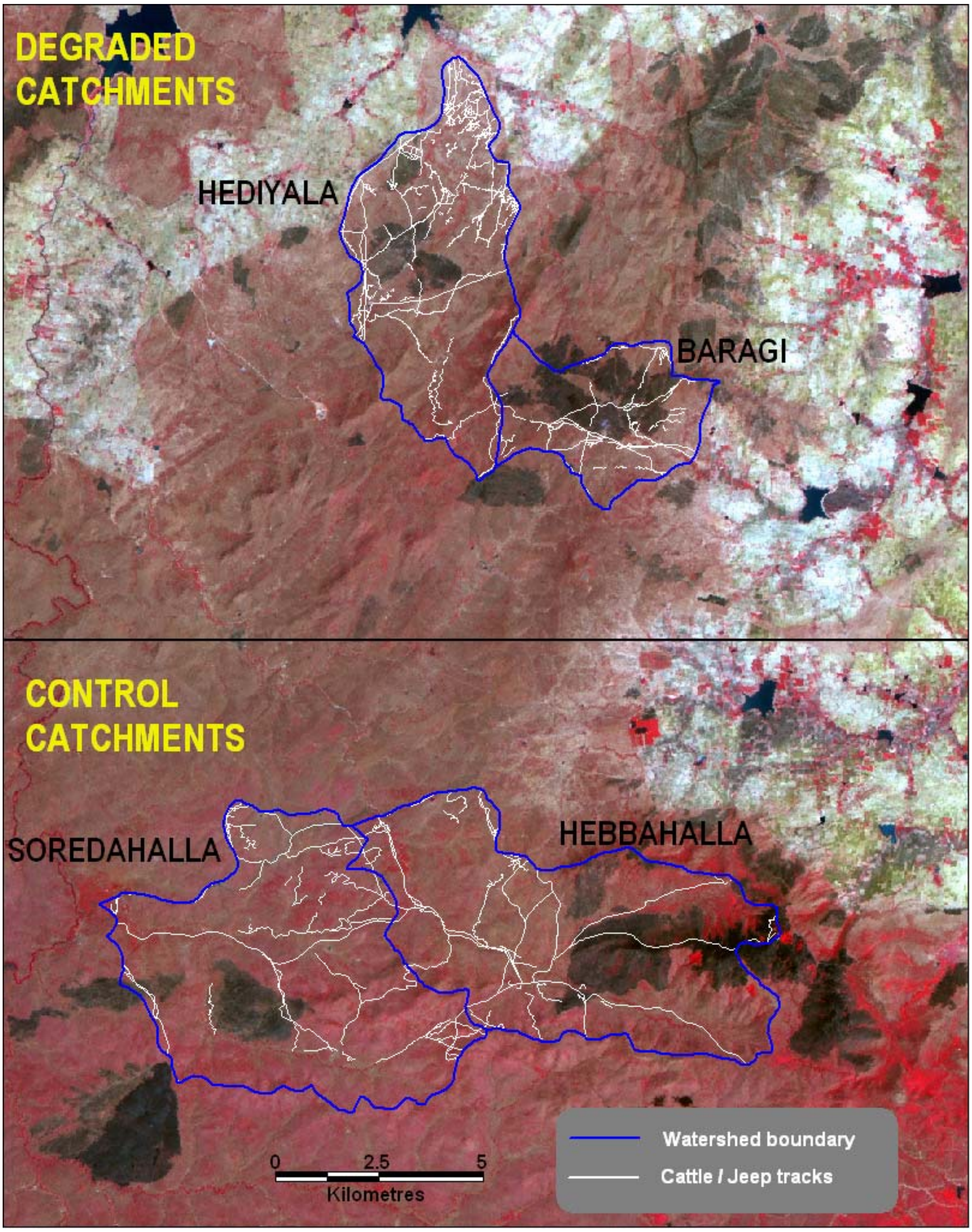

Figure 3-7. Cattle and jeep tracks (digitized from IRS LISS IV images and SOI toposheets)

Fire plays an important role in the land cover pattern of these dry forests. An analysis using satellite images of three dates reveals that large areas of these catchments are affected by fire. The degraded catchment Hediyala shows maximum area burnt in the three dates considered. Even in the control catchments several areas are affected by fire. The cover change in the control catchments are often driven by repeated burning.

Trails and roads made by humans and cattle are a major feature of these forests, and we investigated the impact of these on hydrology, as they can have a major influence on surface hydrology and erosion (Reid and Dunne, 1984; Ziegler and Giambelluca, 1997; Zeigler et al., 2004; Sidle et al., 2004). We found that the degraded catchments have a higher density of trails (3.1 km/sq km) which are also intensively used, relative to the control catchments (1.7 km/sq km)—see Figure 3-7.

We also examined the soil texture and chemical properties of the soils in the catchments (see Appendix for sampling methodology). There is some evidence for the decrease in clay content in degraded sites (Figure 3-8) and an increase in bulk-density (Figure 3-9). These changes can be attributed to selective erosion of finer particles over time and compaction by cattle respectively. The organic matter content in the degraded catchments is also lower (Figure 3-10), as is the pH and the cation exchange capacity (Figure 3-11). Clearly, decades of biomass extraction, cattle grazing and fires in the degraded catchments have significantly impacted surface soil chemical and bio-chemical properties. It may also be noted that, between the two degraded catchments, the Hediyala catchment shows greater signs of degradation, viz., lower organic matter and higher sand content in the surface soil, and higher disturbance index and trail density.

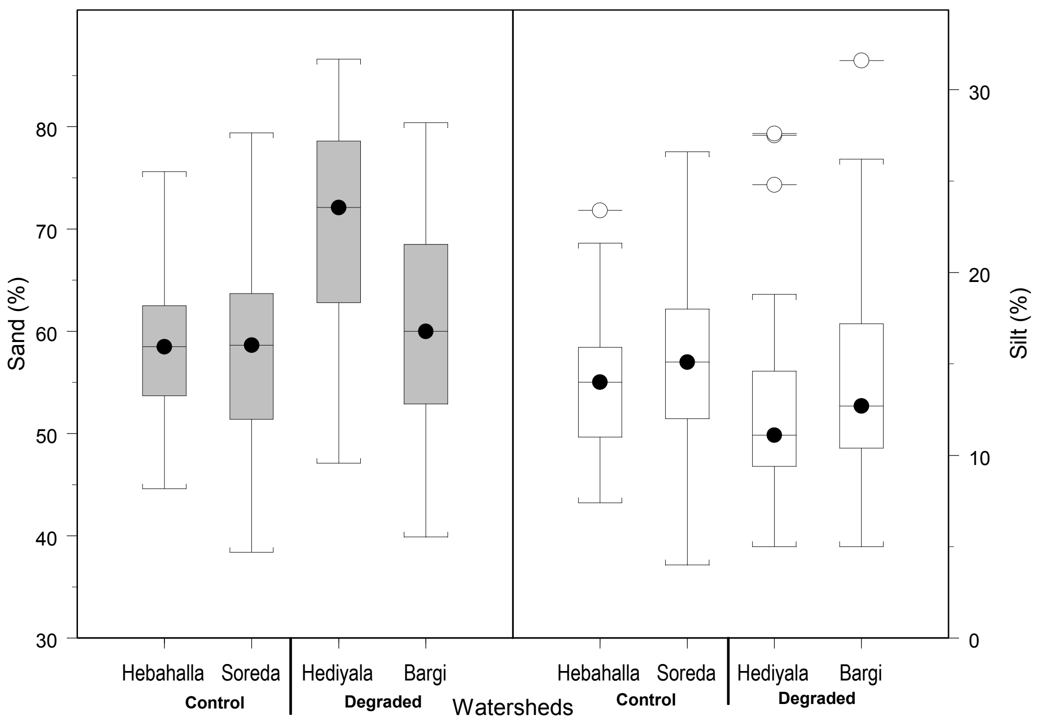

Figure 3-8. Sand and silt content of surface soil samples in the study catchments

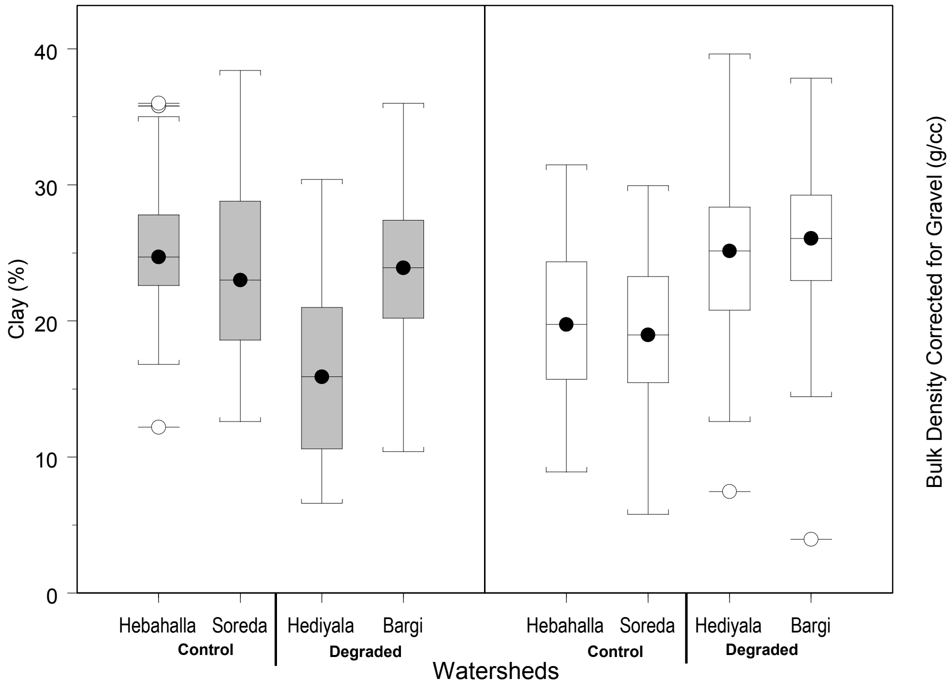

Figure 3-9. Clay content and bulk density of surface samples from the study catchments

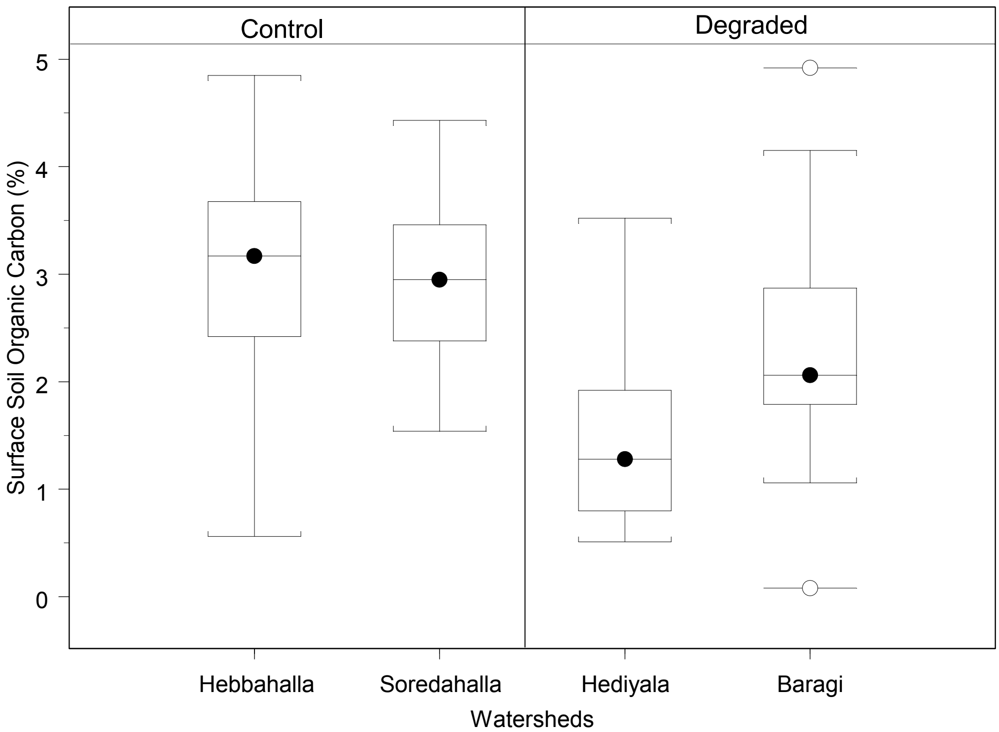

Figure 3-10. Soil organic carbon content of surface samples in the study catchments

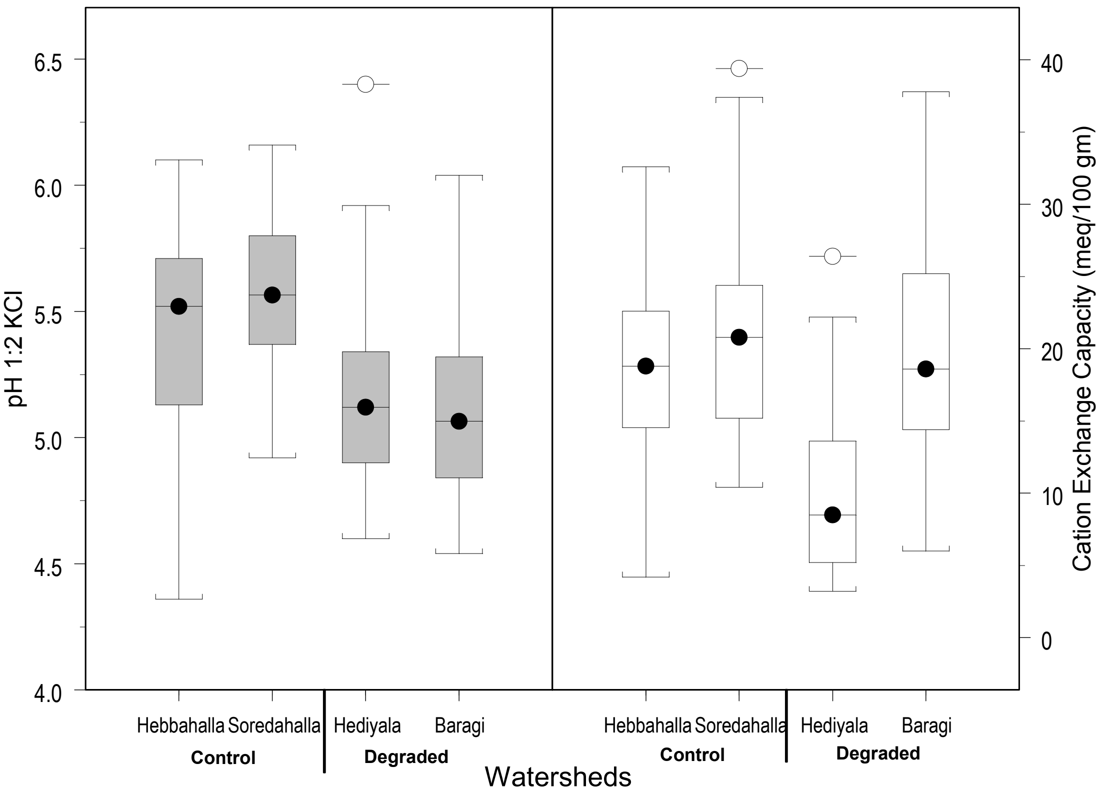

Figure 3-11. pH and cation exchange capacity of surface samples in the study catchments

3.3.2 Variation in soil moisture retention and hydraulic conductivity

Changes in forest cover can lead to not only changes in rates of evapotranspiration by the vegetation, but also in the physical and chemical characteristics of the soil, such as in percentages of clay and organic matter, and in bulk-density and porosity. This leads to changes in moisture retention characteristics as well as the rate at which infiltration can take place in a soil when rain falls on it and the rate at which water moves vertically through different layers of soil.

Available Water Capacity

Of the 200 samples mentioned in the previous section, 24 samples were analyzed to determine soil moisture characteristics. 13 samples were from the northern (relatively) degraded watersheds D1 and D2, and 11 samples from the southern (relatively) protected watersheds. Available water capacity (AWC), computed as the difference in moisture content measured at field capacity (0.3 bar) and at wilting point (15 bar) and the saturated moisture content (SMC), were compared between the degraded and protected watersheds with a pooled variance 2 sample t-test.

AWC in the degraded watersheds (mean=10.64%, s.d.=2.09%) was significantly less than AWC in the protected watersheds (mean=13.1%, s.d.=2.61%) with a p-value of 0.007 (t = -2.684, df = 22). Saturated moisture content was also significantly less in the degraded watersheds (mean= 28.55%, sd= 8.6%) than the protected watersheds (mean = 38.96, sd=10.3%), with a p-value of 0.009 (t = -2.5398, df = 22). We attribute these differences in soil moisture retention capacity in the surface soils to the reduced organic matter in the northern (relatively degraded) sites, as well as the selective erosion of clay from surface soils in the degraded catchments.

Soil hydraulic conductivity

Soil hydraulic conductivity (HC) is an indicator of infiltration rate. It is a function of the degree of resistance from soil particles when water flows in pores. One way of using HC values is to compare surface HC with the intensities of rainfall—if the rainfall intensity exceeds the HC, then water will flow on the surface of the soil ('infiltration excess overland flow'). We therefore measured and compared the surface soil HC in the control and degraded catchments, and compared then with the range of rainfall intensities that we measured.

The surface soil HC values we observed in the 4 catchments are depicted as box and whiskers plots (Figure 3-12) to better indicate the range of variation. It can be seen that there is enormous heterogeneity in the surface HC within each catchment, ranging from less than 10 to more than 100 mm/hr. Therefore, there is no statistically significant difference in the distribution of values between the control and the degraded catchment, although between the degraded catchments, the Hediyala catchment shows somewhat lower HC as compared to the Baragi catchment, consistent with its greater degradedness mentioned in the previous section.

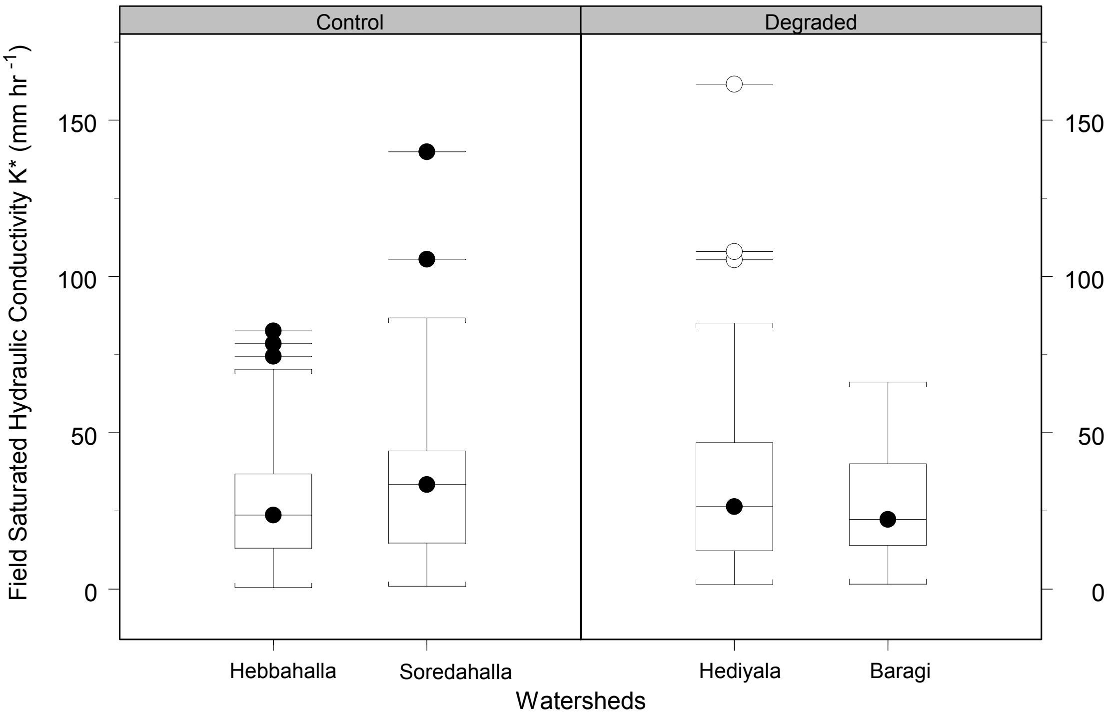

Figure 3-12. Mini-infiltrometer based surface saturated hydraulic conductivity across catchments

Further investigation of the heterogeneity, however, revealed that within all catchments, surface HC was very different on the jeep and cart tracks/trails as compared to away from these trails (see Figure 3-13), with the on-trail saturated HC being as expected generally lower (because of greater soil compaction) and less variable than the off-trail values. Given the higher density of such trails that was pointed out in the previous section, it follows that the degraded catchments have a greater number of pathways of relatively impermeable soils along which surface runoff can move very quickly to generate the kind of flashy response that we report in the next section.

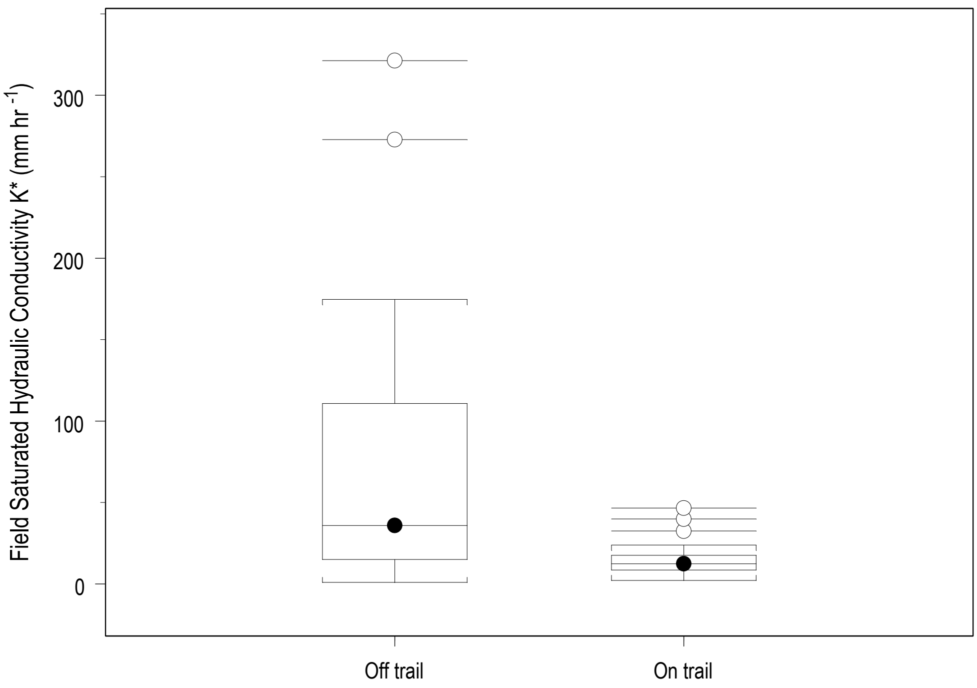

Figure 3-13. Comparison of surface field saturated hydraulic conductivity on and off trails

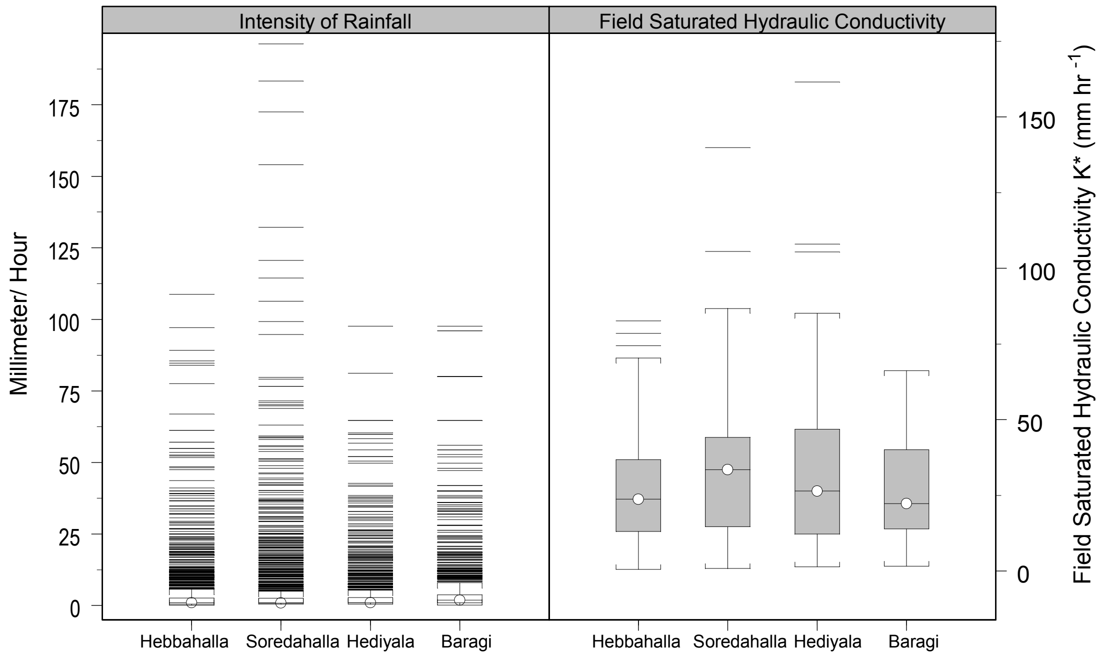

Figure 3-14. Rainfall intensities and field saturated hydraulic conductivity at surface sample sites.

A comparison with the observed rainfall intensities (Figure 3-14) suggests that, on the whole the surface, HC values are comparable with the rainfall intensities, although there are occasions and locations when/where infiltration excess overland flow might occur (particularly in the 40-100 mm/hr range). Again, it is the trails where this happens: using random comparisons of the observed rainfall intensity with hydraulic conductivity of trails, it was found that the probability of rainfall intensity exceeding infiltration on trails was ~5%, and it was similar in control and degraded sites. The greater presence of such trails in the degraded catchments, particularly Hediyala, means that infiltration excess overland flow may be rather significant there.

That overland flow (of either the infiltration excess or saturation excess type) does occur was confirmed by the overland flow detectors that we had installed in catchments Hebbehalla and Hediyala during 2003. We recorded a few events of such flow. Field observations during rain events especially in the degraded Hediyala catchment indicate that cattle trails and roads are major sources of infiltration excess overland flow.

3.3.3 Observed hydrologic response: Individual storm events

We compared the hydrologic response of the catchments to individual storm events, both in terms of % of quickflow as compared to baseflow and duration of baseflow and duration of delayed flow.[23] The rainfall and streamflow pattern in one storm each for the different catchments is given in Figure 3-15 and Figure 3-16. It can be seen from the hydrographs that the streams in the degraded catchments respond (start flowing) very quickly to the rainfall, whereas those in the control catchments respond more slowly. It is also seen that the flow in the control catchments continues for several hours after the rainfall has ceased, while the flow in the degraded catchments ceases immediately.

[23] This analysis was done using the HYDSYS software at LandCare Research in New Zealand.

Table 3-4. Events for which complete rainfall and runoff data were available (those marked in red are outliers).

Catchment	Date	Event number	Rainfall		Flow				% Total Flow/Total Rain
			Total (mm)	30min Intensity (mm/hr)	total quickflow	total delayed flow within events	total delayed flow between events	total flow	
Hediyala (Deg)	May 2005	Event 1	29.3	58.2	1.97	0	0	1.97	7%
Baragi (Degraded)	October 2004	Event 1	6.6	13.2	1.57	0	0	1.57	24%
	October 2004	Event 2	9.5	10.9	0.65	0	0	0.65	7%
	October 2004	Event 3	20	16	7.28	0	0	7.28	36%
	November 2004	Event 4	10	4	0.41	0	0	0.41	4%
	November 2004	Event 5	5	5	0.01	0	0	0.01	0%
	October 2005	Event 6	33.35	44.1	29.67	0.02	0	29.69	89%
	October 2005	Event 7	23.15	60	2.1	0	0	2.1	9%
	October 2005	Event 8	93.55	60	31.53	0.17	0	31.7	34%
Soreda (control)	October 2004	Event 1	20.15	26.7	6.56	3.54	0.03	10.13	50%
	July 2005	Event 2	80.75	18.7	6.79	1.76	0	8.55	11%
	July 2005	Event 3	57.5	15.3	6.86	1.78	0	8.64	15%
Hebbahalla (control)	July 2004	Event 1	17.36	31.4	3.44	0.14	0	3.58	21%
	September 2004	Event 2	18.55	19	0.34	0.04	0	0.37	2%
	September 2004	Event 3	24.8	18	0.11	0.01	0	0.13	1%
	October 2004	Event 4	8.4	19.4	1.46	0.15	0.03	1.64	20%
	October 2004	Event 5	5.4	7.4	8.4	0.23	0.04	8.67	161%
	October 2004	Event 6	3.8	5.2	2.09	1.14	0.02	3.26	86%
	October 2004	Event 7	36.35	9.2	3.42	1.66	0.02	5.11	14%
	November 2004	Event 8	3.3	2.4	0.91	0.12	0.01	1.04	32%

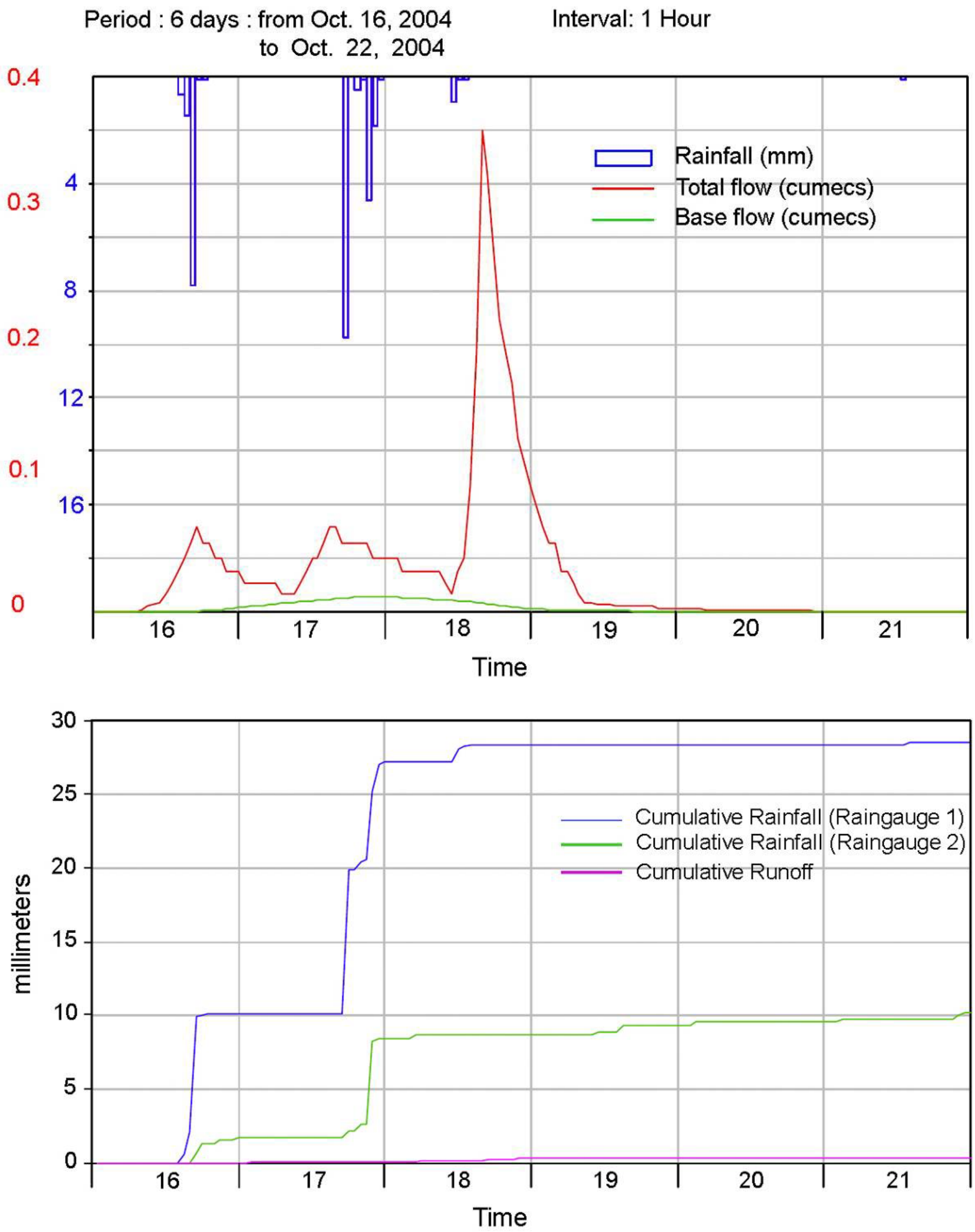

Figure 3-15. Typical streamflow response in Hebbahalla control catchment: note the delayed response in the flow.

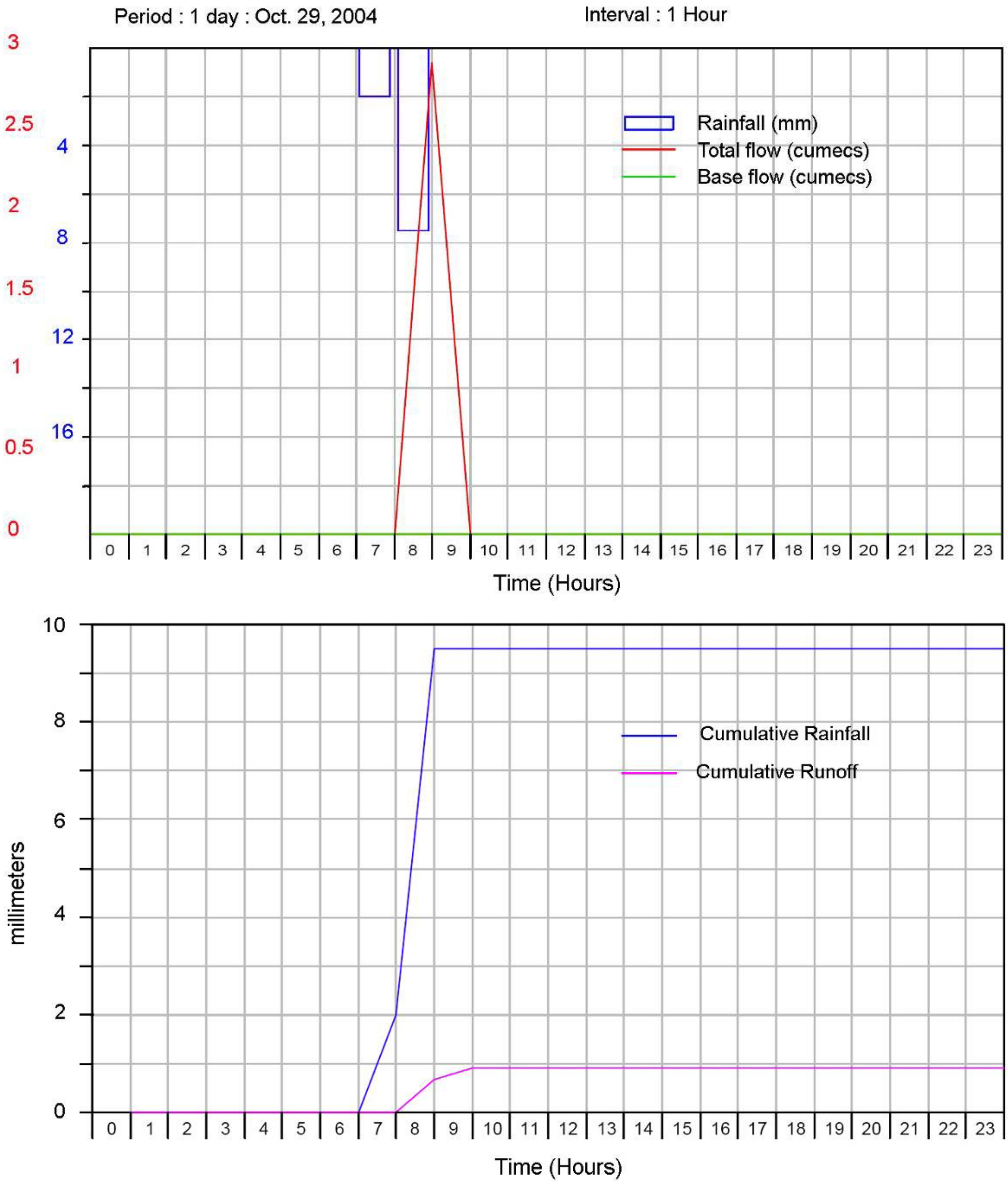

Figure 3-16. Typical streamflow response in Baragi degraded catchment: note the immediate rise in flow after the storm begins.

Complete, well-defined high-quality rainfall-streamflow events were identified in both degraded and control catchments using Hydsys (Table 3-4). Only events with measured rainfall exceeding estimated flow were used for the detailed analyses. The table indicates that there is significant variation in the event-wise Q/P ratios (total flow : total rain), both within and across catchments. These variations are likely to be related to the rainfall intensities and the antecedent moisture conditions, for which further analysis will be required.

If one aggregates the rainfall and the total flow across all events in degraded catchments and similarly for control catchments, it appears that control catchments converted 16 % of the rainfall into streamflow compared to 33 % in the degraded catchments, which fits in with the broad hypotheses of either higher evapotranspiration, higher levels of percolation or both in control catchments relative to the degraded catchments. It may be noted, however, that these events do not include those when there was zero flow and in any case do not represent the complete set of events during a particular season, and so this aggregation probably substantially overestimates the actual Q/P ratios for the season. Nevertheless, the trend is indicative of significant differences between control and degraded catchments.

A more significant difference exists in the relative partitioning of rainfall into quick and delayed pathways during conversion to streamflow: only 0.25 % of the total streamflow in the degraded catchments is classified as delayed flow compared to 25 % in control catchments. Quickflow pathways are prevalent in both control (75 % of streamflow) and degraded catchments (99.8 % of streamflow), but are overwhelmingly dominant in the degraded catchments. This is most likely attributable to the higher density of compacted cattle trails in the degraded catchments, which have very low infiltration and the lower water holding capacity of the degraded site soils.

The recession constant is indicative of the "flashiness" or relative absence of sub-surface flow pathways or bio-pores. This is always higher for catchments which have longer flow pathways for rainfall to get converted into streamflow. Values below 0.9 are generally indicative of flashiness. The estimated recession constant averaged over 0.9 for the control catchment events but was below 0.82 for the degraded catchments, which supports the conclusions drawn from the graphical and aggregated event data.

3.3.4 Observed hydrologic response: Annual totals

The analysis in the previous section was based on only events for which complete data were available. If data from incomplete events and extrapolated streamflows are also included, the estimated values averaged across 2 years and 2 catchments are 8.63 % in degraded catchments as against only 2.14 % in control catchments. Again, while the absolute values may be imprecise, the broad trends are clear. First, the combination of evapotranspiration and ground-water recharge account for the majority of rainfall in both degraded and control catchments. Second, the fraction of rainfall converted to streamflow is definitely higher in degraded catchments than in control catchments.

Before one attributes the differences in the absolute values to the forest vegetation condition, several other factors—specifically scale and rainfall—need to be considered. First, there are some differences in catchment size. While the catchment sizes are in the range of 15 to 40 sq.km. and therefore certainly within the same order of magnitude, one of the degraded catchments (Baragi) is less than half of the control catchments and its effect needs to be considered. Admittedly, the smaller size of Baragi catchment would make it 'flashier' in its response, confounding the effect of degradation. However, the few observed events in the larger degraded catchment (comparable to the control catchments) suggest that, in spite of having larger size and favourable texture, it was even flashier. Similarly, the control catchments have higher rainfall and more clayey soils, which would make them more susceptible to infiltration-excess run-off. In spite of this, the effect of forest degradation on hydrologic processes and pathways is evident in the stream hydrographs, duration of delayed flow, recession constants and estimated quick-flow ratios. Thus, the observed differences are robust.

3.3.5 Summary of catchment hydrology: likely hydrological impact of forest cover change

We had hypothesized that grazing, wood-cutting and fire and a network of cattle and foot-trails and development of barren patches over decadal time scales have changed the surface hydrology and soil properties of degraded catchments. In spite of differences in soil and rainfall characteristics, and the fact that the control catchments are handicapped by having more clayey textures, patches of poorly-drained Black soils, as well as higher rainfall, both soil hydrologic properties and streamflow response suggests strongly that there has been changes in hydrology caused by forest degradation. These include reduction in infiltration rates, especially on cattle trails, increase in over-land flow, decrease in delayed flow, and perhaps a decrease in evapotranspiration as well, leading to an overall increase in annual streamflow, especially towards the end of the wet-season.

3.4 Scaling up to the community catchment

We now address the question of how the results of the catchment hydrology can be translated to the scale and variables that matter to the downstream community, which is primarily in terms of changes in the timing and quantum of inflows into the irrigation tank. For this purpose, we begin with a description of the tank and how it is managed. We then attempt to scale up the measurements taken from the degraded forest catchment to the larger catchment that contributes to the tank. We use a combination of historical and recent data to understand the factors that influence the process of tank inflows, and specifically how changes in inflows might affect the frequency of tank filling.

3.4.1 Basic features of the tank [24]

The Baragi village tank was originally constructed about a century ago. This tank had an FRL of 30.01 m (98.43 feet) and live storage of 4.27 m (14 feet). It provided irrigation to about 85 acres of land. The release of water depended upon whether there was enough to provide for an irrigated paddy crop for the entire command. Some water would be saved for use by livestock.

The tank was taken up for renovation by the Minor Irrigation Department of Karnataka in 1979 and the work was completed in 1982. The objective of this renovation was to increase the storage and hence the irrigated area to 363 acres. For this purpose, the tank bund was raised so that FRL is now 31.84 m (104.43 feet) giving a live storage of 6.19 m (20.43 feet) and a corresponding volume of 1.32 M.cu.m. and a waterspread area of 106.65 acres (43ha). However, the design calculations of the MID have gone awry—the tank does not fill as frequently as they predicted. Moreover, they did not lengthen the irrigation channel adequately for the entire proposed new command. Since 1982, the tank has been irrigating a command area of about 136 acres whenever sufficient water is available for an entire cropping season of paddy, which is approximately once in every 2 years. The photographs in Figure 3-17 and Figure 3-18 provide an idea of the tank and its command area when irrigated.

The catchment of the Baragi tank is 29.35 sq.km and is shown in Figure 3-19. It can be seen that three distinct streams feed the tank, of which the main Baragi stream has by far the largest catchment (15.87 sq.km) and the most forested catchment. The northern stream comes from a largely barren hillock and through cultivated land, and the southern stream comes partly through forest and then through cultivated land. Even the main Baragi stream traverses almost 2 km through agricultural land before reaching the tank. The details of the land cover in the Baragi tank catchment as a whole are given in Table 3-5.

[24] This section is based on discussions with farmers from Baragi village as well as records of the Minor Irrigation Department.

Figure 3-17. A view of the Baragi irrigation tank bund, with the irrigated area on the left.

Figure 3-18. A view of the Baragi tank irrigation channel and irrigated area planted with paddy.

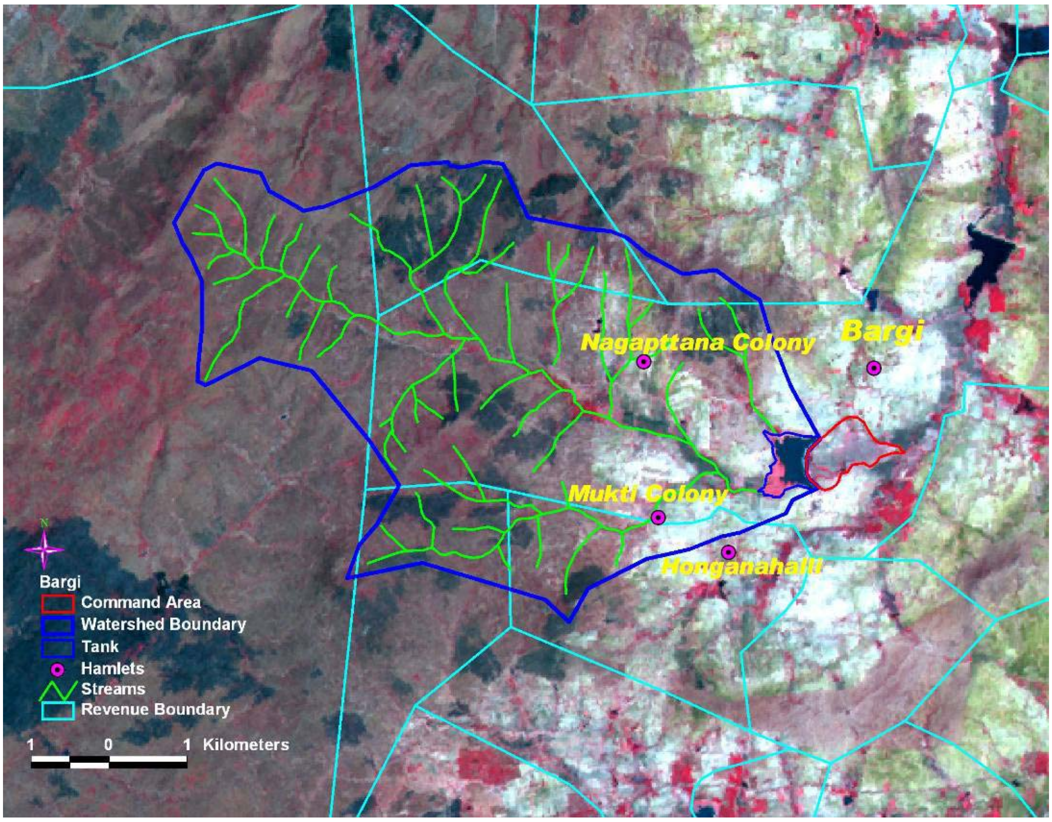

Figure 3-19. Baragi: tank catchment, streams, tank command area, and revenue village boundaries.

Table 3-5. Broad land cover classes in Baragi tank catchment

Land cover type	Area [sq.km.]	%
Open Scrub	2.18	7%
Scrub Woodland to Dense Thicket	3.02	10%
Degraded Dry Deciduous Forest	0.49	2%
Open Dry Deciduous Forest	9.5	32%
Dense Dry Deciduous Forest	2.2	8%
Moist Deciduous Forest	4.73	16%
Cropland & tank submergence	7.23	25%
TOTAL	**29.35**	100%

3.4.2 Relationship between rainfall, catchment response and irrigation decisions

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 3-20), and b) the rains during the monsoon wet the catchment and so per unit rain there is likely to be higher runoff in the post-monsoon period.

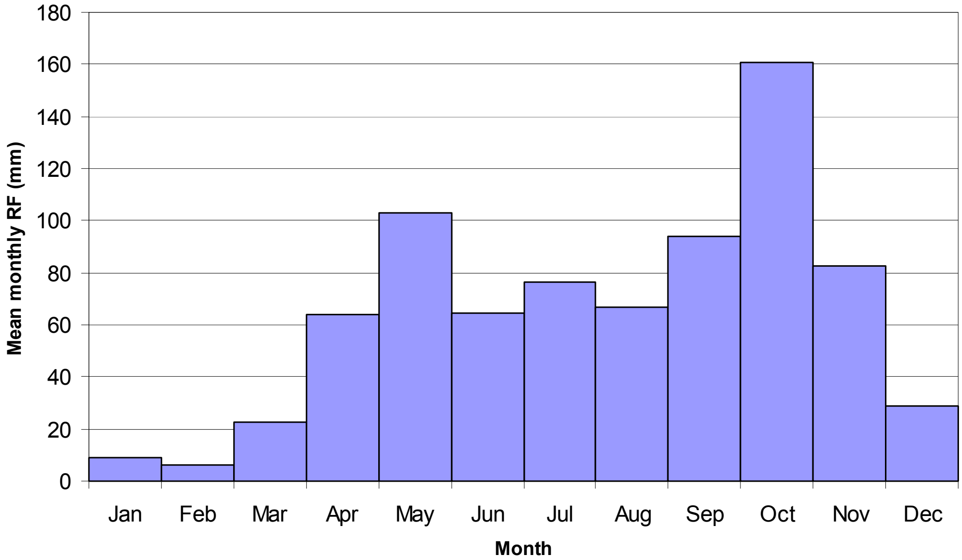

Figure 3-20. Monthly average rainfall near Baragi village (Source: 20 years data from Mookahalli rain gauge)

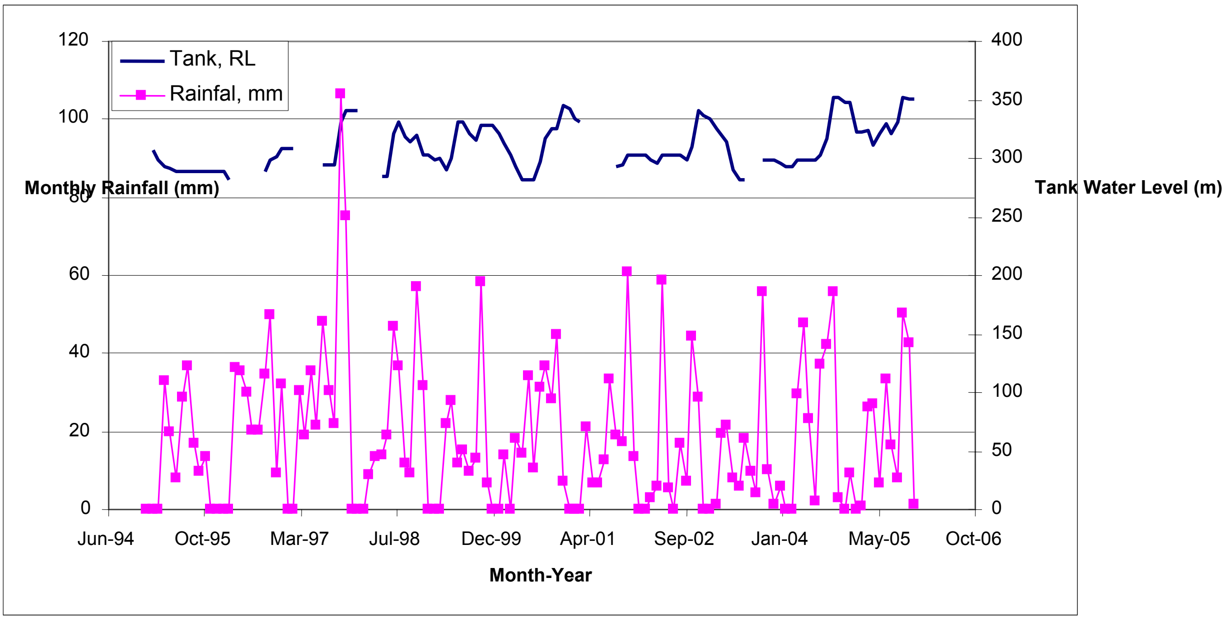

Figure 3-21. Monthly rainfall and tank level of Baragi irrigation tank: 1994-2005

We obtained historical data on tank water levels from the Karnataka Minor Irrigation Department for the period 1994-2005. Irrigation decisions were interpreted from the decline in tank water levels and cross-checked with farmers recollection of these events (see Figure 3-21 below). During this 10 year period, there were a total of nine irrigation events resulting from eight tank fillings in the Baragi tank for paddy cultivation. Of these, seven irrigation events occurred during summer cropping season resulting from six tank fillings events by December, and two irrigations events occurred during kharif cropping season resulting from tank fillings by July. 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. 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 combined with evaporation and seepage losses. From the simple comparison of number of kharif and rabi filling events the importance of kharif filling can be established.

Analysis was carried out to understand the influence of seasonal rainfall patterns on tank filling events suggests that for a tank filling to occur by December (for summer paddy cultivation) the net rainfall occurring between September and November was very critical. A probabilistic analysis of historical rainfall and actual irrigation events followed by tank filling suggests that the probability of a 3-monthly rainfall event during this period occurring such that it generates adequate runoff from the entire upper catchment for tank filling by December is once in 2 years (50%). This also corroborates with the information we have from actual tank water levels and farmers recollection of water releases for summer paddy cultivation.

From the December tank filling events of years 2002, 2004 and 2005 (during these years we found that the tank water level data was more reliable), we found that the average amount of rainfall required for the tank level to rise from dead storage to FRL was 314 mm, which occurred during the period September-November. Water balance studies of the irrigation tank carried out for these periods were used to estimate the quantum of seasonal inflows to the tank. After accounting for tank overflows, evaporation and seepage losses from the tank it is estimated that the upper catchment including forest cover and agricultural area had a gross runoff coefficient of 0.15. This upper catchment includes 22.12 sq.km (75% of the total area) of forests mostly consisting of dry deciduous and open scrub and 7.26 sq.km (25 per cent of the total area) of cultivable area consisting of some portions under grasslands and fallow areas. Proportioning the agricultural runoff will then lead us to quantifying the possible runoff from the forest catchment. A 1D soil-water balance model that combines the SCS-Curve number method to carry out water balance was applied to estimate the runoff from agricultural catchment. Water balance Simulations carried out for 2002, 2004 and 2005 suggest that the average runoff from heavily cultivated upper agricultural catchment was in the order of 10%. Isolating the contributions of the cultivable areas, we obtained the contributions of the forest catchment. Approximately, 18% of the 314 mm rainfall in the forest catchment flows in to the tank in an event of a tank filling. Results from monitoring of the stream flow from the degraded forest catchment at Baragi also suggest that the average event runoff during September and October of 2004 and 2005 was around 23 per cent as compared to 14 per cent in control catchments.

We then assemble the results of catchments' runoff response, rainfall patterns and tank filling events, to predict likely implications of the forest cover change in the heavily-used forest catchment. If the Baragi forest catchment were to change in forest cover similar to that of the control catchment, the runoff response during the period September-November would hence be much lower in magnitude than the current observations of 18 per cent of the rainfall. We infer that rainfall depths greater than the current average of 314 mm may be required for tank filling to match the reduced inflows to the tanks resulting from lower decreased runoff from the forest cover change. This will result in lesser number of tank fillings and hence affect the choice of farmers to cultivate paddy alternate years. (See Figure 3-22).

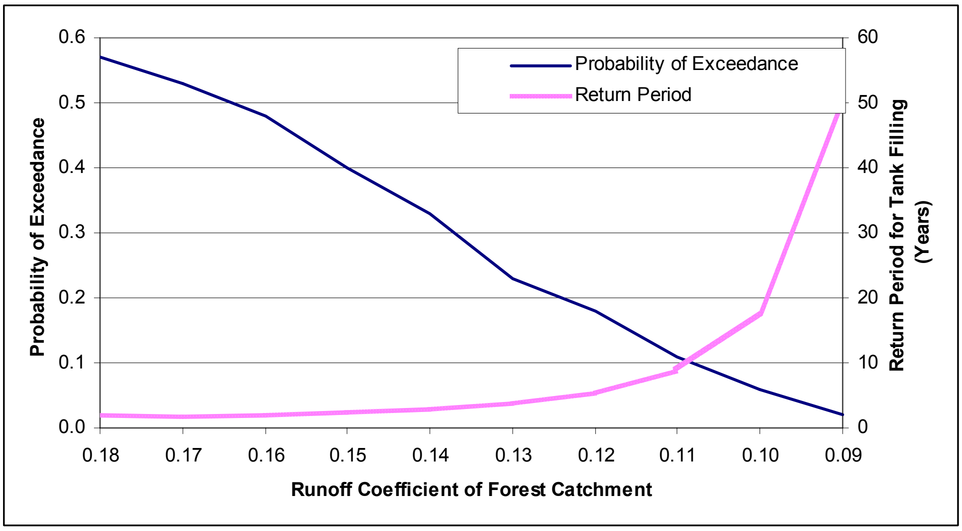

Figure 3-22. Variation in probability of exceedance of rainfall required to fill tank for a certain runoff coefficient during the northeast monsoon (Sep-Dec) period.

The amount of rainfall required for tank filing would increase gradually between 325 mm to 614 mm as the runoff coefficient decreases to makeup for the same volumetric contributions from the forest catchment. However, from the probabilistic analysis of historical rainfall for September-November period, the probability of occurrence of these required rainfall depths is linearly decreasing. Correspondingly, the relevant return period for rabi (Sep-Dec) tank filling gradually reduces from once in two years to once in six years when the runoff coefficient declines from the current 0.18 to 0.12. Any further reduction, even by 1 or 2 percent points will result sharp increase in the return period: e.g., the tank will fill only once in 10 years if the runoff coefficient declines to 11%.

3.5 Relationship between tank filling and agricultural incomes

3.5.1 Overall profile of village community and agriculture

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 have some 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 Hekkon ridge (see Figure 3-19 and Figure 3-23). The total geographical area of the revenue village is recorded as 2795 ha, including 1403 ha that are designated as forest land.

Baragi revenue village contains several hamlets, of which the ones relevant to this study are the main settlement of Baragi itself that is located downstream of the Baragi irrigation tank and 2 hamlets located upstream of the tank, viz., Mukthi colony and Nagapatna (see Figure 3-23).[25] Baragi is a large hamlet, with 392 households drawn from various castes and landholding categories. Nagapatna is a small hamlet (44 households) of mostly backward and scheduled castes and small landholders. Mukthi colony is a settlement of Soligas created when they were resettled out of the Bandipur National Park in the 1970s and given a couple of acres of land per household for settled cultivation. A detailed break-up of the

[25] Defining the relevant 'community' is not easy, because some lands in the Baragi tank command or upstream of Baragi are held by persons living outside these three hamlets. But the bulk of the relevant households are in these three hamlets.

households in these three hamlets along caste and landholding categories is given in Table 3-6. It can be seen that virtually all the households in Mukthi colony (60 out of 66) are in the small holder or landless category, whereas most of the big landholders (29 of 38) reside in Baragi hamlet and belong to the upper castes. The total percentage of landless households is quite significant (23%), but the bulk of the households (58%) are in the smallholder category, and even the big landholders do not have vast holdings.

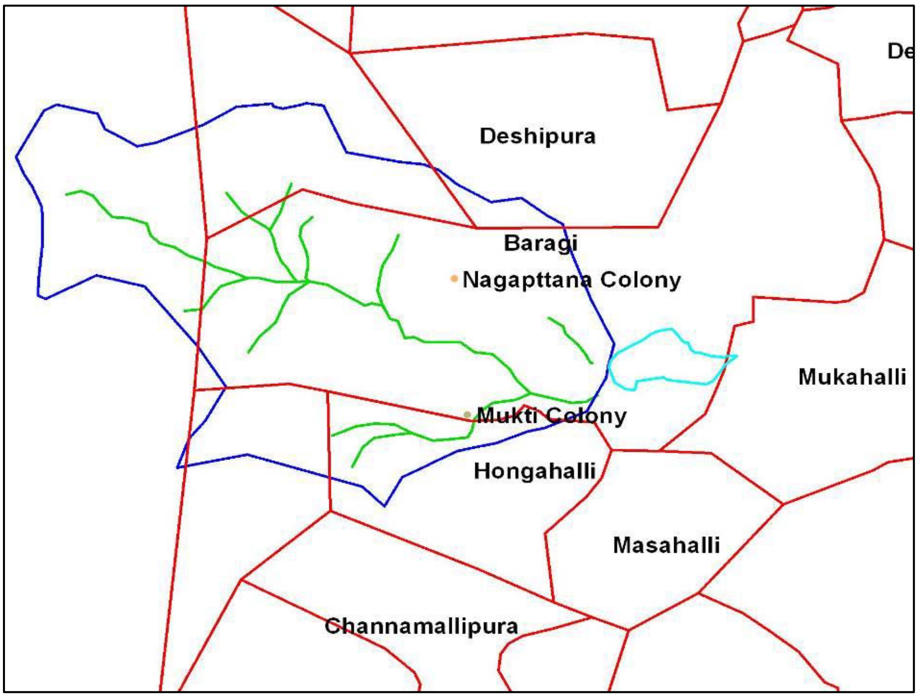

Figure 3-23. Revenue villages and hamlets around Baragi tank (revenue village boundaries are in red, tank command area is shown in sky blue).

Table 3-6. Caste and landholding class composition of studied hamlets (number of households, with % in last row)

Hamlet	Caste groups												
	Scheduled Castes/Tribes				Other backward castes				Upper castes				Total
	LL	Small	Med	Big	LL	Small	Med	Big	LL	Small	Med	Big	
Baragi	3	24	0	0	23	64	2	5	48	143	51	29	392
Mukthi colony	35	25	6	0	0	0	0	0	0	0	0	0	66
Naga-pattana	5	11	0	2	1	20	0	2	0	0	0	0	41
Total	**43**	**60**	**6**	**2**	**24**	**84**	**2**	**7**	**48**	**143**	**51**	**29**	**499**
%	*9*	*12*	*1*	*0*	*5*	*17*	*0*	*1*	*10*	*29*	*10*	*7*	*100*

Notes: a) Upper castes: Brahmin, Lingayat, Aaradhya and Aachari; Other backward castes: Uppar, Vokkaliga, Madival, Belligowda, Kurubas, Nayaka, Rajput, Muslim, Kshatriya, Kumbar/Kumbarshetty, Ganiga; Scheduled castes: Adikarnatakas, Scheduled Tribes: Soligas.
b) Landholding class: Small= <5 acres, medium=5.1-10 acres, big>10 acres. Landholding is calculated in terms of equivalent dry acres using the ratio 1 acre of irrigated land = 3 acres of dry land.

Agriculture is of course the main occupations in these hamlets. The important irrigated crops are paddy (in the tank irrigated area) and sugarcane, turmeric, onion in the bore well irrigated areas. The main dry crops are jowar, ragi, cotton and marigold. Livestock rearing (of 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 also migrate seasonally in search of wage labour, usually to the coffee growing areas in neighbouring Waynaad and Kodagu districts.

While most of the agriculture in Baragi and surrounding villages is rainfed, the irrigated area as a fraction of total cultivated area has increased from about 6% in 1970 to 15% in 2003, including a tank command area of 54.7 ha (135 acres) and a well irrigated area of 19 ha (47 acres). As our analysis below will show, for farmers who own land in the tank command, the tank command land contributes between 40%-70% of their annual average income from agriculture. Households do also depend on tank, stream and ground water for domestic use and 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 bore wells which are not at this stage sensitive to the catchment hydrological changes that we have examined. Third, even the irrigation from bore wells did not seem to be very sensitive to recharge, because most of the wells were located upstream of the tank, where the water table was quite high. Our investigation into the impact of changes in hydrology on agriculture therefore focused primarily on the manner in which tank irrigation decisions affect agricultural incomes.

3.5.2 Link between tank filling, cropping patterns and agricultural incomes

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 for supplying water for cultivating water-intensive crops, typically paddy. If there is adequate water to irrigate the entire command area for the growing season for such a crop, the command area farmers go for an irrigated crop. Otherwise, they do not release water from the tank at all and go for a non-irrigated crop. At a somewhat simplified level, the dependence of cropping decisions on the level and timing of inflows into the tank may be depicted in Figure 3-24. In this simplified version, farmers have to decide by the end of June as to whether there is enough water in the tank to irrigate a 4 month *kharif* paddy crop. If not, they opt to cultivate jowar (a non-irrigated crop). Similarly, if the tank is adequately filled by in early December, the farmers opt for a 6-month duration 'summer paddy' crop, otherwise they leave the command area largely fallow.

The actual linkages and hence the cropping decisions are somewhat more complicated. First, there is some inter-seasonal dependency. If a summer paddy crop is cultivated starting January, it invariably extends till end of June. At that time, if the tank is full, the farmers can easily take up another (kharif season) irrigated paddy crop. But if the tank is not full and the farmers wish to go for an unirrigated jowar crop, they are usually not able to do so because they have missed the timing for land preparation and sowing of rainfed jowar. They then end up cultivating a smattering of short-duration crops in a few of the agricultural plots that have adequate moisture. Second, not taking a summer paddy crop does not mean the tank is empty; it may still be half full. Some portion of this stored water will remain in the tank when the pre-monsoon rains come in April and May, thereby increasing the probability of the tank being full in June for taking an irrigated kharif season crop. Third, occasionally, even if the tank is not full, a few 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 decisions 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, and their implications are discussed qualitatively at the end of the analysis.

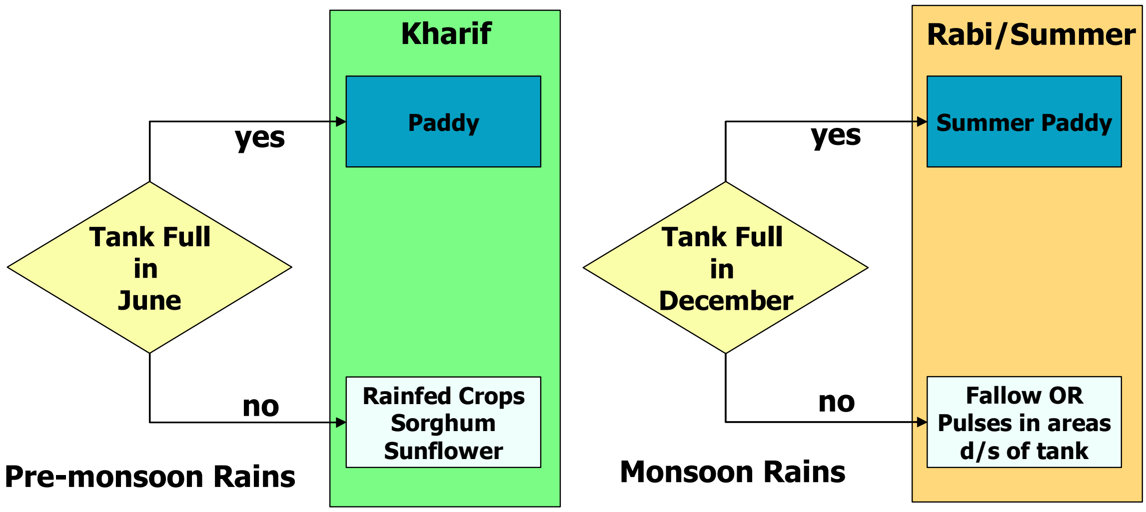

Figure 3-24. Cropping decisions in Baragi command: simplified schema

3.5.3 <u>Agricultural incomes under different cropping patterns in the tank command</u>

The system of tank management described above has two features that shaped our analysis. First, the irrigation tank system is an almost 'binary' or 'threshold-based' system—there are no partially irrigated crops of productivity mid-way between jowar and paddy (in the kharif) or between nothing (or some scattered cultivation of pulses) 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 agricultural incomes*.

Second, the irrigation tank system is also a collective action system, and this means the cropping 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 take place—either all farmers in the command get the benefit or nobody gets the benefit of the inflows into the tank. In such a situation, although there are individual variations in endowments and agricultural practices, the household-wise agricultural production function approach cannot be used to determine the contribution of irrigation to incomes, because the application of water does not vary from household to household (within the tank command). Consequently, we focused on accurately estimating the average differences in agricultural incomes between the case when an irrigated crop is cultivated and the case when irrigation is not carried out.

The notion of 'impact on agricultural income' also needs some elaboration. The primary impact of changes in irrigation water availability would naturally be felt by those whose lands are in the tank command. These impacts would be in total production, including the production of crop residue that may have some value as fodder or fuel, to which in theory some economic value may be imputed. However, there are indirect impacts that also need to be considered. First, changes in cropping patterns affect the demand for agricultural wage labour, which is a significant component of incomes for poorer households. Second, there could be certain interdependencies between the cropping decision taken in the tank command and the cropping decisions for other rainfed lands held by the same farmer. We shall first estimate the direct impacts on agricultural incomes for tank command farmers, including the interdependency question, and then examine the impacts on wage incomes for other farmers or landless households.

Sampling and Data collection

We were able to collect actual data on crop cultivation and agricultural incomes during two growing seasons over the agricultural year 2004-05: kharif (June-Nov 2004) and rabi/summer (Jan-June 2005). The rainfall during this period was such that the kharif season was one of unirrigated jowar cultivation in the tank command (due to inadequate water for irrigation) and the rabi/summer season had irrigated paddy cultivation (due to adequate water being stored by November). The data for these crops were obtained through actual monitoring of crop cultivation practices and production for a sample of farmers. The data for the alternate crops (that would have been grown if the tank had filled differently) had to be collected using oral recall.

The set of 140-odd farmers getting irrigation from the tank includes mostly farmers from Baragi hamlet of Baragi village, but also a few from neighbouring hamlets/villages of Hongahalli and Tenkalahundi. The total number of farmers in the set was slightly larger during the second season (paddy cultivation) because a few farmers whose lands were not strictly within the tank canal command were able to get irrigation from the excess water that flowed through the waste weir and also that seeped into the stream from under the tank embankment. The details of the population of command area farmers are given in Table 3-7. Note that landholdings in the tank command are typically quite small, averaging 0.94 acres for our sample, and these smaller landholdings constitute the bulk of the land in the tank command. Most of the land is held as single parcels, with only about 10-15 farmers (typically the larger ones) having land spread across multiple parcels.

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 summer of 2005, we added to this sample all the 6 farmers 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,[26] as well as soil moisture or water availability. 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-enders) and elevation within the command (upland, mid-land, lowland).[27] So the farmers were classified into landholding classes (Table 3-7) and the field plots were further tagged by soil type, reach and location. The details of the sample selected are given in Table 3-8 and Table 3-9.

Table 3-7. Landholding classes amongst tank command farmers.

Hamlet to which farmer belongs	**Land holding pattern [acres]****				**Total**
	0-1	**>1 – 2**	**>2 - 4**	**>4**	
Baragi	85	23	06	03	117
Hongahalli	18	04	00	00	22
Tenkalahundi	01	04	00	00	05
All hamlets	104	31	06	03	144*

* Includes those who got seepage water from waste weir during summer of 2005.
** Refers only to the land held by the farmers within the tank command, in irrigated acres.

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[26] The Command area has different soil types: Black soil 70%, Sand mixed with black soil 20% and sand mixed with red and white soil 10%

[27] It was observed that low-lying plots were moister due to greater seepage from the tank.

Table 3-8. Sampling design adopted for monitoring of Jowar cultivation in Baragi Tank command: 2004 kharif season

Hamlet to which farmer belongs	Households who cultivated jowar in tank command in 2004 Kharif	Area cultivated (acres)	House-holds sampled	% sampled	Area cultivated by sample hhs
Baragi	111		28	25%	
Hongahalli	22		05	23%	
Tenkalhundi	05		01	20%	
All hamlets	138	135	34	25%	34.1

Note: This does not include six farmers, whose lands are located in an area irrigated by the waste weir, did not cultivate any crops when there was no irrigation because the soil is too poor to grow purely rainfed crops.

Table 3-9. Sampling design for monitoring of paddy cultivation in Baragi tank command year-2005 summer season.

Hamlet to which farmer belongs	Households who cultivated summer paddy in tank command in 2005	Area cultivated	House-holds sampled	% sampled	Area cult. by sample hhs
Baragi	111+6**		34	29%	
Hongahalli	22		05	23%	
Tenkalhundi	05		01	20%	
All hamlets	144	140.5	40	28%	37.8

* * Getting seepage water from waste weir.

Figure 3-25. Hybrid jowar crop ripening in Baragi tank command in September 2004 (L); summer paddy crop harvested in Baragi tank command during July 2005 (R).

The data collection was carried out at two levels. Basic socio-economic data on demographics, education, occupation and so on were collected for the household as a whole. Detailed data on landholding inside and outside the tank command were collected. Detailed data on actual labour, other inputs, costs and production were collected only for land within the tank command. These data were collected 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. The harvest data were directly collected from the fields. 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 (three) cases where the farmer (typically a big landholder) held multiple parcels in 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. We tried to choose the plots in a manner that ensured variation in terms of elevation, reach and soil type.

Average incomes under alternative scenarios for the kharif season

We begin by comparing average gross returns from crop cultivation in the two alternative scenarios for the kharif season: irrigated paddy and unirrigated jowar. We present the analysis for unirrigated jowar first and in more detail, because these data are based on actual monitoring carried out by us. Note that although we use "unirrigated jowar" as a shorthand, small amounts of other crops are also grown when irrigation is not possible in the kharif season.

Figure 3-26. Baragi tank command, with sampled plots indicated on cadastral map.

We first assessed whether the physical yield of jowar is significantly influenced by reach, location, soil type and inputs applied. From the dataset of 34 plots we eliminated 4 plots where 'fodder jowar' was cultivated instead of 'hybrid jowar'. The results of simple comparisons of means across different values of the independent variables for this sample of 30 plots are given in Table 3-10. As can be seen, elevation within the command seems to have the biggest influence on productivity. The upland plots are less productive than the lowland plots due to lower soil moisture availability, which results from less influence of tank seepage on the upland soils in the command area. The soil type also has a significant influence on productivity. This significance, however, drops when elevation and soil type are simultaneously used in a multiple-regression, with elevation becoming the dominant explanatory variable (see Appendix 2). On the other hand, landholding size (as a proxy for various differences of economic class) seems to have no significant effect on productivity. Quantity of farm-yard manure applied or total spending on fertilizers also have no correlation with productivity. 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.

Table 3-10. Kharif jowar productivity and different independent variables

Independent variable	Values	N	Mean Yield kg/gunta	Std. Dev.	Std.error of mean
Landholding size	Small	8	34	11	4
	Medium	13	34	10	3
	Large	9	33	10	3
Reach	Head reach	7	37	6	2
	Mid-reach	10	32	13	4
	Tail-reach	13	33	9	2
Elevation	Upland	4	18**	4	2
	Midland	12	37	8	2
	Lowland	14	36	7	2
Soil type	Clayey Black	19	36	6	1
	Sandy Black	7	35	13	5
	Sandy Red	2	27	18	13
	Sandy White	2	18*	3	2
ALL		30	34	10	2

**: Different from other categories at $p<0.001$; *: at $p<0.1$

The variation in economic returns from hybrid jowar cultivation is a more complex phenomenon, both to estimate and to explain. The market for the main product (hybrid jowar) is quite well developed and hence variation in price of jowar across farmers was negligible. But the markets for the main by-product (straw, which is used as fodder) and main input (labour, draught power) are much thinner.[28] We therefore decided to define net income as

Net income = Gross income - paid out costs only,

because the market value of the inputs (labour and animal) provided by the household would be close to zero. In gross income, we did not include the imputed value of jowar straw because this was again self-consumed by the household. The results of the econometric analysis of net income are given in Appendix 2, and may be summed up with the equation:

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 or mid, 1=upland).*

The result indicates that, apart from the effect of elevation on productivity, the landholding size plays a crucial role. That net income should increase with landholding is obvious, but it

[28] Most households use all household labour that is available before hiring in labour, use own animals for ploughing and consume the straw for their own livestock.

also declines with the square of landholding. This is because larger landholders have to hire more labour as their family labour is not enough. Consequently, 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 while that for medium and large farmers being 26.5 Rs/gunta (significant at 0.90 for N=29).

As mentioned above, 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 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). The economic returns for these minor crops were estimated based on discussions with farmers.

Table 3-11. 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 Jowar	Upland	40	720	160,290	64,775	117,537
	Midland/Lowland	70	1460	535,090	317,385	
Fodder 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

Table 3-12. 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

The estimated production, gross income and net income during the unirrigated kharif season of 2004 from hybrid jowar (and associated minor crops) are given in Table 3-11.

For the alternative scenario of irrigated paddy cultivation during the kharif season, we drew upon discussions with farmers and some quantitative data from our summer paddy survey. The estimates of production, income and employment generation are given in Table 3-12.

The difference between the irrigated and unirrigated kharif scenarios, resulting from the tank filling up in June or no, are given in Table 3-13

Table 3-13. Impact of kharif irrigation on in gross & net income and employment generated

Scenario	Crop	Gross income (Rs)	Net income (Rs)	Employment generated (Rs)	Remarks
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 household		8,450	2,401	1,140	

The main results are:

a) 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) 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.[29]

Average incomes under different crops in rabi/summer season

We used the data from monitoring of sample farmers during irrigated rabi/summer crop during summer of Jan-June 2005 (see Table 3-9) to analyze patterns of variation in productivity, net income, and wage employment generated.

The physical productivity of paddy did not show the reported 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. The variation (or non-variation) in means across some of these categories is given in Table 3-14.

[29] 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.

Table 3-14. Variation in summer paddy productivity

Independent variable	Values	N	Mean Yield kg/gunta	Std. Dev.
Landholding size	Small	7	61.5	9.2
	Medium	17	67.7	9.2
	Large	16	62.6	8.9
Reach	Head reach	11	68.5	7.9
	Mid-reach	13	61.1	8.1
	Tail-reach	16	64.7	10.3
Elevation	Upland	9	66.2	7.7
	Midland	16	61.7	9.6
	Lowland	15	66.6	9.4
Soil type	Clayey Black	23	64.3	10.7
	Other	17	64.9	7.1
ALL		40	64.6	9.3

Our economic analysis therefore focused on the paid out costs of summer paddy cultivation. As in the case of kharif jowar, this cost was regressed against the endowments of the household, including landholding in tank command, other landholding, household labour available, labour occupied in salaried jobs, and large ruminant holding. The results of the regression are given in Appendix 2, and may be summed up by the equation:

Paid out costs for summer paddy = 131.88(tank command land in guntas) + 1692*(no. of adults engaged in non-agri. jobs) – 179.1*(Number of large ruminant units)*

This equation was used to estimate the net income from summer paddy cultivation in the to the tank command farmers, and the estimates are given in Table 3-15 below.

Table 3-15. Estimated aggregate production and income 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	2,087,226	1,457,468	270,645
Paddy	Fed by waste weir	6	2,584	91,861	638,29	11,664
Total		141	2,584	2,167,459	1,512,551	280,963
Total per farmer				15,052	10,504	1,951

The wage employment generated by summer paddy cultivation was estimated using the equation:

Expenditure on hired labour = 38.03(landholding in tank command in guntas) + 0.230*(square of landholding in tank command) + 970*(Number of adults engaged in non-agricultural jobs)*

The difference between the irrigated and the non-irrigated scenario for summer is very stark: when irrigation does not take place, there is no crop taken in the tank command. This means that the totals in the last row of Table 3-15 represent the differences in between irrigation and no irrigation scenarios. The increase when there is irrigation would then be 10,500 in net income per farmer and 1,950 Rs in employment generated per farmer.

While not all those who get wage employment in summer paddy cultivation would sit idle if there was not summer paddy crop, at least half of the Rs. 281,000 of employment generated would be lost. There is the additional impact of reduced migration: when summer paddy is not cultivated, wage labourers and marginal farmers have to migrate during rabi/summer in search of employment. This migration is avoided when summer paddy is cultivating, generating significant non-monetisable social benefits to these households.

Note that the increased income only accrues when irrigation takes place, which is not every year. The difference in expected returns is calculated in the next section.

3.6 Likely impacts of changes in inflows on agricultural income and its distribution

The above analysis provides the basis for us to explore the likely impact of forest cover change-induced hydrological changes on agricultural incomes in the Baragi tank context. Our analysis in sec.3.3 indicated that an increase in forest cover to the level of the control catchments might reduce the rabi (Sep-Dec) season runoff coefficient (Q/P) from 18% to perhaps as low as 12%. The analysis in sec.3.4 indicated that such a decline in Q/P would result a decrease in the probability of the tank filling during the rabi season from 50% to 15%. One may expect a proportionate decline in the probability of the tank filling in the kharif season from the current 20% to perhaps 7% or so. The analysis in sec.3.6 showed that the filling of the tank during the rabi season would result in very substantial gains in terms of income for the tank command farmers and also significant gains for wage labourers. If the changes in forest cover result in the predicted decline of the probability of tank filling, the changes in the expected values of income and employment are given in Table 3-16.

Table 3-16. 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 catchment forest	Rabi/summer	50%	441,742	150,360
	Kharif	20%	756,276	140,482

(Current)	Total for year		1,198,018	290,842
Regenerated catchment forest (Simulated)	Rabi/summer	15%	396,787	129,025
	Kharif	7%	226,883	42,144
	Total for year		623,669	171,170
DIFFERENCE	Absolute change in annual income/ employment		-574,348	-119,672
	% change in annual income / employment		-48%	-41%

It appears that the impacts of such catchment forest regeneration will be significantly negative. Of course, it must be kept in mind that this analysis does not capture the entire set of impacts. In particular, the gains to the villagers from the regeneration of the forest are not taken into consideration here, nor the other form of hydrological impacts, viz., reduced soil erosion and hence lesser silt deposition in the tank when the forest regenerates. Nevertheless, this analysis throws up the interesting possibility that irrigation tank users may actually stand to lose when the forest in the catchment regenerates: a finding that goes counter to the conventional wisdom about forest watershed services.

APPENDIX 1: Details of sampling and measurement methods used for catchment hydrology investigations

Surface hydrology measurements

Each of the control and degraded catchments were instrumented for measuring streamflow and rainfall. Rainfall was measured using a combination of self-recording chart type rain gauges as well as tipping-bucket type rain gauges with data loggers. Stream water level was measured using manually read staff gauges and either automatic chart type or pressure transducer type data logger recorders mounted in stilling wells (see Figure 3-27).

Figure 3-27. Stilling well and staff gauge in Hebbahalla control catchment

Stream water velocity was measured using current meters (see Figure 3-28). Stream discharge is based on the velocity-area method as well as a portable “Montana flume” for low flows and application of Manning’s equation.

Figure 3-28. Taking current meter readings in Soreda control catchment

Shallow piezometers (up to 100 cm) of 2 inches diameter were installed in the streambeds (see Figure 3-29). Perforations made were covered by netlon mesh packed in gravel coarse sand filter. Opportunistic auger-hole tests to estimate aquifer hydraulic conductivity were also conducted when holes were dug at gauging sites.

Figure 3-29. Instream shallow piezometer in Hediyala degraded catchment

Soil hydraulic conductivity and other soil properties

On the map of each of the catchments, a grid of 1 km x 1 km was overlaid, and five of these were selected at random. Ten sampling locations were chosen in each grid at random distances from existing roads/jeep trails. Separately, another sampling was done for saturated hydraulic conductivity using the disc permeameter to measure infiltration characteristics on and off cattle trails, roads and foot-paths as these are known to occupy small parts of the landscape but are potentially the most important sources of surface run-off and sedimentation and soil erosion.

Figure 3-30. Disc permeameter for hydraulic conductivity measurements.

The surface sample was collected using the soil ring and the soil was collected in the zip lock bags and analyzed for bulk-density, texture/particle size, organic carbon and organic matter, pH, cation exchange capacity and nutrient cations (Na, K, Mg, Ca).

A few shallow soil pits were dug and opportunistically available cuttings down to 1.9 m were sampled for soil profile description and soil properties at depth. The soil samples from each major horizon were analyzed for soil physical and chemical properties listed above.

Forest vegetation structure

In the grid ten sampling points in each grid at every 100 m. point were selected The vegetation data was collected within 5 ft from the sampling point (i.e.: number of trees and saplings, tree height, land cover, etc) and at every point GPS reading ware taken. The estimation of canopy cover was done using densiometer at two different heights one at DBH height and at ground level. Shrub height and tree height were also estimated at each point. General characteristics of the vegetation, presence of invasive species and other features were observed and described for every point. Slope was also measured using optical height meter.

Forest disturbance

At each point where soil and vegetation was sampled (10 in each selected grid), signs of human disturbance were scored as 1 if detected and 0 for non-detection. This was done for each of the following: (1) Trails and Tracks (2) Cattle dung or cattle (3) Cut and Broken stems (4) Fire (5) People . The sum of these zeros and ones was defined as a simple index of disturbance for each point.

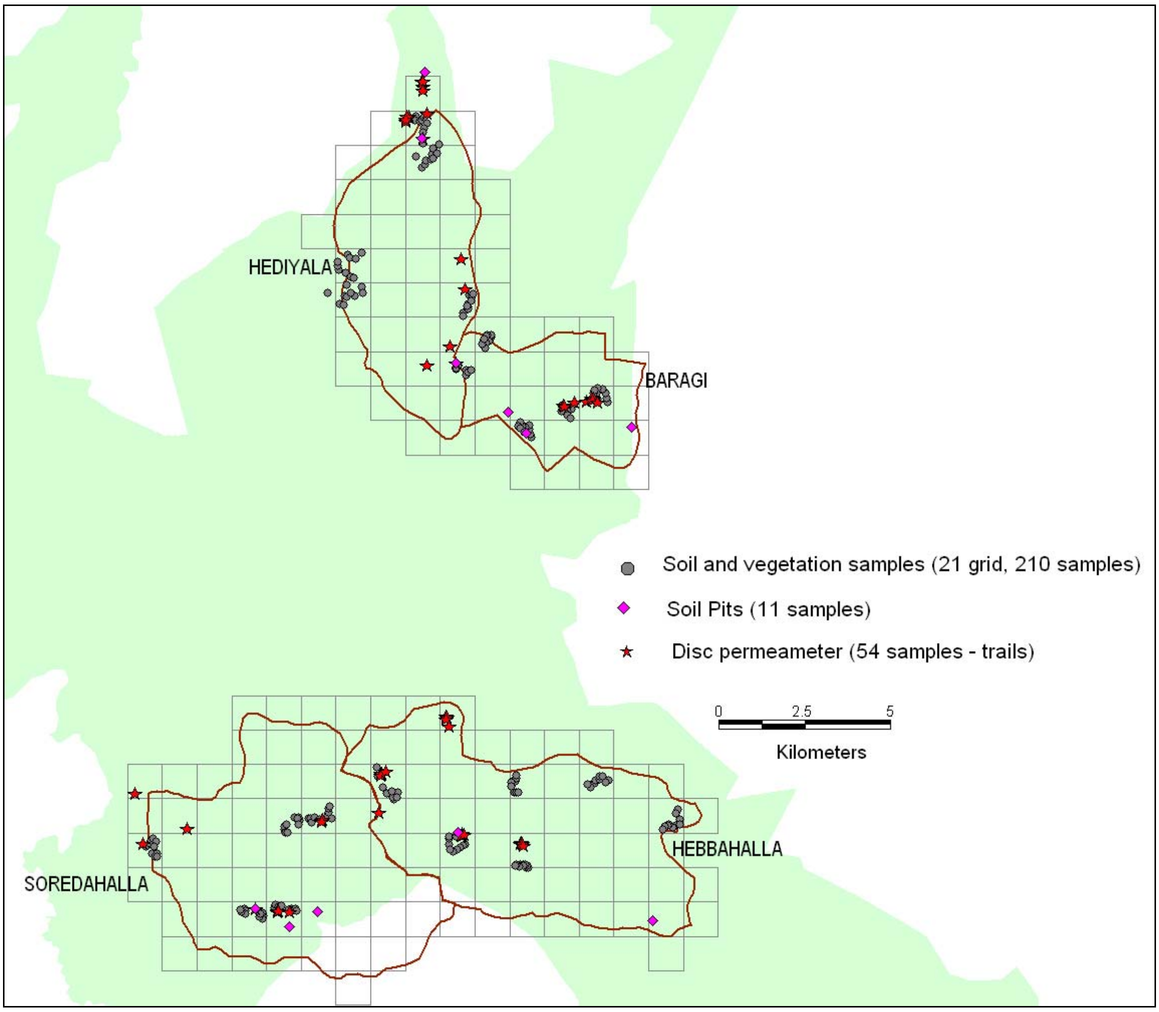

Figure 3-31. Sampling protocol for soil properties

Methodology for tank monitoring

The following table outlines the methodology adopted for monitoring of the two irrigation tanks. Figure 3-32 shows how some of the monitoring was carried out.

Tank	Variable	Method/instrument	Data obtained
Hediyala	Inflows from main stream	Staff gauge & current meter readings	Stage readings for 7 events, current meter readings for 1 event (2004).
	Subsurface water levels & use	Piezometers and weekly monitoring of water withdrawal	Daily data from 17 July 2004 to 15 March 2005.
	Tank storage	Tank water level, level-wise contour plotting	Daily tank water level from 08 July 2004 to 14 June 2005.

Tank	Variable	Method/instrument	Data obtained
	Seepage from Hediyala tank	Piezometer and Staff gauge	Daily data from 08 July 2004 to 14 June 2005, water use data in sugarcane for duration of crop for 31 farmers
Baragi	Surface Inflows	Flow through circular pipes under culvert	Stage readings for 11 events, current meter readings for 2 events.
	Storage	Tank water level, level-wise contour plotting	Daily tank water level from 28 July 2004 to till date.
	Tank releases	Canal flows	From 28 Jan 2005 to 27 April 2005
	Upstream groundwater	Level in unused bore wells	Daily monitoring since 18 June 2005 to till date.

Figure 3-32. Monitoring of tank water level at sluice (L) and streamflow under bridge upstream of tank using staff gauge (R)

Appendix 2: Details of statistical analysis of crop productivity and incomes

Kharif jowar

1. Results of multiple regression analysis of physical productivity of kharif jowar crop

Dependent Variable: Productivity kg per gunta

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1408.3	4	352.1	7.132	.001
Intercept	25710.2	1	25710.2	520.764	.000
ELEVATION	1165.5	2	582.8	11.804	.000
SOILRECO	50.8	1	50.8	1.029	.320
ELEVATION * SOILRECO	173.5	1	173.5	3.515	.073
Error	1234.3	25	49.4		
Total	36824.9	30			
Corrected Total	2642.6	29			

R Squared = .533 (Adjusted R Squared = .458). SOILRECO is a variable constructed by recoding the multiple soil types into two major categories: clayey-black and non-black. Introducing manure applied as another independent variable did not change the results significantly.

2. Results of multiple regression analysis of economic returns from kharif jowar crop
Dependent Variable: Net income: gross income - fodder value - paid out costs

R	R Square	Adjusted R Square	Std. Error of the Estimate
.890	.793	.720	1588.3

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.	R	R-square
Regression	193006261.	7	27572323	10.93	.000	0.890	0.793
Residual	50453731.	20	2522686				
Total	243459993	27					

Coefficients

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-1677.553	1275.392		-1.315	.203
Total other land holding in equiv dry acres	31.732	38.632	.108	.821	.421
Land size in gunta	210.448	37.791	2.176	5.569	.000
Total livestock units owned by household	55.582	159.137	.055	.349	.731
Square of landholding	-.975	.222	-1.674	-4.382	.000
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

Summer paddy

1. Results of multiple regression analysis of physical productivity of summer paddy crop
Dependent Variable: Paddy productivity (kg/gunta)

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	62.287	11.066		5.629	.000
Per gunta fertilizer use	.904	1.762	.087	.513	.611
Soil type recoded	-1.549	3.618	-.084	-.428	.671
Elevation	-1.400	2.327	-.116	-.601	.552
Manure use per gunta (cartloads)	67.939	78.780	.147	.862	.395
Seed variety	-2.652	2.504	-.183	-1.059	.297

R-square = 0.056, F=0.405, p<0.842 (i.e., regression not significant at all)

NOTE: The main components of paid costs were hired labour (~50%) and expenditure on fertilizers (32%), we focused on trying to explain the variation in these costs.

2. Results of multiple regression analysis of hired labour costs of summer paddy crop

Dependent Variable: Total Hired labour cost

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.919	.845	.832	957.9

Coefficients

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-590.182	357.628		-1.650	.108
Landholding in tank command (gunta)	71.012	5.585	.865	12.714	.000
Total working age adults in household	-86.872	85.175	-.070	-1.020	.315
Adults engaged in non-agricultural occupations (jobs, business)	1150.811	427.604	.190	2.691	.011

3. Results of **2nd** multiple regression analysis of hired labour costs of summer paddy crop

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.932	.869	.849	907.1

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	223.824	475.174		.471	.641
Landholding in tank command (gunta)	38.031	15.635	.463	2.432	.020
Square of tank command landholding (gunta^2)	0.230	.102	.436	2.255	.031
Adults engaged in non-agricultural occupations (jobs, business)	970.583	411.477	.160	2.359	.024
Total working age adults in household	-87.108	81.426	-.070	-1.070	.292
All other land in dry land equiv acres	-6.513	17.357	-.025	-.375	.710

a Dependent Variable: Total Hired labour cost

4. Results of multiple regression analysis of chemical fertilizer costs of summer paddy crop

Dependent Variable: Cost of Chemical fertilizer

R	R Square	Adjusted R Square	Std. Error of the Estimate
.967	.936	.930	232.390

Coefficients

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	104.245	68.179		1.529	.135
Landholding in tank command (gunta)	29.468	1.352	.952	21.788	.000
All other land in dry land equiv acres	6.425	4.244	.064	1.514	.139
Adults engaged in non-agricultural occupations (jobs, business)	91.993	100.066	.040	.919	.364

5. Comparison of fertilizer cost across farmer category (proxy for wealth)

Multiple Comparisons (LSD test)
Dependent Variable: Per gunta fertilizer use

(I) Farmer category	(J) Farmer category	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Small	Medium	-.1681	.39720	.675	-.9729	.6367
	Big	.3393	.40080	.403	-.4728	1.1514
Medium	Small	.1681	.39720	.675	-.6367	.9729
	Big	.5074	.30807	.108	-.1169	1.1316
Big	Small	-.3393	.40080	.403	-1.1514	.4728
	Medium	-.5074	.30807	.108	-1.1316	.1169

6. Regression analysis of total paid out costs for summer paddy cultivation

Dependent Variable: Total paid out costs (Hired bullock, hired labour, purch. Manure, manure transport cost, chemical fertilizer, etc.)

R	R Square	Adjusted R Square	Std. Error of the Estimate
.941	.886	.870	1594.0

Coefficients

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	180.525	984.037		.183	.856
Landholding in tank command (gunta)	131.887	9.732	.850	13.551	.000
Elevation	-300.188	353.272	-.052	-.850	.401
Adults engaged in non-agricultural occupations (jobs, business)	1692.786	775.484	.148	2.183	.036
Total working age adults in household	-33.976	162.052	-.015	-.210	.835
Total large animal units (excl. sheep goats)	-179.063	102.457	-.120	-1.748	.090

7. **2nd Regression** of total paid out costs for summer paddy cultivation (including other land assets)

R	R Square	Adjusted R Square	Std. Error of the Estimate
.901	.812	.777	1106.2

Coefficients

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1494.898	719.804		2.077	.046
Landholding in tank command (gunta)	92.545	9.313	.804	9.937	.000
Elevation	-383.592	252.025	-.126	-1.522	.138
Adults engaged in non-agricultural occupations (jobs, business)	938.113	554.295	.146	1.692	.100
Total working age adults in household	-36.557	113.323	-.030	-.323	.749
Total large animal units (excl. sheep goats)	-181.651	79.159	-.226	-2.295	.028
All other land in dry land equiv acres	30.543	23.285	.115	1.312	.199

a Dependent Variable: Total expenditure-only considering Hired bullock, hired labour, manure and its transport cost, Chemical fertilizer and other Hired in costs

Chapter 4. Forest-Water-Community Linkages in Coastal Block

While the previous two chapters describe the findings from multi-year, multi-scale and multi-parameter hydrological and socio-economic studies we carried out in one high rainfall and one low rainfall block, this and the next chapter describe the findings from what we have called as ‘coarse-scale’ analyses, based on relatively limited data and surveys. In this chapter, we describe the findings from the coastal block, the second high rainfall block located in the coastal eco-climatic zone of Uttara Kannada district. In this study, we focused on identifying the broad trends in catchment hydrology and focused on understanding the impacts of hydrological changes on domestic water availability.

4.1 Description of the study area

This area is in many ways similar to the Malnaad block, with 3000-plus mm of rainfall concentrated during a four month monsoon, and agriculture based on areca and paddy cultivation (except right on the coast, where coconut cultivation dominates). More heterogeneous communities, more diffuse control over forests, and a greater preponderance of monocultural plantations (particularly Acacia) created by the forest department are some of the distinguishing characteristics.

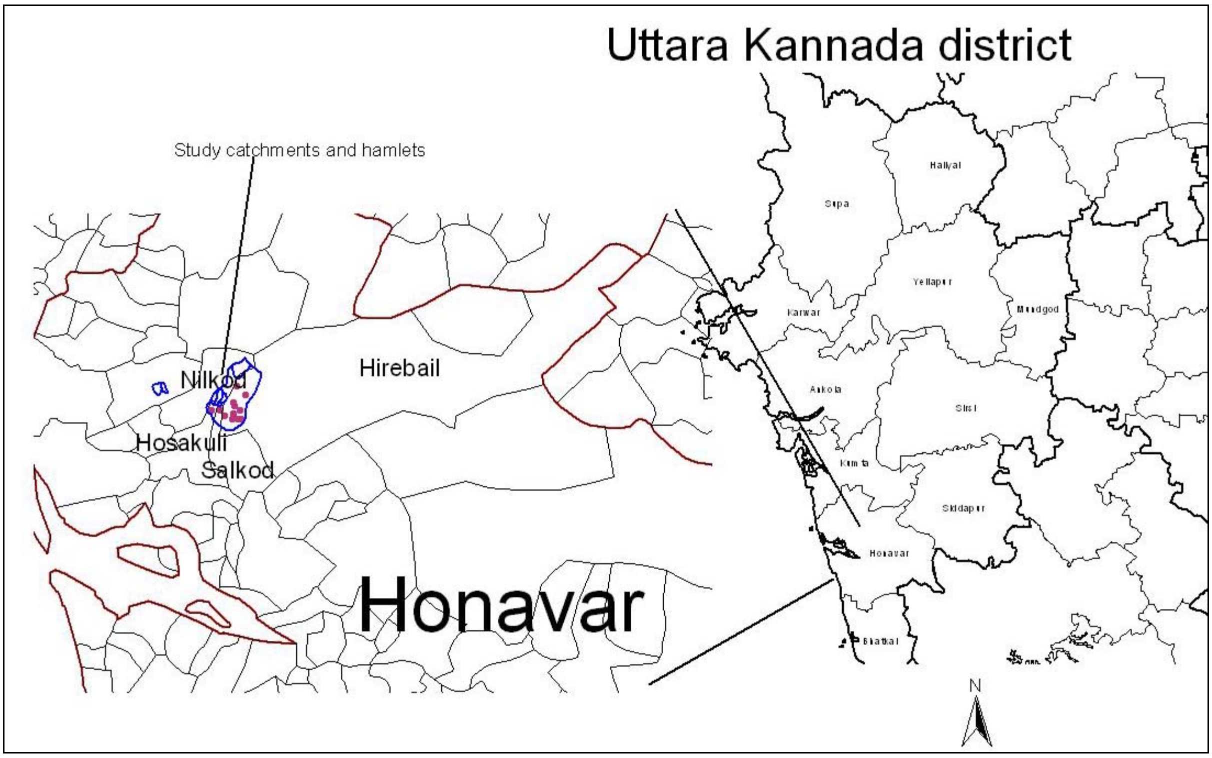

Figure 4-1. Location of coastal block study catchments and hamlets in Uttara Kannada district and Honavar taulka

The sites selected were in Honnavar taluka, about 7 km north-east of Honnavar town, near the village of Areangadi. We selected five catchments for hydrological monitoring: one with dense forest, two with acacia plantations, and two in degraded conditions. Only the densely forested catchment was a significant contributor to any hamlet, and so we used the area downstream of the dense forest catchment as the focus of the socio-economic study. The boundaries of the catchments selected for hydrological monitoring, the boundary of the community catchment and the land-cover in these catchments are shown in Figure 4-2.

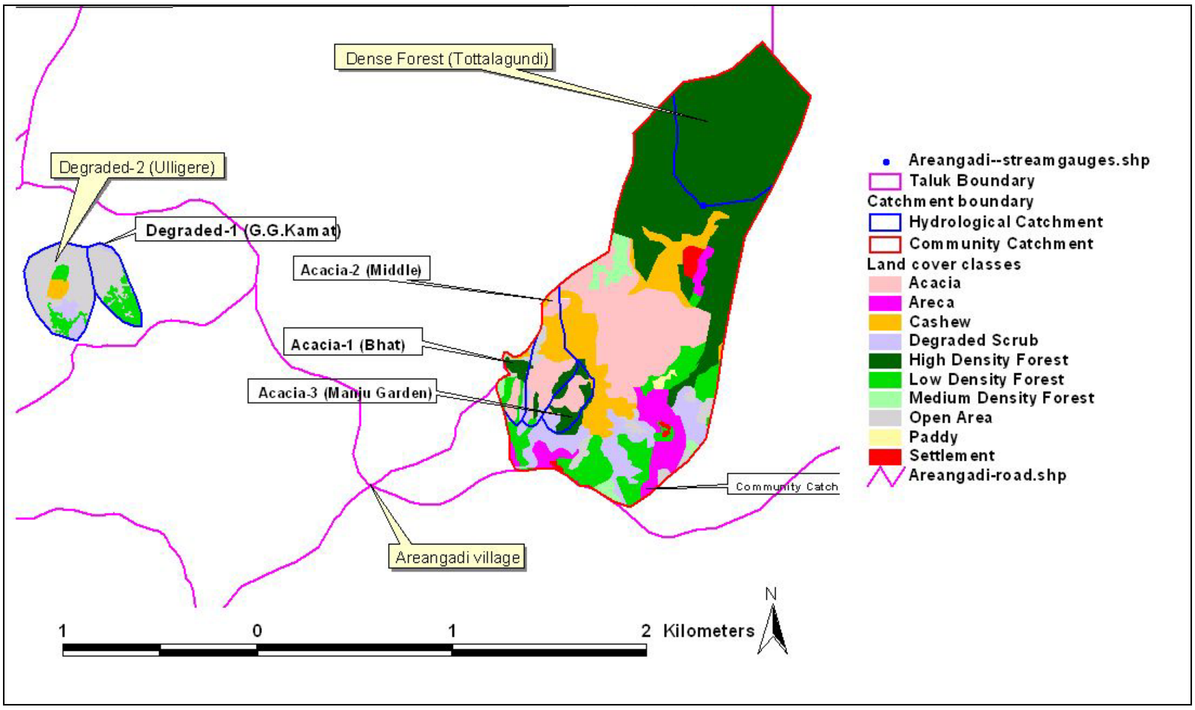

Figure 4-2. Catchment boundaries and land-cover

4.2 Catchment hydrology

The results of hydrological monitoring aggregated at monthly and annual scales are presented in Figure 4-3 and Table 4-1, respectively. The highest specific discharge and the specific peak discharge were observed in the degraded watershed and the minimum in forested watershed. These values for acacia watershed are lesser than the degraded watershed but closer to the values observed in the forested watersheds. However, peak specific discharge values are almost equal in both forest and acacia watersheds. Also, from these tables, it is noticed that, there is an increase in specific discharge by 12.8 % and 18.7 % in the year 2004 and 15.9% and 24.9% during the year 2005 respectively for Acacia and Degraded forest in comparison of natural forest. This marginal increase in specific discharge during the year 2005 may be attributed to an increase of rainfall by 22% to that of rainfall in 2004.

Table 4-1. Runoff Characteristics under different land-use type for 2004 and 2005

Sl No	Land use type	Area (ha)	Rainfall (mm)	Runoff (mm)	Specific Discharge (cumec/ha)	Specific Peak Discharge	Percent Runoff
2004	**Acacia**	7	3446.60	1148.08	0.93	0.04	33.00
	Degraded	7		1467.62	3.91	0.15	43.00
	Natural	23		1209.95	11.20	0.37	35.00
2005	**Acacia**	7	4015.6	1476.543	1.19	0.07	36.77
	Degraded	7		1790.294	4.76	0.26	44.58
	Natural	23		1536.93	14.23	0.81	38.27

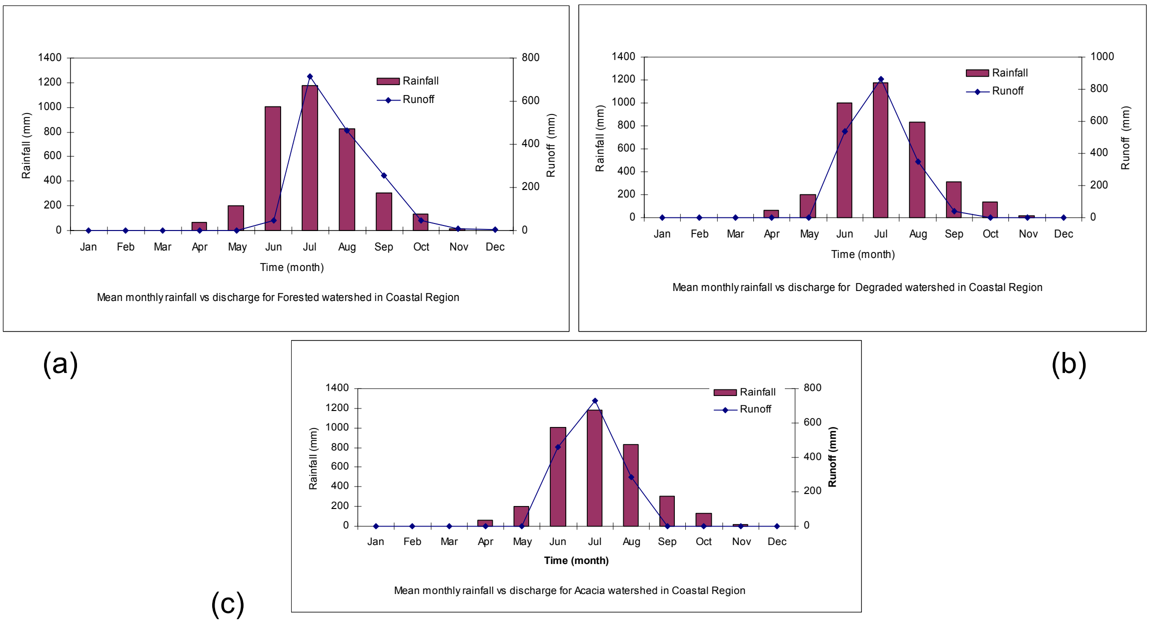

Figure 4-3. Temporal distribution of measured discharges under different land-use: (a) Forested Watersheds, (b) Degraded Watersheds, (c) Acacia watersheds in Coastal region

4.2.1 Peak flow analysis

We analysed the peak flows observed in these catchments in some detail (Table 4-2 and Figure 4-4 to Figure 4-6). The analysis indicates that there is an increase in the peak flow up to 123% in degraded and 82% in acacia watershed in comparison with that of the forested watershed. The probability plot (Figure 4-4) shows that the peak flows in forested watershed are much lower than that of the acacia and degraded watersheds. However the lower peak flow values are matching in both acacia and degraded watershed. This is further substantiated that storms lesser than 150 mm result in peak flows that are more or less similar, but bigger storms yield a lower peak flow in forested watershed compared to other two watershed.

The highest rainfall event received during the study period is 254 mm, which occurred on later part of June 2005. Since June is the beginning of the monsoon and there is all possibility that the soils in forested watershed (23 ha area) might not have reached the saturation. Whereas the other two watersheds which have similar catchment area (7 ha), have attained the saturation due to the rainfall event and have generated the higher peak flow (Figure 4-5 and Figure 4-6). Otherwise, the response to the different storm size is similar in all watersheds.

Table 4-2. Peak flow for selected rainfall events for 2004 and 2005

Date	Rainfall (mm)	Natural forest	Degraded	Acacia
Year 2004				
10-Jun-04	123.40	0.24	0.37	0.33
9-Jun-04	122.40	0.03	0.29	0.14
13-Aug-04	115.60	0.28	0.61	0.49
11-Jun-04	106.20	0.46	0.52	0.44
3-Aug-04	104.00	0.30	0.65	0.57
13-Jul-04	98.00	0.20	0.63	0.36
6-Jun-04	97.80	0.00	0.00	0.00
8-Jun-04	94.60	0.01	0.14	0.00
27-Jun-04	79.00	0.07	0.27	0.14
3-Jul-04	74.40	0.11	0.35	0.33
Mean	**101.54**	**0.17**	**0.38**	**0.28**
Percent increase of Runoff over forested watershed			123.19	62.57
Year 2005				
22-Jun-05	254.40	0.09	1.17	1.05
5-Jul-05	152.20	0.32	0.70	0.53
24-Jul-05	138.00	0.53	0.54	0.49
21-Jun-05	137.80	0.03	0.75	0.64
12-Jul-05	129.20	0.66	0.75	0.53
23-Sep-05	129.00	0.64	0.16	0.00
23-Jun-05	127.80	0.12	1.04	0.91
20-Jun-05	125.20	0.00	0.60	0.57
8-Apr-05	96.60	0.00	0.00	0.00
14-Jul-05	86.00	0.40	0.48	0.36
Mean	**137.62**	**0.28**	**0.62**	**0.51**
Percent increase of Runoff over forested watershed			122.23	82.26

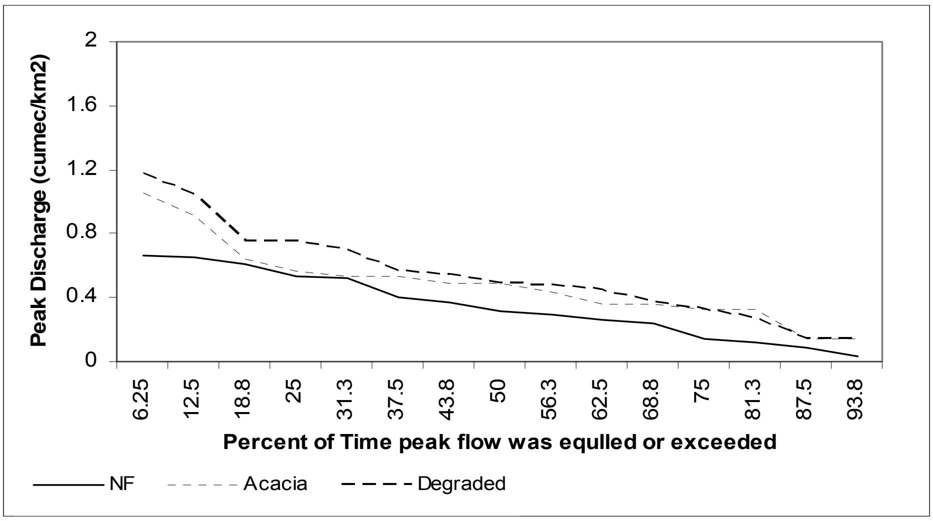

Figure 4-4. Frequency plot of peak discharge under different land-use

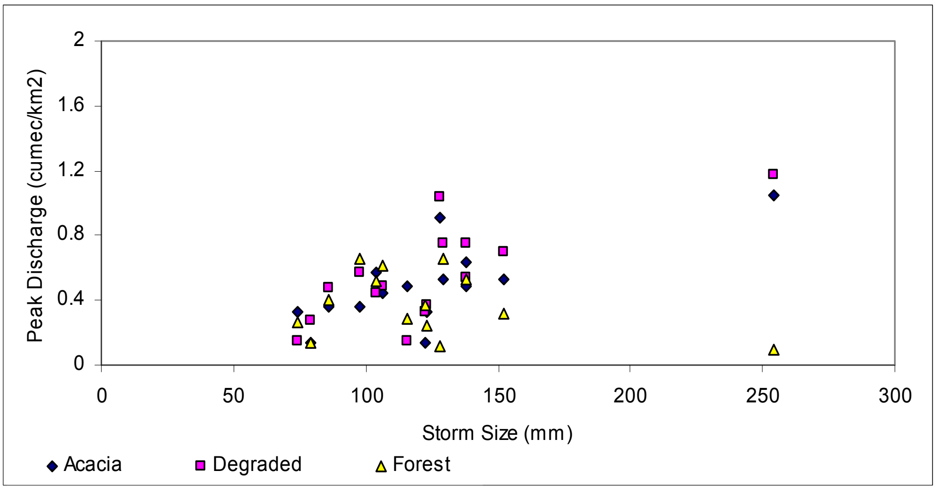

Figure 4-5. Peak flow response to different storm size under different land-use during the study period

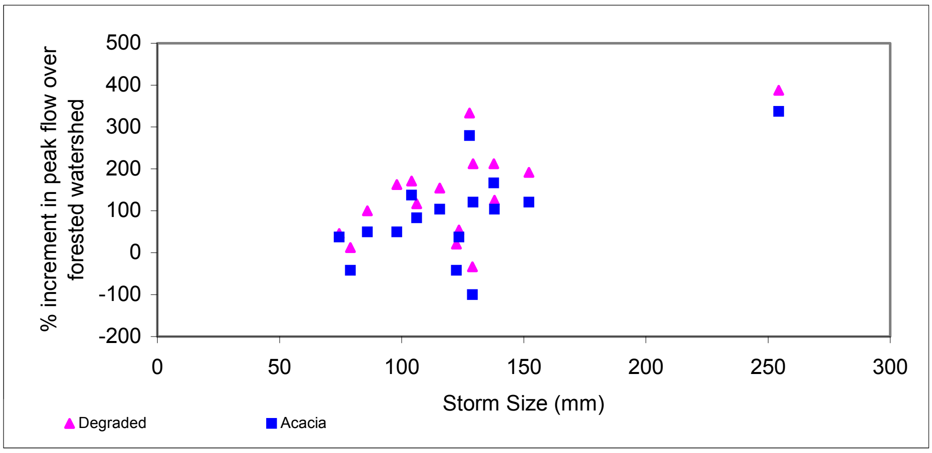

Figure 4-6. Percent Increase of peak flow for different storm size under Acacia and Degraded watershed in comparison with forested watershed

4.2.2 Analysis of soil-hydraulic properties

Figure 4-7. Typical soil profile in Thottalgundi forest catchment

Published results of infiltration capacity and soil saturated hydraulic conductivity for tropical residual soils are relatively few in number and are quite variable in nature. In most of the cases, the values are quite high and exceed most of the rainfall intensities (Dykes et al., 2000). The soil hydrological effects of land clearing and subsequent land use in the humid tropics have been studied in some detail (Ghuman, et al., 1991; Alegre and Cassel, 1996; Arevalo et al; 1998; Gijsman and Thomas, 1996, Horwitz, et al., 1999; Bonell and Malicova, 2003; Martinez and Zinck, 2004; Elsenber et al; 2006, Purandara et al, 2006). One of the important issue which is not addressed adequately in literature is the hydrological response to secondary growth and plantation forests with respect to soil hydrology. Therefore, the present investigation focuses on saturated hydraulic conductivity as it is one of the significant parameter in runoff generation process.

Table 4-3 shows the results of analysis of the field data collected from forest, acacia and degraded watershed characterized by similar soil, geology and slope characteristics. In all the three watersheds, it is common that, there is decrease in Ks with depth. In forested watershed, Ks is maximum (logarithmic mean 107.11 mm/hr) in the surface layer and showed a sharp decline (more than twice than the surface layer) at a depth of 0.1 m ((log mean 40.37 mm/hr). The rate further reduced to 17.57 mm/hr at a depth of 0.45m. Beyond this depth the decrease is quite gradual up to a depth of 1.5 m. Rainfall intensity analysis carried out for the study area showed that with a 2 years return period (maximum intensity 34.06 mm/hr calculated from 15 minutes interval) the saturated hydraulic conductivity is quite higher (107 mm/hr), both at the surface and 0.1 m depth, in comparison to the average rainfall intensity of 34.06 mm/hr. However, at a depth 0.45 m, there is a low permeable which acts as a throttle and may result in saturation overland flow. This is quite common in coastal soils.

Table 4-3. Hydraulic conductivity values for selected watersheds in Coastal area

Soil Type / *Land use*	Layer	No of Samples	K* mmh^{-1}			Antilog SI
			Arith. Mean	Log Mean	Range	
Acacia	0.00 m	6	40.75	32.55	10.24 to 75.63	0.769
	0.10 m	6	20.32	17.69	6.12 to 39.76	0.611
	0.45 m	6	20.35	19.43	11.56 to 31.44	0.335
	0.60 m	6	15.87	15.05	8.75 to 22.15	0.367
	0.90 m	6	15.19	14.58	9.75 to 21.4	0.316
	1.20 m	6	14.06	13.58	7.64 to 17.11	0.306
	1.50 m	6	12.05	11.94	9.8 to 14.71	0.151
Degraded	0.00 m	5	24.59	22.84	11.88 to 37.97	0.443
	0.10 m	5	14.96	14.29	9.88 to 21.78	0.341
	0.45 m	5	14.86	14.38	10.78 to 9.88	0.275
	0.60 m	5	14.96	14.27	10.18 to 18.12	0.341
	0.90 m	5	13.49	13.22	9.65 to 16.11	0.222
	1.20 m	5	11.98	11.77	11.43 to 7.65	0.211
	1.50 m	5	10.00	9.91	11.88 to 37.97	0.156
Natural Forest	0.00 m	6	110.68	107.11	77.36 to168.78	0.275
	0.10 m	6	42.088	40.37	27.17 to 61.7	0.314
	0.45 m	6	18.35	17.57	12.8 to 27.8	0.316
	0.60 m	6	16.948	16.83	13.14 to 19.23	0.134
	0.90 m	6	15.69	15.40	11.9 to 19.95	0.214
	1.20 m	6	14.05	13.74	9.86 to 19.1	0.236
	1.50 m	6	12.38	12.06	7.19 to 15.71	0.270

In the Acacia auriculiformis catchment, which contained a plantation of age about 7-8 years old, the maximum Ksat values showed variation between 10.24 mm/hr and 75.63 mm/hr at the surface with log mean value of 32.55 mm/hr. Similar to the situation as observed forest catchment, there is a sudden change at 0.1 m reducing it to almost half of the surface layer. As we proceed deeper, i.e. at a depth of 0.45 m, it is noted that the hydraulic conductivity increased slightly (17.69 mm/hr to 19.43 mm/hr) and thereafter a gradual decrease is observed. This increase is easily explained based on textural characteristics of the soil, i.e. the sand percentage showed an increase from 24 % to 34.9%.

Investigations in the degraded forest indicate that, the saturated hydraulic conductivity in surface layer is considerably less than the acacia plantation and the variation is quite conspicuous in forest soils, i.e. it reduced by 5 times in comparison to forest soils. The variation observed at various depths in degraded forest is narrow whereas in the case of forest and acacia it is quite wider. The higher conductivity and wide variations found in similar soils could be attributed to the presence of macro-pores and pipeflows (Sollins and Radulovich, 1986; Bremes, 1994; Thomas, 1994). Saturated hydraulic conductivity (Table 4-3) shows that there is a sharp decline in Ksat with depth. The surface conductivity is considerably high in forest and Acacia as compared to degraded land.

Generally, it is reported that the forest soils are noted for the development of macro-pores, especially in the surface layers, because of the high density of roots and biomass production (Bonell, 1993; Purandara et al; 2003). Field observations made in the study area showed large number of visible pores and cracks through out all the exposed soil profiles. Such macro-pores allow the vertical by-passing of the unsaturated soil matrix (Bouma and Dekker, 1978; Beven and German, 1990; Bonell, 1993). In agreement with the present observations, Putty and Prasad (2000a) in the upper reaches of the streams of Western Ghats region reported that a significant contribution to runoff is by subsurface pipe flow. They suggest that the pipe flow and return flow is the dominant pathway in evergreen forests. Putty and Prasad (2000b) further made observations on infiltration rate and runoff collectors within trenches plus a large number of vertical faces of soil exposed at road cuttings near valley bottoms. No overland flow was observed on the slopes although the occurrence of saturation overland flow in the riparian valley bottom areas was still considered very important(Dunne and Black, 1970a, b). The lack overland flow was attributed to the very high infiltration capacities of the forests (61 mm/hr to 780 mm/hr) which far exceed the maximum short term intensities (60 mm/hr). Similar observations were made by Purandara et al, 2006 in different parts of the Uttara Kannada district.

In figures (Figure 4-8, Figure 4-9, Figure 4-10) variations in the hydraulic conductivities of the three land cover types as a function of depth are presented.

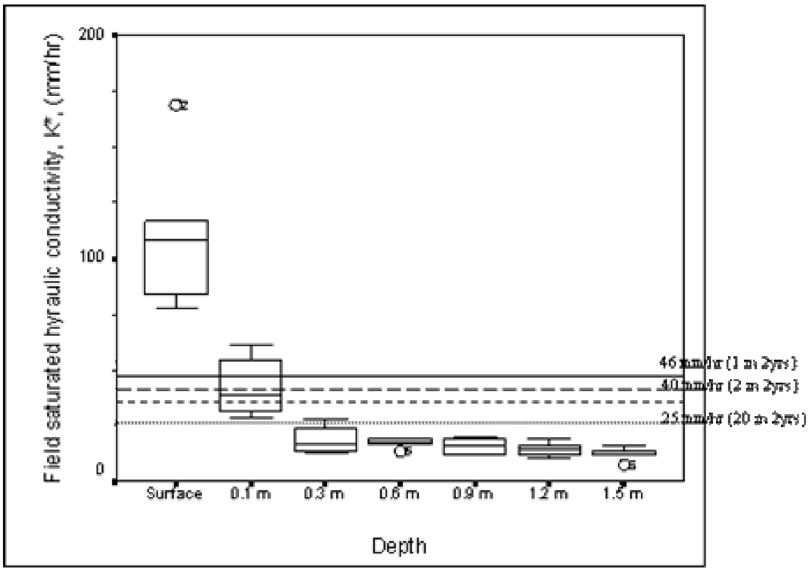

Figure 4-8. Field saturated hydraulic conductivity, K* as a function depth under Forest watershed

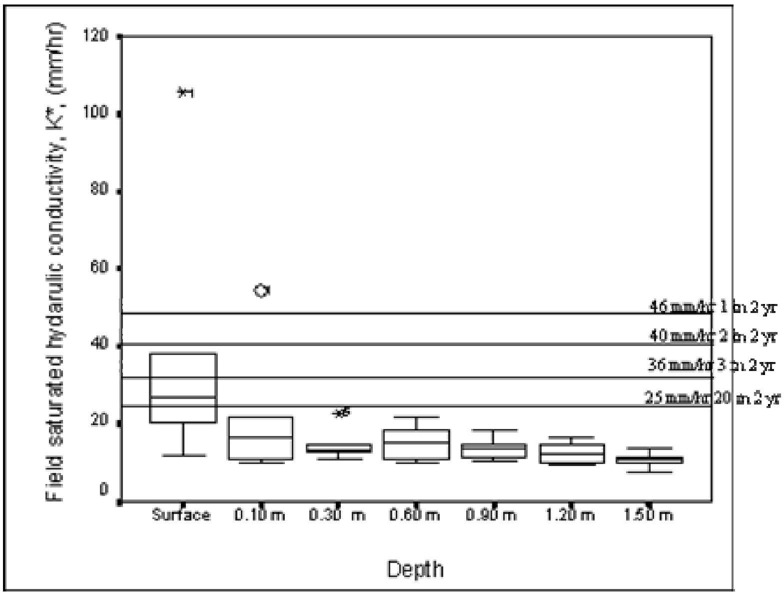

Figure 4-9. Field saturated hydraulic conductivity, K* as a function depth under Degraded watershed

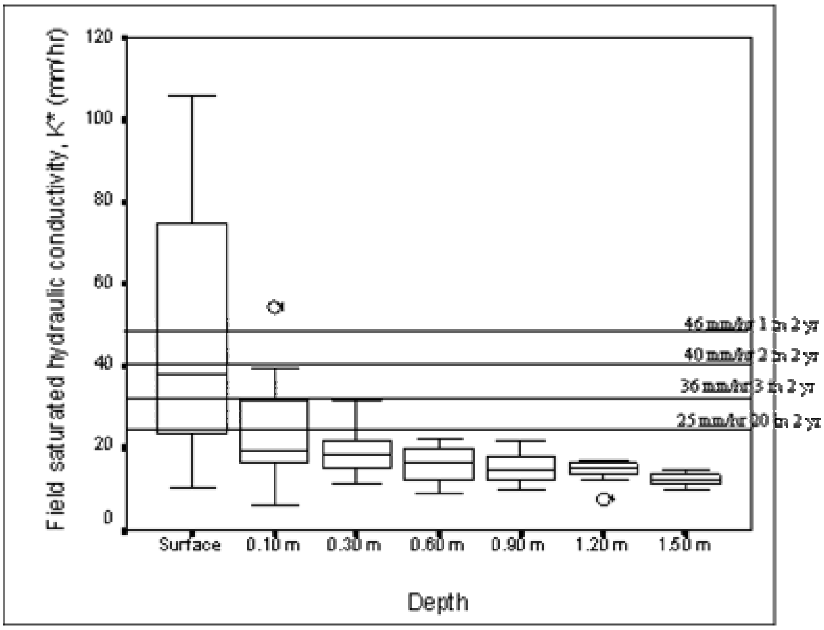

Figure 4-10. Field saturated hydraulic conductivity, K* as a function depth under Acacia watershed

The scatter plot (Figure 4-11) between surface and 0.1 m depth indicate there are two prominent clusters, i.e. one dominated by natural forest and the other by degraded forest. It is noted that the Ks values observed for Acacia auriculiformis are intermediate in nature. This could be due to the improvement in soil structure and texture after afforesting with acacia auriculiformis.

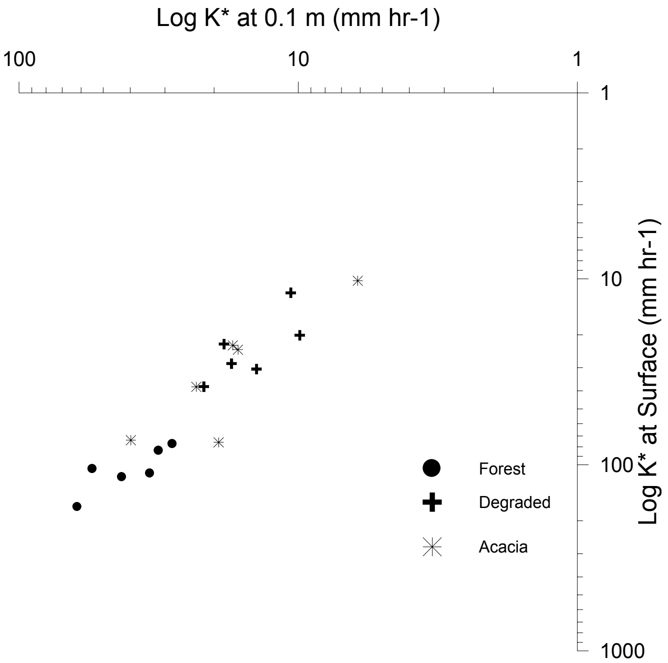

Figure 4-11. Scatter plot of Log K* at Surface vs. 0.1 m depth.

In Figure 4-12, it is observed that there is no separate cluster for the three types of land covers, instead it group as one. From this, it is evident that, at a depth of 1.2 m to 1.5 m, the major influence on hydraulic conductivity is exhibited by soil type and texture. Texture is almost similar in all the cases. Therefore, in all the cases, the variation in soil hydraulic conductivity beyond 0.1 m depth is comparatively less.

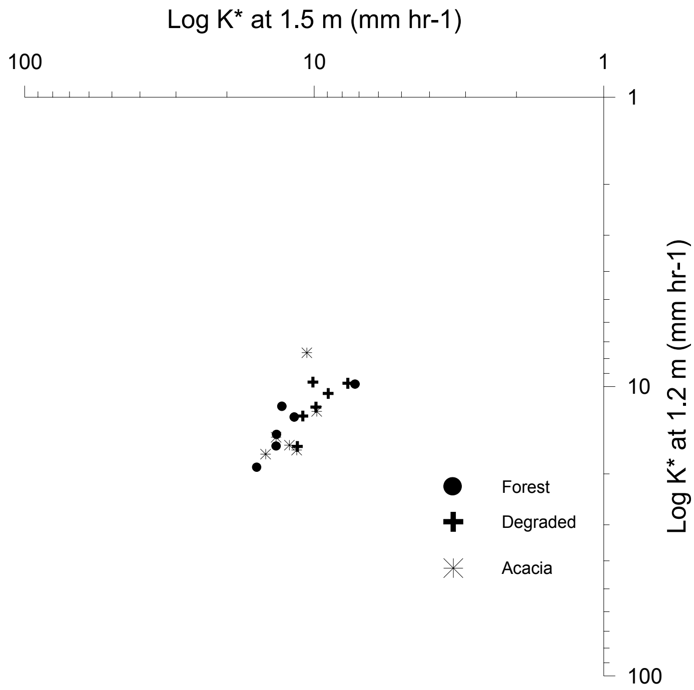

Figure 4-12. Scatter plot of Log K* at 1.2 m vs. 1.5 m depth

Soil moisture retention characteristics estimated for the various type soils in the study area indicate the presence of abundant pores of large and extremely small diameters (presented in Table 4-4). In the case of degraded forests, a retention curve behaves slightly different from the above due to the aggregation of soil particles. In general, abundance of large pores and macro-pores by contraction of wetted silt and clay particles in humid temperate climate influence the amount of water during the wet periods.

Table 4-4. Soil Moisture Retention Characteristics under different Land covers

	SMC	0.3 bar	3 bar	5 bar	7 bar	10 bar	15 bar
Forest							
Down to 1 feet	0.281	**0.273**	0.252	0.23	0.226	0.215	**0.206**
1-2 ft	0.257	**0.24**	0.198	0.17	0.16	0.15	**0.14**
2-3 ft	0.306	**0.292**	0.251	0.166	0.164	0.162	**0.141**
3-4 ft	0.296	**0.28**	0.258	0.228	0.213	0.179	**0.176**
4-5 ft	0.287	**0.261**	0.217	0.212	0.208	0.174	**0.157**
5-6 ft	0.31	**0.261**	0.239	0.227	0.176	0.169	**0.16**
Degraded							
Down to 1 feet	0.41	**0.397**	0.28	0.262	0.243	0.221	**0.218**
1-2 ft	0.257	**0.24**	0.198	0.17	0.16	0.15	**0.14**
2-3 ft	0.306	**0.292**	0.251	0.166	0.164	0.162	**0.141**
3-4 ft	0.296	**0.28**	0.258	0.228	0.213	0.179	**0.176**
4-5 ft	0.287	**0.261**	0.217	0.212	0.208	0.174	**0.157**
5-6 ft	0.234	**0.226**	0.221	0.216	0.209	0.203	**0.179**
Acacia							
Down to 1 feet	0.332	**0.312**	0.195	0.192	0.188	0.168	**0.156**

1-2 ft	0.291	**0.28**	0.256	0.198	0.193	0.174	**0.162**
2-3 ft	0.29	**0.273**	0.198	0.179	0.162	0.157	**0.137**
3-4 ft	0.268	**0.26**	0.213	0.124	0.119	0.105	**0.101**
4-5 ft	0.286	**0.279**	0.246	0.234	0.228	0.211	**0.172**
5-6 ft	0.304	**0.267**	0.233	0.175	0.167	0.156	**0.13**

Texturally, soils are dominated by sand and silt particles. It is also observed that, there is a significant variation between gravel and sand per cent. This results in variation of Ksat with depth.

Table 4-5. Soil textures in the three land cover types

Depth Range	Sand	Silt	Clay
Forest			
Up to 1 ft	44.6	54	1.4
1-2 ft	24.2	74.8	1
2-3 ft	41.1	58.02	0.88
3-4 ft	34.9	64.18	0.92
4-5 ft	34.7	64.38	0.92
5-6 ft	30.8	68.24	0.96
Degraded			
Up to 1 ft	4.23	92.7	3.07
1-2 ft	15.1	83.78	1.12
2-3 ft	29	70.08	0.92
3-4 ft	29	70.08	0.92
4-5 ft	25.1	73.94	0.96
5-6 ft	27.6	71.56	0.84
Acacia			
Up to 1 ft	56	42.5	1.5
1-2 ft	42.8	56.2	1
2-3 ft	27.7	71.34	0.96
3-4 ft	37.1	61.94	0.96
4-5 ft	41.4	57.72	0.86
5-6 ft	11.8	87.16	1.04

4.2.3 <u>Soil moisture analysis</u>

The soil-moisture characteristics show that there are two layers of soil, one dominated by sandy soil and the other dominated by silts. There is an increase of moisture between 60 cm – 75 cm depth. The maximum increase is seen in the case of degraded land because there is no root growth at this depth. However, in the case of forest and Acacia, the roots penetrate below this depth so the increase is quite marginal. But in all the cases there is depletion of moisture below 75 cm depth. It is also observed that, in the case of degraded land the moisture content is quite negligible below 135 cm. The rock strikes at this depth. The monthly soil moisture variation (Figure 4-13) observed shows that there is a gradual decrease of moisture with time after the recession of rain.

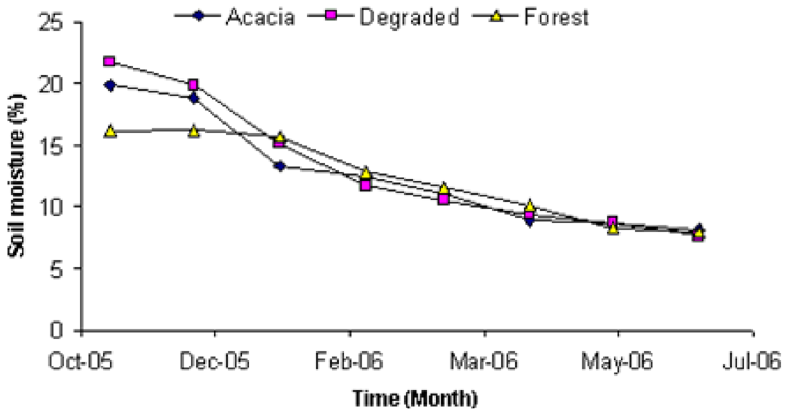

Figure 4-13. Temporal variation of soil moisture under different land-use in coastal region

From the soil moisture analysis results presented in Figure 4-14, it can be noticed that, the soil moisture in Acacia and Forested watersheds are waving type between surface to 120 cm and thereafter, the moisture content in the acacia watershed in increasing and whereas in the forested watershed it decreasing. This is quite obvious as the forested watershed has the trees of varying age and height with the longer root depth. However, Acacia plants are of 7-8 years old with the lesser root depth. Since the root in the acacia is not deep, there fore a possibility of moisture retaining at the lower depths.

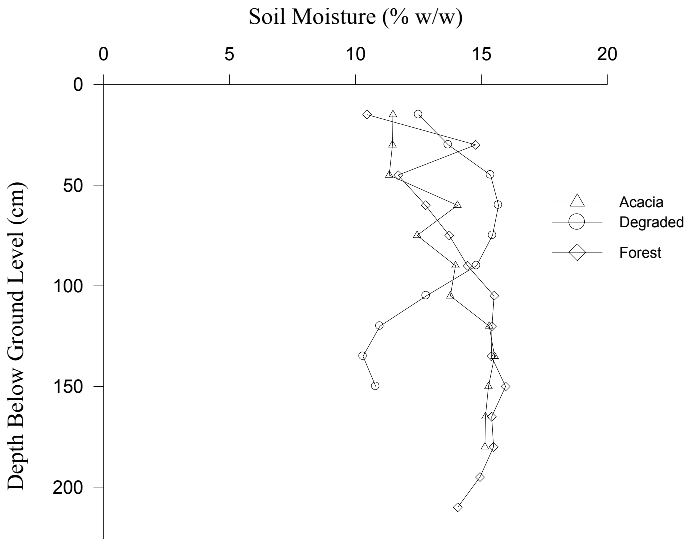

Figure 4-14. Mean Soil moisture profile observed under different Land covers during Post-monsoon period

4.2.4 Estimation of Evapotranspiration

The evapotranspiration can be estimated using the soil moisture measured during the Oct'04 to July'05 (entire non-monsoon season). The measurements during Aug to Sept were not done as the soils were completely saturated and enough moisture is available for the transpiration. Also, it is observed that, the humidity during the monsoon season is very saturated. Keeping these points in mind, the evapotranspiration estimates were limited to the non-monsoon season only, where the plants are using the moisture available in the soil mass for their physiological activities. From the table below show that, the forest is having the largest evapotranspiration value and degraded is the lowest.

Table 4-6. Estimated Actual and Potential Annual Evapotranspiration for the three land-use types

Region	Land-use	Based on Soil moisture depletion	Turc method (Potential)	Hargreaves method (Potential)
Coastal	Forest	1656.72	904.65	1820.90
	Acacia	1497.87		
	Degraded	787.35		

4.2.5 Application of SWIM Model to estimate runoff , ET and groundwater recharge

Hydrological processes involving soil-water interactions in the field, and particularly, the flow of water in the rooting zone of most crop plants, occur while the soil is in unsaturated condition. The ability of the soil to absorb, retain and transmit water gives rise to the notion of this zone behaving as a leaky reservoir. The water movements in the unsaturated zone, together with the water holding capacity of this zone, are very important for the water demand of the vegetation, as well as for the recharge of groundwater storage (Lakshman, 1993). A fair description of the flow in the unsaturated zone is crucial for predictions of the movement of pollutants into groundwater aquifers. Input at the soil surface is in the form of precipitation or irrigation out of which a part is absorbed and the other runs off. The water that infiltrates into the soil is later partitioned between that amount which returns to the atmosphere by evapotranspiration and which seeps downward and recharges the saturated zone. Soil Physicists, in the recent years have offered analytical solutions for describing water movement in the unsaturated zone and validated through several laboratory experiments. However, the natural conditions existing in the field soils are in no way comparable to the idealised and controlled laboratory conditions. Therefore, it is necessary to apply mathematical models to simulate the soil moisture profiles under field conditions.

Water in the rooted part of soil is quite mobile. Its distribution over time and depth is important because it determines the amount of water available to the crop. Water enters the soil as rain or irrigation water and also by capillary rise from the groundwater table. It leaves the soil by evaporation, drainage, and is taken up by roots for their transpiration needs. Gravity and gradients in moisture suction cause water movement within the soil. Soil physical characteristics (e.g. hydraulic conductivity) codetermine the rate of water flow. A soil profile generally consists of different layers with distinct physical characteristics and root activity. The thickness and physical characteristics of each layer must be specified for soil moisture simulations. The mathematical equations describing the soil processes are the same for all layers, but the outcome is specific to each layer in view of varying parameter values. Spatial variability of the soil water content at a given depth in the field is caused by spatial heterogeneity of physical characteristics of soil layers, irregularities at the surface, artificial drainage structures and by heterogeneous root distribution. This spatial variability is difficult to include in the models. One of the predominant factors which can affect the movement of soil moisture in the unsaturated zone is the type of land use cover such as forest, grass, agriculture, barren land etc. Different land uses may have different effects on movement of the water through unsaturated zone. Forest soils are noted for the proliferation of macro-pores, especially in the surface layers, because of the high density of roots and soil fauna activity. Such macro-pores allow the vertical by-passing of the unsaturated matrix and allow preferential flow of water to reach the saturation zone more quickly than the soil matrix.

The present study has been carried out to estimate runoff, evapotranspiration, and deep percolation under different land covers in a coastal block (Honnavar) based on data collected during 2004-2005, using the SWIM model. SWIM is an acronym that stands for Soil Water Infiltration and Movement. It is a software package developed within the CSIRO

Division of soils for simulating infiltration, evapotranspiration, and redistribution. The model is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, soil evaporation, deep drainage and leaching. The physical system and the associated flows addressed by the model are shown schematically in Figure 2. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g., precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model. The governing partial differential equation (Richards' equation) applicable for one-dimensional flow in the unsaturated zone can be written as:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} K \left[\frac{\partial \psi}{\partial x} + \frac{dz}{dx} \right] + S$$

where, θ = volumetric water content [cm3/cm3]
t = time [h]
x = distance into the soil[cm soil];
K = hydraulic conductivity[cm2 water/cm soil/h]
ψ = metric potential [cm water];
z = gravitational potential[cm];and
S = sink strength[cm3 water/cm3 soil/h]

The model deals with a one-dimensional soil profile. For a vertical soil profile, this means that it may be vertically inhomogeneous, but must be horizontally uniform. This assumption has two consequences of importance in many common simulations. There is only one hydraulic conductivity function for each layer, so that any macropore, or bypass flow can only accounted for in a limited way. Secondly, the calculated solute concentrations apply to the whole soil layer, which means that there is no concentration gradient from the bulk soil to near the root surface. The presence of such a concentration gradient may in reality affect the soil osmotic potential and hence water and solute uptake (Verburg, et al, 1996).

Table 4-7. Water Balance Components from SWIM simulations

Sl. No	Months/Y	Rainfall mm	Runoff	ET	GW Recharge
Forest Catchment					
1	May'04	355.8	39.18	127.96	213.48
2	June'04	956.6	210.32	54.56	421.8
3	July'04	942.6	301.64	66.71	452.35
4	August'04	942.4	371.89	67.55	476.59
5	Sept'04	147	58.8	74.19	57.43
6	Oct'04	85.6	19.9	113.4	25.68
7	Nov'04	13.6	-	143.4	-
8	Dec'04	0	-	177.19	-
9	Jan'05	0	-	187.64	-
10	Feb'05		-	169.69	-
11	Mar'05		-	196.29	-
12	April'05	125	-	176.44	-
	Total			1555.02	-
Degraded Catchment					
1	May'04	355.8	159.5	107.9	77.54
2	June'04	956.6	525.8	41.67	117.1

Sl. No	Months/Y	Rainfall mm	Runoff	ET	GW Recharge
3	July'04	942.6	611.33	46.45	119.15
4	August'04	942.4	637.57	47.97	144.32
5	Sept'04	147	72.6	49.56	31.43
6	Oct'04	85.6	51.9	101.4	5.38
7	Nov'04	13.6	Neg	123.4	-
8	Dec'04	0		137.37	-
9	Jan'05	0		147.34	-
10	Feb'05			129.36	-
11	Mar'05			146.91	-
12	April'05	125	NIL	136.44	-
	Total			1215.77	-
Acacia Catchment					
1	May'04	355.8	0	128.4	213.48
2	June'04	956.6	429.43	50.034	374.78
3	July'04	942.6	459.5	50.79	384.28
4	August'04	942.4	494.89	51.25	376.12
5	Sept'04	147	21	54.24	44.55
6	Oct'04	85.6	5.1	111.67	11.23
7	Nov'04	13.6	0	117.7	-
8	Dec'04	0	0	123.65	-
9	Jan'05	0		142.7	-
10	Feb'05			151.45	-
11	Mar'05			164.84	-
12	April'05	125	NIL	166.21	-
	Total			1312.934	-

ET estimates calculated based on soil moisture depletion method differ significantly from the estimates arrived at using SWIM model. This could be due to the higher slope condition as seen in the case of coastal watersheds.

4.3 Socio-economic Impacts of hydrological change on the domestic water sector

This study looks at the short-term impacts of seasonal shortages in water supply. We look at three discernible impacts of differences in water availability in two consecutive years - shift of source, changes in consumption and changes in labour spending by the households.

4.3.1 <u>Background</u>

Most assessments of impacts of changes in availability of drinking water have been done by agencies which undertake water supply projects (or other environmental projects) and do ex-post evaluations of benefits in terms of particular health benefits or in terms of time saved by women in bringing water. In the watershed literature, the effectiveness of watershed interventions has been measured by comparing villages with and without projects in comparable socio-economic communities. Very rarely a priori measurements are undertaken to measure the physical levels of availability, which in turn are never accurately defined. These assessments can be easier when the source of water shifts closer home or where piped water supply is made available and the household can be said to access a different service level altogether. However, little or no assessments are available when no 'investments' are per se undertaken and the change in water availability occurs solely due to a change in the catchment water levels and a change in their longevity through the summer period. These assessments become important especially in the context of watershed interventions where the water level increases occur in terms of higher well levels or availability of water through out the year. The present study is an exploratory attempt in this direction.

Differences in water availability might affect the household in different ways. Seasonal shortages might have a very different impact as compared to a shortage of water availability through out the year. Similarly, long term impacts of water shortages or poor service levels of availability will have a more wide ranging impact affecting not only labour allocation of the households, its choice of productive activities, health and life span of the households and its total welfare. In the short-term water shortages primarily mean longer hours spent in water collection or reduced consumption. Thus, impact analysis depends on whether the researcher is looking at the long-term impacts or the short term impacts. Again, the period of stress might affect livelihoods considerably. If water scarcity is an accepted part of a community's linkages with its land then migration in the lean season becomes a common livelihood strategy. However, adoption of a pastoral lifestyle as against an agrarian one itself culturally represents a human response to low water availability areas.

As compared to many studies that look at the economic benefits/costs of changes in groundwater recharge on agriculture production, there are few that look at the domestic costs for the households. Acharya and Barbier (2002) value the groundwater recharge function performed by the Hadejia-Jama'are floodplain through domestic consumption of groundwater resources. They estimate that a change in the recharge function due to reduced flooding within the wetlands, will cause an average daily loss of approximately 0.23% of monthly income for purchase only households, 0.4% of monthly income for collect only households, and 0.14% of monthly income for collect and purchase households. Pattanayak (2004) analyses the downstream economic benefits of watershed protection to generate watershed values of watershed services using household level economic and environmental data to the farming communities of the Manggarai in Indonesia. Their results suggest that a 100 mm increase in baseflow (10% increase from current levels) can lower per trip collection costs by 30 Indonesian rupiahs. A study in Basavapura watershed in Gowribidanur (Chandrakant et al, 2004), a drought prone area in Karnataka concluded that water harvesting structures improved economic access to water resource for irrigation by increasing groundwater recharge, reducing the cost of irrigation and increasing the net returns per acre of gross irrigated area. The study confirms the positive role of watershed development programmes (WDP). The cost per acre-inch of groundwater reduced by 48% using 'Before -After' approach for WDP and 22% using the 'With -Without' approach. Using 'Before-After' figures, after the WDP, the net return per acre of gross irrigated area (GIA) increased by 96 per cent and using the 'With-Without' figures, with the WDP, net return per acre of GIA increased by 60 per cent.

In a comparative study of two coastal villages in Kerala (with and without project), time saved from water collection could be the most important benefit of improved water supplies (Rosen and Vincent, 1999). Pushpangadan (2002) has estimated the social returns from investing in water supply, sanitation and hygiene education. An amount of Rs. 2431 is saved per household per annum when the value of time saved is taken into account due to improved water supplies, while the value of energy saved is estimated to be Rs. 6618. Even in a high rainfall region like Konkan in India it was found that in every household, on an average, women spend about 1 hr and 50 minutes a day in fetching and storing the water required which accounts for almost 25% of the time women spend in tasks other than those they spend on housework (Joy and Paranjape, 2005). Another study in Banaskantha, Gujarat (Francis, undated) proved that improvements in water supply can release time previously spent by households to collect water, which can then be used in rural enterprise to generate additional household income which might also use water as a productive input. Although the returns per enterprise vary widely (even among villages) existing rural enterprise has the potential to generate nearly Rs. 3 million for the 40,000 SEWA women members in the district. A breakdown in regular water supply during the three summer months, in villages where women are engaged in rural enterprise, can cost each woman, on average, the equivalent of 4 days of labour at the daily minimum wage, as well as around 14 hours of time that could have been spent in other personal or social activities. For all the 40,000 SEWA women in Banaskantha together, this is a loss of around Rs. 2 million. Other studies note important benefits from improvements in domestic water supplies on health, an increase in school enrolment and improved educational environment, a reduction in conflicts at water points, an increase in rural enterprises by women and many other social and cultural improvements (Ahmed, 2005; WaterAid, 2001; White et al, 1972).

4.3.2 Sample and Methodology

Initial group discussions conducted in the informal visits and pilot survey revealed a number of important insights, which helped in the formulation of the questionnaire and the framework of the problem. All data was collected by the recall method and no measurements were undertaken except an occasional visit to the house well and an inspection of other water

The differences in water levels are pegged to differences in rainfall in two consecutive rainfall years. As per the usual pattern of rainfall in the region they get pre-monsoon showers in April and May, while it is rainy season from June till November. The summer of 2003 was considered a “bad” one as compared to the summer of 2004. This was because the two years before 2003 were years of bad rainfall we need to mention how much was the rainfall 2001, 2002 and 2003 to show it as bad rainfall. (a period of drought for many villages across India) and monsoon was delayed even in 2003. This meant that the summer period was a long one with a late relief. Many wells dried up and this caused considerable hardship to many households. In 2004, however, monsoon arrived early and the scarcity was relieved earlier. This meant that the households had a shorter scarcity period by 45 days and the water levels in the community catchment were restored.

The present study values the socio-economic impacts on the household due to the period of extended scarcity or drought. It would be useful to note one important point here. As is widely recognized in environmental literature, there might be certain threshold limits or kinked trajectories in the system due to which the socio-economic costs of a drought of 45 days might differ drastically from a drought of lets say 60 days. The scheme of periodisation used to classify both the years are presented in the table below:

Table 4-8. Periodisation used in the study

Period	**Year 1 Good year (July 2003–July 2004)**	**Year 2 Bad year (July 2002-July 2003)**
Period 1: July 4th – March 4th	Period of abundant water	Period of abundant water
Period 2: March 4th – May 11th	Scarcity period	Scarcity period
Period 3: May 11th – July 4th	No scarcity due to rains on time	*Extended scarcity period*

4.3.3 Profile of the population

The caste profile of the studied population are given in Table 4-9The majority of the population from Honnavar region were Havyak Brahmins constituting 45% (19) of the sample, followed by 9 (21%) Ganiga households. Havyak Brahmins are an upper caste group generally holding considerable land while Ganiga households belong to the lower caste and have smaller holdings. In Narmundigai, Naik Namdaris constituted 80% (12) of the sample in the Nirmundigai region and there were only 2 Havyak Brahmin households here. Naiks belong to a low caste group and tend to have smaller holdings.

Table 4-9. Stratification of households by caste and landholding, and numbers sampled from each category for domestic water use survey (in brackets)

Hamlet	Caste category[1]				Landholding category[2]				
	Lower Caste	Middle Caste	Upper Caste	Total	Land Less	Small	Med.	Big	Total
HONNAVAR									
Benagodu		1	7(3)	8(4)	1(1)	0	1 (1)	6 (2)	8 (4)
Hodalugadde			2(2)	2(2)		0	1(1)	1 (1)	2 (2)
Hynagadde	2(2)	2(1)	1	5(3)	2(2)	1 (1)	0	1 (0)	4 (3)
Kalbaga		3(1)	5(2)	8(3)		1 (1)	1 (0)	4 (2)	6 (3)
Kerekon		4(2)	10(4)	14(6)		4(3)	3 (1)	5 (2)	12 (6)
Kubiramanakere		8(4)	8(2)	16(6)	2(1)	3 (2)	7 (1)	3 (2)	15 (6)
Meganamani	7(2)	11(7)		18(9)	1 (1)	8 (1)	5 (5)	3 (2)	17 (9)
Nadabaga		1(1)	5(3)	6(4)		2 (1)	1 (1)	3 (2)	6 (4)
Totalgundi		5(2)		5(2)		2 (0)	2 (1)	1 (1)	5 (2)
Unchutti			5(3)	5(3)		1 (1)	3 (1)	1 (1)	5 (3)
COASTAL Total	9 (4)	35(19)	43 (19)	87 (42)	6(5)	22 (10)	24 (12)	28 (15)	79 (42)
UPGHAT (Narmundigai)	0	21(13)	2(2)	23 (15)		10 (8)	8 (4)	5 (3)	23 (15)
Total	9(4)	56(32)	45(21)	110(57)		24 (13)	39 (23)	39 (20)	102 (56)

Source: Field Survey and Village Account Office

[1] Upper caste (U)- Avadhani, Havyak Brahmin, (M)- Vokkaliga Gowda, Ganiga and Shetty, Lower caste (L)- Namdari Naiks, Madiwala, Mahalaya. Mogaveera

[2] 2.5 ac tari paddy land is converted to 1 acre arecanut equivalent; Big (> 2 ac), Middle (>1 ac and < 2 ac), Small (< 1 ac), Landless. For 8 households in the coastal block, landholding information could not be obtained at the time conducting the survey of domestic water use

Land categories can be broadly divided into three types in the study area – arecanut (betel nut), paddy better not to use local names like tari and put readers in more complications and soppinabetta lands (beta, bena, haadi etc). Arecanut is the most important crop in both the regions. Nirmundigai (use common spell) has some paddy lands whereas there were no tari landholders from Honnavar. Over the years, most tari lands are being converted to areca if sufficient water is available through out the summer period. The average land holding of areca was 2.77 acres per household in Honnavar and in Nirmundigai it was 0.88 acres, average tari holding was around 1.25 acres for Nirmundigai. The soppinabetta holdings are somewhat higher in Nirmundigai area at 3.57 acres as compared to 2.77 acres in Honnavar. Nirmundigai is the traditionally areca area having better soils, greater water availability and yields are known to be a little better. More lands in Honnavar are irrigated however and farmers grow subsidiary crops such as betel leaves.

Table 4-10 below gives the livestock holding across various income groups. Income groups have been broadly defined according to land holding category. The richer households own a larger number of livestock in Honnavar as compared to the lower income groups. In

Nirmundigai the lower income groups own a greater number of livestock as compared to the lower income group of Honnavar. The local cow is the most commonly held animal. 22 households in Honnavar and 10 in Nirmundigai owned at least one local cow while 14 households in Honnavar and 3 households in Nirmundigai held at least one jersey or a cross bred cow. 14 households in Honnavar and 10 in Nirmundigai held at least one buffalo. Only one household had a bullock in Honnavar while 6 households owned a bullock in Nirmundigai. Only the medium and higher income groups own jersey or crossbreed cows.

Table 4-10. Livestock holding

Type/Region	Livestock holding					
	Sum			Mean		
Honnavar	Low	Medium	High	Low	Medium	High
Total adult livestock	10	26	50	0.83	1.86	3.13
Total calf	11	10	29	0.92	0.71	1.81
Poultry	14	0	25	1.17	0	1.56
Nirmundigai						
Total adult livestock	19	20	10	2.71	4	3.33
Total calf	3	5	4	0.43	1	1.33
Poultry	14	26	0	2	5.2	0

The terrain of both the sites is rugged with hillocks and valleys. Location of the household and its water sources would therefore be a crucial variable determining water availability and water security to the household through out the year. Location would bear upon the household in four ways – one the location of the household/sources upstream or downstream, the location of water sources near or far away from a stream, the geological features over which communities are settled and the depth at which they are able to dig into the water-table. There are stretches of hard rock, which don't allow households to dig open wells beyond a certain depth. It's difficult to compare households which are located at different altitudes and whose sources might be at a different altitude with different depths into the water table. Households in the midstream and the downstream area are expected to have better availability as compared to households upstream. Households whose sources of water are located on the stream bank or near to the stream have a greater possibility of having longer duration of water availability as compared to those households, which have wells further up/away from the stream. However, a careful hydro-geological study will be needed to index households as situated in a "good" or "bad" location by using a combination of all the indicators. In the present study, from the impressions of the researchers from the topography and from a study of the contours at 10 m interval on the toposheet, hamlets were classified as upstream, midstream and downstream. Households, which are located on hardrock, have been deleted from analysis while considering location.

4.3.4 <u>Waterscape in the region</u>

Most households have access to a private source of domestic water, which is usually an open well and also have access to water extracting devices, usually, an electric motor, pipelines into the house and a storage tank. But as summer approaches households are forced to shift sources compromising either on quality of water or accessing more distant sources and spending more manual labour to secure the water needs of the household. Currently the households don't view availability of domestic water as an issue of major concern as the shortage and resultant hardship is only seasonal. Their primary concern is the reduced availability of water for irrigation, which is affecting yields of areca and thus their incomes.

Most households depend on open wells used exclusively for domestic water through out or for at least a part of year. In Honnavar 69% (29) households and 73% (11) in Nirmundigai reported using an exclusive open well. 21 households in Honnavar and 1 household in Nirmundigai have a well, which is used for both domestic as well as for agricultural purposes. There were households, which were using a neighbour's well or a public well dug by the government and sometimes a well was semi-private where two households that are usually related share one common well. Overall use of open well was the most common even when the household did not exclusively own it. Other communal sources were the stream and farm pond. 4 households in Honnavar and 3 in Nirmundigai did not have a private source. About 48% households in Honnavar and 27% households in Nirmundigai can rely on private sources alone through out the year. Out of these 40% of the households in Honnavar have more than one source while only 7% households in Nirmundigai have more than one source for domestic water purposes. All other households (around 46%) depend on one or more public sources through out or at least for a part of the year. Four households in Honnavar depend on gravity to carry water from a lake or through the stream up to the house for most part of the year. Otherwise the use of stream, lakes and ponds is limited. More households in Nirmundigai reported use of stream as compared to Honnavar. Many households, which had their own motors installed on wells stall fed the cattle and therefore dependence of livestock on communal sources is not dominant. 3 households in Honnavar used hand pumps installed by the government and 3 households reported using a bore well.

Fourteen households have deepened their wells in the last 15 years and 9 households have deepened their wells since 2002. This could be considered as a first response to the scarcity caused by low rainfall the last 3 years. 19 households in Honnavar and 8 households in Nirmundigai dug wells in the last 15 years. 28 households invested in pumps in the last 15 years and 18 households installed tanks. Even this basic data shows that the intensity of use and investment in water extracting devices has intensified considerably over the last few years. The average depth of open wells ranged between 5 to 45 feet with an average depth of 23 feet and that of bore wells ranged between 185-225 feet. 74% of the sample households own at least one pump (some households have more than one), which is mostly an electric one having an HP ranging from 0.5 to 2 to pump water for storage tank. Most of these households have a pipeline connecting multiple taps to the houses. 40% of the households have one storage tank of cement or sintex and other households have tin/plastic drums.

Thus, the community is at a stage where it is heavily dependent on shallow groundwater with limited dependence on surface water and where it's at the nascent stages of exploring deep groundwater sources. This in spite of the fact that the study area is a relatively 'high rainfall' area expected to be rich in water sources.

It is difficult to differentiate the households in terms of having a good water situation or a difficult one by merely looking at the number of sources they own or access at any point of time. Some households have one domestic water well which meets all their requirements even in an year of low rainfall. Other households have one well to meet only the requirements of drinking water, which is withdrawn manually while for other domestic purposes water is pumped out. However, both these might dry up during the summer period forcing the household to access other public sources. A household, which is able to meet all its needs through out the year from a stream, might be considered a greater asset as compared to having an open well. Therefore, there will be some bias of the researcher in categorizing the households as better or poorer in terms of access to resources.

In spite of this we have tried to classify the households in a broad manner, which is expected to affect the hardship and time required to spend on water collection. Though water consumption and the time spent on collection can be a factor of the socio-economic status, location or household production activities, these factors are expected to be constrained by the choice of the household to invest in own sources and invest in water extracting devices. We have referred to this as the water asset status of the household in terms of owning own sources, pumps, tanks etc. At least in our present context this intermediary variable is expected to affect total water consumption and the variations in the seasons and also the total time spent through out the year and in specific seasons. The status of the household in terms of owning these assets will of course be a result of variables such as income or social status, family size etc. The costs of investments needed for procuring a comfortable level of domestic water supply in the study region are generally on the lower side and have a limited range. Therefore, given the present sample size for our study it was difficult to understand the determinants of water-asset status in the households.

Table 4-11. Asset Categories

Category	Honnavar	Nirmundigai
No water source	3 (7)	3 (20)
One water source	8 (19)	6 (40)
At least one water source and one pump	13 (31)	5 (33)
More than one water source and at least one pump	18 (43)	1 (7)
Total	42 (100)	15 (100)

Figures in brackets are percentages

4.3.5 Short term Impacts of changes in groundwater levels

We look at three short term adjustment costs of a seasonal scarcity due to delayed rains and resultant fall in water levels of the catchment. The two major short term impacts expected are a decrease in water consumption and an increase in time spent on water collection. However, impacts on households are not always amenable for quantification through the above two indicators. Often accessing a neighbour's house might involve some social constraint. One household reported alternating use between 5 different neighbours to avoid continuous dependence on one household's source. Other households shift to a private bore well for meeting domestic water requirements and therefore compromise on quality as water from the bore well was said to have an astringent taste and smell. One household had to shift from using a stream to private open well, while others have to shift from a domestic well to a farm well or bore well. Here, the hardship of the household is not reflected either in time spent or in quantity consumed. Therefore, we begin by looking at the patterns of the shift in source to get an indication of the above factors.

Thus, the labour time calculated by us would have a bias towards the lower side due to these gains in labour time. For some households, there is a shift for domestic water usage alone, while for others the shift would be for their entire domestic needs which usually increase hardship. For yet others, the collection time need not differ at all when it's a shift from own well to a neighbour's well, still there is a hardship in terms of restricted usage of water. For yet others, again differences in time might not be significant where when the shift occurs most activities are conducted at source.

Parmeshwara Subraya Hegde's household in Kerekona depends upon their open well through out the year. However, water levels fall drastically and towards the end of the dry period they are able to get a few pots of water in the morning and then they have to wait for the well to recharge before drawing further water. Also, the recharge is so low that there is not enough to draw through pots and the household has to use smaller utensils to draw water. The water that is drawn is often muddy and the household has to wait for the sediment to settle before it can be used. In some households, like in the case of Parameshwar Vishnu Avadhani, in Hodelgadde the compromise is in terms of quality rather than quantity. The first shift for him occurs in the month of March from one open well to another and the next shift occurs in April end when water levels fall too low and he has to depend on his bore well to get additional supplies. However the water from bore well is not preferable due to its rusty smell and taste. In the case of Manju Ram Jooge in Hyangadde whose house is located on a hill top, the alternate sources are as far as 2000 feet away and he has to travel on his bicycle to get water from a hand pump. 3-4 households in Nirmundigai have to travel to a farm pond 1000 feet away to get water. One common farm pond is dug in the paddy fields every summer which is not deeper than 4-5 feet and households spend considerable time getting water. Keriya Annapa Naik in Nirmundigai has to alternately draw water from 5 different neighbour's wells once he faces water shortage from April. Households, which get water by gravity through most of the year, start getting more water from other sources when water in the stream starts receding. Their water collection might actually go up as compared to when they conduct activities at source itself. These increases too actually indicate a worse-off position rather than an increase in water use per se.

4.3.6 Shift in source

Table 4-12 shows the incidence and pattern of shift in source in the water stressed year. 15 households in Honnavar and 4 in Nirmundigai who do not need to shift source at all and can be said to be most secure in terms of water availability in the catchment. The first shift occurs in November itself and 5 households in the sample have to shift source before March itself. Households which have to shift source before reaching the mid of May can be said to be the most vulnerable in terms of facing seasonal water shortage as their sources dry up before the arrival of rains even in a year of normal rainfall. Thus for 29 households (51%) the water level in the study region is not sufficient in summer to meet the domestic requirements in the optimum method of supply preferred by the households. In spite of the considerable investments undertaken by households to procure an optimum level of supply given the other socio-economic factors, these investments fall short to maintain the status of supply in the summer season. In a year of low rainfall, the hardship is increased as all the households who had shifted pattern in the second period have to continue using the sources or make a second shift in source as the dry period progresses. 9 households need to shift due to a period of extended scarcity. These are the households who suffer only in a year of delayed rainfall.

Table 4-12. Source shift across the year

Block	Honnavar	Nirmundigai
No shift	15 (36)	4 (27)
Period 1	5 (12)	2 (13)
Period 2	15 (36)	7 (47)
Period 3	7 (17)	2 (13)
Total	42 (100)	15 (100)

Figures in brackets are percentages

Table 4-13 summarizes the type of shifts households make. 10 households in Honnavar need to shift from a private source to another for meeting the major part of their needs, while another 10 households needs to shift to an outside source. In Nirmundigai, the majority of the households making a shift are to a non-private source. For 5 households the shift is only to the extent of meeting their drinking water needs, which generally does not consist of more than 10 pots per household.

Table 4-13. Variation in the kind of shifts taking place in response to water scarcity

Nature of shift of source	Honnavar	Nirmundigai
No shift	15	4
Private to private source	12(2)	1
Private to other source	11(1)	7
Stopped using a separate source for drinking water	1(1)	0
Others	3(1)	3

Total	42	15

Note: The number in brackets indicates households that shifted source only for their drinking water requirements
Source: field survey

Six households in Honnavar and 2 in Nirmundigai need to make a second shift in their source indicating a further compromise. For 3 of these households the shift needs to be undertaken only in a year of delayed rainfall.

Table 4-14 shows the water usage and shift pattern between surface and ground water. As can be seen 16 households depending on open wells need not shift source and another 25 households shift from an open well to another. Only in Nirmundigai 6 households shift from groundwater to surface and this is because of their dependence on a farm pond, which is dug especially to meet the summer shortages in a low lying field.

Table 4-14. Shift between ground and surface water

Type of source shift	Block			
	Honnavar		Nirmundigai	
	Frequency	Percent	Frequency	Percent
Surface - Groundwater	1	2.4		
Groundwater – Deep Groundwater	2	4.8		
Groundwater – Groundwater	20	47.6	5	33.3
Groundwater	12	28.6	4	26.7
Surface - Deep Groundwater	1	2.4		
Surface – Surface	1	2.4		
Surface	3	7.1		
Groundwater – Surface			6	40.0
Total	42	100.0	15	100.0

The timing of this shift is given in Table 4-15. A greater percentage of the lower income group need to shift source as compared to the higher income groups and a majority of them need to shift in period 2 itself indicating hardship in the summers of normal rainfall year too. Since the above data is for the year of delayed rainfall, the households, which have to shift in period 3, are spared from the need to shift in a year of timely rainfall. In a good year 74% of the lower income group need to shift source, while only 48% of the middle income groups will need to shift source and only 31% of the higher income groups need to shift source. Out of the 6 households in the middle and higher income group who have to make a shift in period 3, for 3 households the shift is only for a change in drinking water source implying small quantities, and for one household the shift is within the household's own sources and for two households from own well to a neighbour's well. For all the three lower income households however this shift is from a private open well to a public source – farm pond or hand pump.

Table 4-15. Shift pattern across income, asset and location groups

Factors	Shift period	No Shift	Period 1	Period 2	Period 3	Total
Income[30]	Low	2 (11)	3 (16)	11 (58)	3 (16)	19 (100)
	Middle	9 (47)	3 (16)	6 (32)	1 (5)	19 (100)
	High	8 (42)	1 (5)	5 (26)	5 (26)	19 (100)
Asset Categories	No water source	2 (33)	2 (33)	2 (33)	0	6 (100)
	One water source	3 (21)	1 (7)	8 (57)	2 (14)	14 (100)
	At least one water source and one pump	9 (50)	1 (6)	4 (22)	4 (22)	18 (100)
	More than one water source and at least one pump	5 (26)	3 (16)	8 (42)	3 (16)	19 (100)
Location	Downstream	7 (33)	3 (14)	7 (33)	4 (19)	21 (100)
	Midstream	7 (37)		9 (47)	3 (16)	19 (100)
	Upstream	5 (29)	4 (24)	6 (35)	2 (12)	17 (100)
Total		19 (33)	7 (12)	22 (39)	9 (16)	57 (100)

The asset group that is having at least one source and one pump seem to be well off in terms of having to shift source the least. 72% of the households don't have to shift source in a year of good rainfall, only 22% have to shift source in the third period. The fourth group has not been able to improve their vulnerability greatly by investing in an extra source. This also indicates that beyond a point its some other variables like location, which might play a crucial role in determining water availability. 42% of the households still have to shift source in period 2 itself. In the group that has one source 57% of the households have to shift source in period 2 itself.

The factor location does not show any definite patterns. The first shift occurred for a household in Meghanmane (upstream) during the end of November. They shift from their domestic well to their farm well. Their domestic well, which is just 10 feet deep and the farm well, is about 20 feet. The shift occurs for another household in Meghanmane from a domestic well to a farm well, the farm well is 10 feet shallower than the domestic well, which is of 20 feet. However, it's situated 150 feet away from the household indicating that it might be situated in a valley or near a stream. Detailed information not only regarding the location of the household but the location and the quality of its water sources will have to be compiled to better analyze and make a composite index capturing relative water availability across households.

4.3.7 Change in quantities consumed

The demand for domestic water would a priori be considered fairly inelastic especially in a considerably homogenous group such as ours. There are few amenity users in the rural area and neither are there households, which are unable to meet even 'basic access' through out the year. Yet there are considerable variations in the per capita water used, which could depend upon the livestock ownership, watering of home gardens, household's status, household's access to water, conducting activities at source etc.

Since we depended on respondent's recall rather than using any direct observation methods, the quantities of water used by the households might not be very accurate. The households couldn't answer definitely as different people collected different amounts of water for different purposes at different times in the day. Households having a motor just pumped the water without waiting for their tanks to be emptied. Also, information was collected primarily on water collected from different sources and not on quantities used for various activities. Therefore, though most households felt that did cut down on consumption in summer they couldn't say by how much and in what uses. Therefore, it's difficult to pin down the reasons for differences in water consumption across households. Households, which have easy access might use greater quantities for water home gardens, stall feed the cattle or use water for other uses. Similarly households, which conduct some of their activities e.g. livestock watering, washing, bathing etc., at the source itself do not collect the water per se and there might be a tendency to underreport this consumption. Similarly, in the rainy season some of the households harvest considerable amounts of rainwater directly and there is no manual 'collection' of such water. The exact reasons for differences in water consumption and also more accurate estimates of water consumption itself would have to be arrived at through more participatory tools requiring longer commitments of time. An activity diary comprising of water consumption for different purposes through out the day kept over a few days for each season would have reflected the total water consumption at the household level more accurately.

Water consumption at the household level does not indicate any definite relationship with family size, livestock holding, size of the house, or income of the household. This could be due to inaccurate data as discussed above. The Pearson's correlation shows a significant association 0.379 with livestock, .305 with size of house, and 0.765 with income in Honnavar and 0.702 with size of house and 0.700 with income in Nirmundigai. However, if we consider the rank correlations to nullify the effect of outliers, we can see that there is no correlation of any of the independent variables with pots consumed. Here we look at the differences in household consumption across the three periods over income, asset and location groups.

Figure 4-15-Figure 4-17 show the mean per capita consumption per day across the three periods of the bad year. We can see that the seasonal changes within groups are relatively of a smaller magnitude, as compared to the differences across various groups. The important points emerging from the figures are as follows.

Consumption is generally lower in Nirmundigai as compared to Honnavar across all groups. The percentage cut is also greater in Nirmundigai as compared to Honnavar. There is an increase in water consumption over the asset categories in both the blocks. When rains are delayed as they were the last year, then water consumption in period 3 falls lower than in period 2 indicating a fall in water levels and intensification of hardship due to delayed rains. This seasonal variation is reflected in spite of 8 households which are actually able to increase per capita water use in period 2 and period 3 as the household's requirement of water increase in the dry summer period. Across income groups too, generally water consumption rises significantly, except for middle-income group of Nirmundigai. All income groups need to cut consumption in the dry period but the percentage cut is greater for the lower income groups. The compromises that occur due to this reduction for the lower income households might affect more basic uses of water such as hygiene. The consumption is lower for the upstream users as compared to the down and midstream users.

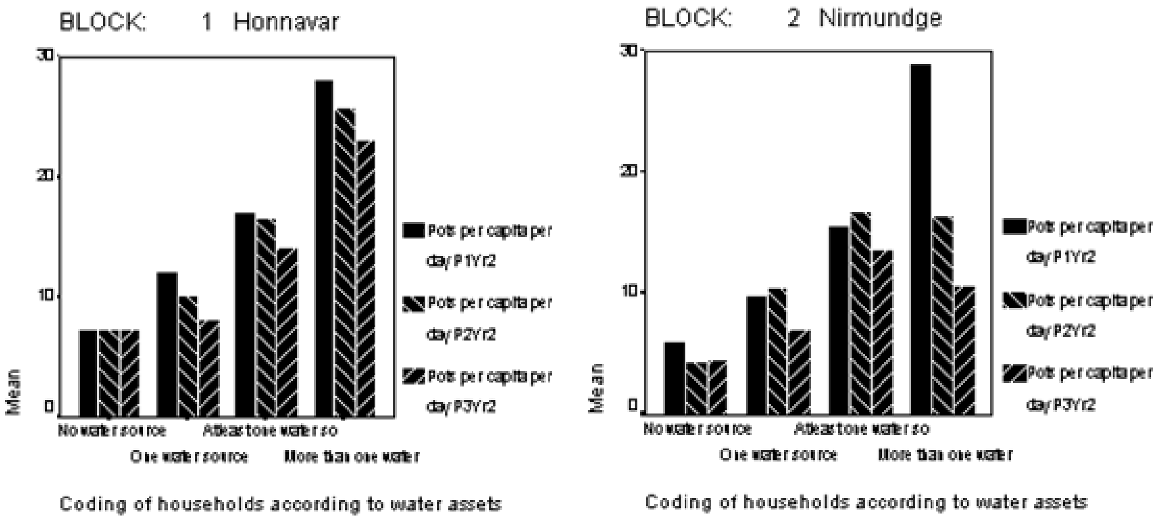

Figure 4-15. Water consumption across seasons according to asset categories

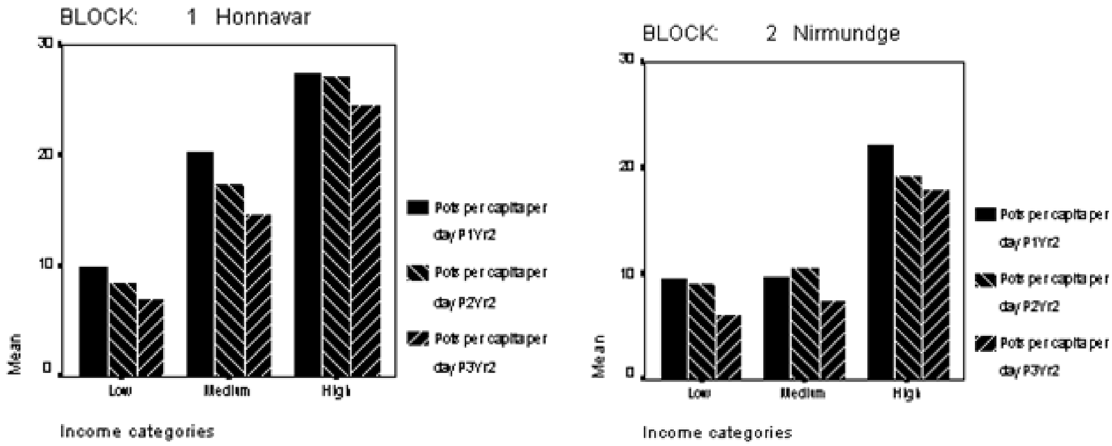

Figure 4-16. Water consumption across seasons according to income categories:

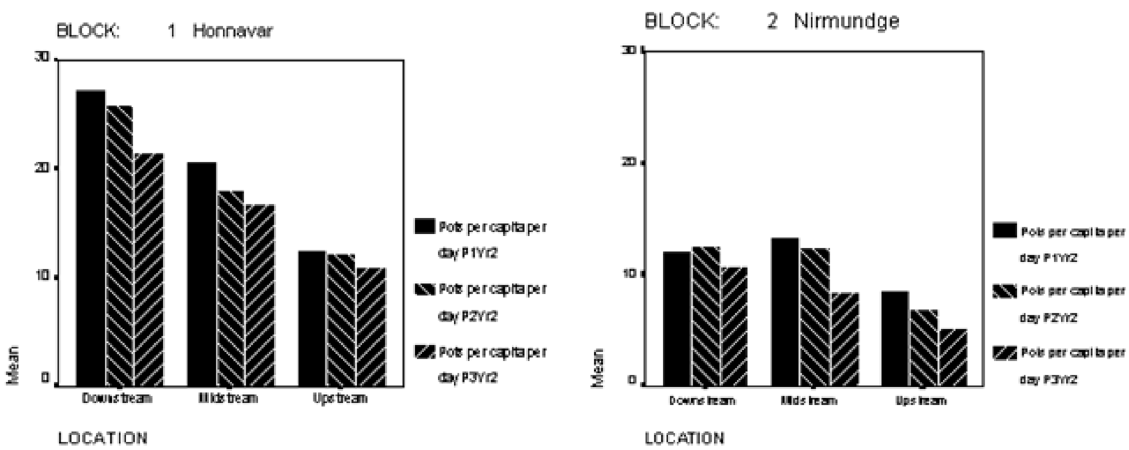

Figure 4-17. Water consumption across seasons according to location categories:

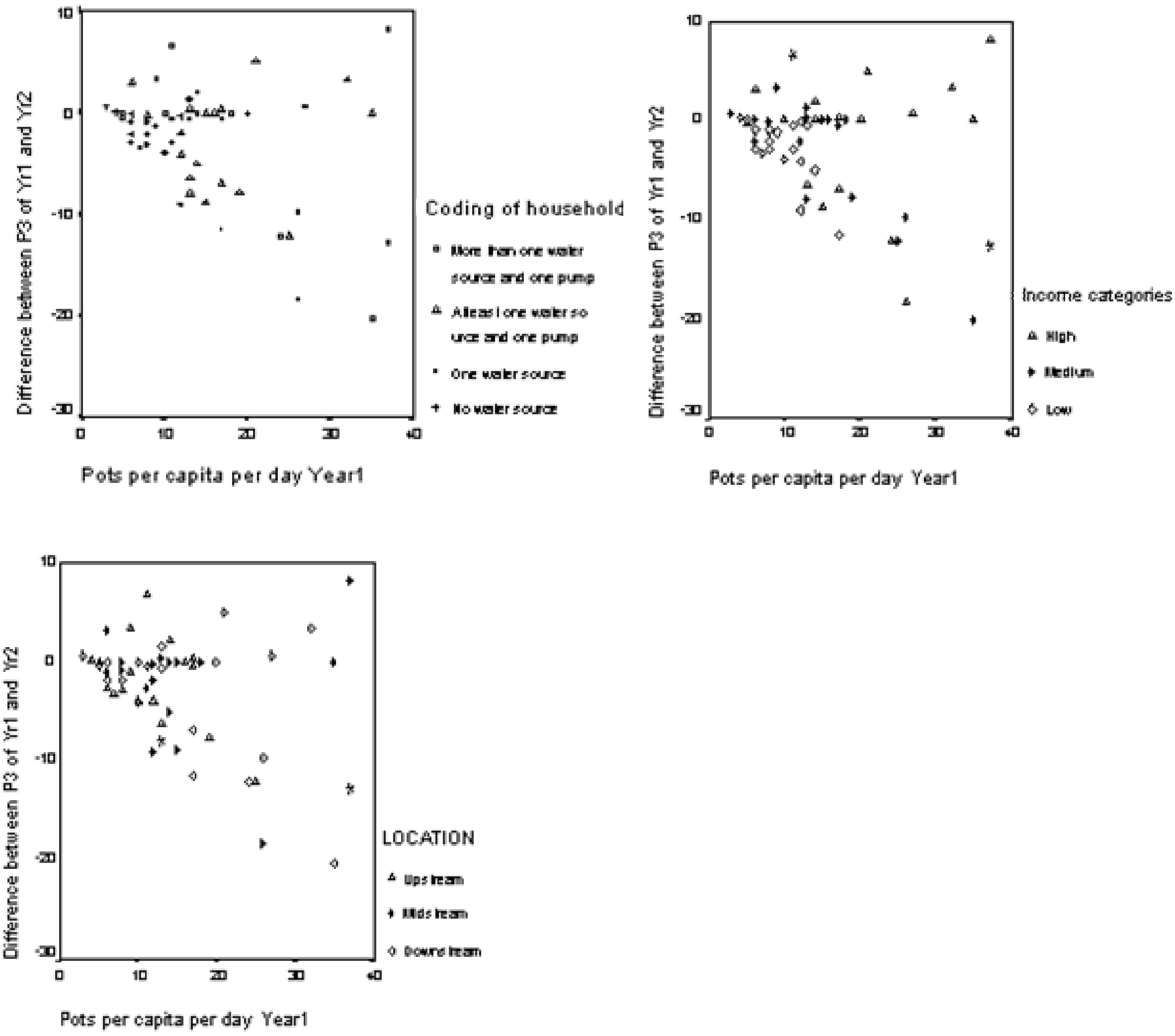

Figure 4-18. Difference in the third period of year 1 and year 2 across asset, income and location categories

The scatters in Figure 4-18 help to understand which households increase/decrease consumption and the extent of the variation across asset, income and location groups. The households have been arranged from left to right on the x-axis based on their per capita consumption figures for year 1. The y- axis is the difference in per capita consumption between periods 3 of both the years. This is also indicative of the difference in consumption between period 1 and period 3 of year 2, as the households were able to resume their consumption to the levels of p1 in the good year. The figures show that it's the higher water users who cut down or increase their consumption significantly. On the left side variation is much lower. The first scatter, which is marked for asset-categories indicates that these significant increase or decreases in consumption are made by the upper two asset groups. The no water source, or one water source can rarely increase their consumption in the dry period, but these households still face a cut that cannot be drastic as they are already the lower water users. This indicates that the upper groups use higher quantities of water when it is available even if they have to cut down on water consumption in the dry period, it still keeps their water consumption above that of the lower asset groups. A similar pattern emerges for the income-categories. The lower income groups are the lower water users who can't increase water consumption in the dry period, however they face cuts in their consumption in the scarcity period. All higher income groups increase their consumption in the period 3 this year as compared to the period 3 last years. The location scatter shows a similar pattern. The upstream users are the lower water users who face small cuts in consumption. The households, which decrease consumption by more than 5 pots, are generally the downstream or midstream users.

4.3.8 Changes in labour time spent

The following patterns were observed in the field:

- Many households draw water (about 5-10 pots per day) manually from open wells for drinking purposes even when they own a pump to draw the rest for other domestic needs

- A few households need to collect drinking water from other (not private or distant) sources, though they have other convenient sources to access domestic water for other purposes

- Most households spend manual labour in collection of water in the dry period as their own regular sources dry up and they have to depend on public or neighbour's sources.

- The labour used is mostly household labour and only 1-2 households were seen getting the work done from labourers.

- Women are involved in most of the collection on a regular basis, however in the dry period when water needs to be carried from far away places, more men participate in the activity.

Time spent per trip was also not collected by direct observation. Instead we asked the respondents to tell us the time spent per trip from each water source. It's possible as with quantities consumed that this may be subject to a person's subjectivity in stating the time required for a trip. Total time taken to collect water has been calculated based on the amount of time taken to make a trip to the source, draw water and get back. Since the number of pots carried per trip by person varies from source to source depending on the terrain for each household and member-to-member, an average of 1.5 pots per trip was assumed for all members. At best we rarely saw women carrying more than 2 pots at a time even when the trip was to a nearby open well, and where women had to climb down steep slopes they could not carry back more than just one pot at a time due to the danger of slipping. The time spent by different members in water collection calculated according to the total pots collected on any day on an average by men, women and children from each particular source.

Table 4-16 reflects the person days that were required to be spent on collection in both the years (the additional days of year 2 reflecting the increased labour costs due to scarcity period) and the three periods of the bad year.

Table 4-16. Total number of person-days spent in year 1 and 2 and period-wise for year 2

Block	Honnavar			Nirmundigai		
	Sum	Mean	SD	Sum	Mean	SD
Total Person days spent in Yr 1	1564	37	42	1018	68	51
Total Person days spent in Yr 2	1890	45	44	1229	82	59
Person days in period 1y2	946	23	28	582	39	33
Person days in period 2y2	422	10	11	333	22	19
Person days in period 3y2	509	12	14	310	21	16

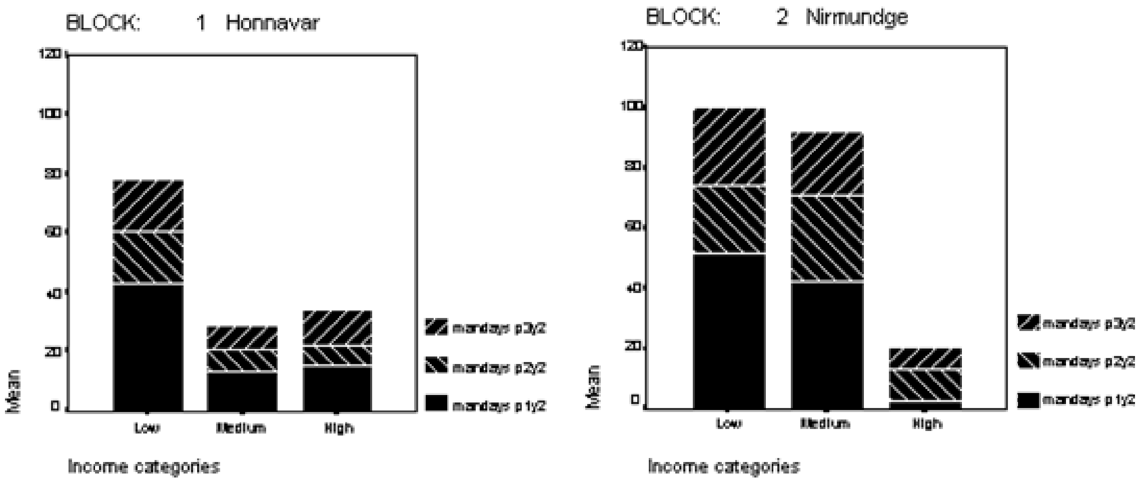

Figure 4-19. Person-days spent according to Income categories across seasons

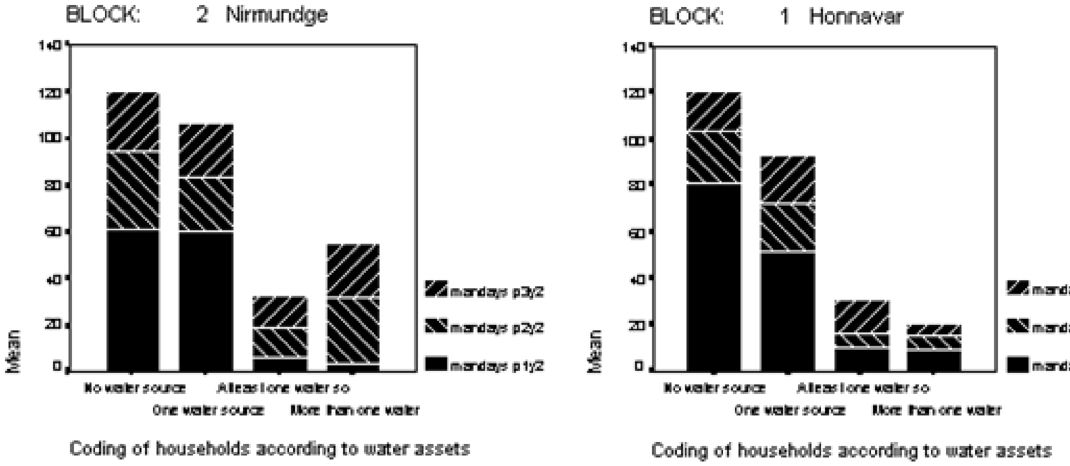

Figure 4-20. Person days spent over different seasons according to asset-categories

The low-income groups as expected spend a larger proportion of person-days in the availability period that is period 1. The total number of person-days spent for the high income groups is much lower than the low income groups. The proportion of person-days spent by the medium and high income groups in the period 2 and 3 equals the total number of person-days spent in the availability period which is spread over 8 months. A similar pattern emerges from the asset-category classification in Figure 4-20. The person-days spent by the households, which have more than one source and pump are considerably lower but the proportion of it increases in the dry period. (A classification by location was left out because it didn't produce any significant variation)

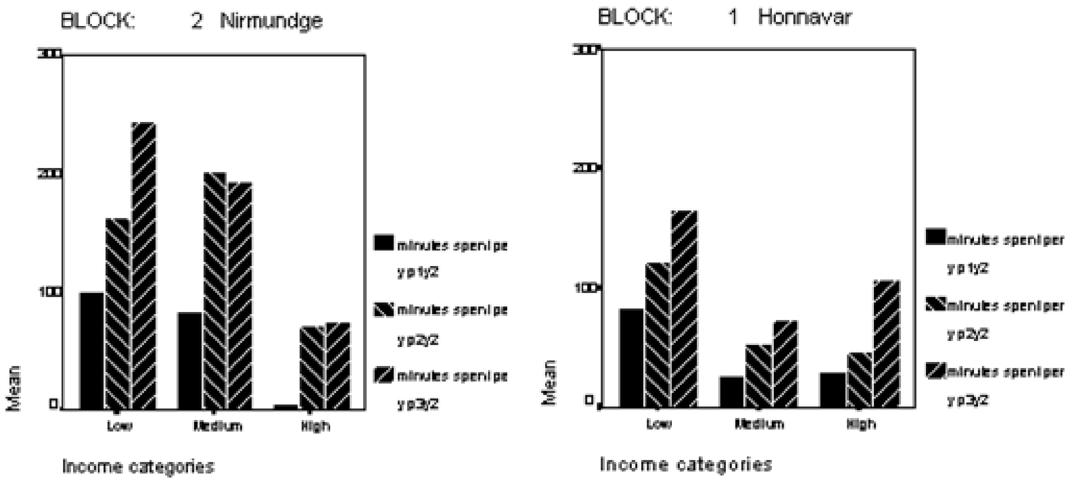

Figure 4-21. Minutes spent per day in different seasons across income categories

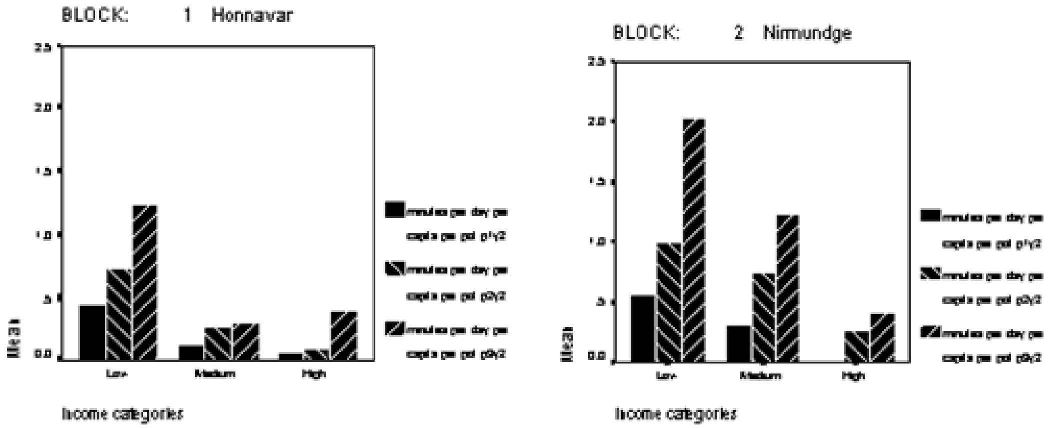

Figure 4-22. Minutes spent per capita per day per pot in different seasons across income groups

A similar picture emerges when we look at the minutes spent per day by different households in water collection and the minutes spent per day per capita per pot over different seasons across income and asset categories. Minutes spent per day is much higher for period 1 for the low income but the figure rises for the dry season for the other groups, however the impact still remains high on the lower income groups.

4.3.9 Distribution of additional days spent over income groups:

Table 4-17. Distribution of additional days spent over income groups.

Income groups	Honnavar				Nirmundigai			
	Mean	SD	Sum	Percentage of total	Mean	SD	Sum	Percentage of total
Low	8	14	98	31	16	12	115	55
Medium	5	10	73	23	15	20	73	35
High	9	17	143	46	8	13	23	11
Total	7	14	314	100	14	15	211	100

Table 4-17 shows the distribution of the additional days over income groups. The patterns are quite different for Honnavar and Nirmundigai. The average days spent in a bad year is much greater across all groups in Nirmundigai as compared to Honnavar. However, in Honnavar, a greater percentage of additional person days are being borne by the high income group as compared to Nirmundigai where the largest share of additional person days is being born by the lower income groups.

The above pattern might have significant implications for the valuation of labour time spent by the richer households. It's possible that the willingness to pay for the additional water in the drier periods is much higher than can be valued by labour time. Of course, in places where unskilled labour is available in plenty, at the least these households might be willing to pay the cost of labour to procure additional water in the absence of which they might be spending household labour to procure water for domestic needs. Or in spite of the availability of labour, it might not be economical or accepted practice to hire labour only to procure domestic water. However, a higher price might be paid if water vendors were prevalent in the area. As noted above, the richer households are investing considerably on an annual basis to procure water at a comfortable level of service and they might be willing to avoid the extra labour time spent in procuring water at a significant price if markets were existent. A contingent valuation might be better able to capture the full benefits (for e.g. Social status of household women not needing to carry water) of water availability at levels that are available in Period 1 to the households.

4.3.10 <u>Valuation of Labour</u>

Almost all the households (51 households) have women-participation in procuring water in both period 1 and 3. The number of households in which there is male participation in procuring water increases from 14 to 25 households from period 1 to period 3. In about 6 households children also participate in water collection. Table 4-18 shows the proportion of time spent by men, women and children in water collection. As with consumption and time spent before there are a few complications that must be noted. Different households have a different division of labour for fetching water, which differs over seasons and also depends upon the source used. Generally, the men contribute labour in fetching water when the household has to depend upon a far away source as we can see from Table 4-18. The contribution of children is restricted to a few households however, the time spent by them is considerable. Certain paradoxical situations can emerge when division of labour for fetching water is tied to the water source. If children are required to fetch water only from nearby and convenient sources then often their contribution decreases in the dry period. Which means that when a dry period extends, then its not necessary that the contribution from children will go up. However, the labour time spent by men will go up with the length of the dry season. Again, since data was not collected by direct observation its possible that these linkages are far more complex at the ground level.

More woman days rather than man-days are spent in procuring water. Even when the contribution of men rises in the dry period, it is the women who bear the major burden of bringing water even in the dry period. When a dry period extends women have to bear 63% of the extra time required to spend on bringing water to the household.

Table 4-18. Distribution of person days spent across various population groups

Block	Men	Women	Children
Honnavar			
Period 1	148 (16)	781(83)	17(2)
Period 2	83 (20)	322(76)	17(4)
Period 3	137(27)	346(68)	25(5)
Total	368(20)	1449(77)	59(3)
Extra days	103 (33)	195 (63)	13 (4)
Nirmundigai			
Period 1	43(7)	474(82)	63(11)
Period 2	70(21)	227(68)	37(11)
Period 3	76(25)	198(64)	35(11)
Total	189(15)	899(74)	135(11)
Extra days	70 (34)	111 (54)	23 (11)

Figures in brackets are percentage of person days spent

4.3.11 <u>Valuing according to shadow wage rate:</u>

Women are paid Rs. 35/day with out food and Rs. 30/day with food and men are paid Rs. 60/day sometimes without breakfast (Kodgibail report). This was taken to be the representative of both Honnavar and Nirmundigai. No child labour was noted in the study area, however, we have imputed a value of Rs. 20/day for children. However, in valuing the benefits of water related projects, it is assumed that the value of time spent collecting water should be valued at one-half of the wage rate for an unskilled labourer in the project area (P. Webb, M. Iskandarani, 1998). The above table shows the extra costs incurred by the households in terms labour spent alone valued at the shadow price of labour. Table 4-19 provides the figures for both the estimates.

Table 4-19. Valuation according to shadow wage rate (Rs)

Alternative valuation approaches	**Honnavar**	**Nirmundigai**
At the full wage rate of unskilled labour		
Men	6180	4200
Women	6825	3885
Children	260	460
Total	13265	8545
Cost per household	316	570
At half the wage rate of unskilled labour		
Men	3090	2100
Women	3413	1943
Children	130	230
Total	6633	4273
Cost per household	158	285

4.3.12 <u>Valuation of additional energy spent on water collection:</u>

The person-days spent can be also valued according to the total calorie wasted by the households in fetching water which would be the real costs faced by the households.

The general formula for calculating the total time saved can be arrived at by the equation (1) (Abelin, 1997).

T = (2D/1000 S + q/60 + V/60 Qd)(1000/V) … (1)

Where:

T = Travel time for fetching water (hours/m3)
D = Distance from home to the source (meters)
S = walking speed (km/hour)
q = queuing time (minutes per trip)
V = volume collected (litres/trip)
Qd = water delivery rate at source (litres/minute)
1.m3 = 1000 litres.

For our study the queuing time is not valid as there was no crowding reported even at government wells with enough space for drawing the water. We have ignored the discharge rate in our study. This leaves only the time spent travelling additional distances. We use the additional person-days spent on getting the water as representative of additional distances travelled as a rough measure instead of using the above formula. This is not an unreasonable assumption since most increases in time spent are due to reaching farther sources. Assuming average weights for female as 45 kg and average weight of male as 55 kg and walking speed as 2 km/hour (Pushpangadam, 2002) a value of 1.37 calories can be imputed as calories lost per minute for females and 1.63 calories lost per minute for males in bringing water. Thus, for valuing a person day spent on water collection for females the calorie spent per day would be 657.6 and for men it would be 782.4. The results are given in Table 4-20

Table 4-20. Costs according to energy expenditure

	Extra days	Additional calories spent	Value in Rupees*
Honnavar			
Men	103	80587.2	424
Women	195	128232	675
Children	13	8548.8	45
Nirmundigai			0
Men	70	54768	288
Women	111	72993.6	384
Children	23	15124.8	80

The conversion of energy expended into money value is based on poverty estimates. The poverty level in the rural area per person per month in Karnataka is Rs. 309.58 per capita per month for the year 1999-2000 from Government of India (2001): Poverty Estimates for 1999-2000. These have been inflated to the 2004 value based on prediction of inflation rates (http://www.chass.utoronto.ca/link/meeting/ctryrep/india0304.htm#table3). The per capita income needed for buying 2400 calories worth of food, the poverty line, is Rs. 379.21 in 2004. This conversion factor is used for the valuation of energy expended.

4.3.13 Concluding Observations

The study has attempted to estimate socio-economic costs of hydrological change using a simple methodology. Though the study region is a high rainfall region supposedly water-rich, there are seasonal water shortages, which impose significant costs on the households in terms of labour time spent on water collection. This region needs to be highlighted because most of the government drinking water projects concentrate on drier regions, explaining that there is not much drinking water problems in the high rainfall regions, which is not true. Households have to cut down on water consumption and walk longer distances to get the water required for domestic uses. The seasonal variation in consumption is not uniform over the different socio-economic groups. The rich households who have invested in more sources and pumps and who are located downstream or midstream are generally the higher users of water as compared to the lower income, lower asset upstream households. Seasonal variation affects the already lower water using groups. An increase in consumption during the dry period is specific to the groups who have more assets, better incomes and are located downstream. A decrease of more than 5 pots per capita per day occurs only for the upper groups, in spite of which the average per capita consumption remains above that of the lower groups. Similarly, the richer households spend fewer hours in water collection in the availability period as compared to poorer households. In the summer period however, more hours need to be spend by the richer households as well, as the motor-tank apparatus becomes useless when the private well dries up. Valuing this additional time spent in water collection brings low estimates of costs per household, which might justify the reason why the households find a greater burden of water scarcity on agriculture as compared to that on domestic water.

The study faces limitations as the water quantities consumed by the household and time taken for water collection from different sources was not noted from direct observation. Secondly, information was collected primarily on water collected from different sources and not for water used for different activities. For example, easy access to water might allow the households to apply greater quantities of water to home gardens, use greater quantities of water for livestock instead of using open or communal sources, undertake activities for home consumption etc. Drawing an exhaustive list of water-involving activities would enable a better socio-economic assessment of costs on household due to decreased availability.

Chapter 5. Rainfall, Groundwater and Agricultural dynamics: the case of Arepalya in BR Hills block

The case studies in the previous three chapters pertain to situations where surface water flows and stocks were the primary focus, since the social use of water was primarily in this form. The case of Arepalya village and its catchment, presented in this chapter, is one where the focus is largely on groundwater. Thus, while representing (along with Bandipur) the lower rainfall end of the range that we have sampled, this case calls for a nuanced understanding of groundwater recharge and its use by local communities—a situation that is probably typical of many of the dry parts of peninsular India today.

We will first provide a background to the study site in terms of physical location, the nature of agriculture and so on. We will explore in greater detail the manner in which groundwater availability is linked to catchment recharge and rainfall, the impact of pumping on groundwater depletion and finally the economic consequences of this to farmers in Arepalya.

5.1 The study area

5.1.1 Location, topography and climate

The Biligiri Rangan Hills (popularly known as the BR Hills) are part of the north-eastern protrusion of the Western Ghats that bridges the Nilgiri hills with the Eastern Ghats in Tamil Nadu. The BR Hills also form the southern edge of erstwhile Mysore district, and straddle the boundary between Chamarajnagar, Yalandur and Kollegal talukas, all of which now comprise Chamarajnagar district (see Figure 5-1).

The region is characterised by a climate classified by the Indian Meteorological Department as 'Tropical Savanna, hot, seasonally dry'. Locally, however, the rainfall ranges from a mean of 800 mm in Kollegal to over 1500mm at the top of the BR Hills. This region, unlike the other locations in this study, receives significant rainfall from both the southwest and the northeast monsoon. Indeed, typically only about 40% of the annual rainfall comes from the southwest monsoon (June-September), with a similar amount coming from the northeast monsoon during the October-January period. The geology of the region is characterised by Charnockites. Soils on the slopes of BR Hills are generally shallow, rocky, gravely-clay soils classified as Ustropepts (Inceptisols). Stream channels often are extremely rocky with rock outcrops in the upper slopes, and a sandy downslope.

Arepalya is a village that nestles in a valley on the western side of the BR Hills at its northern end, approximately 10 km away from Kollegal town in what is now Chamarajnagar district. (See Figure 5-1 for details). The settlement is located in a narrow east-west valley, surrounded by steep hills on three sides, with the eastern end rising sharply into the BR Hills. Three streams emerge from the hills, and merge soon after they reach the valley, to constitute Hebbahalla stream. The catchments of these streams have steep slopes, (slope values ranging up to 37%) and the typical shallow soils of 0-1m, underlain with weathered rock. The stream beds in the catchment are laid with a more than 0.5 m thick layer of gravel and boulders with stretches of rocky outcrops and steep falls, while in the valley portion the stream bed is laid with more than 1.0 m thick layer of sand and pebbles. The streams are highly seasonal.

5.1.2 Social composition and livelihood systems

Latest data (collected through our own survey) suggests that there are 215 households in Arepalya and a population of 1,090 - The village consists of five hamlets viz., Yerekatte, Arepalya, Mullekatte, Tamil Colony and Uparshetty Colony?. Arepalya is the main hamlet, populated largely by Vokkaliga Gowdas. While cultivation in the Arepalya valley has been going on probably for a 100 years or so, it was being done by cultivators living in the neighbouring villages of Surapura and Madhuvanahalli till 50-60 years ago, when Arepalya hamlet was settled. On the other hand, the Soligas who reside now in Yerekatte had mostly lived in the forest area upstream of the village prior to the settlement of the village by non-tribal communities.

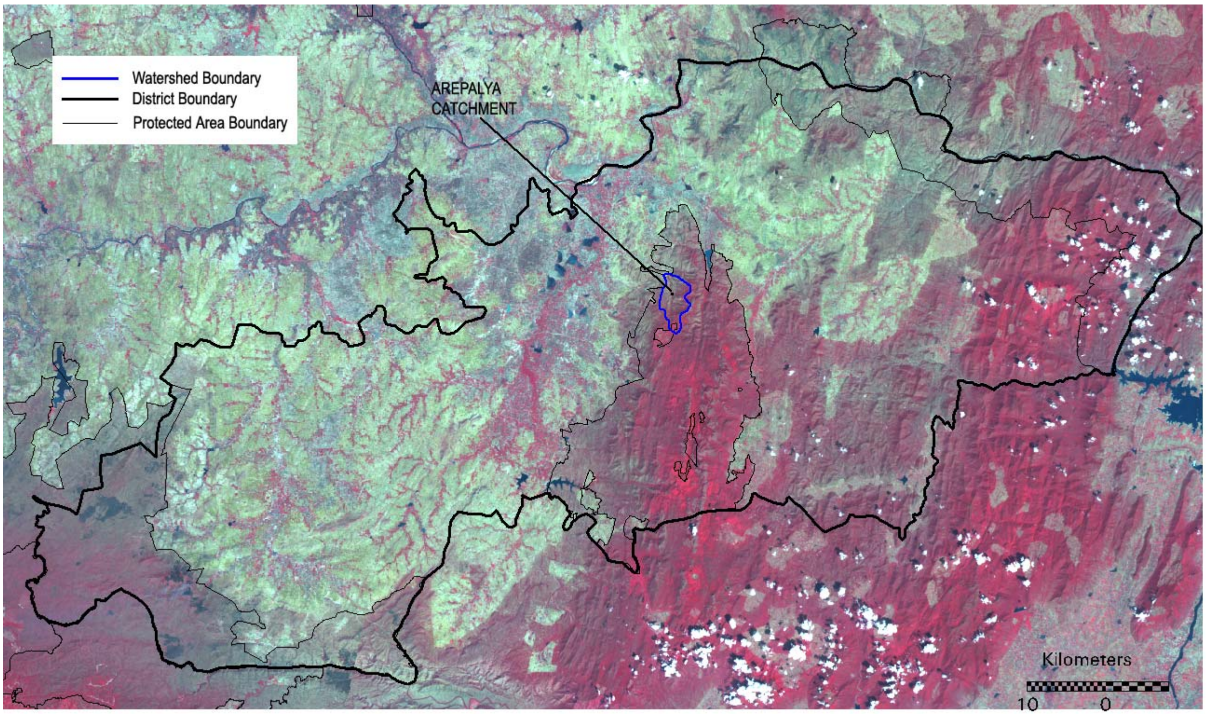

Figure 5-1. Location of BR Hills region and Arepalya catchment in Chamarajnagar district

Agriculture, as suggested above, is the main source of livelihood in Arepalya (including now for the Soligas). Most cultivable land is under rainfed crops, though approximately 30 per cent of land is irrigated, and mainly consists of ragi (millet) and horsegram and more recently maize. Mulberry was a major commercial (rainfed and irrigated) crop until the early 1990s when the market demand for mulberry collapsed. Today, many mulberry farmers have either left their lands fallow or sold them and migrated to Bangalore.

5.1.3 Role of water in livelihood systems and the critical hydrological variables

Hebbahalla stream meanders through the valley and then empties into Suvarnavathi river, a tributary of the Cauvery that emerges from the southern portion of the BR Hills. In the mid-1970s, a barrage was constructed across Hebbahalla at a point downstream of Arepalya village, diverting much of its waters northwards into Kote Kere, a minor irrigation tank.[31] But

[31] Subsequently, the Kabini right bank canal entered this region and rendered many of these local irrigation structure irrelevant. However, the Kabini canal command does not include any part of Arepalya village, which is uphill from the canal.

there being no such tank in Arepalya village, the cultivation in Arepalya has historically largely depended upon rainfall.

By the 1980s, open-well irrigation assumed some importance. Six farmers constructed open wells in the 1980s with loan assistance from the primary land development bank. As a result, approximately 5 per cent of total cultivated land was irrigated. However, it was in the 1990s that irrigated agriculture grew significantly due to the expansion of bore wells. Whereas there were only three open cum bore wells in Arepalya in the 1980s, eight new wells (open cum bore wells and bore wells) were dug in the 1990s. Another nine bore wells were dug between 2000 and 2002. Irrigated area, therefore, expanded to about 30 per cent of total cultivated area. Paddy, sugarcane and turmeric accounted for most of the irrigated agriculture.

The growth of bore well irrigation seems to have led to both the rendering of open wells defunct and declining water tables. While local people ascribe a number of reasons to declining water availability in open wells including decline in rainfall, less base flow in the stream etc., the fact that shallow aquifers (which are tapped by open wells) are underlain by deeper aquifers suggests that the increased sinking of deep bore wells also contributes to the above phenomena. Other factors linked to bore well expansion are state subsidies in the form of flat rate electricity supply and the influx of capital for land purchase.

It must be noted, however, that the availability of groundwater from deeper aquifers is related to the type of hydrogeology (see description of geology in the ATREE site description section). For example, farmers perceive that areas with black rocks (basalts) have poorer ground water availability than white rock (quartzite) or sand rock areas (fractured quartzite-*maralu mishritha kallu*). Notwithstanding declining groundwater tables and site specific constraints on digging bore wells, groundwater irrigation has increased and continues to increase.

5.1.4 Role of forests and pattern of forest cover

The forest vegetation in the lower catchment is scrub-thorn jungle of the Anogeissus latifolia –Phyllanthus indofischeri type. In the upper reaches of the catchment, on the other hand, dry and moist deciduous forests, and even some patches of evergreen shola forests and shola grasslands at the highest altitudes exist (see Figure 5-2).

Forest use varies to some extent by community. All households depend upon forests for firewood and grazing to different degrees. However, the Soligas are given exclusive rights to the collection of non-timber forest products, which they do from the more densely forested areas. Such collection provides a significant portion of total income for the Soliga households, who are almost exclusively dependent upon rainfed agriculture and small landholdings.

The BR Hills forests were declared a wildlife sanctuary in 1974. The greater (eastern) part of Arepalya village's forests fall within the sanctuary (WLS), and a smaller part is a Reserve Forest (RF) adjoining the sanctuary. Consequently, access to the WLS portion of the catchment is somewhat curtailed. That the RF portions (the slopes to the north and south of the settlements) are more heavily depleted, covered today only with scattered shrubs, is an indication of both the proximity and accessibility of these areas vis-à-vis those inside the sanctuary boundary (to the east of the settlements). On the whole, however, there has been no detectable decline in forest cover in the catchments in the post 1980 period. The fluctuations that one sees in groundwater are therefore not directly and significantly related to changes in forest cover.

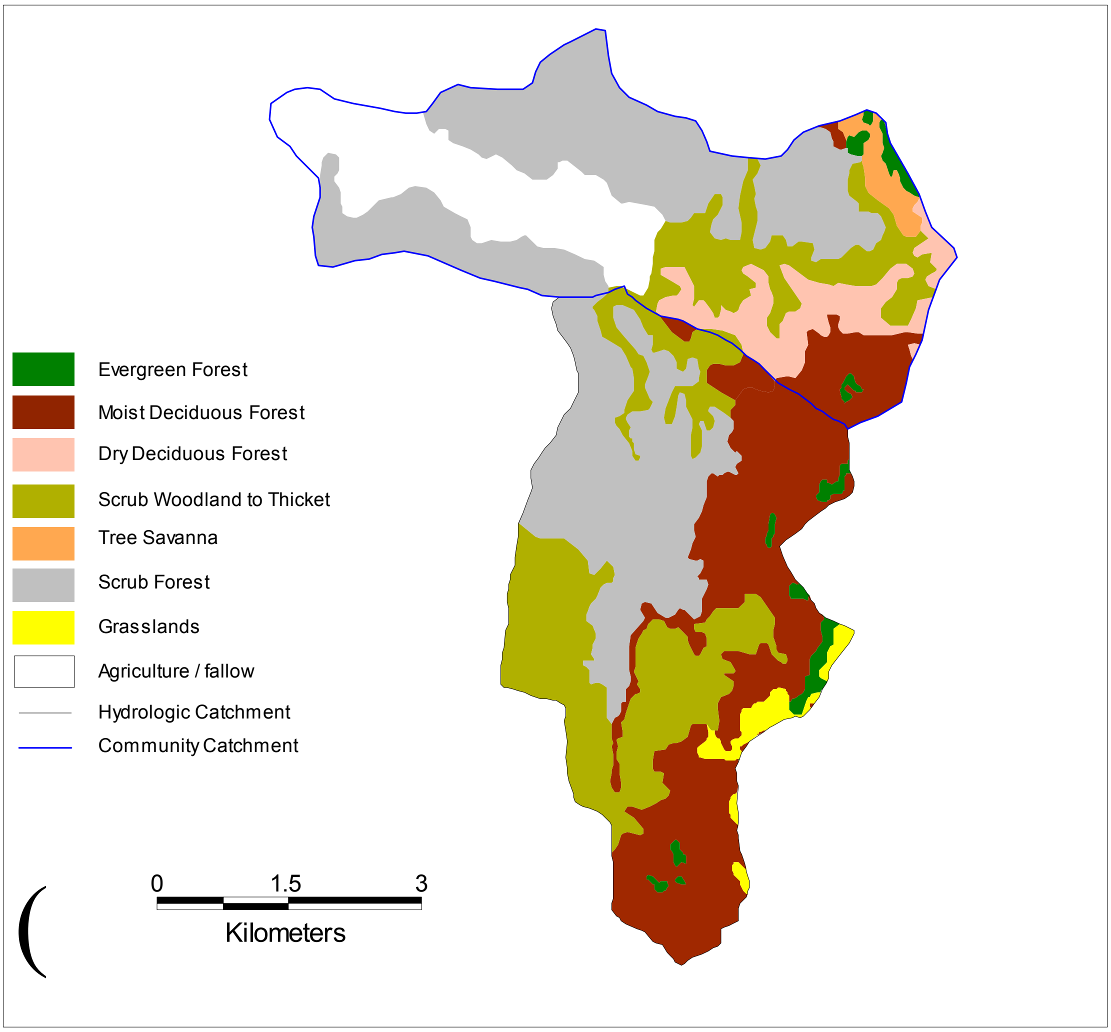

Figure 5-2. Forest cover in Arepalya catchment (lower catchment is the one monitored).

Table 5-1. Forest cover details of Arepalya catchment

Landover	**Dominant species**	**Area (km^2)**
Evergreen Forests	Mesua Ferrea – Palaquim ellipticum type	0.58
Moist Deciduous	Terminalia crenulata – Terminalia bellarica type	8.07
Dry Deciduous	Anogeissus latifolia – Terminalia crenulata type	1.81
Tree Savanna	Anogeissus latifolia – Chloroxylon swietenia type	0.43
Scrub Woodland to Thickets	Anogeissus latifolia – Chloroxylon swietenia type	7.79
Scrub Forests	Anogeissus latifolia –Phyllanthus indofischeri type	12.61
Grasslands		0.49
Agriculture/Fallow		3.92
Grand Total		**35.70**

5.2 Framing the problem

It is clear from the above that groundwater is the form in which water is used by the local community. In our preliminary discussions with the village community in Arepalya, the farmers repeatedly articulated the problem as one of declining groundwater tables. But they asserted that they did not think forest cover change had played a major role in this decline as our analysis of forest cover change also suggests. Rather, as we suggested above, they attributed this decline to a combination of declines in rainfall and increased groundwater consumption. Preliminary observations also indicated that the major impact of changes in groundwater availability would be felt in the agricultural sector, and would be in the form of changes in cultivated area, cropping pattern and/or crop productivity.[32] Therefore, our enquiry was reorganized to focus on the following questions:

1. What is the current magnitude of annual groundwater recharge in this catchment? And how sensitive is it to inter-annual rainfall fluctuations?

2. What is the likely impact of forest cover change on groundwater recharge?

3. What is the magnitude of current groundwater extraction? How does it compare with recharge and is it therefore likely to affect groundwater availability?

4. How do changes in groundwater availability due to the above factors affect agricultural incomes?

In the next sections, we indicate the answers we have obtained to the above questions.

5.3 Estimating recharge from the catchment and the effect of rainfall

To understand the sensitivity of groundwater to rainfall, and of agriculture to changes in groundwater levels, we have used 2003 and 2005 as years representing 'low' and 'high' rainfall. The actual magnitudes of rainfall for these years for stations surrounding Arepalya are given in the table below, and they clearly show the difference in the rainfall between those two years.

Table 5-2. Rainfall variation between 2003 and 2005

Station	**RAINFALL (mm)**		
	2003	**2004**	**2005**
Kollegal	654	1090	1095
Yalandur	507	967	1188
Gundal	699	962	1332
BR Hills	1032	962	1818
Arepalya	Not available	795	1123

32 This is not to say that falling groundwater tables would not affect the domestic sector. But in the particular context of Arepalya, the advent of borewells in many households as well as state interventions in the form of public borewells and handpumps have staved off any negative manifestations of this fall. In fact, drinking water is more accessible now than it was earlier.

The notion of 'recharge' and the socially relevant component of recharge itself needs careful definition before proceeding to its estimation. Open wells typically draw water from the shallow open aquifer, which is recharged by the monsoonal rains and then gradually moves along the groundwater gradient and eventually empties itself out as baseflow. The geology underlying the shallow aquifer in Arepalya is typical of the hard-rock region of Karnataka, consisting of several layers of XXXX. In a hard-rock region, the connection between the shallow aquifer (and the recharge that occurs in it) and the deeper aquifers may often be very weak. Since the bore wells tap the deeper aquifer, what constitutes 'available recharge' to these bore wells becomes a very difficult question. However, in the case of Arepalya, our qualitative observations over 3 years indicated that the bore wells were quite sensitive to the shallow groundwater level. Following heavy rains in the monsoon of 2005 and early 2006, we found that most of the bore wells had a substantially higher discharge as compared to their discharge in late 2003/early 2004 (see Table 5-3), just as the shallow open wells showed signs of recharge in early 2006. This suggests that the deeper aquifer in Arepalya is well connected with the shallow aquifer, and hence the recharge entering the latter is quickly available to bore wells tapping the former.

Table 5-3. Impact of rainfall on bore well discharge

Bore well discharge (based on farmer estimates)[33]	Year	
	2003 (low rainfall)	2005-6 (high rainfall)
In Kharif cu.m./hr	5.5	10.6
In Rabi, cu.m./hr	5.0	9.9

A further point to be noted is that 'recharge available' to the well users located in the valley portion is quite different from the 'recharge occurring' in the catchment as a whole. The 35.7 sq.km. catchment comprises largely of steep hills (31.96 sq.km.).

sq.km.), but the wells all occur in the flat valley portion at the bottom in an area of less than 4 sq.km. The recharge that takes place on the hillslopes thus ends up largely in the groundwater in the valley. Furthermore, farmers believe that the water in their open wells is greatly influenced by the duration for which Hebbehalla stream actually flows during a year—longer flows resulted in significantly higher well water levels. This suggests that perhaps the surface flows that emerge from the hilly catchment spread along the valley and contribute further to the groundwater available in the valley.

We therefore used intra-annual fluctuations in the open wells in the valley to estimate the annual recharge. The information on pre and post-monsoon water levels was elicited from one farmer who has one of oldest open wells in the community and is relatively progressive in terms of practising agriculture. The main observations for the low rainfall year of 2003 and high rainfall year of 2005 are given in Table 5-4 below.

[33] XXXSHRINI TO GIVE THE METHOD OF CONVERTING INCHES TO CUM PER HOURXXX

Table 5-4. Water levels in a sample open well

Year	Monsoon (June-Dec) rainfall (mm) & rainy days in brackets	Pre-monsoon water level (above bottom of well)	Post-monsoon water level (above bottom of well)	Rise during monsoon (above bottom of well)
2003	569 (46)	0.6m	2.4m	+1.8m
2005	1044 (68)	0.6m	4.5m	+3.9m

This well's fluctuation, if assumed to occur across the entire cultivated area of 760 acres (307 ha) amounts to 0.8 million cu.m. and 1.82 million cu.m. of water (for an assumed specific storage of 0.15) of added to the groundwater during 2003 and 2005 monsoons respectively. We further assume that this volume of water came into the valley from the infiltration followed by groundwater recharge that occurred across the entire catchment of 35.70 sq.km. This amounts to contributions from rainfall in the order of 26mm and 57mm in 2003 and 2005, respectively.

Representing the groundwater in the entire valley using only one open well may be a risky approach. But this well was probably the only well that had water at some depth during pre-monsoon season of 2003; we therefore believe that calculations based on this well would provide a lower (conservative) estimate of groundwater fluctuation.

Note that the groundwater recharge estimated in this fashion using the fluctuations in the shallow aquifer is only an indicator of the lower limit of recharge that may have occurred from the entire 35.70sq.km. catchment in the two rainfall scenarios. Groundwater recharge may have contributed to the deeper aquifer or flowed out of the catchment system as regional groundwater flow may add to higher gross recharge from the catchment system. Though not quantified, greater availability of groundwater from deeper aquifers was acknowledged by the farmers during our interactions.

The above estimates indicate that the groundwater accessed by both open wells and bore wells is highly sensitive to the inter-annual variations in the quantum of rainfall (even though the bore wells are tapping a deeper aquifer). Thus, the total quantum of rainfall during monsoon as well as the number of rainy days is a very significant factor in determining the actual rate of recharge in the aquifer system.

5.4 Forest cover influence on recharge

To understand the role that forest cover might play in influencing recharge, we would have to carry out both a water balance, but also understand the physical process through which water that infiltrates into the soil is apportioned between evapotranspiration by forest vegetation and groundwater recharge. Unfortunately, the data on rainfall and runoff that we collected are inadequate to answer this question precisely.[34] We managed to carry out streamflow observations for only one of the three streams that contribute to Hebbahalla for 2004 and 2005 calendar years. These readings are at the point prior to the stream joining Hebbahalla, and just where it emerges from the slopes onto the flat valley. These data can, however, be interpreted to provide some broad indication on the recharge pattern.

[34] As mentioned in the introductory chapter, the control catchment in this block was too small to be comparable with the Arepalya catchment, and we were unable to gather sufficient data in that catchment in any case due to logistic difficulties.

In brief, in 2004, out of an estimated catchment rainfall of 1000 mm, 430 mm (43 %) was streamflow. In 2005, out of an estimated catchment rainfall of 1100 mm, 435.5 mm (39.6 %) was the estimated streamflow. This is a surprisingly high fraction. But it is corroborated by measurements from the neighbouring catchment of C-Doddi carried out by us for 2004 and 2005, during which the annual streamflow was around 47% of the annual rainfall. Our qualitative observations of the behaviour of the other tributaries of Hebbahalla suggest a similar pattern.

We believe that the explanation of this high fraction lies in the topography and geology of the catchments. As mentioned earlier, the catchments are rather steep, with slopes ranging up to 37%. And our observations indicate shallow soils and a very rocky geology. This suggests that the soils may not hold much of the infiltrated water but it would move very rapidly along the slope towards the stream bed.[35] This excessive drainage feature cannot be modified dramatically by any changes in forest vegetation. Furthermore, with such rapid movement of water, the fraction of water available for evapotranspiration by the forest vegetation would be limited, as would be the contribution to recharge.[36] This implies that changes in forest vegetation would not have a significant impact on the streamflow or groundwater recharge in this particular catchment.

Figure 5-3. Cross-section of Hebbehalla stream showing the porous streambed.

[35] It is also possible that a significant fraction enters the groundwater in the catchment through cracks and fissures in the rocks.

[36] This would also imply that the groundwater recharge occurring in the hilly catchment is also limited. This could be explained by the possibility that a significant portion of the groundwater recharge may be happening in the streambed in the valley portion, where the stream bed is highly porous (accrued sediment). This is consistent with the villagers' observation that groundwater in their wells rises significantly only when Hebbahalla in the valley floods.

Indeed, it appears that the major recharge is taking place not in the hilly catchment but in the streambed in the flatter valley portion. The streambed is highly porous (consisting of several metre thick layers of accrued sediment)—see Figure 5-3. This is consistent with the villagers' observation that groundwater in their wells rises significantly only when Hebbahalla in the valley floods.

5.5 Estimating groundwater extraction

In the absence of detailed information of pumping hours and rates, we adopted a back-of-the envelope approach to estimate the amount of groundwater applied.

Step 1: We assumed that the use of groundwater for non-agricultural purposes is negligible, compared to the gross utilization for agricultural purposes.

Step 2: Cropping pattern information for 2003 and 2005-06 was collected for all the households (23) that owned open and/or bore wells in 2005-06 (see Table 5-5)

Table 5-5. Area under different irrigated crops in 2003 and 2005

Irrigated crops	Year 2003-04				Year 2005-06				%Change in gross irrigated area
	Kharif Area (acres)	Rabi Area (acres)	Summer Area (acres)	Gross irrigated area (acres)	Kharif Area (acres)	Rabi Area (acres)	Summer 2006 Area (acres)	Gross irrigated area (acres)	
Haldi	12	0	0	12	14	0	0	14	12%
Sugarcane	12	0	0	12	41	3	0	44	280%
Paddy	5	0	2	7	6	1	2	9	38%
Maize	21	1	3	25	13	0	8	21	-17%
Mulberry	10	0	0	10	10	4	0	14	40%
Oilseeds	2	0	0	2	0	2	0	2	33%
Banana	0	0	0	0	2	4	2	8	0%
Ragi	0	0	0	0	1	1	0	2	0%
Grass	1	0	0	1	1	0	0	1	100%
Vegetables	3	2	4	9	2	0	0	2	-74%
Flowers	2	0	0	2	0	0	0	0	-100%
Total	65	3	9	78	90	14	11	115	49%

Step 3: Monthly crop water requirements for irrigated crops were estimated[37] accounting for monthly *effective rainfall* depths. That is, it was assumed that a certain portion of the monthly rainfall was available to the crops for evapotranspiration, using the formula developed by the International Water Management Institute for Indian semi-arid conditions for rainfed and irrigated crops,[38] viz.,

Effective Rainfall = (1-0.2*(Rainfall/125)), if net monthly rainfall is less than 250 mm
Effective Rainfall = (125+0.1*Rainfall), if net monthly rainfall is more than 250 mm

Step 4: If one were to further assume that the farmers actually provided this full crop water requirement through groundwater pumping, then the amount of water consumed by the irrigated crops was 149747 cu.m. and 190144 cu.m. respectively, for irrigating a gross area of 77.5 acres in 2003 and 134.6 acres in 2005-2006. This quantum of water lifted from the

[37] Using FAO 24 and FAO 56 Guidelines for Estimating Crop Water Requirements.

[38] IWMI, 2005. PODIUM-SIM: Country Policy Support Program Report 10. ICID-CIID, New Delhi.

deeper aquifers accounts to less than 1 per cent of the rainfall that occurred during those respective years in the entire contributing catchment of 35.70 sq.km.

It is important to note here that although the quantum of recharge available or utilized for irrigated agriculture in Arepalya seems significantly low, most attribution to irrigated agriculture occurred from the contributions of *effective rainfall* that was 559 mm in the dry year in comparison with 849 mm in the wet year, more than 1.5 times the crop water utilization from *effective rainfall* in the dry year. In spite of an increase in irrigated area of 68% in 2005, the gross groundwater extraction/utilization during the wet year increased by merely 27 per cent. It is also important to note that the discharge capacity of an average bore well increased from 6.8 cum/hr in 2003 to 10.1 cu.m./hr in 2005 due to rise in the deep groundwater table. This also resulted in an estimated reduction of total annual pumping hours from 1101 hrs to 672 hours on an average among the functioning 20 and 28 wells in 2003 and 2005, respectively; a net reduction of annual average pumping hours per well from 138 hrs in 2003 to 84 hours in 2005.

From above analysis and arguments, though some of it based on assumptions of aquifer specific storage and representativeness of the sample well, we believe that this calculation provides robust evidence that the extent of groundwater pumping in Arepalya is far lower than the annual recharge that is available in the valley. The present rate of pumping is therefore not the main or even significant contributing factor to inter-annual fluctuations in groundwater levels in the valley.

5.6 *Economic impacts of groundwater fluctuations*

Whatever the source of change in groundwater levels, such changes may have a significant impact on agriculture. To understand the magnitude and nature of this impact, including its variation across different socio-economic classes, we compared the agricultural situation in the 'low rainfall year' of 2003 with the 'high rainfall year of 2005'.[39] Our analysis pertains to the area between the edge of the forest to the east and Tamil Colony to the west/northwest, a valley length of 4.5 km. We did not include other hamlets of Arepalya that are located further downstream, because there other streams join Hebba Halla and hence dilute the relationship between the contribution of the BR Hills catchment and groundwater. We begin by presenting an overall profile of the households in the various settlements, and then focus on the farmers who had wells in both years to see what impact the groundwater fluctuation had on their cultivation.

5.6.1 Profile of the village and the sample farmers

There are 215 households in Arepalya and a population of 1,090.[40] All the households are engaged in agriculture. As Table 5-6 illustrates a large per cent of households have less than 5 acres of land including 47 households who are landless. The extent of landlessness is highest in Mulekatte followed by Yerekatte and Arepalya. On average, landholdings are bigger further downstream in Arepalya, Tamil Colony and Uparshetty Colony.

[39] Note that, due to the peculiarities of oral recall, the cultivation reported for 2003 is for the calendar year, whereas that report for 2005 is actually for kharif of 2005 and rabi and summer of 2006

[40] This is based on our household survey and not the 2001 Census.

Table 5-6. Hamlet wise land holding information (in acres)

Hamlets	Landholding class							Total cultivated land
	0	1--2	>2--3	>3--5	>5--7	>7--9	>9	
Yerekatte	9	15	2	1	0	0	0	**27**
Mullekatte	10	10	3	0	0	0	0	**23**
Arepalya	21	23	11	14	4	4	3	**80**
Tamil Colony	3	6	20	8	3	0	0	**40**
Upparshetty colony	4	20	3	12	3	3	0	**45**
Total	**47**	**74**	**39**	**35**	**10**	**7**	**3**	**215**

Note: 0 in land size column indicates land less households

As our main interest is to look at the impact of land use on hydrology, from the socio-economic point of view, it requires a closer look at only those who have access to irrigation. It is important to highlight, therefore, that irrigated land comprises 249 acres out of a total of 762 acres of cultivated land (rainfed land comprises 513 acres). More importantly, only 29 households out of a total of 215 had wells, approximately 15 per cent of households. Those who do not have wells not only do not come directly in to our analysis, but equally importantly one could argue do not have a direct stake in watershed and catchment cover management. This illustrates how socially contextual the idea of a hydrological service is, a point we return to later.

In order to examine the impact of 'change' in water availability, we had to first of all identify the farmers who had wells at the time of the survey and then only focus on those who had both wells in 2003 and 2005. In order to identify these households, we first spoke with all 29 households who currently have wells. We gathered information with regard to water availability (depth and discharge) during pre and post-monsoon periods in what farmers perceived as good and bad rainfall years. Specifically, information was collected pertaining to the year the well was dug, the cost incurred, the type of motor used, the soil and rock type near the well, the depth of the well, the level at which water is available and the extent of land irrigated.

The second survey included only 19 households. Those who entered the well-owning category after 2003 had to be excluded as the change they experienced in terms of water availability was not related to rainfall-recharge. We gathered socio-economic information with regard to caste, landholdings, occupational structure, cropping pattern, labour availability, migration and forest use. The latter information was necessary to understand the relationship between socio-economic characteristics and groundwater availability.

Details are given pertaining to the households interviewed. Out of the 19 households interviewed, 13 (68 per cent) are from the main hamlet of Arepalya, 4 (21 per cent) from Tamil colony, 1 (5 per cent) from Yerekatte and 1 (5 per cent) from Mullakate. Among the sampled households 18 belong to OBC (Vokkaliga Gowdas and Tamil Padiyachi Gowdas) and one belongs to ST (Soligas). Six households have between 1-2 acres of irrigated land, four have between 2.01-4 acres, five between 4.01-6 acres and four households 6.01+ acres. Households total land holdings (irrigated and rainfed) were calculated after standardizing land holdings by converting dry land into irrigated land, i.e. 3 acres of dry land equals 1 acre of wet land. Based on this conversion, seven households have between 1-3 acres, eight households have between 3-5 acres and nine households have 5+ acres.

Table 5-7. Caste-wise irrigated land ownership

Caste	1-2acre	>2-4acre	>4-6acre	>6and above	Total
OBC	5	4	5	4	18
ST	1	0	0	0	1
Total	6	4	5	4	19

Table 5-8. Land Holdings (after converting to equivalent dry acres) among sampled farmers

Farmers category	Number	Percent
Small	5	26
medium	7	37
Big	7	37
Total	19	100

Note: 1-3 acre small, >3-5 acre Medium and >5and above are the big farmers)

The average extent of land owned by different class farmers is presented in Table 5-8. These 19 households own a total of 24 wells out of which 18 are bore wells, 4 are bore wells within open wells and 2 are open wells. Sixteen households own one well, whereas two households have two wells and one household four wells. The three households that have more than one well are all Vokkaliga Gowdas and they reside in the main hamlet of Arepalya. However, amongst these three households there are significant variations in the extent of land they own. The household that has four wells owns 35 acres of land under irrigation whereas the households that have two wells have 8 acres and 6 acres of irrigated land, respectively. The distribution of wells and irrigated area across landholding classes is given in Table 5-9.

Table 5-9. Well ownership and irrigated area across landholding classes

Farmers category	Number of wells	Irrigated area, acres	Average irrigated area/well, acres
Small	5	18	3.6
Medium	7	23	3.3
Big	12	74	6.2
Total	24	115	

The cropping pattern has varied both across time and across size of farmers. In the 1980s, the main irrigated crops were mulberry and groundnut. However, in the 1990s, chillies, maize and onions were the dominant irrigated crops. From 2000 onwards, the major irrigated crops have been haldi, sugarcane and maize with banana assuming importance over the last two years and sunflower occasionally being irrigated as well (see Figure 5-4). While cropping patterns vary significantly from farmer to farmer, even with a particular size class, medium and large farmers grow substantially more sugar cane than small farmers. This suggests *a priori* that bigger farmers (amongst the irrigated farmers) have more water availability. In the section that follows, we analyze the impact of the good rainfall year on farmers with irrigation facilities vis-à-vis gross cultivated area, gross irrigated area, crop type, productivity and income.

Figure 5-4. Sugarcane and banana cultivation in Arepalya valley (bore well pump house also visible)

5.6.2 Agriculture in good and bad years

Increases in water availability for irrigation can have three types of impact on the nature of agriculture: (1) conversion of fallow and dry land to irrigated land, (2) changes in irrigated crops to more remunerative ones and (3) increased cropping of irrigated land (mostly in the form of increased rabi crop). In the case of Arepalya, increased water availability in the good year has resulted in all three phenomena. In order to understand the impact of increased water availability, we first look at the overall changes in terms of extent of irrigated and rainfed land between 2003 and 2005. The total extent of cultivated land increased from 109 acres to 136 acres. While the extent of cultivated rainfed (dry) land decreased from 31 acres to 21 acres, the extent of irrigated land increased from 78 acres to 115 acres. In addition to dry land becoming irrigated land fallow land (which was not cultivated at all because of water shortage) was cultivated in 2005. Also one acre of land was purchased in 2004.

Table 5-10gives details pertaining to changes in irrigated agriculture across seasons and crops. First, the major increase in irrigated agriculture is due to increases in irrigated kharif crop. Whereas in 2003, 65 acres were irrigated during the kharif season, in 2005, 90 acres were irrigated. The extent of rabi irrigated land increased from 3 acres in 2003 to 14 acres in 2005, whereas the extent of summer irrigated land increased from 9 acres to 11 acres only. Second, the large increase in kharif irrigated area was due mostly to the significant increase in irrigated sugarcane. Third, other crops for which irrigated area increased slightly were turmeric, paddy, mulberry and banana. Much of this increased area, however, was due to increases in irrigation during the rabi season. Fourth, irrigation decreased slightly in the case of maize and vegetables.

Table 5-10. Crop-wise Irrigated Area, 2003 and 2005

Crops/Season	2003				2005-06			
	Kharif	Rabi	Summer	Total	Kharif	Rabi	Summer	Total
Turmeric	12	0	0	12	14	0	0	14
Sugarcane	12	0	0	12	41	3	0	44
Paddy	5	0	2	7	6	1	2	9
Maize	21	1	3	25	13	0	8	21
Mulberry	10	0	0	10	10	4	0	14
Oil Crops	2	0	0	2	0	2	0	2
Banana	0	0	0	0	2	4	2	8
Ragi	0	0	0	0	1	1	0	2
Grass	1	0	0	1	1	0	0	1
Vegetables	3	2	4	9	2	0	0	2
Flowers	2	0	0	2	0	0	0	0
Total	**65**	**3**	**9**	**78**	**90**	**14**	**11**	**115**

So how has better water availability impacted overall production? Although overall production has changed with regard to both dry land and irrigated crops, for our purposes it suffices to look at production data from irrigated crops as we are primarily interested in understanding the impact of increased (and improved) irrigation. Table 5-11 gives details of total production and average production per acre for different crops in 2003 and 2005. What is evident is that overall production of irrigated crops has gone up from 4,253 quintals in 2003 to 15,194 quintals in 2005. This increase is largely the result of a significant increase in overall sugarcane production from 3,550 quintals in 2003 to 14,550 quintals in 2005, The only other significant increase has been in terms of turmeric production, i.e., from 132 quintals in 2003 to 164 quintals in 2005.

Table 5-11. Production and productivity of main irrigated crops in Arepalya, 2003 and 2005

Crop	2003			2005		
	Area (acres)	Total Production (qtl)	Produc-tivity (qtl / acre)	Area (acres)	Total Production (qtl)	Produc-tivity (qtl / acre)
Sugarcane	11.5	3550	309	44	14550	333
Turmeric	12.25	132	11	14	164	12
Paddy	6.5	108	17	09	116	13**
Banana	0.0	0.0	00	08	-*	-
Maize	24.75	359	15	20	291	14
Mulberry	10.0	3.2	0.3	14	34	02
Oilseeds	1.5	5.0	3	02	08	04
Ragi	00	00	00	02	06	04
Grass	0.5	--*	-	01	-*	-
Vegetables	8.5	45	5	02	25	11
Flowers	2.0	51	26	00	00	00
Total	**78**	**4253**	**55**	**115**	**15194**	**132**

*Productivity data not available.

** Productivity was low due to pest attack.

More important than changes in production, from the farmers' perspective, are changes in income. In order to understand how better water availability and irrigation has impacted overall incomes, it is necessary to look at both incomes from dry land and irrigated land for both time points. Table 5-12 provides details of total gross and net incomes for both dry land and wet land crops in 2003 and 2005. Data for 2005 has been adjusted downwards to account for inflation. The WPI increased by approximately11 per cent between 2003 and 2005. What the table illustrates is that both dry and irrigated land net incomes have increased between 2003 and 2005 although irrigated incomes have increased much more substantially. This suggests a number of things. First, that despite the decline in dry land cultivation between 2003 and 2005 of the sampled farmers, due to better production (presumably because of better rainfall) incomes increased. Second, the most substantial benefits of the increased rainfall have come in the form of increased incomes from irrigated agriculture. Whereas in 2003, the net income from irrigated agriculture was 6,11,100 in 2005, it had increased to 12,29,620 – almost double. As a result total net income also increased substantially from 6,69,910 to 12,98,106.

Table 5-12. Changes in gross and net incomes from agriculture between 2003 and 2005

Dry Land				Irrigated Land				Total Cultivated Land			
2003		2005		2003		2005		2003		2005	
Gross Income	Net Income	Gross Income	Net Income	Gross Income	Net Income	Gross Income	Net Income	Gross Income	Net Income	Gross Income	Net Income
93910	58810	106311	68486	1026600	611100	2169442	1229620	1120510	669910	2275753	1298106

Table 5-13 gives details with regard to specific crops. What is evident, not surprisingly, is that net incomes have increased largely because of increased incomes from sugarcane. Net income from sugarcane increased from around 2 lakhs in 2003 to about 7 lakhs in 2005. Total net incomes increased from around 6.7 lakhs in 2003 to almost 13 lakhs in 2005. The other noticeable change is the substantial income from banana in 2005. Income from turmeric has also increase slightly but income from paddy and mulberry has decreased.

Table 5-13. Net incomes from dry land and irrigated crops, 2003 and 2005

Crops	2003						2005					
	Rainfed		Irrigated		Total		Rainfed		Irrigated		Total	
	G.I.	N.I.	G.I.	N.I.	G.I.	N.I.	G.I.	N.I.	G.I.	N.I.	G.I.	N.I.
Maize	80630	49630	177850	97850	258480	147380	95372	64667	129726	77216	225099	141884
Ragi	7180	4880			7180	4880	4272	2492	3204	1424	7476	3916
Horsegram	3600	2600			3600	2600						
Turmeric			309200	183200	309200	183200			311411	192863	311411	192863
Sugarcane			338250	217250	338250	217250			1312817	735136	1312817	735136
Paddy			61150	36150	61150	36150			61223	25801	61223	25801
Mulberry			95400	55400	95400	55400			68130	26300	68130	26300
Oil Crops			7500	4500	7500	4500	6666	1326	8544	4094	15210	5420
Banana									249200	145960	249200	145960
Grass			2000	1800	2000	1800			3560	3293	3560	3293
Vegetables	2500	1700	18750	7450	21250	9150			21627	17533	21627	17533
Flowers			16500	7500	16500	7500						
Total	**93910**	**58810**	**10266000**	**611100**	**1120510**	**669910**	**106311**	**68486**	**2169442**	**1229620**	**2180073**	**1298141**

5.7 Concluding remarks

We began this chapter by posing a series of four interconnected questions relevant to the situation in this site, which is characterised by heavy dependence on groundwater for agriculture. The questions were related to the extent of recharge, the likely influence on this recharge of inter-annual fluctuations in rainfall and of forest vegetation, the relative role that might be played by groundwater extraction in influencing the groundwater table, and the economic impacts of changes in groundwater availability. To answer these questions, we compared rainfall, streamflow, groundwater levels, and cropping patterns between a high rainfall year and a low rainfall year.

The results of our investigations are as follows. First, the groundwater is level extremely sensitive to each year's rainfall. Second, in comparison and given the nature of the catchment soils and geology, the influence of forest vegetation change on recharge is likely to be negligible. The recharging of the permanent groundwater table and other linked aquifers seems to happen primarily when the stream floods in response to a heavy rainfall event. Third, while there have been increases in groundwater extraction, the extent of extraction today does not seem to be at all in excess of the annual recharge for an average year. And in a drought year, the low groundwater level prevents extraction beyond a point anyway, forcing the farmer to switch crops and reduce water use.

Fourth, changes in groundwater levels result in very significant changes in agricultural incomes, as the area irrigated and the crops cultivated change dramatically. A good year can result in the doubling of net incomes from agriculture as compared to a low rainfall year. Of course, the gains from this use of groundwater for irrigation are distributed in a highly uneven manner across and within communities, with the members of the Soliga tribe who live at the head of the valley not being able to capture much of these benefits.

It appears therefore that even though significant portions of the slopes of the Arepalya valley (particularly those outside the National Park boundary) have become denuded of most tree vegetation due to an open-access situation, improving water availability for irrigation is unlikely to provide a significant incentive for forest conservation in the prevailing hydro-geological and technological conditions.

Chapter 6. Conclusions

In the introduction, we identified a series of questions related to the links between forest cover, hydrology and local communities. We then presented a set of four case studies situated in different eco-climatic zones of the Western Ghats of Karnataka. In each of these studies, we sought to examine both the biophysical and the socio-economic aspects of this linkage, within the limitations of our resources and abilities. The purpose of those chapters was to present an integrated narrative that might be representative of a particular eco-climatic and social context. We can now step back and highlight the somewhat more generalisable insights that emerge from this multi-site exploration.

Hydrologically speaking, we now know that considerable recharge to ground-water is possible under relatively undisturbed dense evergreen forests, in spite of high predicted evapotranspiration. The “Calder-ian” fear that such dense might be transpiring large fractions of the rainfall and hence leading to depletion of streamflows seems to have little relevance in the Western Ghats, where soil hydraulic conductivity is generally very high, rainfall is concentrated into 4-5 months, and ecosystems have adapted to moisture stress during the dry season by encouraging more deciduous behaviour in the trees. It is clear that, in high rainfall regions, all land cover types contribute substantially to groundwater recharge.

The major impacts of intensive human use of forests seem to be in the form of changes in surface soil-hydraulic properties, leading to overland flows and ‘flashier’ behaviour of streams. Here again, there are significant variations between the highly degraded sites near Honnavar in the coastal foothills, and the more mixed tree savanna-grassland combinations of the upghat ‘soppinabettas’, with the more haphazardly utilized fringes of the Bandipur National Park perhaps coming somewhere in between. The case of Arepalya illustrates the possibility of extreme scenarios where geological conditions dominate over all other factors, and influence of forest cover on recharge may be minimal. On the other hand, it appears that at least Acacia plantations may have the capacity to maintain or even restore soil hydraulic properties to somewhere closer to natural forests.

Whether the changes induced by forest use or afforestation are socially desirable or not is a highly contextual and complex matter. In high rainfall areas, the reduced infiltration due to heavy use of the forest for firewood removal and grazing may not significantly affect baseflows available to agriculture unless the use and possibly degradation of the landscape occurs on a widespread scale. Even then, the direct and indirect benefits of forest use in a region where the productivity of agriculture critically depends upon inputs of forest products may far outweigh the losses due to hydrological change, if any.

On the other hand, in the Bandipur region, the increased and earlier runoff induced by heavy use of forests may actually benefit those who have adopted a technology based on storage of surface flows and using them for water-intensive crops. These may turn out to be short-term benefits that are eventually overshadowed by the siltation of these storage facilities—our data do suggest that there may be significant soil losses occurring. But, unlike in the Malnaad region, the communities using the forest may be (and often are) quite different from those utilizing this early runoff, and will pose serious challenges even if these short-term hydrological gains from forest use fizzle out. In other situations such as Arepalya, technological change is significantly altering the relative importance of surface flows versus ground water recharge and the configuration of stakeholders in water and forest management.

We began this study with a brain-storming and review workshop in January 2003 where we sought to gather many of those who had made important contributions to understanding forest hydrology and ecosystem service issues in the Western Ghats. In the proceedings of that workshop (Krishnaswamy *et al.,* 2006), we identified several of the gaps in current understanding of both the biophysical and social aspects of the forest-water-community linkage. This study is one of the first attempts to systematically explore and fill some of these gaps in our understanding of the links between forest cover, hydrology and communities. The study has been challenging at various levels: in its conceptualization, in its implementation in the field, in the interpretation of complex results, and as an attempt at interdisciplinarity. We believe that while it is a modest beginning towards understanding a fairly complex linkage, the study provides some significant empirical as well as methodological pointers that would provide the basis for further investigations in this region and elsewhere.

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