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Land Use Change and its Impact on Selected Biophysical and Socio-economic Aspects of Karuvannur River Basin in Thrissur District of Kerala

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ABSTRACT OF THE PROJECT PROPOSAL

1. Project No	:	KFRI/421/04
2. Title	:	Land use change and its impact on selected biophysical and socioeconomic aspects of Karuvannur River Basin in Thrissur district of Kerala
3. Objectives	:	Study the nature and extent of landuse and cropping pattern changes and important socio-economic drivers affecting it.
	:	Examine the effects of landuse on hydrology- run-off, stream flow, ground water table, temperature and humidity- in the watershed.
	:	Analyze the effects of landuse/cropping pattern changes on vegetation, sedimentation, agricultural production and socio-economic conditions of the people.
	:	Assess economic value of water resource, surface water use pattern, pricing and use conflict over water resources among different sections in the society.
	:	Examine the linkages between ecological and socio-economic systems of the upland and downstream areas of the watershed in determining overall development.
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7. Investigators	:	P.K. Muraleedharan Jose Kallarackal A.R.R. Menon M. Balagopalan N. Sasidharan P. Rugmini
8. Research Fellows	:	John P. Inchakalody, P. Muhammed Rasheed and U.V. Deepa
9. Study area	:	Karuvannur River Basin

CONTENTS

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ABSTRACT

Degradation of watersheds is one of the major problems in Kerala, which has brought about ineffaceable and irreversible landuse and ecological changes, leading to impairment of its hydrological functions. Unscientific landuse and cropping pattern changes in a watershed often cause problems in water conservation both in upland and downstream areas. This accelerates the run-off rate and soil erosion and alters stream flow quality and quantity, which in turn affect onsite production and/or off-site production or consumption. In a watershed both upland and down stream areas are closely interlinked. However, the nature and extent of their interlinkage, especially in a forested watershed has not been studied in depth in Kerala. This study is a modest attempt to fill this gap.

Manali watershed of Karuvannur River Basin, where a major part of the forest area of the basin is located, was selected for detailed study. The broad objective was to examine landuse change and its effects on eco-hydrology and socio-economic conditions of the people in the study area. Specific attempts were made to study the nature, extent and socio-economic factors affecting landuse changes and forest degradation and its effects on sediment production and water discharge rates and onsite and off-site agricultural production. Assessment of surface run-off and stream flow from watersheds, economic value of water resource, surface water use pattern, pricing and use conflict over water resources among different sections in the society was also made. Further it examined linkages between ecological and socio-economic systems of the upland and downstream areas of the watershed in determining overall development.

A nested catchment approach was used to select upstream and down stream areas of the watershed. Based on the elevation data, the river basin, with several micro watershed, has been divided into upstream and downstream watersheds. One micro watershed, representative of the upstream catchment (Olakara) and another from the downstream catchment (Kavallur) have been chosen for detailed monitoring and studies.

The study indicated that there were landuse changes, particularly conversion of forest land to agricultural land in the study area during the analysis period 1960-61 to 2004-05. For instance, during 1996-2004, area under agriculture increased by 50 per cent, mostly through conversion of forests. Migration, encroachment, and expansion of agricultural activities were the major socio-economic drivers of landuse changes in the study area. Side by side with conversion of forest land to agricultural fields, there was change in cropping pattern in the study area- from subsistence agriculture to commercial crops. Variation in the relative price of crops was one of the major factors, which influenced the cropping pattern change. Although this change has increased income of the farmers, it reduced food security, employment opportunity and water availability in the study area.

There existed more sustained stream flow in forested watershed as compared to agricultural watershed. The upland areas where plant diversity was more, was prone to seasonal fire in the past, indicating the degradation. Sedimentation was low in forested watershed, while it was high in the upper part of downstream areas. Degradation of forests and frequent crop shifts in upland areas resulted in sedimentation in Peechi Dam (annually 0.9%). The study suggested the need for undertaking conservation and afforestation measures in the degraded forest areas for better availability of water.

Since water is a naturally existing and freely available commodity, most people do not attach any value to it. Therefore, total economic valuation of the Peechi wet land was attempted. Per hectare economic value of Peechi wet land was found to be Rs.146,039/-. Willingness to pay for regular and steady supply of water from Peechi reservoir was also assessed. About 80 per cent of the people, who use drinking water from Peechi, were willing to pay more for timely and regular supply of water whereas 20 per cent agreed with the existing price.

There was conflict over water resources from Peechi Dam among farmers, between farmers and users of drinking water and between urban dwellers and villagers. This was due to increase in demand and inefficient management. There existed a close interaction between upland and down stream areas of the watershed and also between watershed and market shed (demand, supply, price, among others). Further, bio-physical and socio-economic factors in upland and down stream areas were also interlinked. They may be taken into account while implementing any watershed projects.

The study also suggested to undertake proper pricing of water from the Dam to generate more funds to meet cost of supply and water resource development. Promotion of integrated watershed development programmes through effective participation of local people for preventing further ecological degradation in the study areas was also suggested.

Chapter 1

INTRODUCTION

Forests are known to bestow a variety of benefits to the society. In addition to the customary ecological, economic and social benefits, forests protect water resources, reduce run-off, abate floods, control soil erosion and improve water quality. It is widely accepted that, since independence, there has been a rapid decline of area under and/or quality of the forests in most parts of India (Rawat and Rawat, 1994). This was consequential to a variety of factors, of which policies of the successive governments, shortfalls in the implementation of forest development programmes and increased activities due to population pressure. Deforestation has resulted in ineffaceable and irreversible landuse and ecological changes, impairing the hydrologic response and/or watershed functions of most forests (Lal, 1996). Further, the unsustainable exploitation of the forest ecosystem is detrimental to the other ecosystems embedded in it viz., forested wetlands, man-made wetlands and also adjacent agricultural system. In other words, the forest ecosystem and the other ecosystems embedded in it and nearby agricultural ecosystem are closely related and the interlinkages among these ecosystems are so interdependent that, the change in one ecosystem directly affects the other ecosystems.

Water conservation functions of the forests have not been adequately emphasized while managing forests, particularly in Kerala (Kallarackal, 2000). It is well known that a large number of socio-economic and ecological factors affect water-yielding functions of forest areas. To be more precise, because of the population increase and land hunger, most of the forest areas or upland watersheds in the State have experienced increasing levels of encroachment. Plantation activities in the upland areas brought about landuse changes that caused ecosystem alterations and soil erosion. Similarly, changes in the cropping pattern, soil erosion and sedimentation in the down stream areas also lead to changes in ecology and agricultural production.

The pertinent questions are: what are the reasons for landuse changes in upland areas and how do they consummate in ecosystem and economic changes which in turn adversely affect water conservation/yield? A variety of factors such as population increase and implementation of extravagant government policies (Grow More Food Programme, for example) had resulted in changes in landuse in the past. When the market economy began to play the primary role, alteration in marketshed (parallel to watershed) started to influence the changes in watershed. For example, a drastic change in price of a crop is often followed by a crop shift in the watershed. Similarly a change in the production of crops also affects the market shed. This inter-relationship is more powerful in the current economy, especially with the recent liberalization policies, in the context of globalization. Unscientific landuse practices often cause problems in *in situ* water conservation, as water holding and infiltration capacity of the soil are adversely affected. Landscape transformation caused by forest disturbance is predicted to have dramatic effect on run-off rate, soil erosion, stream flow and quality and quantity of water which in turn affect onsite and/or off-site production or consumption (Bisht and Tiwari, 1996).

In the context of vagaries of monsoon, the burgeoning drought situation, and augmenting water resource availability both for drinking and irrigation purposes, research on hydrological functions of forest assumes colossal importance. The benefit of irrigation and drinking water, at a subsidized rate, is largely restricted to the urban and suburban areas and seldom reaches the rural poor. This necessitated undertaking more studies, particularly micro level studies linking landuse changes, forests and water resources. Keeping this in view, a detailed study was undertaken in the Manali watershed of Karuvannur river basin in Thrissur district, Kerala.

1.1 The study area

The Karuvannur river basin lies between 10^0 15’ to 10^0 40’ North latitude and 76^0 00’ to 76^0 35’ East longitude within Thrissur and Western

Boundary of Palakkad districts of Kerala (Fig.1.1). It is bounded by Thrissur and Chavakkad Taluks of Thrissur district in the North, Mukundapuram and Kodungallur Taluks of Thrissur district in the South, Alathur and Chittor Taluks of Palakkad district in the East and the Arabian Sea in the West. Karuvannur River basin, constituting an area of 1054 km^2, lies in Southern Western Ghats and covers 32 panchayats, 9 blocks and 2 districts. The river originates from the Western Ghats and is fed by its two main tributaries, *viz.*, the Manali and the Kurumali. The Manali river originates from Ponmudi in the boundary of Thrissur and Palakkad districts at an elevation of + 928 m. The Chimony and Muply, the two sub-tributaries of the Kurumali originate from Pundimudi at an elevation of + 1116 m. This is one of the major river basins with the actual utilizable water resources of 623 Mm^3 of which the net utilizable surface and ground water resources are 519.8 Mm^3 and 103.2 Mm^3 respectively. Karuvannur river has a drainage area of 1054 km^2, stream length 48 km, average monsoon flow of 1275 Mm^3, average lean flow 55 Mm^3 and total flow 1330 Mm^3. (Rajagopalan and Sushanth, 2001). The average rainfall in the low land of the river basin was estimated to be 2858 mm, the midland 3011mm and the highland 2851 mm. About 60 per cent of the rainfall is received during south west monsoon period, 30 per cent from north east monsoon and 10 per cent in the pre-monsoon period.

Manali is one of the important sub-watershed systems in the river basin. This is also one of the important forest areas of the river basin as well as the district. Keeping the above facts in mind, Manali sub-watershed was selected for detailed study. Total area of this watershed is 274 km^2 and lies in Thrissur district of Kerala (Fig.1.1). It is spread over 13 villages, constituting a little over of 11 per cent of the total area of the district (3032 km^2). The utilizable annual surface water is 40.6 per cent of the available annual surface water and 25.5 per cent of the mean annual rainfall. The available annual surface water (mean runoff) is 62.8 per cent of the mean annual rainfall (Rajagopalan and Sushanth, 2001).

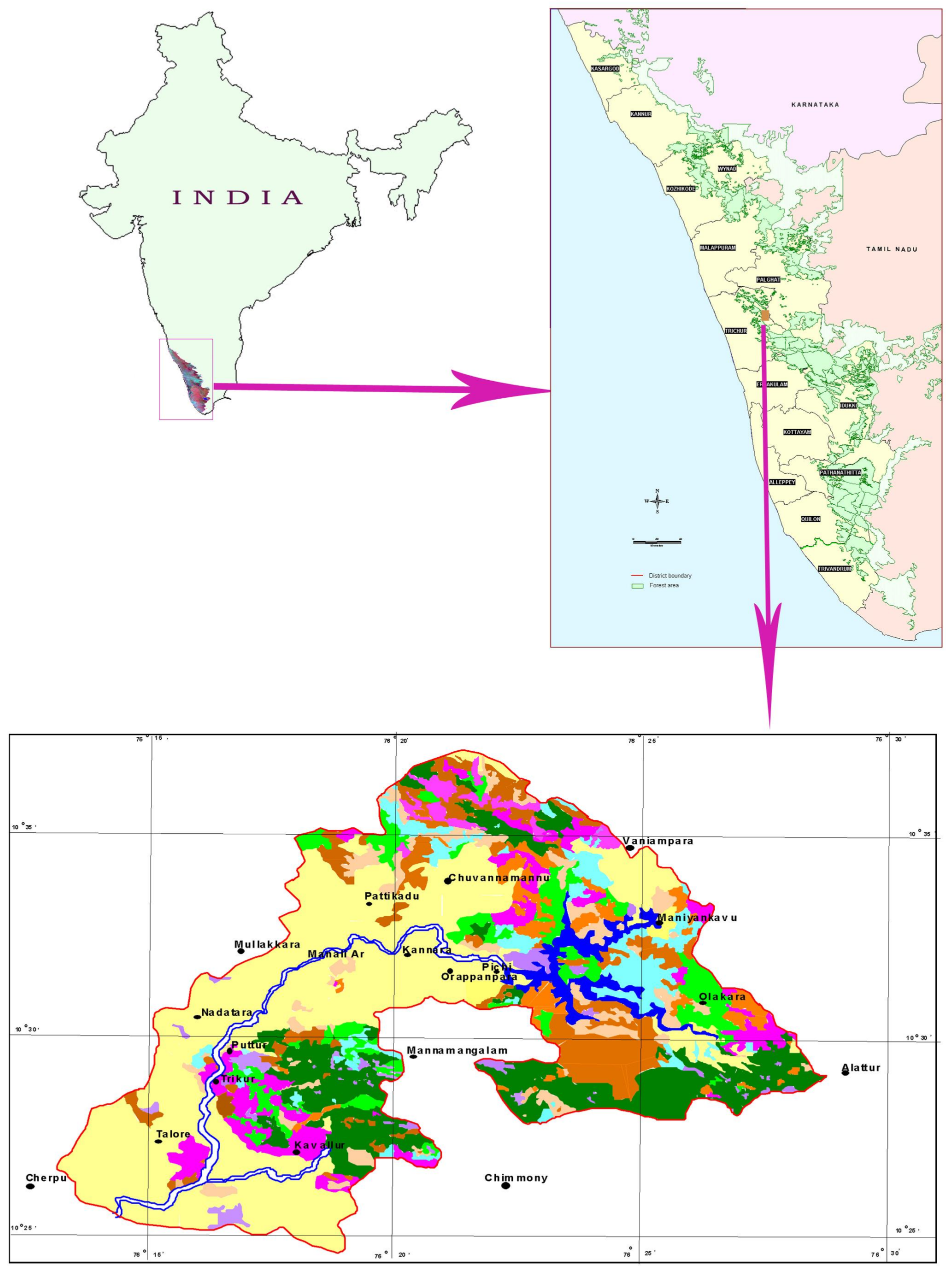


Fig.1.1 Location map of Karuvannur River Basin

1.2 Ecological and economic problems in the study area

Major forest areas of the watershed are concentrated at Peechi region of Peechi- Vazhani Wildlife Sanctuary which was established in 1958, constituting an area of 76.5 km^2. Evergreen, semi-evergreen, moist deciduous and scrub types of forests are the main vegetation types of which the first three account for 22, 17 and 28 per cent respectively. Owing to inadequate protection/conservation effort, this Wildlife Sanctuary is characterized by high degradation levels and low density of wildlife. Of the total forest area, highly and moderately degraded areas account for 14 and 16 per cent respectively (Deepa, 2000). Peechi Reservoir is located in the watershed which supplies major share of the irrigation and drinking water in Thrissur district.

Forest dwelling tribes were the early inhabitants of this area and depended up on collection of non-timber forest products (NTFPs) for their livelihood. Influx of settlers to this area can be traced back to early 1950's at the time of construction of Peechi dam across the Manali river and encroachment has been further accentuated in the subsequent years. The settlers are mostly agriculturists who cultivate a variety of crops such as vegetables, banana, rice, tapioca, cashew, rubber, etc. Ownership rights of many settlers are undecided. People (tribal and other local communities) living immediately around the natural forests are highly dependent on the forests for agriculture, NTFPs, firewood, cattle grazing and small construction needs, resulting in degradation of forest areas. In other words, the degradation of forest was caused by biotic pressures such as illicit cutting, grazing, fire, etc. which are anthropogenic in origin. This has resulted in structural and other changes in the forest, including inadequate regeneration (Swarupanandan and Sasidharan, 1992).

Our pilot survey indicated that there have been significant changes in the landuse which have had adverse effects on forest ecology, water yield, dry season flow, soil erosion, stream sediment load, etc. and agricultural production. Originally, the Peechi Irrigation Project was aimed at supplying irrigation water to agricultural sector, including Kole lands. But due to urbanisation and the influence of the well-to-do people in the district, more water has been diverted for drinking purpose. This in turn has brought about two major changes in the economy. First, with the decrease of supply through irrigation canal, especially during summer season, the water tables in the well in the study area has gone down, resulting in shortage of water. Secondly, in the absence of adequate irrigation water supply, particularly in the mid and tail end regions of the canals, the productivity of the crops have been declined which in turn adversely affected food security and income levels of the people.

The area under crops in the watershed and also other irrigated areas in the district have significantly declined over a period of time. The demand of water for irrigation, drinking, industrial and other common needs is much higher than the supply. There is no reliable information regarding demand-supply gap of water resources in Manali watershed. However, in the Karuvannur River Basin, where this watershed is located, the deficit is expected to be 22 Mm^3 in rabi season and 151 Mm^3 in summer season (Rajagopalan and Sushanth, 2001) indicating that water shortage is very severe during summer. The drinking water supply from Peechi Reservoir is estimated to be 50.5 Mm^3 per day which meets a good part of the water requirements of the urban and semi-urban areas of the district, but not that of villages.

The sustainability in the resource use is imperative for better livelihood opportunities, environmental balance and rural development. Further, the biophysical and socio-economic linkages between the upland and downstream areas of a watershed and its influence on overall economic development have been widely accepted (James *et al.,* 2000). The changes in the upland areas have their own impact on downstream, as both are closely interlinked. For instance, soil erosion is a natural process but it gets accelerated due to excessive anthropogenic activities and its implications are mostly economic, affecting welfare of the society (Kumar, 2000). Soil erosion has both onsite (direct) and off-site (indirect) impacts which affect productivity of the upland areas and economic activities in the downstream area. It also imposes economic and environmental costs on people living in both the regions, which ultimately affect their development. This requires a comprehensive environmental auditing of soil, water and production loss arising from landuse change in a watershed. This study is a modest attempt in this line.

1.3 Objectives

The broad objective of this study is to examine landuse change and its effects on eco-hydrology and socio-economic conditions of the people in the study area. Specific attempts were made to:

1. Study the nature and extent of landuse and cropping pattern changes and important socio-economic drivers affecting it.
2. Examine the effects of landuse on hydrology- run-off, stream flow, ground water table, temperature and humidity- in the watershed
3. Analyze the effects of landuse/cropping pattern changes on vegetation, sedimentation, agricultural production and socio-economic conditions of the people
4. Assess economic value of water resource, surface water use pattern, pricing and use conflict over water resources among different sections in the society
5. Examine the linkages between ecological and socio-economic systems of the upland and downstream areas of the watershed in determining overall development.

Chapter 2

METHODOLOGY

Broadly, the study examines selected biophysical and socio-economic aspects of the problem and integrates them to understand their implications in the development perspective. The methods employed to study major aspects of the problems are given below.

2.1 Selection of micro watersheds

A nested catchment approach has been followed in the selection of a micro watershed considering the large area covered by the Karuvannur River Basin. The river basin, with several micro watersheds, has been divided into upstream and downstream watershed, based on the elevation data. One micro watershed, representative of the upstream catchment (Olakara) and another from the downstream catchment (Kavallur) have been chosen for detailed study.

2.2 Land use dynamics

Satellite data products

Satellite data products on 1:250,000 scale (hardcopy) and digital data of IRS1C LISS III/IRS1D LISS III of January 1996 and IRS P6 (PAN+LISS3 merged product) of January 2004 were used in the present study.

Ancillary data

The following ancillary data were used directly or indirectly for the study purpose.

i. Survey of India topo-sheets on 1:250,000 and 1:50,000 scales.
ii. Forest type maps of India (Champion and Seth, 1968)
iii. Biogeographical map (Rodgers and Panwar, 1988)

iv. Management maps/Stock maps of State Forest Department

v. Forest Vegetation maps on 1:250,000 scales and 1:50,000 scale available with Forest Survey of India for Forest density layer and other relevant information as base details.

2.3 Vegetation classification scheme

In the present study, Level II vegetation classification is attempted. Following classification scheme was adopted for stratification, using Remote Sensing Digital data.

Forest Vegetation

I. Forests

1. *Dominant phenological types*

- 1.1. Evergreen
- 1.2. Semi-evergreen
- 1.3. Moist deciduous
- 1.4. Dry deciduous

2. *Gregarious types (single species dominated*)

- 2.1. Bamboo

3. *Local specific classes*

- 3.1. Mangrove
- 3.2. Sholas
- 3.3. Riverian
- 3.4. Sacred groves

4. *Degradation types*

- 4.1. Degraded forest stages (eg.10-40 per cent tree density, signs of erosion and composition are not confirming with any of the above types).

II. Scrubs

III. Grasslands

Non-forest vegetation

IV. Major Wetlands

V. Plantation (Tea/Coffee/Coconut gardens etc.)

VI. Agriculture

VII. Fallow/Barren

VIII. Water body

IX. Settlement

2.4 Digital classification of satellite data

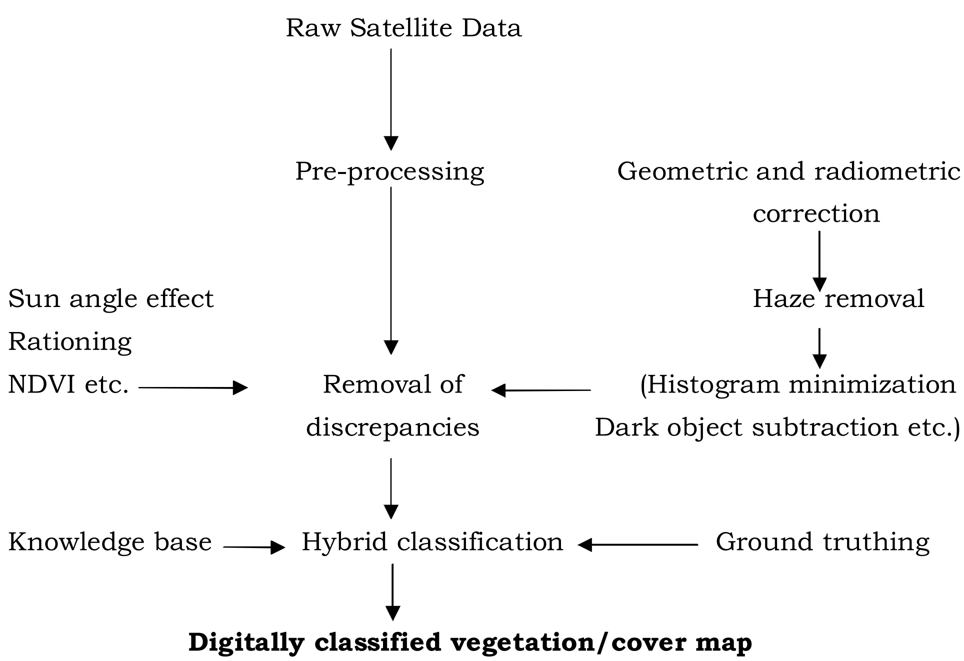
Pre-processing: The raw digital data was enhanced using contrast stretching or ratio based techniques to facilitate better discrimination during ground data collection or locating sample points.

Reconnaissance survey: The reconnaissance survey was undertaken for getting better acquaintance with the general nature of vegetation of the area. Major vegetation types and few prime localities of characteristic types were noted during reconnaissance survey. The variations and tonal patterns were also observed on existing images/maps. Traversing along major drainage, roads, paths, etc. for ground truthing, existing literature survey, and interaction with forest officials were also made during field survey.

2.5 Vegetation characterization using satellite data

Satellite data in digital form were analysed to characterize the vegetation using interactive digital analysis procedures. The preparation of vegetation map assumes a critical step in the vegetation characterization procedure.

The study area falls in a single satellite scene. The scene was geometrically corrected with reference to Survey of India 1: 50,000 scaled Topo-sheets. The Vegetation classification was performed as per the scheme mentioned earlier. The different scene was classified using *Maximum likelihood* method. After complete classification, misclassified areas were checked and reclassified considering small Area of Interest (AOI) or through interactive editing for improved accuracy. Finally the classified sub-scenes were mosaiced and the edges were smoothened. The approach for land cover mapping is as follows:



2.6 Accuracy evaluation

The classification performance was evaluated by redundant training areas and field sample points based on the *commission and omission error matrix* and hence overall classification accuracy was calculated. It should be noted that overall classification accuracy is more than 85 per cent.

Phytosociological data Collection

Phytosociological analysis provides the real meaning to any biodiversity and vegetation analysis by quantifying the structural parameters of the communities. The sampling principle was based on inventorying the homogeneous strata identified by remote sensing data analysis. According to the spectral signature variability in consonance with the vegetation type and orientation of terrain, sample points were marked on 1: 50,000 scale SOI toposheets in the study area. The plot size in the sample points was of 33 m x 33 m covering approximately an area of 0.1 hectare. Taxonomical census of each plot as well as menstruation of individual woody members qualifying as tree and shrub yielded the data essential for arriving structural status.

Sampling strategy

Stratified random sampling with probability proportion to the size (PPS) was adopted for analysing vegetation composition of all the types encountered. To sample an area of nearly 0.01 per cent of total area of each type, percentage sampling procedure was adopted. In view of the time, money and availability of other resources, optimum number of sample points has been taken up, covering all vegetation type, in different density/disturbance regimes.

For each vegetation type, the size of the quadrat was determined through 'Species-Area curve method' (Muller – Dombois and Ellenberg, 1978). The plot size was restricted to 0.1 ha. (32 m x 32 m). A minimum of 8-10 quadrats were analysed for each vegetation type.

Marking location of sample plots

Each sample site was located on survey of India toposheets. Exact longitude and latitude and location height (msl) were noted down using Global Position System (Garmin III plus and Trimble GeoXT).

Creation of watershed boundaries and masks

The precise watershed boundaries as obtained from Survey of India toposheets were used and the bit map was created to use them as watershed mask. It was ensured that the SOI watershed boundaries are properly registered on the geometrically corrected image and geo-referenced map.

Plot method and enumeration

At each sample plot, complete enumerations of species were done. The circumferences at breast height (cbh) or 1.3 m above ground level, of all tree species were recorded. The individuals with cbh >30 cm were considered as tree and with >17 cm and <30 cm cbh as saplings. The number of seedlings of various species was counted and average girth of each species was recorded. For shrubs, a plot of 10 m x 10 m was laid within the main plot. For herbaceous layer or ground flora, the nested quadrat methods with 1 m x 1 m plot size were taken in two opposite corners and wherever required number of samples were increased up to five (four in corners and one in centre).

Species identification

Each plant was identified in the field itself (either botanical name or local name). Specimens of unidentified plants if any were collected with proper field notes (plot number, locality, habit, flower colour etc.). The specimens were preserved as per standard procedures and were taken to KFRI herbarium. Expertise of experienced taxonomists was availed during the field sampling.

Phytosociological analysis

For each vegetation type, the structural attributes and Importance Value Index (IVI) were computed as described in Muller-Dombois and Ellenberg (1978) and explained below:

$$\text{Frequency} = \frac{\text{Total number of quadrats in which species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Density (per quadrat)} = \frac{\text{Total number of individuals of the species}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of species occurring}}{\text{Total number of quadrats in which species occurred}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Sum of frequency of all species}} \times 100$$

$$\text{Relative density} = \frac{\text{Density of a species}}{\text{Sum of density of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Total stand basal cover of species}}{\text{Total stand basal cover of all the species}} \times 100$$

$$\text{Basal cover} = \frac{(\text{cbh})^2}{4\,\text{II}}$$

Sum of basal cover of individual plants of a species will yield total stand basal cover of that species.

Importance Value Index (IVI) = Relative Frequency + Relative Density + Relative Dominance

Plant diversity

The plants were enumerated by line transect method. Three enumerations in the months of January, March and October were carried out to have a representation of plants occurring in different seasons of the year. Plants were mostly identified in the field during enumeration. Species which could not be identified in the field were brought to the Institute and identified with the literature (Sasidharan and Sivarajan, 1996) and by comparing with authentic herbarium specimens in the Kerala Forest Research Institute Herbarium.

2.7 Hydro meteorological observations

Historical data on rainfall and stream flow data for the last few years, sometimes as early as 1963 were collected from the Hydrology Department, Government of Kerala.

Rainfall distribution during study period

Tipping bucket rain gauges (Onset Computer Corporation, USA) were installed and daily data from January 2005 till December 2006 were recorded at both watersheds of Olakara and Kavallur.

Stream flow measurement

Three streams were identified in both the watersheds for measurement. Daily measurements for the flow were taken. Flow measurement was taken using velocity float method. The depth of the flow through the outlet was measured twice a day at 8.00 a.m. and 2.30 p.m.

Velocity float method

In the velocity float method, discharge rate was computed using the formula,

$$Q = AV = (bd)\, L/t$$

where, Q = Discharge rate (m^3/sec)

A = Area of cross section of flow (m^2)

V = Velocity of flow (m/sec)

d = Depth of flow (m)

b = Width of flow (m)

t = Time taken by the float (sec) to travel specified distance in m

Depth of flow and time taken by the float to reach the length were noted everyday. Velocity was calculated. By multiplying velocity with area of flow the discharge was measured.

At Olakara, three streams were monitored in the micro watershed for stream flow. All the three streams were flowing through forested areas. At Kavallur also, three streams were monitored:

Stream 1	Originating and flowing through a felled *Eucalyptus* plantation
Stream 2	Originating from a forest and flowing through plantation which is planted under social forestry project
Stream 3	Originating and flowing through agricultural land

2.8 Water table fluctuation studies

Ten wells from each micro watershed were selected for the water table fluctuation studies. Observation regarding the water level was taken at 15 days interval. The depth of water table was taken as the depth from the ground level to top of water level in the well. Fluctuations were calculated and depicted in the graphical form.

Relative humidity and temperature

Data loggers (Gemini Tiny tag data loggers, UK) for measuring daily temperature and relative humidity (with thermistor and humicap sensors) were installed at both watersheds. Hourly data were recorded.

Ground water table observation

Open dug wells are basic groundwater source for both sites. Based on the physical survey carried out, 11 open wells were selected for ground water table studies from Kavallur and 8 from Olakara. Kavallur area comprises of paddy fields, coconut, banana, vegetables and rubber plantations. All the wells selected in Olakara were located within the forest area. Data were collected fortnightly using a measuring tape.

Soil physico-chemical properties

Twenty-five plots of 33 m x 33 m size were laid out in the experimental area at Olakara. In each plot, three soil pits of 60 cm x 60 cm x 30 cm dimensions were taken and soils collected from 0-20 cm, 20-40 cm and 40-60 cm depths. The soils from three pits of the same depth were mixed and made into a composite sample. The samples were air dried and processed for determination of gravel, particle-size separates, bulk density, maximum water holding capacity, pH and organic carbon.

In six plots at Olakara, locally fabricated sediment collectors were installed. The sediments were collected at periodic intervals in July, August and October 2005 and June, August and September 2006. The collected sediments were quantified and the nutrient contents (Nitrogen, Phosphorus and Potassium) were found out. Attempts were also made to assess sediment yield in the Kavallur area. Unfortunately no data could be collected as the sediment collectors installed in the field were destroyed.

2.9 Socio-economic aspects

Socio-economics

The socio-economic part of the study is based on both primary and secondary data. The primary data were gathered from a sample of households. The study area was spread over 13 villages (Marakkal, Vaniyampara, Chuvannmannu, Pattikkad, Kannara, Peechi, Maniyankinaru, Olakara, Kavallur, Puttur, Nadathara, Manamangalam, and Pudukkad) in Trichur taluk of which six villages, that is, three each from upland and downstream areas were selected at random for primary data collection. Data were collected from 100 households located in the selected villages. Primary data were gathered from 100 farmers in the upland and downstream areas using multi-stage stratified random sampling technique. The time series data relating to change in the economic variables such as production, price and cropping pattern, etc. were gathered from secondary sources *viz.,* publications of the State Planning Board, and Kerala State Land Use Board. Historical data were gathered from age-old people in the study area.

2.10 Economic valuation of water resources

In the study area, the reservoir is used for supplying water for irrigation and drinking purposes, fishing, ecotourism and education and research. It also gives a number of functional benefits such as increasing agricultural productivity, soil conservation, recharging of ground water and regulation of stream flows. Thus, value of the water resources might be much higher than one generally perceives. An attempt was made to estimate market and non- market benefits of the water resources in the Peechi Reservoir in the total economic value framework.

Total economic value of Peechi-wetlands was undertaken using the standard tools for valuation of ecosystem. Munasinghe (1992) has classified of the major categories of value assigned to nature (Fig.2.1). This was used as an analytical tool to determine the main values associated with the functions of the wetlands and to identify suitable valuation tools to assess their monetary value. Munasinghe (1992) divided the total economic value of nature into use and non-use values. The use values are divided into the direct and indirect use values and option values. The non-use values are divided into existence and bequest values. The TEV is embedded in the total value concept, which is detailed in the following section.

Total value

The total value (TV) of an ecosystem is the sum of two components: a primary value (PV) and a secondary value (SV).

$$TV = PV + SV \qquad (1)$$

Primary value

The Primary value (PV) or 'glue' value or 'intrinsic' value is not associated with the ecosystem's use, but is beyond its value to humans (Turner *et al.,* 1994). The PV is rather perceived as a non- anthropocentric or 'ecocentric' value which is inherent to the ecosystem's self organizing capacity, and hence to its existence and continuity, independently of human preferences, and irrespective of human desires or will.

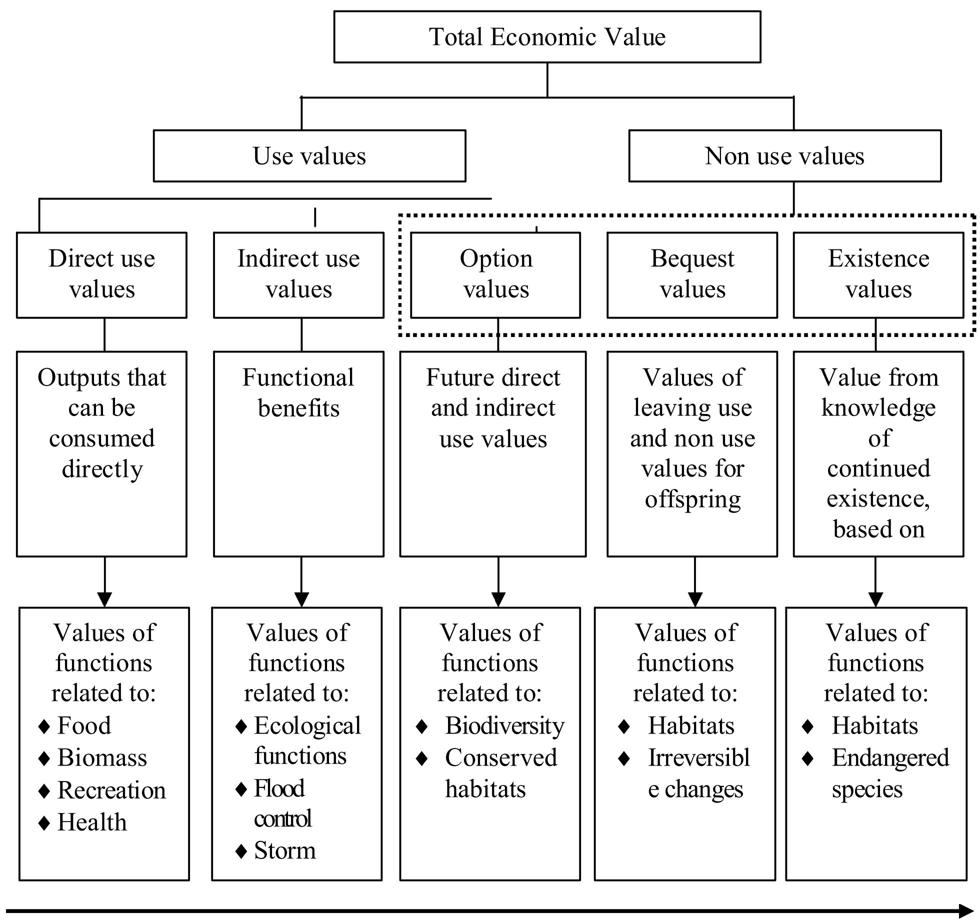


Fig. 2.1 Classification of total economic value, (*Source*: Munasinghe, 1992)

Secondary value

The secondary value (SV) or 'instrumental' value or 'economic' value is rather an anthropocentric, utilitarian value, which fully relies on human self-interest, and is derived only from individual preferences. It is equal to the total worth of the ecosystem's goods and services provided for the individual. It is the commonly known concept developed by the economic science (Pearce, 1999), called total economic value (TEV), and consisting of use values (UV) which include direct use values (DUV), indirect use values (IUV) and option values (OV) and non-use values (NUV) which include existence value (EV) and bequest value (BV).

$$SV = UV + NUV \tag{2}$$

$$UV = DUV + IUV \tag{3}$$

$$NUV = EV + BV \tag{4}$$

Combining equations (3) and (4); EV = (DUV+IUV+OV)+(EV+BV) (5)

Use values

According to the classification adopted by Turner *et al.* (1994), the use values (UV) are disaggregated into direct use values (DUV), indirect use values (IUV) and option values (OV).

Direct use value

Direct consumptive use

The direct use value (DUV) is broadly determined by the production of measurable and merchantable (or at least potentially merchantable) outputs. For wetland ecosystems, DUV is subdivided into consumptive values (CV), and non-consumptive values (NCV), such as recreation, sightseeing, spiritual use. DUV is practically equal to the net income generated from the ecosystem. For assessing the value of tangible benefits *viz.,*, fish, the following formula was adopted.

$$\text{DUV} = \sum_{i}^{n} (P_i Q_i - C_i) \tag{6}$$

where,

P_i is the price of product i,

Q_i is the amount of product i, being harvested, and

C_i is the cost involved in the harvesting of product i.

Direct non-consumptive use

The recreation benefits/tourism benefits were estimated using travel cost method (TCM). Travel cost method was applied in the study area for estimating the consumer surplus of the visitors. The dam is under the control of Irrigation Department and prior permission is not required for the same. A nominal entrance fee of Rs 2/- is charged for the visitors of dam.

The Clawson and Knetsch (1966); TCM demand function is of the form:

$$V_i = f(P_i, X)$$

where,

V_i = Visitation rate of i th population

P_i = Cost of visiting the site from zone 1

X = Vector of socio economic variables affecting travel cost demand curve

The individual travel cost method was applied in the study to estimate the demand function. The study adopted a semi log function to estimate the demand function. The consumer surpluses were estimated from the coefficients obtained from the demand function (Hangley, 1989).

The estimated demand function is of the form;

$$V = f(X_1, X_2, \ldots X_8)$$

where,

V = Number of visits by each visitor

X_1 = Residence of the respondent (local=1, 0 otherwise)

X_2 = Education (dummy variable)
X_3 = Willingness to pay (Rs.)
X_4 = Income (Rs. year^{-1})
X_5 = Visiting day (weekend=1, weekdays= 0)
X_6 = Opportunity cost of time (income corrected for hours spent at the site (Rs.)
X_7 = Travel cost (expenses incurred on travel Rs/person)
X_8 = Distance traveled (km)
X_9 = Infrastructure (dummy variable; improve present condition=1; 0 otherwise)
X_{10} = Local travel cost (expenses at the site in Rs.)

Three basic steps are involved in travel cost models. First, it is necessary to undertake a survey of a sample of individuals visiting the site to determine their costs incurred in visiting the site. These costs include travel time, any financial expenditure involved in getting to and from the site, along with entrance (or parking) fees. In addition, information on the place of origin for the journey, and basic socio-economic factors such as income and education of the individual is required. The resulting data is manipulated to derive a demand equation for the site. This relates the number of visits to the site to the costs per visit. The third step is to derive the value of a change in environmental conditions. For this, it is necessary to determine how willingness to pay for what the site has to offer alters with changes in the features of the site. The domestic tourists frequented the site while foreigners visited very rarely or occasionally. Hence demand function was estimated for only domestic tourists.

Indirect use values

The indirect use values (IUV) are derived basically from the functional services provided by the ecosystem to support current production and consumption (eg. hydrological cycle stability, natural filtration of polluted water, climate regulation, recycling of nutrients, biodiversity, etc.).

Option values

Contrary to direct and indirect use values which refer to (potential) effective use of the ecosystem's goods and services by humans at present, the option value (OV) refers to option of a potential use of these goods and services, by people themselves or by future generations. In the context of OV, people preserve ecosystem functions for possible use in the future, even if others will use them.

Non-use values

The concept of non-use values (NUVs) is more complicated to define and measure; they are also referred to as 'passive' use values; they are not associated with actual ecosystem's use, or even with the alternative to use a good or service. According to the classification adopted by Turner *et al.* (1994), NUVs are disaggregated into existence value (EV) and bequest value (BV).

Existence value and bequest value

The existence value (EV) is the satisfaction value derived by individuals from the pure fact that an ecosystem and/or its constituents exist, for their own, regardless of necessarily seeing it or having any intention of using it directly (Turner *et al.,* 1994). The bequest value (BV) is perceived as the moral value people derive from knowing that an ecosystem and/or its constituents will be passed on to future generations to enjoy it.

Contingent valuation method

Primarily, contingent valuation method was used to know the willingness to pay. Contingent Valuation (CV) surveys directly ask people what they are willing to pay for something they value or are willing to receive in compensation for tolerating a cost. Personal valuations for increase or decrease in the quantity of some goods based on a hypothetical market are undertaken. The aim is to elicit valuations or bids, which are close to what would be revealed if an actual market existed. CV employs a questionnaire format where respondents are asked how much they would be willing to pay or willing to accept compensation for a specified gain or loss of a given good or service. Economic value estimates yielded by CV surveys are 'contingent' upon the hypothetical market situation that is presented to respondents and allows them to trade off gains and losses against money. WTP/WTA questions may be asked in a number of ways, including open-ended, where the respondent states their maximum WTP/WTA, and dichotomous choice, where the respondent is required to answer yes or no to a 'bid'.

Simple CVM exercises can be based on the "open ended" elicitation formats, where the individual is simply asked to state his/her maximum WTP or minimum WTA for a given environmental change. However, this approach becomes biased when the respondent state a WTP/WTA lower or higher than the true one in order to influence the decision making process for the sake of his own profit. To avoid the drawbacks of open – ended format, an iterative technique called the "bidding game" is used. In this technique the respondent is asked whether he accepts to pay a given amount of money. If he refuses, the proposed amount is reduced (increased) by a given percentage (say 10%). The procedure is repeated until the respondent answers "yes". The penultimate amount is taken as his maximum WTP (minimum WTA) for obtaining (to give up) the environmental improvement. If the individual accepts the proposed amount is increased (decreased) of say 10 per cent. The procedure continues until the individual answers "no". Here also the last amount proposed is taken as his maximum WTP (minimum WTA) for obtaining (to give up) the environmental improvement. Some of the data relating to pricing of water have been drawn from studies carried out in the study area recently (Sreelakshmi, 2005)

The stakeholders of Peechi wetlands were classified into three, *viz.,* drinking water users, irrigation users and fishermen for the purpose of the study. Data were gathered from 120 drinking water users, 270 irrigation users and 50 fishermen who catch fish from Peechi reservoir. Primary data collected from the farmers and those who use drinking water were used to study water use efficiency and use conflict. Data collected from 500 tourists were used for estimation of recreation value.

The study also made use of relevant secondary data collected from the 20 respective village offices, forest range offices, Irrigation Department and office of the Kerala Water Authority.

Chapter 3

LAND USE AND CROPPING PATTERN CHANGES

The extent, magnitude and intensity of land use and its resultant changes in the agricultural sector are discussed in this section. This chapter is organized and presented under three headings *viz.*, land use change, cropping pattern change and socio-economic drivers of land use and cropping pattern changes.

3.1 Land use change

Land is defined as an area where all human activities are conducted and it is also the source of the materials needed for this anthropogenic conduct (Briassoulis, 2000). Human use of land resources gives rise to land use and generally, the two broad sets of dynamic factors/forces, which influence the land use, are human needs and environmental features and processes. The operations of these forces are continuous resulting in frequent changes in the land uses and the magnitude of land use change varies with the time period being examined as well as with the geographical area. These changes have at times been beneficial and at times caused detrimental impacts or effects. The latter is the chief cause of concern, as they impinge variously on human well-being and welfare (Meyer and Turner, 1994).

The terms land use and land cover, though not strictly synonymous, have been used inter-changeably worldwide. Therefore, an understanding of the different land related terms assumes significance while taking up any study on land use change. Land cover is the biophysical state of earth's surface and the immediate subsurface (Turner *et al.*, 1995). Originally, the term referred to the type of vegetation that covered the land surface, but has broadened eventually to include human structures, such as buildings or pavements, and other aspects of the physical environment (Moser, 1996). The land use involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation- the purpose for which the land is used (Turner *et al.*, 1994). In other words, land use denotes the human employment of land (Turner *et al.*, 1995). In this study, the words land cover and land use changes are used synonymously and the same is analysed on a watershed level for a period of 44 years i.e. from 1960 to 2004.

General classifications of land use followed by Kerala State Land Use Board are forest area, land put to non agricultural use, barren land, cultivable waste, cultivable fallow, net area sown, area sown more than once and total cropped area. The compound growth rates of various land use categories during the period 1960 to 2004 are given in Table 3.1. The land use categories such as area under forests, barren land and area sown more than once and total cropped area showed a negative growth rate while the other categories showed a positive trend. Further, all categories except cultivable fallow showed a deceleration trend, indicating that more agricultural lands are put to fallow. In the context of declining food production and low growth rate of agriculture in the state, this is not a healthy trend.

Table 3.1: Land use change over the years: Trend analysis (1960-2004)

Variable	Trend equation	Cgr (%)	A/d
Forest area	In FA = 11.8693 - 0.00835t	-0.83	D**
Land put to non agri-use	In LPTNAU = 9.4678 + 0.02144t	2.17**	D**
Barren land	In BARAN = 8.5654 - 0.0483t	-4.72*	D*
Cultivable waste	In CUWA = 7.3567 + 0.0239t	2.43*	D*
Cultivable fallow	In CUFA = 7.4162 + 0.0361t	3.68**	A**
Net area sown	In NE AR S = 11.8259 +0.0060t	0.61*	D*
Area sown more than once	In AR S M O = 11.4932 - 0.0162t	-1.61*	D*
Total cropped area	In T CR AR = 12.3152 - 0.0015t	-0.15	D*

*Cgr= Compound growth rate, A= Acceleration; D=Deceleration; *=1% Level of significance; **= 5% Level of significance*

Total area under forests in Thrissur district was estimated as 1389 ha during 1960-61 which gradually declined to 1214 ha during 1982-83 and then to 1036 ha during 2004-05 (Table. 3.2). Peechi-Vazhani Wildlife Sanctuary is one of the major forest areas of Thrissur district and Karuvannur river basin and is also the main forest area in Manali watershed. The rate of forest denudation in Thrissur Forest Division shows that about 23 per cent forests were cleared for various purposes during the 30 year period between 1930 and 1960 and during the period 1960 to 1984 the rate almost doubled (50%) (Menon, 1986).

Table 3.2. Area under forests in Thrissur district 1960-61 and 2004-05

YEAR	AREA (ha)
1960-61	1389.04
1961-62	1389.00
1962-63	1388.46
1963-64	1388.32
1964-65	1388.75
1965-66	1385.25
1966-67	1383.32
1967-68	1383.32
1968-69	1383.32
1969-70	1383.30
1970-71	1383.30
1971-72	1383.30
1972-73	1383.30
1973-74	1383.30
1974-75	1383.30
1975-76	1383.52
1976-77	1384.74
1977-78	1378.51
1978-79	1378.49
1979-80	1345.23
1980-81	1325.37
1981-82	1318.36
1982-83	1214.25
1983-84	1137.35
1984-85	1098.25
1985-86	1036.19
1986-87	1036.19
1987-88	1036.19
1988-89	1036.19
1989-90	1036.19
1990-91	1036.19
1991-92	1036.19
1992-93	1036.19
1993-94	1036.19
1994-95	1036.19
1995-96	1036.19
1996-97	1036.19
1997-98	1036.19
1998-99	1036.19
1999-2000	1036.19
2000-01	1036.19
2001-02	1036.19
2002-03	1036.19
2003-04	1036.19
2004-05	1036.19

Source: State Land Use Board, Thiruvanthapuram

Between 1995 and 1973 different categories of forests in Thrissur district showed a declining trend. For instance, area under dense forests (canopy cover >40%) showed a decline to 78 km^2, open forests (canopy cover between 20-40%) were declined to 177 km^2 and degraded forests (< 20% canopy cover) were reduced to about 50 km^2 (Jha *et al.,* 2000). In Pattikad and Peechi forest ranges where the Manali watershed is located, natural forest area declined from 225 km^2 in 1930 to 179 km^2 in 1960 and further to 109 km^2 in 1984 (Menon, 1986). The loss during the period 1930-1960 was about 20 per cent while it was about 32 per cent during 1960-1984. This trend continued in the subsequent period also. Our analysis on land use/cover change in Manali watershed during 1996-2004 indicated that the area under forests had been converted to agricultural land on a large scale over the years (Figs. 3.1 & 3.2).

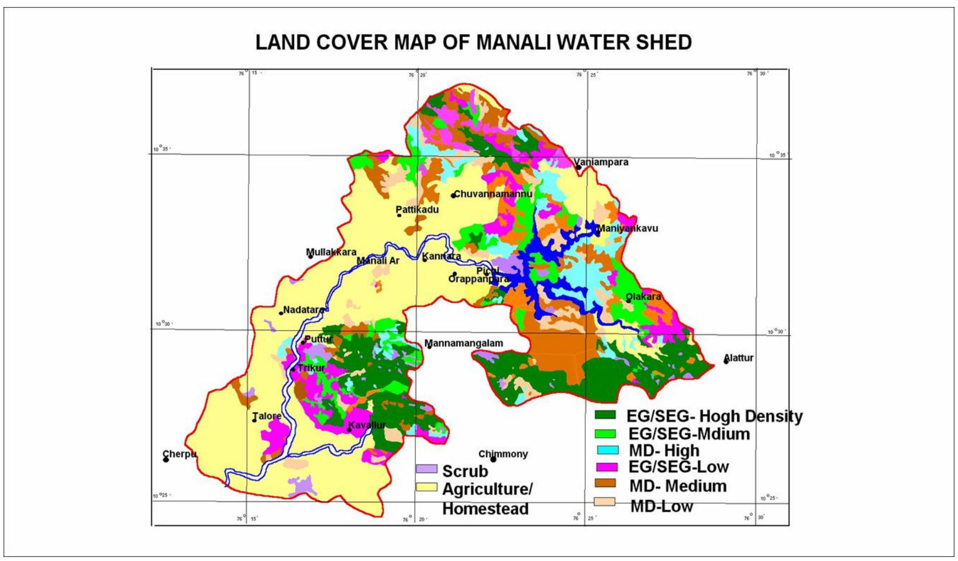


Fig. 3.1 Land cover map of Manali watershed based on 1996 IRS1C satellite imagery

For instance, between 1996 and 2004, the area under agriculture projected a 50 per cent increase (Table 3.3), which was effected mostly through conversion of forests.

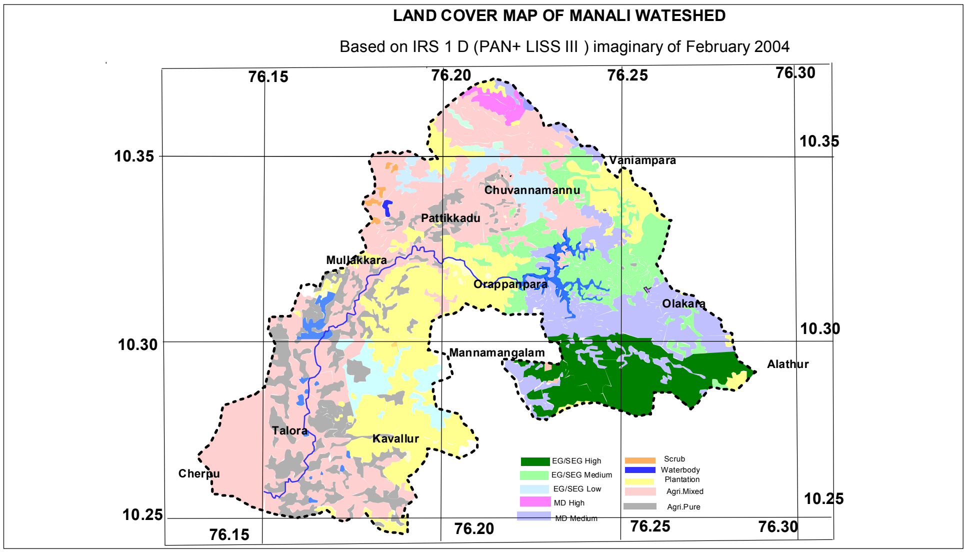


Fig.3.2 Land cover map of Manali watershed based on 2004 IRSP6 (PAN+LISS3 merged) satellite imagery

Table 3.3. Major changes in land cover classes (1996-2004)

Sl. No.	Cover type	Year	Area (sq km)	Percentage
Study area – 360 sq km				
1	Agricultural land	1996	150	40
2	,, ,,	2004	220	60
Increase of agricultural land --50%				
3	Forest land	1996	210	60
4	,, ,,	2004	140	40
5	Water holdings	2004	10 new units	
6	Change of river course at Kavallur area			

There may be different conditions under which the land use changes might occur. These are given in Table 3.4. These conditions and responses are different in different areas.

Table 3.4 Land use changes in a watershed: Conditions and responses

Conditions	Land use change in upstream	Land use change in Downstream
Upstream crops are more lucrative (upstream unit profit> downstream unit profit)	No change in land use	Change in land use More inputs leading to low productivity and land degradation. An early shift to other lucrative crops
Downstream crops are more lucrative (downstream unit profit> upstream unit profit)	Change in land use More inputs leading to low productivity and land degradation An early shift to other lucrative crops	No change in land use
Downstream unit profit=upstream unit profit	Land use change influenced by external independent factors, viz., innovative cropping (adapting new crops on experimental basis, socio-economic factors induced land use change etc); social/cultural drivers	Land use change influenced by external independent factors, viz. innovative cropping (adopting new crops on experimental basis, socio-economic factors induced land use change etc); social/cultural drivers
Relative profitability of crops in upstream and downstream; high input in upstream alone	Change in upstream cropping pattern due to economic drivers	Forced change in land use owing to sedimentation, pollution and land degradation by the upstream users.
Relative profitability of crops in upstream and downstream; high input in downstream alone	Forced change in land use owing to land degradation, ecosystem imbalance and water scarcity as a result of use by downstream users.	Change in downstream cropping pattern due to economic drivers

3. 2 Cropping pattern

Cropping patterns denote area put under different crops. Agriculture is one of the main sources of income of the inhabitants of the area. Rice is the staple food crop cultivated and crops like coconut, arecanut, tapioca, banana and pulses are also cultivated in the command areas of the Peechi Irrigation Project. Rice occupied about 24 per cent of the net cultivated area of the farmers and was followed by banana (22%), rubber (17%), coconut (9%), vegetables (10%) and pepper (7%). Cropping pattern varied in upland and down stream areas of the watershed (Table 3.5).

Table 3.5. Cropping pattern in up land and down stream areas during 2005-06

Sl No.	Crop	Total area (ha)	Percentage to total area	Upland (ha)	Percentage to total area	Down stream (ha)	Percentage to total area
1	Paddy	30.71	23.78	1.16	2.43	29.55	36.26
2	Coconut	11.08	8.58	2.74	5.76	8.34	10.23
3	Arecanut	1.73	1.34	0.78	1.64	0.95	1.16
4	Pepper	8.96	6.94	5.65	11.86	3.31	4.06
5	Jack	0.61	0.47	0.25	0.53	0.36	0.44
6	Mango	0.92	0.71	0.37	0.77	0.55	0.67
7	Cashew	1.40	1.08	1.16	2.44	0.23	0.29
8	Tamarind	0.12	0.10	0.03	0.07	0.09	0.11
10	Tapioca	5.75	4.46	4.44	9.32	1.32	1.62
11	Nutmeg	1.29	1.00	0.15	0.31	1.14	1.40
12	Vegetables	12.32	9.54	5.60	11.75	6.72	8.25
13	Pulses	1.35	1.04	0.85	1.78	0.50	0.61
14	Banana	28.20	21.84	8.46	17.77	19.74	24.22
15	Ginger	0.82	0.64	0.33	0.68	0.49	0.61
16	Turmeric	0.70	0.54	0.59	1.23	0.12	0.14
17	Medicinal Plants	0.13	0.10	0.00	0.00	0.13	0.16
18	Rubber	21.89	16.95	14.67	30.80	7.22	8.86
19	Vanilla	0.13	0.10	0.02	0.05	0.11	0.13
20	Others	1.02	0.79	0.37	0.79	0.64	0.79
21	Fallow	0.00	0.00	0.00	0.00	0.00	0.00
22	Forest area	0.00	0.00	0.00	0.00	0.00	0.00
	Total	129.14	100.00	47.63	100.00	81.51	100.00

In the upland areas, a variety of crops like coconut, arecanut, rubber, pepper, banana, vegetables and tapioca were grown. Rubber was the major crop cultivated in the uplands, accounting for 31 per cent of the net cultivated area. This was followed by banana which accounted for 18 per cent. Vegetables and pepper constituted 12 per cent each and tapioca occupied 10 per cent of the net cultivated area. In the down stream areas of the watershed, rice constituted the major crop occupying 36 per cent of the area cultivated by the selected farmers, followed by banana (24%), coconut (10%) and rubber (9%). Cultivation of vegetables was undertaken in about 8 per cent of net cultivated area.

Cropping pattern changes from 1975-76 to 2005-06

A comparative analysis of area under different crops in the watershed during 1975-76 and 2005-06, based on data collected from the selected farmers, revealed that there was a shift in area under the crops (Table 3.6). The area under rice showed a definite decline, during the analysis period, accounting for only 27.68 per cent. A significant decrease in the area was noticed in the case of cashew also. Among the crops that showed an increasing trend, tapioca and rubber were at the top, followed by banana and coconut. The cultivation of rubber in the upland areas had been initiated during the mid 1950's. Later large areas were brought under rubber with the intention of evading the proposed land reforms in the state, which favoured the plantations. Later on, a higher demand and price boom resulted in the area expansion of rubber plantations. For instance, the price of a quintal of rubber in 1970 was Rs. 465 which increased to Rs. 1154 in 1980, to Rs. 2174 in 1990 and to Rs. 5660 in 2005 (Government of Kerala, 2005).

Table 3.6 Cropping pattern: A comparative data of 1975-76 and 2005-06

Sl NO	Crop	Area in hectares 1975-76	Percentage to total area	Area in hectares 2005-06	Percentage to total area	Percentage change
1	Paddy	39.21	30.36	30.71	23.78	-27.68
2	Coconut	9.63	7.46	11.08	8.58	13.07
3	Areca nut	1.43	1.11	1.73	1.34	17.24
4	Pepper	7.38	5.71	8.96	6.94	17.65
5	Jack	0.59	0.46	0.61	0.47	2.91
6	Mango	0.89	0.69	0.92	0.71	2.75
7	Cashew	3.35	2.59	1.40	1.08	-139.55
8	Tamarind	0.16	0.12	0.12	0.10	-28.55
10	Tapioca	3.26	2.52	5.75	4.46	43.35
11	Nutmeg	1.12	0.87	1.29	1.00	13.08
12	Vegetables	9.63	7.46	12.32	9.54	21.85
13	Pulses	1.26	0.98	1.35	1.04	6.47
14	Banana	19.38	15.01	28.20	21.84	31.28
15	Ginger	0.76	0.59	0.82	0.64	7.32
16	Turmeric	0.68	0.53	0.70	0.54	3.26
17	Medicinal Plants	0	0.00	0.13	0.10	100.00
18	Rubber	13.56	10.50	21.89	16.95	38.06
19	Vanilla	0	0.00	0.13	0.10	100.00
20	Others	4.35	3.37	1.02	0.79	-327.43
21	Fallow	9.25	7.16			
22	Forest area	3.25	2.52			
	Total	129.14	100.00	129.14	100.00	

3.3 Land use and cropping pattern changes: Bio-physical and socio-economic drivers

It was clearly evident that there have been drastic changes in the land use and cropping pattern in the watershed under study and this posed a very pertinent question as to what are the drivers/causes of land use and cropping pattern changes in the study area. For the purpose, an attempt has been made to analyze and examine the major causes for land use and cropping pattern changes in the watershed.

Generally, a number of drivers trigger land use and cropping pattern changes and for analysis purpose, these may be grouped into direct and proximate causes (Briassoulis, 2000). Some of these causes are biophysical in nature and others are socio-economic. The biophysical drivers include natural factors such as weather and climatic variations, soil types, plant succession, drainage pattern, etc. The socio-economic drivers consist of demographic, social, economic, political and institutional factors. Since it is pointed out that the biophysical drivers usually do not cause direct land use and cropping pattern changes in micro watersheds (Briassoulis, 2000), this study gives more emphasis on socio-economic drivers of land use and cropping pattern changes.

Socio-economic drivers

As observed in the survey, the major socio-economic drivers that influenced land use changes in the study area are given below.

Deforestation, encroachment and population increase

The deforestation in the study area could be traced back to a period as early as 1940. Towards the end of the 2^{nd} world war, a huge deficit in food production was experienced, which forced the authorities to launch grow more food scheme. This encouraged people to cut the forests and cultivate food crops. In the erstwhile Cochin state where Thrissur was located, departmental cultivation of paddy was attempted during this period in easily accessible forestland. Since the cultivation was not profitable, the Forest Department gave up this scheme and the cleared lands were then leased out to persons for food production (Karunakaran, 1986). This initiated encroachment and migration of the people towards Peechi area.

Except tribes, most of the people in the upland areas were settlers, who migrated from different parts of Kerala, particularly from erstwhile

Travancore state during the 1950's and 1960's (Jayanarayanan, 2001). Availability of forest land was one of the major attractions for immigration. Immigration and encroachments continued rapidly till 1980 and then dwindled due to policy changes in favour of forest protection. These were very high in its early years as the same were not considered a serious punishable offence during that period and also there were many instances in which encroachment were regularized by the government. Further, implementation of Forest Conservation Act of 1980 prevented clearance of forests for agriculture or other purposes. It was reported in our survey that there were only less than 500 people in Peechi village during early 1950's. Over the years this has been changed and it continues to show an increasing trend. According to the Census 2001, the total population of Peechi village was 22409, with 11066 males and 11343 females. It was estimated that there were about 60 tribal and 70 settler families living within the sanctuary and they possessed an area of 170 ha of land (Narayanankutty and Nair, 1990). Almost all the people who live in and around the Manali watershed depended on forests for their livelihood; by collecting forest goods and using water either from Dam or river.

Agricultural expansion

There were no reliable time series data to examine the expansion of agriculture in the watershed. However, it may be assumed that cropping in the upland areas of the watershed was undertaken by clearing forest land and therefore agricultural practices began with encroachment and migration to this area. At present about 80 per cent of the watershed area is under agricultural crops.

Construction of reservoir

The construction of Dam has significantly affected the land use in the watershed. The availability of water was one of the reasons for conversion of forest land to agricultural lands. The construction of two canals from the reservoir enabled the farmers to get water for irrigation easily and cheaply and they allocated the land under different crops, in accordance with the availability of water. Tapioca was cultivated initially in the deforested lands and later they slowly shifted to more valuable crops such as vegetables and paddy.

Cropping pattern changes: Reasons

The reasons for conversion of paddy land to other crops are more complex in the study area and assume prime importance. Indeed, changes in average farm prices (at current price) between 1970 to 2004 indicate that among the major crops grown in Kerala, rice registered the lowest price increase of 699 percentages (Table 3.7). This may be one of the major factors which influenced the shift from rice to other crops. In addition, labor-management issues and the conversion of land to meet population needs, such as housing and infrastructure, were some of the factors that induced conversion of rice land.

Table: 3.7. Percentage increase of prices of selected commodities during 1970-2004

Commodities	Unit	1970 (Rs.)	1996 (Rs.)	2004 (Rs.)	Increase (with respect to 1970
Paddy	100 kg	90	607	721	7 fold
Coconut	100 nos.	56	480	611	10 fold
Tapioca	100 kg	20	300	392	18 fold
Banana	100 nos.	16	161	1167	69 fold
Pepper	100 kg	616	8780	6975	10 fold
Ginger	100 kg	271	4214	10558	38 fold
Cashew	100 kg	139	2730	3123	21 fold
Rubber	100 kg	429	4900	5181	11 fold

Source: Government of Kerala, 2005

Another important change in the cropping pattern was the increased area under banana, at the expense of rice. The benefit–cost ratios for rice and banana at Peechi were worked out to be 1.34 and 1.71 respectively (Suresh, 2000). The entry of Kerala Horticultural Development Programme (KHDP), currently known as Vegetable and Fruit Promotion Council of Kerala (VFPCK) into commercial banana production since 1993 has also promoted area under the banana. They helped farmers and even landless labour to procure land on lease and advanced/facilitated loan with the help of commercial banks. For instance, area under banana in Thrissur district during 1975-76 was 1384 ha which increased to 1549 ha during 1980-81, 1842 ha in 1990-91, 2128 ha in 1995-96 and 2475 ha in 1998-99 (Government of Kerala, 2000). Between 1970 and 2005, there was a phenomenal increase in the price of banana (Table 3.6).

Another reason for reduction of paddy land was conversion of the same to clay mining. Karuvannur river basin, particularly that of Manali is one of the important centres of clay mining. The history of clay mining in the study area could be traced back to over 100 years and this was at its peak during the mid 1970's, when there was a boom in the construction activities in the state (Gopinathan and Sundaresan 1990). A number of tile factories and brick kilns were also established in the area. Our survey showed that many *padasekharams* (fields) have been completely degraded due to severe clay mining and many of these areas have been flooded, which prevented flow of water to the river, resulting in reduction of availability of water in the river.

The price of cashew has increased over a period of time but its area has declined. Area under coconut showed an increasing trend though its price showed only minimum increase (Table 3.6). In the case of cashew nut, intercropping was not practiced, while in the coconut gardens, other crops such as pepper, plantain, arecanut, tapioca, and tubers were also widely cultivated, which gave higher cash income to the farmers.

Thus, the overall effect of reduction of wet lands was the reduction of area under rice. Wet lands are flood plain areas where water is held for a long time. This helps to maintain water table in the nearby areas. The reduction of wet lands also affects ground water availability of the area. Many of the selected farmers in the low land areas reported that there was a drastic reduction of ground water table in recent years in their areas.

Another important aspect behind the changes in the cropping pattern is people's attitude towards agriculture. For the older generation agriculture was a way of life, while, for the present generation, it is a commercial activity. The latter therefore, utilizes it to earn as much money as possible at a minimum cost and in the shortest time possible. Coconut responds favourably to cultural operations and once it starts yielding it does not require close attention. The inter-cropping system provides farmers with a range of outputs; it represents a logical approach to coping with variable environments. The total value of the yield from mixed crops is often greater, particularly if root and shoot formations of coconut allow these crops to use light, water, and nutrients efficiently. Inter-cropping not only diminishes the incidence of pests and weeds, but reduces water loss and soil erosion by providing greater ground cover as well. Still income received from a unit of rubber cultivation was much higher than total income from a unit of garden lands in the study area. Further, adverse terms of trade, that is price paid by the farmers is higher than price received by the farmers, also forced the farmers to undertake the above activities in the farming sector.

Chapter 4

HYDROLOGICAL STUDIES

Effect of landuse changes on hydrology in the study area is attempted in this chapter. The study analyses the effects of landuse changes at river basin as well as selected watershed levels. The results and discussions are presented separately in two sub-sections in this chapter.

Section 1 Results

4.1 Historical data on annual rainfall distribution

For the sake of hydrological studies, Karuvannur basin is divided into three zones - Zone 1 comprises of the area in the upper portions of Karuvannur river basin that form the catchment area of Peechi, Chimony and Muply reservoirs, of which Peechi and Chimony are existing reservoirs, and Muply is a proposed one. Zone 2 consists of a portion of the Karuvannur river basin upstream of the lowest discharge station at Karuvannur Bridge excluding Zone 1. Zone 3 comprises the portion of the Karuvannur river basin downstream of the lowest discharge station at Karuvannur bridge. The annual distribution of rainfall since 1966 (since 1973 for Zone 1) is given in Fig.4.1. The details of each zone are given in Tables 4.1 to 4.3.

Almost the same trend was shown in the three regions. The average annual rainfall in highland (Zone 1) is estimated as 2851 mm, for midland (Zone 2) 3011mm, and the low land (Zone 3) it is estimated as 2858 mm. About 60 per cent of the rainfall was received during Southwest Monsoon period and 30 per cent during Northeast monsoon and the remaining 10 per cent as summer rainfall in all the three zones.

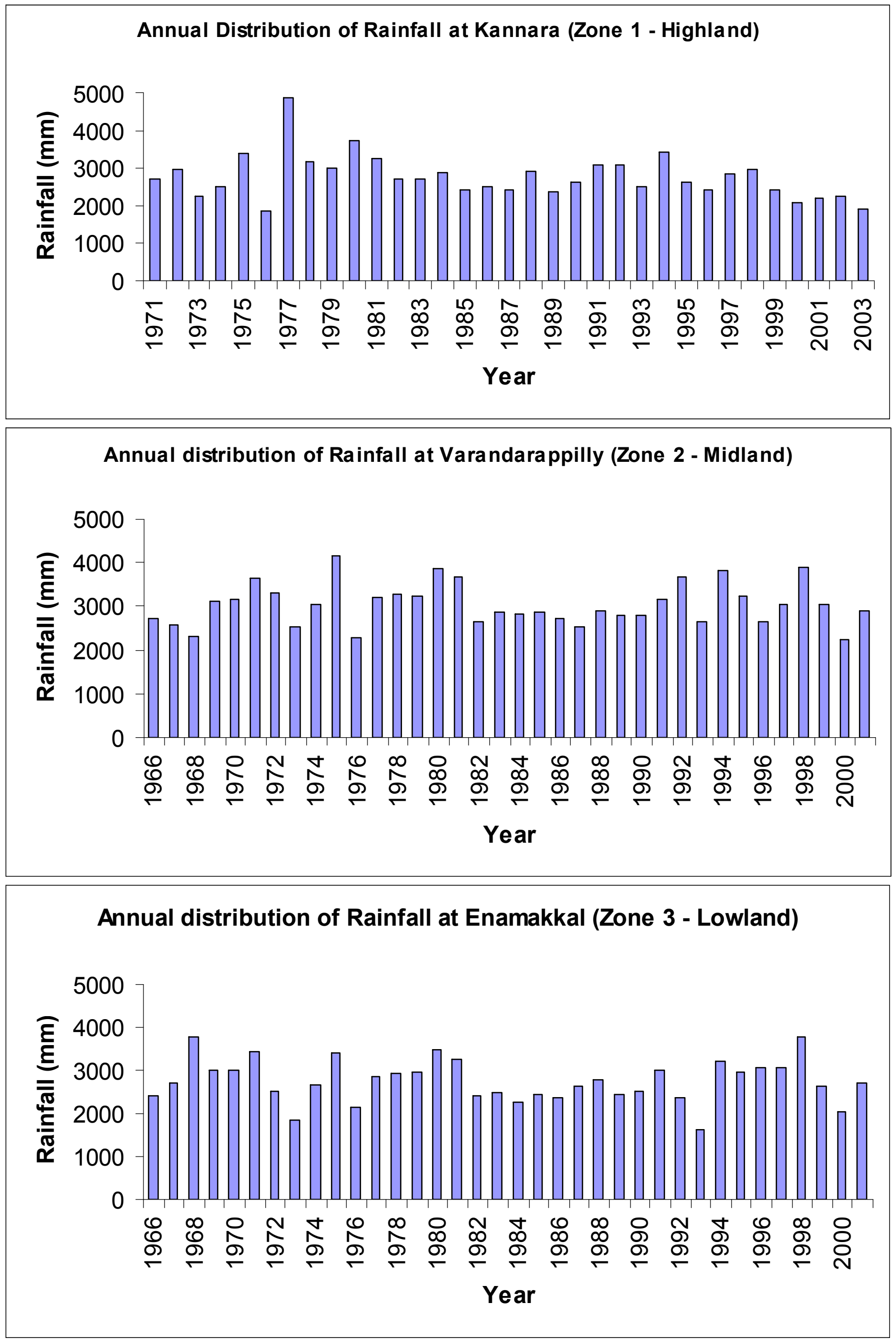


Fig.4.1 Annual rainfall distribution from the three zones in the Karuvannur river basin

Table 4.1 Mean monsoon, non-monsoon and annual rainfall in Zone 1 of Karuvannur River Basin

Description of Zone 1 : Upper portions of Karuvannur river basin that form the catchment area of Peechi, Chimony and Muply reservoirs Peechi and Chimony are existing reservoirs, and Muply is a proposed one

Area of Zone 1 : 220 sq. km

Sl. No.	Rainfall Stations Falling within Zone 1	Period for which Rainfall Data is considered			Mean Rainfall in millimetres (mm)		
		Starting Year	Ending Year	Number of Years	Monsoon (Jun - Nov)	Non-monsoon (Dec - May)	Annual (Jun-May)
1	Irumpupalam	1980-81	2000-01	22	2,499	262	2,786
2	Kallichitra	1968-69	1989-90	22	2,977	350	3,516
3	Pottimada	1979-80	2000-01	23	2,149	247	2,413
	For the Zone as a whole in mm						
			*	**Mean**	**2,542**	**286**	**2,905**
			*	**Maximum**	**2,977**	**350**	**3,516**
			*	**Minimum**	**2,149**	**247**	**2,413**

Table 4.2. Mean monsoon, non-monsoon and annual rainfall in Zone 2 of Karuvannur River Basin

Description of Zone 2 : The portion of the Karuvannur river basin upstream of the lowest discharge station at Karuvannur Bridge excluding Zone 1

Area of Zone 2 : 505 sq.km

Sl. No.	Rainfall Stations Falling within Zone 2	Period for which Rainfall Data is Considered			Mean Rainfall in millimetres (mm)		
		Starting Year	Ending Year	Number of Years	Monsoon (Jun - Nov)	Non-monsoon (Dec - May)	Annual (Jun-May)
1	Ollukkara	1969-70	2002-03	34	2,339	280	2,651
2	Peechi	1966-67	2001-02	36	2,408	250	2,676
3	Echipara	1979-80	2001-02	23	2,794	315	3,155
4	Kannara C.P.C.R.I	1971-72	2002-03	32	2,472	294	2,981
5	Pudukkad Estate	1971-72	2000-01	30	2,660	398	3,060
6	Muply Estate	1969-70	1999-2000	31	2,736	366	3,109
7	Varandrappilli	1966-67	2001-02	36	2,661	360	3,055
8	Karikadavu	1967-68	2001-02	35	2,768	414	3,199
	For the Zone as a whole in mm						
			*	**Mean**	**2,651**	**335**	**2,986**
			*	**Maximum**	**2,794**	**414**	**3,199**
			*	**Minimum**	**2,339**	**250**	**2,651**

Table 4.3 Mean Monsoon, Non-monsoon and Annual Rainfall in Zone 3 of Karuvannur River Basin

Description of Zone 3 : The portion of the Karuvannur river basin downstream of the lowest discharge station at Karuvannur Bridge

Area of Zone 3 : 325 sq.km

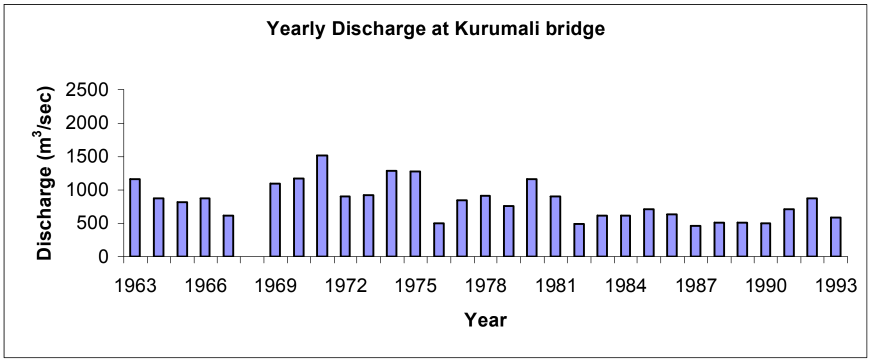
Sl. No.	**Rainfall Stations Falling within Zone 3**	**Period for which Rainfall Data is Considered**			**Mean Rainfall in Millimetres (mm)**		
		Starting Year	**Ending Year**	**Number of Years**	**Monsoon** (Jun - Nov)	**Non-monsoon** (Dec - May)	**Annual** (Jun - May)
1	Enamakkal	1966-67	2000-01	35	2,392	343	2,750
2	Trichur I.C.C	1982-83	1997-98	16	2,449	269	2,718
3	Trichur R.S	1971-72	1993-94	23	2,416	268	2,641
4	Trichur T.O	1967-68	1994-95	28	2,363	249	2,612
5	Irinjalakuda	1978-79	2002-03	37	2,377	300	2,699
	For the Zone as a whole in mm						
			*	**Mean**	**2,398**	**286**	**2,684**
			*	**Maximum**	**2,449**	**343**	**2,750**
			*	**Minimum**	**2,363**	**249**	**2,612**

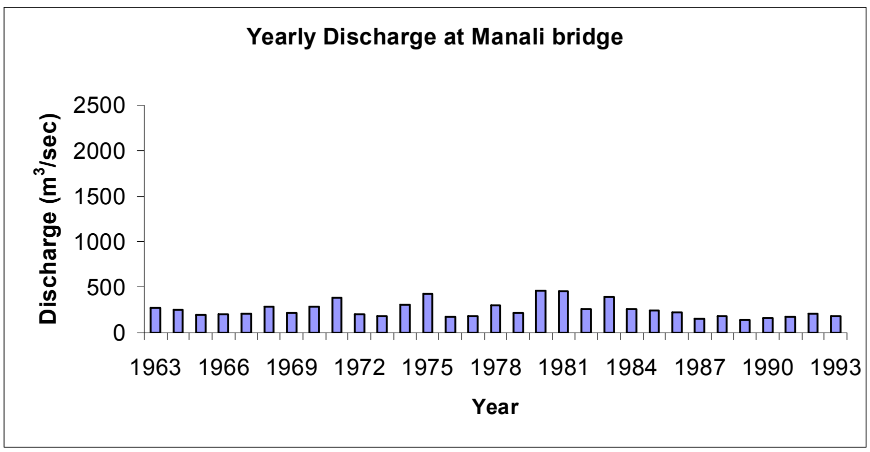
River discharge

Data regarding river discharge at the various stations of the Karuvannur river basin were collected from the Hydrology Department of the Government of Kerala. Graphs showing the annual river discharge are given (Fig.4.2).

Rainfall

Details of monthly total rainfall for 2005 and 2006 received in the watersheds at Olakara and Kavallur are presented in the Table 4.4.





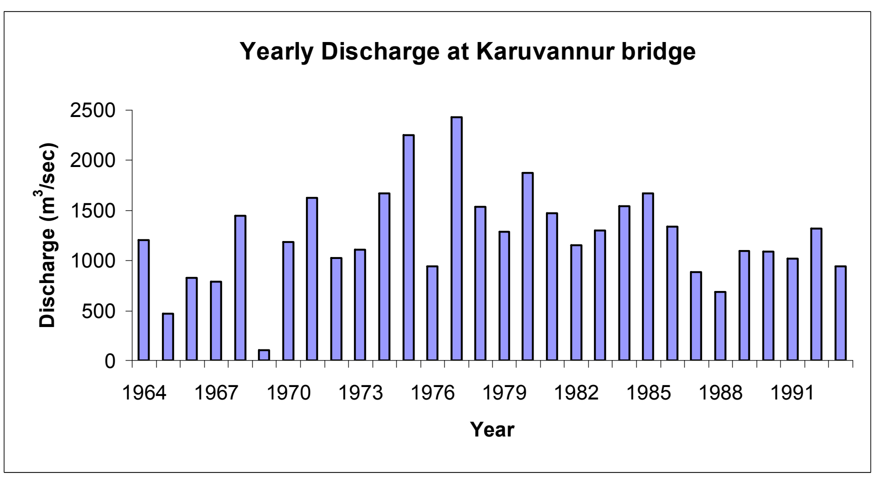


Fig.4.2. Annual river discharge in the Karuvannur river basin

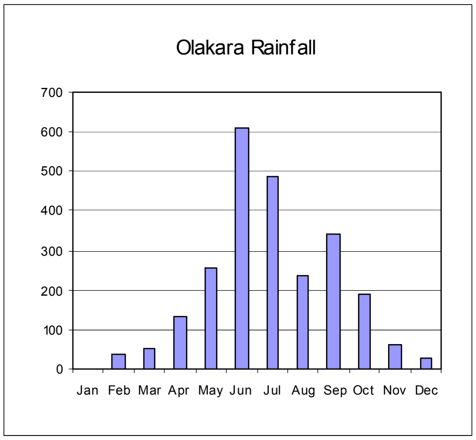
Table 4.4 Rainfall for Olakara and Kavellur recorded during 2005 to 2006

Olakara	**Rain fall (mm)**		
Months	**2005**	**2006**	**Mean**
Jan	0	0	0
Feb	70	1	35.5
Mar	12.8	92.4	52.6
Apr	165	104	134.5
May	68	446.8	257.4
Jun	614.7	607.4	611.05
Jul	552	423	487.5
Aug	98	373.4	235.7
Sep	339.6	345.4	342.5
Oct	62.8	313.6	188.2
Nov	49.4	74	61.7
Dec	26.2	0.0	26.2
Total	2058.5	2781	2432.85

Kavallur	**Rain fall (mm)**		
Months	**2005**	**2006**	**Mean**
Jan	0	0.4	0.2
Feb	90.6	0.0	45.3
Mar	17.4	89.6	53.5
Apr	171.4	83.0	127.2
May	85	511.8	298.4
Jun	677.6	538.7	608.2
Jul	665.8	507.8	586.8
Aug	102.4	304.0	203.2
Sep	349.2	296.6	322.9
Oct	112.8	157.9	135.3
Nov	38.08	49.1	43.6
Dec	12.67	0.0	12.7
Total	2323.0	2538.8	2437.2

The Table 4.4 indicates that the total mean annual rainfall during the period (2005-06) was 2432 mm and 2437 mm for Olakara and Kavallur respectively. For both sites, maximum rainfall was received during the period June and July followed by September. For both watersheds, approximately 60 per cent of the total rainfall was received during June and July.

The percentage distribution of rainfall during the months of June, July and September for Kavallur was 24.95 per cent, 24.07 per cent and 13.24 per cent out of the total rain respectively while for Olakara it was recorded as 25.11 per cent, 20.03 per cent, and 14.07 per cent out of the total rain respectively. The monthly rainfall was less than 50 mm during December, January and February for both the areas. From the above rainfall data analysis, it was clear that both sites experienced a seasonal distribution of rainfall. Mean monthly distribution of rainfall for both sites is given in the graph (Fig.4.3). The seasonal pattern and the quantity of rainfall received at both the locations were similar.



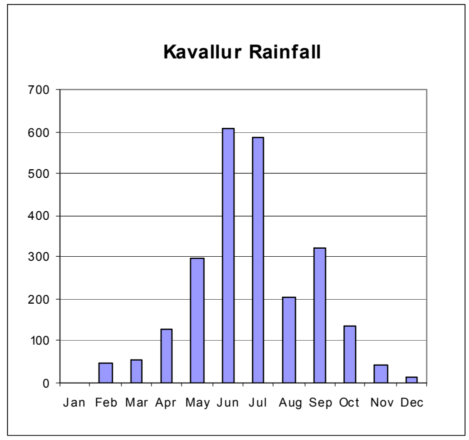


Fig.4. 3 Monthly distribution of rainfall at the two selected watersheds of Olakara and Kavallur

Seasonal distribution of rainfall

Details of seasonal rainfall for Kavallur and Olakara sites are given in Table 4.5. For Kavallur, it was found that out of the total rainfall 78 per cent accounts for the monsoon period (June-November), 10 per cent post monsoon (December – April) and 12 per cent during pre monsoon (May). A similar seasonal distribution was found for Olakara (Table 4.5).

Table 4.5 Seasonal Distribution of rainfall at Kavallur and Olakara

Season	Kavallur	Olakara
Premonsoon (May)	298.4 (12 %)	257.4 (11 %)
Monsoon (June- November)	1900 (78 %)	1676.75 (79 %)
Post monsoon (December-April)	238.9 (10 %)	276.1 (10 %)

Stream Flow

Run off is the portion of precipitation that makes its way to stream channels as surface or subsurface flow. The peak run off rate and run off volume are of great importance in the planning and design of soil conservation works. For the measurement of run off, gauging stations were installed at both the micro watersheds at Kavallur and Olakara. Stream of Kavallur is flowing through mixed plantation area while Olakara it is through a moist deciduous forestland (plate 1). The drainage area of the stream at Kavallur is calculated as 2.6 km^2 and that of Olakara is 3.2km^2.

Plate 1: Run-off measurement at Olakara

The observed values of the stream flow for Kavallur and Olakara watershed for the period 2005-2006 is given on the Tables 4.6 and 4.7.

Table 4.6 Stream flow recorded at Olakara during 2005 to 2006

	Stream flow (m^3/sec)		
Months	**2005**	**2006**	**Mean**
January	0	0	0
February	0	0	0
March	0	0	0
April	0	0	0
May	0.019	0.010	0.014
June	0.239	0.443	0.341
July	0.302	0.797	0.549
August	0.272	0.205	0.238
September	0.111	0.244	0.177
October	0.048	0.258	0.153
November	0.021	0.053	0.037
December	0.003	0.007	0.005

Table 4.7 Stream flow recorded at Kavallur during 2005 to 2006

	Stream flow (m^3/sec)		
Months	**2005**	**2006**	**Mean**
January	0	0	0
February	0	0	0
March	0	0	0
April	0	0	0
May	0.002	0.023	0.012
June	0.296	0.640	0.468
July	0.327	0.426	0.376
August	0.205	0.471	0.338
September	0.176	0.370	0.273
October	0.039	0.068	0.053
November	0.001	0.002	0.002
December	0	0	0

In Olakara watershed, maximum flow was recorded during the month of July both in 2005 and 2006 followed by June, while in Kavallur watershed maximum flow was recorded during June followed by July in 2006. The flow at Kavallur area decreased drastically after September and thereafter negligible flow was recorded. But, in Olakara watershed, the duration of flow was more than that of Kavallur lasting up to December. There was no flow during the first four months of the year. The duration of flow at Olakara, which has a forested stream is higher than other one. This difference in the discharge pattern at the two sites may be due to the difference in the landuse pattern of the sites under study. This implies the lag time available for rainwater for recharge in the case of forested area (Olakara), but in Kavallur, predominantly plantation and agricultural area, the peak flow coincides with peak rainfall and hence surface runoff is more. It may be due to the fact that water retention capacity of the forested watershed is higher than that of the non-forested watershed. It is because the watershed under forest on which a thick layer of mulch of leaves and grasses have accumulated, the surface runoff becomes less and more amount of rainfall is absorbed by the soil due to increase in infiltration rate and formation of resistance in the flow path of the water over ground surface, resulting in a more sustained base flow. Details of mean monthly stream flow for both the watersheds are given in the graph (Fig.4.4).

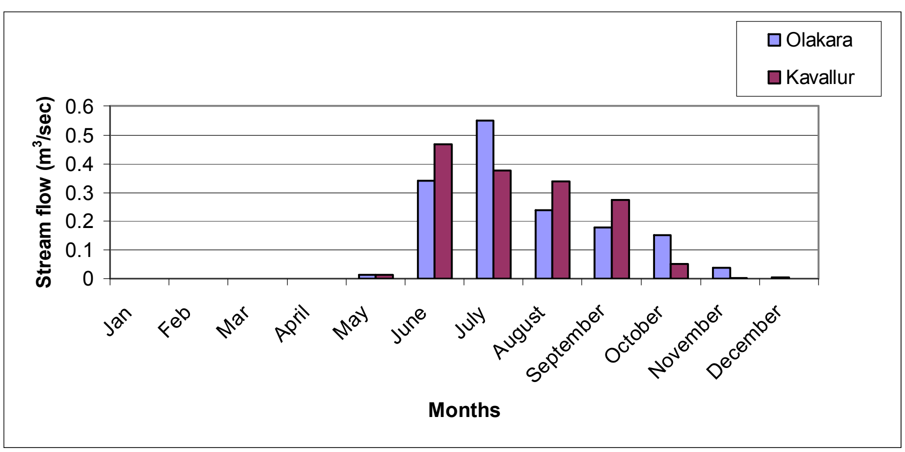


Fig.4.4. Monthly stream flow for both the watersheds during the year 2005 to 2006

From the graph it may be noted that maximum flow for Olakara was in the month of July while for Kavallur it was in June. Flow at Kavallur becomes negligible after October, but in Olakara flow lasts up to December. For both watersheds peak flow occurs during the months of June and July. Tables 4.8 and 4.9 present the total monthly stream flow as the percentage of total monthly rainfall. For the same purpose the stream flow is converted in terms of depth of flow and given in the above Tables.

Table 4.8 Stream flow at Olakara as a percentage of the rainfall

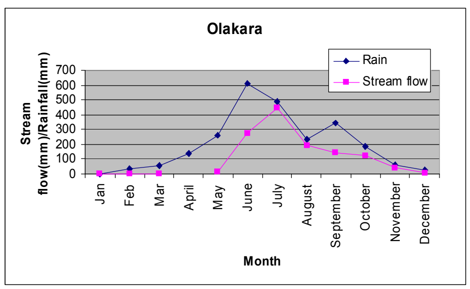
Month	Rainfall (mm)	Stream flow (mm)	Stream flow as percentage of Rain fall
January	0	0	0
February	35.5	0	0
March	52.6	0	0
April	134.5	0	0
May	257.4	11.664	8.6
June	611.05	276.372	45.2
July	487.5	444.852	91.2
August	235.7	193.104	81.9
September	342.5	143.532	41.9
October	188.2	123.768	65.7
November	61.7	43.092	69.8
December	26.2	5.508	21.02

It may be noted that the initial percentage of runoff with rainfall for both sites was almost similar. Olakara recorded a runoff percentage of 8.6 per cent while Kavallur it was 9.6 per cent. As the rain increased with the monsoon the percentage of run off also increased for both sites. The rate of increase in percentage of runoff with rainfall for Olakara was recorded in the range of 8.6-91.2 per cent while in Kavallur site the rate was 9.6-165.8 per cent, an increase of 1.8 times than that of Olakara. The monthly rain recorded during June was 611.05 mm for Olakara in June

Table 4.9 Stream flow at Kavallur as a percentage of the rainfall

Month	Rainfall	Stream flow (mm)	Stream flow as percentage of Rain fall
January	0.2	0	0
February	45.3	0	0
March	53.5	0	0
April	127.22	0	0
May	298.4	12.312	9.6
June	608.16	466.56	76.7
July	586.775	414.72	70.6
August	203.214	336.96	165.8
September	322.88	272.16	84.29
October	135.33	53.136	39.26
November	43.585	36.936	84.74
December	12.67	0	0

and the run off observed in the same month was 276.37 mm, which accounted for 45.2 per cent of rainfall. But in Kavallur watershed, the highest rainfall recorded in the same month was 608.16 mm and the run off recorded was 466.56 mm, constituting 76.7 per cent of the rainfall. This shows that percentage of surface run off was much more in Kavallur watershed. For both watersheds, the rainfall received during August was lower than that received in June and July; the percentage run off was higher than these months which were 91.2 per cent and 165.8 per cent for Olakara and Kavallur respectively. During the initial months of the monsoon period, the rate of stream flow was found less in both sites. This may be because of rainwater infiltration into the soil for filling the pore spaces during the period immediately following commencement of the rainy season. As the soil gets saturated, the infiltration rate decreases and the rate of run off increases. As rainfall continues, soil becomes increasingly saturated and infiltration is stabilized, thereby more water is available for both surface and base flow runoff. From the data it can be seen that the percentage run off with respect to rainfall was less in forested watershed than other non-forested watershed although there was even distribution of rainfall in both watersheds. So it can be concluded that forested area have higher water accumulation capacity than the non-forested watershed resulting in more sustained base flow. The relationship between rainfall and stream flow at Olakara and Kavallur is shown in Fig. 4.5.



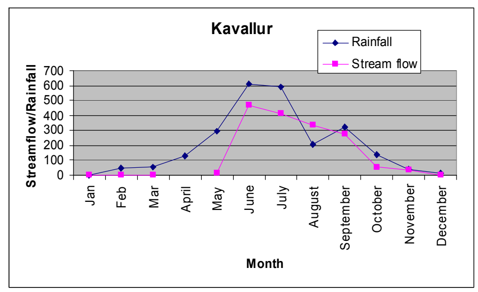


Fig.4.5. Relationship between rainfall and stream flow at Olakara and Kavallur

From the graph it can be noted that as the amount of rainfall increases, stream flow also increases. But the amount of flow generated is higher in Kavallur area than that at Olakara.

4.2 Average seasonal stream discharge at the study area

Data on mean seasonal flows for the three streams calculated for both Olakara and Kavallur watersheds are given in Table 4.10. Maximum flow was recorded in both watersheds during monsoon period. For Olakara, total flow during monsoon season was 1224 mm, accounting for 98 per cent of total stream flow. The flow in Kavallur during monsoon season was 1580 mm, constituting 99 per cent of total run off. Flow during post monsoon and pre monsoon seasons through Kavallur was less than that of Olakara site by one per cent because the duration of the flow at Olakara site was more than that of Kavallur site.

Table 4.10 Seasonal distribution of stream flow at Olakara and Kavallur worked out as a mean from the data for 2005 and 2006

Season	Olakara (mm)	Kavallur (mm)
Pre monsoon	11.664 (9.39%)	90.072 (5.39%)
Monsoon	1224 (98%)	1580 (99%)
Post monsoon	172.368 (13.87%)	90.072 (5.3%)

Stream flow as a percentage of the rainfall worked out for the years 2005 and 2006 is given in Table 4.11. The total run off observed during the period was 1241.89 mm for Olakara site against a total rain fall of 2432.85 mm which is 51.04 per cent of the total rainfall.

Table 4.11 Stream flow as a percentage of the rainfall worked out for the years 2005 and 2006

Site	Total Rainfall (mm)	Total Stream flow (mm)	Percentage of Runoff with Rainfall
Olakara	2432.85	1241.89	51.04
Kavallur	2437.23	1592.78	65.35

At Kavallur site the total runoff was 1592.78 mm for a rainfall of 2437.23 mm, constituting 65.35 per cent of the total rainfall. Percentage of water yielded as surface and base flow total runoff is less in forested area compared to the non-forested watershed. The correlation between the rainfall and stream discharge has been established. The regression equations depicting the relationship are given below.

Olakara $Y=0.615X-21.32$ $R^2=0.71$

Kavallur $Y=0.752X-20.026$ $R^2=0.76$

where Y= stream flow and X= rainfall

Both sites showed a positive relationship between stream flow and rainfall.

4.3 Ground Water Table

The ground water table observations for the watersheds of Olakara and Kavallur are given in Tables 4.12 to 4.16. The monthly observations show very little variations for the same well during any given month. For both watersheds, highest water table was observed between the months of June and July during 2005 and 2006. For Kavallur, the lowest water table was observed during the month of April for 2005 and 2006 while the lowest water table for Olakara was in the month of March during 2005 and 2006 (Fig. 4.6 and 4.7)

Table 4.12 Monthly water table depth in different wells at Olakara during 2005 and 2006 (m)

Months	OW-1	OW-2	OW-3	OW-4	OW-5	OW-6	OW-7	OW-8
Mar 05	5.06	2.36	4.25	7.45	4.09	7.51	4.96	8.06
Apr 05	4.97	2.28	4.27	7.60	4.63	7.58	4.96	8.08
May 05	5.31	2.56	4.86	7.74	4.34	7.81	5.07	8.41
Jun 05	3.78	2.05	3.39	7.55	3.43	6.38	4.08	7.68
Jul 05	1.90	0.55	2.32	6.20	2.62	4.21	1.17	5.68
Aug 05	2.30	0.62	2.53	6.12	2.51	4.33	1.60	5.25
Sept 05	2.71	0.67	2.47	6.03	2.72	5.01	3.62	6.02
Oct 05	3.58	1.03	2.52	6.21	2.72	5.80	4.30	6.70
Nov 05	3.85	1.38	2.93	6.66	2.81	6.19	4.57	6.96
Dec 05	3.92	1.85	3.27	6.88	2.83	6.51	4.64	7.22
Jan 06	4.04	2.05	3.53	6.88	2.89	6.91	4.72	7.38
Feb 06	4.42	2.31	3.95	6.99	3.47	7.44	4.87	7.74
Mar 06	4.79	2.49	4.40	7.35	4.49	7.58	4.98	8.18
Apr 06	4.64	2.51	4.35	7.43	4.79	7.64	4.96	8.12
May 06	5.15	2.60	4.82	7.61	4.54	7.89	5.04	8.34
June 06	4.31	1.70	4.01	6.78	3.69	6.86	4.05	7.61
Jul-06	2.89	0.85	2.64	4.75	2.41	5.49	2.75	6.28
Aug-06	2.65	0.65	2.32	4.57	2.24	5.32	2.34	6.05
Sep-06	1.82	0.62	2.14	3.12	1.80	3.87	2.01	5.58
Oct-06	1.85	1.05	1.76	2.74	1.83	3.18	2.00	3.58
Nov-06	2.90	1.57	2.18	5.05	2.83	4.15	2.98	4.02

* Values recorded in meters as the depth from the ground level.

Table 4.13 Monthly water table depth at Olakara during 2005 and 2006 (m)

Months	OW-1	OW-2	OW-3	OW-4	OW-5	OW-6	OW-7	OW-8	Average
Mar 05									
Apr 05	0.10	0.08	-0.02	-0.15	-0.54	-0.07	0.00	-0.02	-0.08
May 05	-0.34	-0.28	-0.59	-0.14	0.29	-0.23	-0.12	-0.33	-0.22
Jun 05	1.53	0.51	1.47	0.20	0.92	1.44	0.99	0.73	0.97
Jul 05	1.88	1.51	1.07	1.35	0.81	2.17	2.91	2.00	1.71
Aug 05	-0.41	-0.07	-0.21	0.08	0.12	-0.12	-0.43	0.44	-0.07
Sept 05	-0.41	-0.06	0.05	0.09	-0.22	-0.69	-2.03	-0.77	-0.50
Oct 05	-0.87	-0.35	-0.04	-0.18	0.00	-0.79	-0.68	-0.68	-0.45
Nov 05	-0.28	-0.36	-0.41	-0.45	-0.09	-0.39	-0.27	-0.26	-0.31
Dec 05	-0.07	-0.47	-0.34	-0.22	-0.02	-0.32	-0.07	-0.26	-0.22
Jan 06	-0.12	-0.21	-0.27	0.00	-0.06	-0.40	-0.08	-0.17	-0.16
Feb 06	-0.38	-0.26	-0.42	-0.11	-0.59	-0.53	-0.16	-0.36	-0.35
Mar 06	-0.37	-0.18	-0.46	-0.36	-1.02	-0.15	-0.11	-0.44	-0.38
Apr 06	0.15	-0.02	0.05	-0.08	-0.30	-0.06	0.02	0.06	-0.02
May 06	-0.52	-0.09	-0.47	-0.18	0.25	-0.25	-0.08	-0.22	-0.19
June 06	0.84	0.90	0.81	0.83	0.85	1.03	0.99	0.73	0.87
Jul-06	1.42	0.85	1.37	2.03	1.28	1.37	1.29	1.33	1.37
Aug-06	0.24	0.20	0.32	0.18	0.17	0.17	0.41	0.23	0.24
Sep-06	0.83	0.03	0.18	1.45	0.44	1.45	0.33	0.47	0.65
Oct-06	-0.03	-0.43	0.38	0.38	-0.03	0.69	0.01	2.00	0.37
Nov-06	-1.05	-0.52	-0.42	-2.31	-1.00	-0.97	-0.98	-0.44	-0.96

Table 4.14 Monthly water table depth during 2005 to 2006 at Kavallur (m)

Months	KW-1	KW-2	KW-3	KW-4	KW-5	KW-6	KW-7	KW-8	KW-9	KW-10	KW-11
Mar 05	6.29	3.93	7.25	4.84	5.95	7.10	4.34	4.52	4.90	7.14	7.54
Apr 05	6.78	4.17	7.30	4.88	5.97	7.86	4.37	4.79	4.25	7.25	7.39
May 05	7.35	4.13	7.14	4.98	6.05	7.85	4.33	4.81	4.69	7.67	7.85
Jun 05	6.13	2.89	5.86	3.32	4.45	6.09	2.50	3.66	2.38	5.32	5.72
Jul 05	2.98	2.67	4.11	2.78	3.96	3.97	1.74	3.11	2.14	3.72	4.03

Table 4.14 contd...

Months	KW-1	KW-2	KW-3	KW-4	KW-5	KW-6	KW-7	KW-8	KW-9	KW-10	KW-11
Aug 05	3.44	2.87	4.70	3.55	4.73	4.84	1.98	3.26	2.71	3.76	3.84
Sept 05	2.94	3.07	3.93	3.13	4.21	4.03	2.10	3.40	1.50	3.95	4.19
Oct 05	4.16	3.04	5.28	4.15	5.27	5.88	2.61	3.73	2.98	5.42	5.46
Nov 05	4.44	2.96	5.47	4.20	5.33	6.26	2.72	3.82	2.88	5.56	5.77
Dec 05	4.76	2.98	5.75	4.45	5.55	6.50	2.87	3.94	3.07	5.88	6.31
Jan 06	5.02	3.12	5.98	4.59	5.68	6.69	3.39	4.01	3.17	6.08	6.42
Feb 06	5.42	3.25	6.21	4.99	6.06	6.92	4.14	4.39	3.63	6.47	6.71
Mar 06	5.64	3.69	6.45	4.67	6.62	7.69	4.72	4.46	4.07	6.83	7.05
Apr 06	5.77	3.80	6.57	4.76	6.77	7.79	4.77	4.56	4.15	6.94	7.17
May 06	5.73	3.82	6.56	4.71	6.78	7.82	4.79	4.55	4.15	7.03	7.34
June 06	4.89	2.82	5.57	3.62	5.63	6.57	3.57	3.75	3.23	6.24	6.46
Jul-06	3.30	2.72	4.59	2.93	4.08	6.29	3.27	3.29	2.96	5.81	6.06
Aug-06	2.77	2.31	4.02	2.42	3.63	5.72	2.80	2.84	2.41	5.30	5.57
Sep-06	2.55	3.12	3.98	3.21	4.22	4.12	2.10	3.45	1.25	4.12	4.08
Oct-06	2.12	2.66	3.68	2.95	3.98	4.10	2.08	3.14	1.02	4.01	3.98
Nov-06	2.75	3.01	4.10	3.21	4.25	4.87	2.54	3.55	1.80	4.58	4.25

Values recorded in meters as the depth from the ground level.

Table 4.15 Water table fluctuations in the different wells during 2005 and 2006 at Kavallur (m)

Months	KW-1	KW-2	KW-3	KW-4	KW-5	KW-6	KW-7	KW-8	KW-9	KW-10	KW-11	Average
Mar 05												
Apr 05	-0.49	-0.24	-0.05	-0.04	-0.02	-0.76	-0.04	-0.27	0.65	-0.11	0.15	-0.11
May 05	-0.56	0.04	0.16	-0.10	-0.08	0.01	0.04	-0.02	-0.44	-0.42	-0.46	-0.17
Jun 05	1.22	1.24	1.28	1.67	1.61	1.77	1.83	1.15	2.31	2.36	2.13	1.69
Jul 05	3.15	0.23	1.76	0.54	0.49	2.12	0.77	0.56	0.24	1.60	1.69	1.19
Aug 05	-0.46	-0.21	-0.60	-0.78	-0.77	-0.87	-0.24	-0.16	-0.57	-0.04	0.20	-0.41
Sept 05	0.50	-0.20	0.77	0.42	0.52	0.81	-0.12	-0.14	1.21	-0.20	-0.36	0.29
Oct 05	-1.22	0.03	-1.35	-1.02	-1.06	-1.85	-0.52	-0.33	-1.48	-1.47	-1.27	-1.05

Table 4.15 contd...

Months	KW-1	KW-2	KW-3	KW-4	KW-5	KW-6	KW-7	KW-8	KW-9	KW-10	KW-11	Average
Nov 05	-0.28	0.08	-0.19	-0.06	-0.06	-0.38	-0.11	-0.09	0.11	-0.14	-0.31	-0.13
Dec 05	-0.33	-0.02	-0.28	-0.25	-0.22	-0.25	-0.15	-0.12	-0.19	-0.32	-0.54	-0.24
Jan 06	-0.26	-0.15	-0.23	-0.14	-0.13	-0.19	-0.52	-0.07	-0.11	-0.21	-0.12	-0.19
Feb 06	-0.41	-0.13	-0.23	-0.41	-0.38	-0.23	-0.75	-0.38	-0.46	-0.39	-0.29	-0.37
Mar 06	-0.22	-0.44	-0.24	0.32	-0.56	-0.77	-0.58	-0.08	-0.44	-0.36	-0.35	-0.34
Apr 06	-0.13	-0.11	-0.13	-0.09	-0.15	-0.10	-0.05	-0.09	-0.08	-0.12	-0.12	-0.11
May 06	0.04	-0.02	0.02	0.05	-0.02	-0.03	-0.02	0.01	0.00	-0.09	-0.17	-0.02
June 06	0.84	1.00	0.99	1.10	1.15	1.25	1.22	0.80	0.92	0.80	0.88	0.99
Jul-06	1.59	0.10	0.97	0.69	1.55	0.28	0.30	0.46	0.27	0.43	0.39	0.64
Aug-06	0.53	0.41	0.57	0.51	0.45	0.57	0.47	0.45	0.55	0.51	0.49	0.50
Sep-06	0.22	-0.81	0.04	-0.79	-0.59	1.60	0.70	-0.61	1.16	1.18	1.49	0.33
Oct-06	0.43	0.46	0.30	0.26	0.24	0.02	0.02	0.31	0.23	0.11	0.10	0.23
Nov-06	-0.63	-0.35	-0.42	-0.26	-0.27	-0.77	-0.46	-0.41	-0.78	-0.57	-0.27	-0.47

Table 4.16 Mean monthly water table fluctuations averaged over two years 2005 and 2006 for Olakara and Kavallur

Months	Mean monthly water table fluctuation (m)	
	Olakara	Kavallur
January	-0.161	-0.191
February	-0.348	-0.367
March	-0.384	-0.336
April	-0.023	-0.108
May	-0.193	-0.094
June	0.871	1.340
July	1.368	0.915
August	0.240	0.046
September	0.648	0.268
October	0.373	-0.267
November	-0.347	-0.189
December	-0.221	-0.240

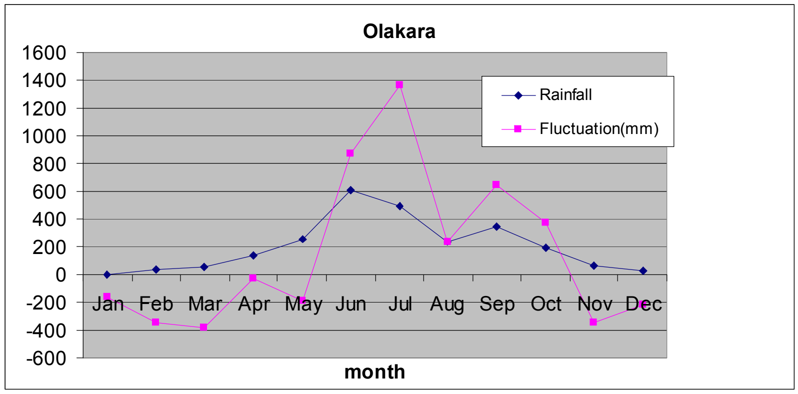


Fig.4.6 Monthly rainfall and water table fluctuations at Olakara during 2005 to 2006

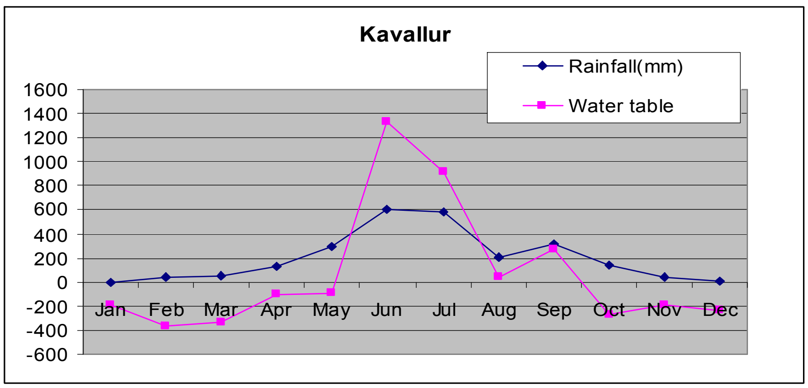


Fig. 4.7 Monthly rainfall and water table fluctuations at Kavallur during 2005 and 2006

The mean monthly water table fluctuations for the sites of Olakara and Kavallur are given in Tables 4.17 and 4.18. From the tables, it can be seen that there was a rise in water table from June to September in Kavallur. Maximum water table fluctuation was observed in the months of June and July, that is, 1.368 m. After November, there was a lowering of the water table. Highest decrease in water table was observed between the months of February and March which accounted for 0.384 m.

At Olakara the rise in water table was observed from June to October. Maximum rise in water table was recorded between the months of May and June that is 1.340 m. The highest decrease in water table was recorded between the months of January and February.

Table 4.17 Mean seasonal change in water table at Olakara

Well No.	Between premonsoon and monsoon	Between monsoon and post monsoon	Between post monsoon and monsoon
OW-1	2.01	-0.71	-1.31
OW-2	1.12	-1.04	-0.07
OW-3	1.85	0.10	-1.95
OW-4	2.00	0.67	-2.67
OW-5	1.23	-0.27	-0.96
OW-6	2.75	-0.11	-2.64
OW-7	1.84	-1.36	-0.48
OW-8	2.22	0.51	-2.73
Mean	1.88	-0.28	-1.60

Table 4.18 Mean seasonal change in water table at Kavallur (m)

Well No.	Between Premonsoon and monsoon	Between Monsoon and post monsoon	Between Post monsoon and monsoon
KW-1	2.60	-0.93	-1.67
KW-2	1.05	-0.30	-0.75
KW-3	2.24	-0.96	-1.28
KW-4	1.72	-1.01	-0.71
KW-5	1.91	-1.10	-0.81
KW-6	2.37	-1.27	-1.10
KW-7	1.97	-0.83	-1.14
KW-8	1.25	-0.55	-0.70
KW-9	1.98	-0.80	-1.18
KW-10	2.31	-1.14	-1.17
KW-11	2.33	-1.15	-1.18
Mean	1.98	-0.91	-1.06

Seasonal changes in mean water table fluctuations at Olakara and Kavallur watersheds were calculated between pre-monsoon and monsoon. Seasonal rise in water table was in the range of 1.12 m to 2.22 m at Olakara, while in Kavallur, the rise in water table was in the range of 1.05 m to 2.60 m. The tendency of decreasing the water table is found between monsoon and post monsoon and post monsoon and monsoon seasons for both sites.

The graph gives the fluctuation of ground water table for the entire period. Both the sites show almost similar trend in the fluctuation of the ground water table.

The correlation between the rainfall and water table fluctuation has been established and the regression equations depicting the relationship are given Fig. 4.8 and Fig. 4.9.

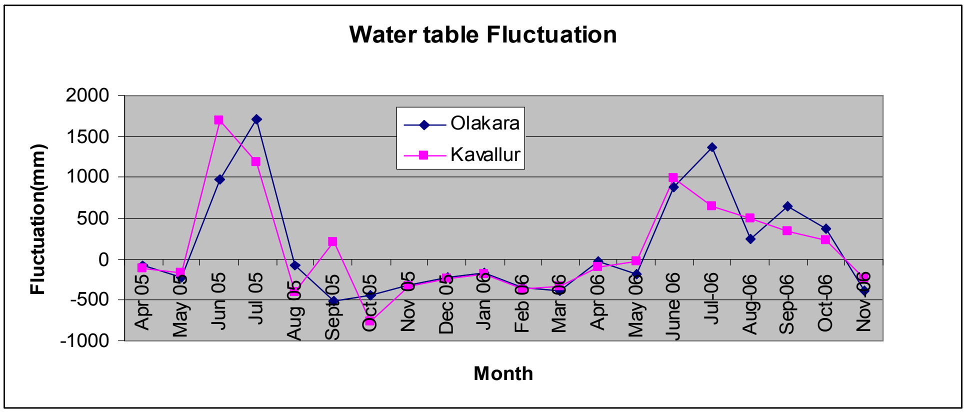


Fig. 4.8 Water table fluctuations at Olakara and Kavallur during 2005 and 2006

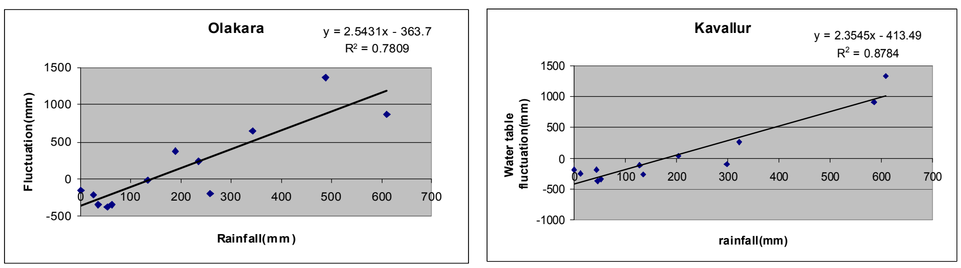


Fig.4. 9 Graphs showing the correlation between rainfall and water table fluctuations at Olakara and Kavallur

Kavallur Y=2.345X-413.49 R^2 =0.88; Olakara Y=2.5431X-363.7 R^2 =0.78

Both sites show a significant relation between rainfall and water table fluctuation.

4.4 Water level in Peechi Reservoir

Monthly average water levels in Peechi reservoir for the years 2000 to 2006 are shown in Fig. 4.10. It may be noted that the maximum water level in the Peechi reservoir is 80 m. The maximum water level is usually achieved during the month of August, which is retained till December. The level falls afterwards, which is due to the lack of inflow from the catchment area as well as releasing of water for irrigation purpose.

Fig. 4.10 Monthly average water level in Peechi Reservoir for the years 2000-06

However, from the water level data recorded for six years, it is clear that the reservoir is able to hold the water level usually at 70 m or slightly less than that.

4.5 Temperature and Relative Humidity

Data loggers for measuring daily temperature and relative humidity were installed at both watersheds. Data were collected from both sites during January 2005-December 2006. Graphs showing the details are given in Fig. 4.11and Fig. 4.12

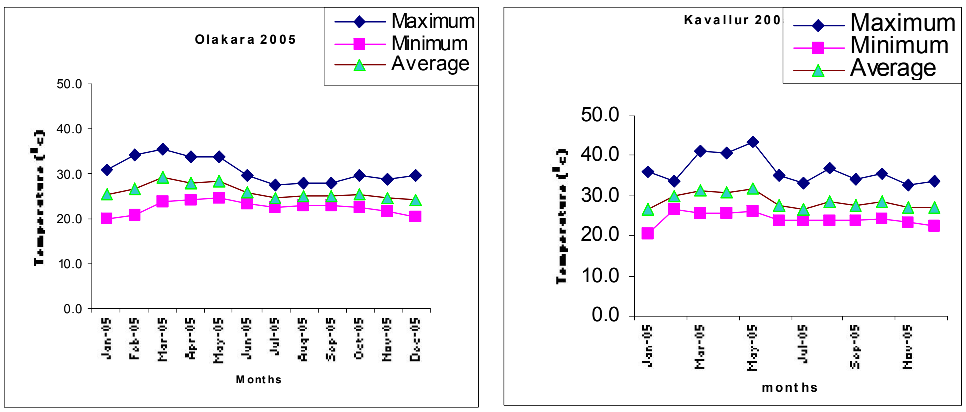


Fig. 4.11 Maximum, minimum and average temperature at Olakara and Kavallur during 2005

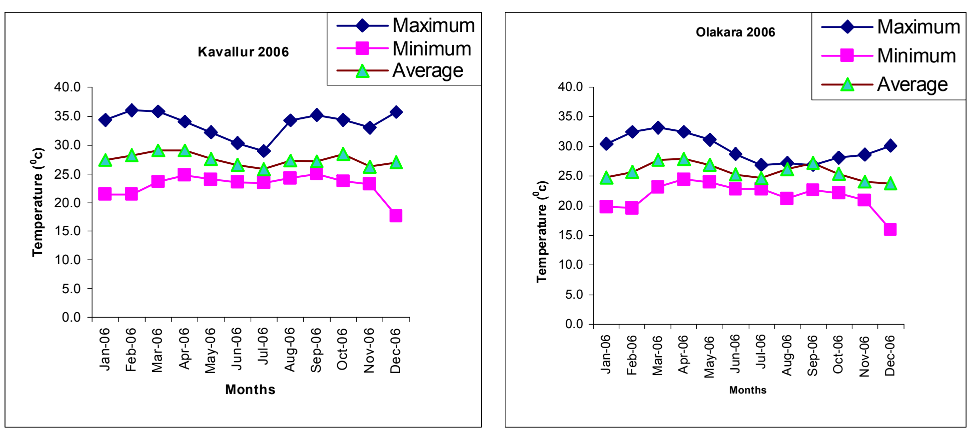


Fig. 4.12 Maximum, minimum and average temperature at Olakara and Kavallur during 2006

During 2005, the maximum temperature at Olakara watershed was recorded as 35.3^0 C in May and minimum as 20.1^0 C in January. The average temperature ranged between 24.4^0 C and 29.0^0 C during the year. In 2006, maximum temperature was recorded as 33.2^0 C in March whereas minimum was 19.8^0 C in January. However the average temperature was between 24.7^0 C and 28.0^0 C. Maximum temperature during 2005 was recorded as 43.4^0 C at Kavallur in May, whereas it was 36.0^0 C in February 2006. Minimum temperature recorded was 20.8^0 C in January 2005 and 21.4^0 C in January 2006. The average temperature ranged between 26.8^0 C and 31.8^0 C during 2005 and 25.8^0 C and 29.0^0 C for the year 2006.

4.6 Seasonal distribution of temperature

Data on seasonal distribution of temperature are given in Table 4.19. The table shows that temperature at Olakara is less than that of Kavallur. Hence forests are probably helping to regulate the microclimate to a great extent.

Table 4.19 Seasonal distribution of temperature at Olakara during 2005 and 2006

Seasons	Olakara		Kavallur	
	Max. Temp.	Min. Temp.	Max. Temp.	Min. Temp.
Pre monsoon	33.3	23.1	37.1	24.8
Monsoon	27.8	22.6	33.5	23.9
Post monsoon	29.4	21.0	34.2	22.6

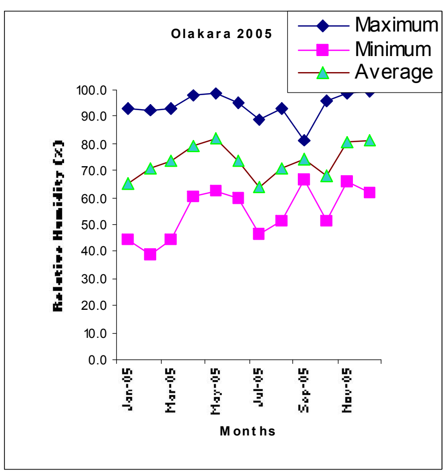
From the Table it may be noted that for both the watersheds the maximum temperature experienced was during premonsoon season. The temperature was lower during monsoon season. Temperatures experienced in all seasons at Olakara are less than that of Kavallur.

4.7 Relative Humidity

Data on relative humidity collected from both sites during January 2005-December 2006 are given in Fig. 4. 13 and Fig. 4.14.

At Olakara maximum relative humidity was in the range of 88.2 -95.2 per cent during 2005 and 84.2-94.4 per cent during 2006. Minimum relative humidity (RH) recorded was in the range of 56.3-82.5 per cent during 2005 and 55.2-83.7 per cent during 2006. Maximum humidity at Kavallur ranged from 85.4 per cent to 94.2 per cent during 2005 and 84.2 per cent to 94.3 per cent during 2006. Minimum humidity ranged from 54.2 per cent to 80.7 per cent during 2005 and 54.3 per cent to 81.2 per cent in 2006.

Seasonal distribution of relative humidity was calculated and given in Table 4.20. From the Table 4.20, it can be seen that both sites showed almost similar range of relative humidity during the study period, but Olakara showed slightly higher values when compared to those of Kavallur. This could be due to the presence of forests in Olakara compared to the more open agricultural ecosystem at Kavallur.



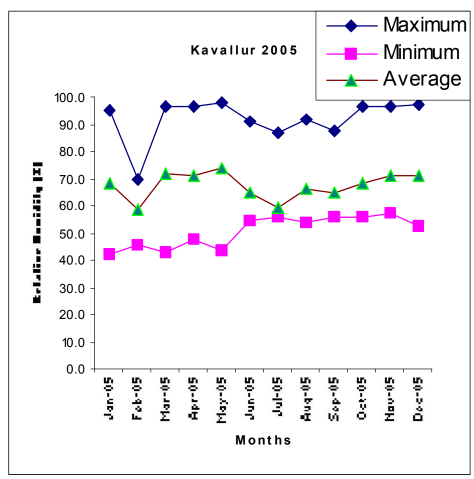


Fig. 4.13 R.H. measured at Olakara and Kavallur during 2005

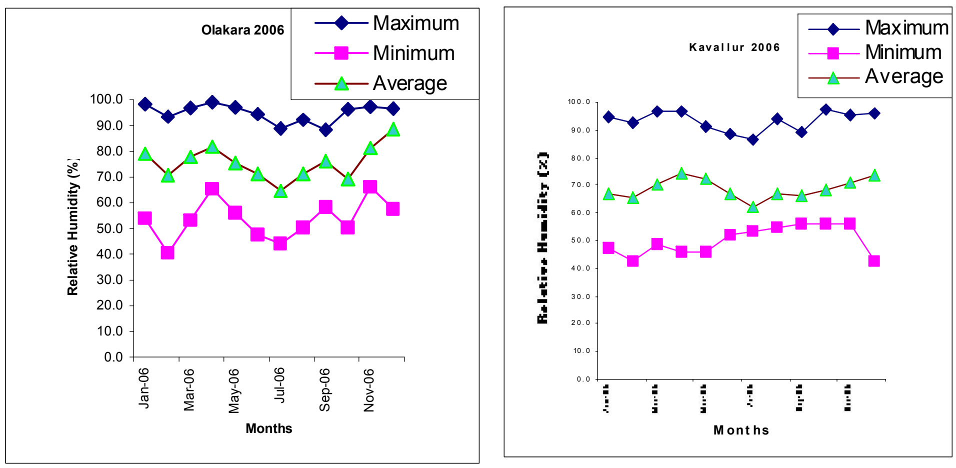


Fig. 4.14 R.H. measured at Olakara and Kavallur during 2006

Table 4.20 Seasonal distribution of relative humidity calculated from the data for 2005 and 2006

Season	Olakara		Kavallur	
	Max. RH	Min. RH	Max. RH	Min. RH
Pre monsoon	87.5	60.2	86.0	57.3
Monsoon	93.9	81.0	92.9	79.3
Post monsoon	90.6	69.5	89.2	67.8

Section 2 Discussion

4.8 Discussion

Landuse pattern studied in the Karuvannur river basin shows that the upstream areas are mostly covered by moist deciduous forests and the downstream locations have been occupied by tree plantations and annual agricultural crops. An analysis of the river basin in this study has shown that during a period of eight years (from 1996 to 2004), the land area under agriculture has been increased from 41 per cent to 61 per cent at the cost of forest land, which showed a corresponding decrease in the area from 59 per cent to 39 per cent. Thus the forest area has decreased at the rate of 2.5 per cent a year. This large scale decrease in forest area forces us to ask the question, if the landuse change has affected the water yield in the river basin.

An examination of the rainfall data for the river basin at three representative stations from 1966 onwards reveals that there is no indication for the decrease in rainfall. However, yearly variations do occur, which is not an abnormal situation. The river flow discharge observed from 1963 also reveals that there is no tendency for its decrease during the entire period. Here also, there are some irregular fluctuations from year to year.

The linkage between landuse change and water yield has been reviewed in the past by several investigators (Bosch and Hewlett 1982, Bruijnzeel, 1990 and 2004, Wilk 2000). The above authors present solid evidence from all climatological regions that forest removal will cause an initial increase in total annual streamflow. This is due to the reduction in transpiration and interception. However, as new vegetation grows in its place, the change in water yield is lessened. The final change in water yield is dependent on the evapotranspiration characteristics of the new vegetation in relation to the old, the soil depth and fertility which changes with time and the degree of soil and undergrowth disturbance during and after conversion. If the forest is replaced with plantation forest, the final change in water yield will be small. For example, in Kenya, where bamboo forest was replaced by pine wood plantations, an initial increase in water yield disappeared with the onset of pine maturation.

In the Karuvannur river basin, the conversion of the forest area into agricultural land has been occurring at a slow pace all through, though we have satellite map evidences for eight years only. In spite of this, it is surprising that we do not see any evidence for decrease or change in the yearly discharge observed at different locations. Permanent changes in streamflow have been recorded in studies where forests were replaced by agricultural holdings. In Tanzania, Zambia and Malaysia, such a change has resulted in increased water yield (Edwards, 1979; Mumeka, 1986, and Abdul Rahim, 1988). Although the change in water yield is not apparent when we consider the Karuvannur river basin as a whole, the change is very much pronounced when the two micro watersheds – Olakara and Kavallur are taken individually. Kavallur with a predominantly agricultural landuse shows almost 165 per cent of the rainfall going out as surface runoff and base flow combined in the month of August during two consecutive years of measurement. This was only 81 per cent of the rainfall in Olakara, which was a forested micro watershed. This is in spite of the similarity in rainfall in both the watersheds.

Thus, from the previously cited reviews and the present study, it appears that there is a strong case of reduced annual water yield under forest cover as opposed to cleared or cropped land. However, most of the studies have been conducted on small watersheds. When we consider larger basins having a variety of landuse types, different land management practices and vegetation of different species at various stages of growth, the fluctuation in water yield is difficult to notice (Bruijnzeel, 1990). It is probably because of this reason that the Karuvannur river basin does not show any consistent fluctuation in water yield. Streamflow changes could not be detected in catchments ranging from 7 to 727 km^2 in China after a 30 per cent loss in forest (Qian, 1983) and in a catchment of 14500 km^2 in northern Thailand after 40-50 per cent removal of forest (Dyhr-Nielsen, 1986) and the agriculture replacing four northern Thai catchments since 1950 (Alford, 1992). In large catchments, forest conversion is a gradual process although the change in forest cover may seem very large. Especially in a river basin such as Karuvannur, felling of trees and removal of forests must have been quickly replaced by plantations and agriculture, which can buffer the hydrological changes.

Landuse changes and dry season flow

Observations in the Karuvannur river basin from 1974 to 1982 show that there is no discharge from the river as observed at Pazhoor (CWRDM, 1995) during January to May (5 months). In the micro watershed observations, it may be noted that there is no streamflow at Olakara from January to April (4 months) and no streamflow in Kavallur from December to April (5 months) during 2005 to 2006. This means that the baseflow stops soon after the monsoons. In the forested watershed at Olakara, it seems that the baseflow persists till December in contrast with the Kavallur watershed, where it stops in November itself.

The change in baseflow due to removal of forests from different places is rather conflicting. For example, Myers (1986) has reported that as a result of loss of forest cover, the major rivers of tropical Asia now tend to release rainy season water in floods, followed by extended period of low streamflows. However, a study from Malaysia involving transition from indigenous forest to oil palm plantations showed significantly increased baseflow (Abdul Rahim, 1987). A South African study shows decreased baseflow when a grassland was reforested with pine trees (Bosch, 1979). These conflicting results could be interpreted in terms of altered soil infiltration conditions and evapotranspiration rates. For example, forested catchments with several layers of litter will provide high water infiltration and storage compared to soils without organic matter (Pritchett, 1979). Likewise, replacing indigenous forests with exotic species such as eucalypts with deep rooting system can considerably increase the water loss due to evapotranspiration (Kallarackal and Somen, 1997). In the present study site at Olakara, the indigenous forest is a moist deciduous forest, which will start leaf shedding in November and remain leafless till end of March. This could be the reason for slightly prolonged baseflow at Olakara compared to Kavallur. However, it is surprising that there is no baseflow from the leafless moist deciduous forest watershed during January to March in spite of the negligible evapotranspiration during this period and the presence of soil with relatively rich litter content and with a relatively high rainfall during the monsoons. However, the slightly more sustained streamflow at Olakara as compared to Kavallur favours the idea of a forested catchment as compared to predominantly agricultural catchment. In spite of this, the water table depth and fluctuations at both the watersheds were more or less similar.

The Reservoir

Karuvannur river basin is characterized by the presence of the Peechi reservoir in the upstream location. This reservoir is functional since 1959. From studies conducted on this reservoir it is known that this water body gets silted at the rate of 0.9 per cent every year (Ratheesh, 2006). Since most of the catchment areas of this reservoir is forested, the rate of silting should be assumed as lower compared to other reservoirs where the catchment areas are predominantly agricultural. From the water level data collected during 2000 to 2006, it may be noticed that the reservoir reaches its maximum storage capacity after the Southwest monsoon and this level is maintained till December due to the baseflow. During the dry season (January to April), this reservoir supplies water for irrigating the agricultural land downstream. Presently, the city of Thrissur and some of its suburban villages are getting their drinking water supply from this reservoir.

Much debate has occurred on the environmental impacts of dams and reservoirs. In spite of all these environmental impacts, hydrologically the Peechi reservoir is a success. As observed from the baseflow data, there is no baseflow from even the forested watershed (Olakara). This means that the Manali river across which the Peechi dam has been constructed would have been dry during the summer months. Construction of this dam has created a fairly large reservoir, which would satisfy the potable and agricultural water requirement of the Karuvannur river basin at least partially. Silting and sedimentation are the worst threats of dams in monsoonal locations. Further expansion of agriculture and annual cropping of the catchment area should be discouraged to the maximum. High priority should be given for the protection of the forests in the upstream locations of the Peechi reservoir.

This study also raises an important issue related to the capacity of a moist deciduous forest (MDF) to help in the streamflow during the dry period. In a MDF, evapotranspiration will be negligible during dry part of the year, due to the shedding of leaves and hence watershed with MDF is expected to generate much baseflow. However, in the present situation, it is not true. The baseflow will be lasting only till December, leaving the following four months rather dry. This situation calls for further studies on this matter and also requires means of conserving water in such locations. This is all the more important, as many of Kerala's river basins experience this kind of water shortages during the dry months.

Chapter 5

EFFECTS OF LAND USE/CROPPING PATTERN CHANGES ON VEGETATION, SEDIMENTATION AND SOCIO-ECONOMIC CONDITIONS OF THE PEOPLE

It is often said that unsound agricultural activities in the upland areas deplete vegetation, augment sedimentation and affect socio-economic conditions of the people. This chapter deals with effects of land use/cropping pattern changes on vegetation, sedimentation and socio-economic conditions of the people.

5.1 Plant diversity in the Olakara watershed area

The vegetation in the Olakara watershed area is Southern moist mixed deciduous forests. The dominant trees in this forest area are *Terminalia paniculata, T. crenulata, Schleichera oleosa, Lagerstroemia microcarpa, Bombax insigne, Grewia tiliifolia, Dillenia pentagyna, Hymenodictyon orixense, Xylia xylocarpa* etc. The lower staratum trees consist of *Naringi crenulata, Catunaregam spinosa, Cordia wallichii, Careya arborea, Sterculia urens,Helicteres isora*, among other. Species in the evergreen forests such as *Aporosa cardiosperma*, *Carallia brachiata, Hydnocarpus pentandra, Stereospermum colais* etc. are common along the side streams and other moisture rich area with other shrubaceous members. *Acacia caesia, A. torta, Spatholobus parviflorus, Dalbergia volubilis* are the common woody climbers in the area. Undergrowth is thick with herbs and shrubs. Gregarious tropical weeds such as *Lantana camara* and *Chromolaena odorata* form thickets in many areas. Another exotic weed *Hyptis capitata* is getting established in the forests especially along the sides of the watercourses. Diversity of fern is low; Adiantum and Selaginella spp. are the common terrestrial ferns in the area. However, an epiphytic fern *Drynaria quercifolia* is common on the trees. Orchid diversity, both terrestrial and epiphytics is low. *Cymbidium aloifolium,* *Pholidota imbricata* and *Vanda testacea* are the common epiphytic orchids in the area. Grasses in the canopy covered areas are relatively few. The notable ones are *Panicum notatum, Centotheca lappacea,* and *Cyrtococcum oxyphyllum.* The endemic wild rice, *Oryza officinalis* ssp. *malampuzhensis* is fairly common along the stream sides. In the open rocky areas, exotic grasses *Pennisetum americanum* and *P. pedicellatum* are common along with the indigenous *Ischeamum indicum.*

Habit wise, 122 herbs, 33 shrubs, 54 climbers and 50 trees were identified. Among the 259 species enumerated in the area, there are only 29 peninsular Indian endemics. This may be due to the habitat and lower elevation of the area. The occurrence *of Securinega virosa*, *Careya arborea*, *Catunaregam spinosa* etc. indicates that the area was prone to seasonal fire in the past. The list of plants in the watershed is given in Appendix 1.

5.2 Vegetation analysis

Species distribution can be well understood from AB/F ratio (Tables 5.1 and 5.2). Preponderance of contiguous distribution prevails in Olakara with a rarity of random distribution and absence of regular distribution of species. Most of the species in Kavallur exhibited random distribution followed by contiguous and regular distribution. The distribution pattern that prevails in a given community depends in part on the habitat, including its history and in part on characteristics of the species in a community.

The main species distributed contiguously in Olakara area *Lagerstroemia lanceolata*, *Lagerstroemia microcarpa*, all *Terminalia* species except *T. paniculata, Xylia xylocarpa,* and *Tabernamontana heynearna.* The random distribution is exhibited by *Bombax ceiba*, *Dillinia pentagyna*,*Grewia tiliifolia*, *Sterculia guttata* etc. in Olakara area and *Bombax ceiba , Dillinia pentagyna, Casssia fistula*, etc. in Kavallur area. It is also notable that in Olakara area competition between individuals are on a higher scale.

Table 5.1 Vegetation analysis of Olakara

Sl. No	Species	D	F	RD (%)	RF (%)	AB	BA(cm²)	RBA (%)	AB/F	IVI
1	*Xylia xylocarpa*	576	92	31.17	13.86	6.26	1276.12	3.52	0.068	48.55
2	*Dillenia pentagyna*	212	84	11.47	12.65	2.52	1070.02	2.95	0.030	27.07
3	*Terminalia paniculata*	216	72	11.69	10.84	3.00	1408.65	3.89	0.042	26.42
4	*Grewia tilifolia*	132	52	7.14	7.83	2.54	1244.71	3.43	0.049	18.41
5	*Lagerstroemia microcarpa*	92	36	4.98	5.42	2.56	1201.74	3.32	0.071	13.72
6	*Terminalia crenulata*	24	12	1.30	1.81	2.00	3050.62	8.42	0.167	11.52
7	*Bombax ceiba*	56	32	3.03	4.82	1.75	1058.53	2.92	0.055	10.77
8	*Cleistanthus collinus*	76	24	4.11	3.61	3.17	757.40	2.09	0.132	9.82
9	*Tectona grandis*	40	16	2.16	2.41	2.50	1828.16	5.04	0.156	9.62
10	*Lagerstroemia lanceolata*	80	12	4.33	1.81	6.67	863.68	2.38	0.556	8.52
11	*Sterculia guttata*	32	28	1.73	4.22	1.14	872.82	2.41	0.041	8.36
12	*Ficus tjakela*	4	4	0.22	0.60	1.00	2436.08	6.72	0.250	7.54
13	*Dalbergia latifolia*	4	4	0.22	0.60	1.00	2325.99	6.42	0.250	7.24
14	*Macaranga peltata*	44	20	2.38	3.01	2.20	619.82	1.71	0.110	7.10
15	*Pterocarpus marsupium*	8	8	0.43	1.20	1.00	1801.72	4.97	0.125	6.61
16	*Terminalia chebula*	8	8	0.43	1.20	1.00	1777.86	4.91	0.125	6.54
17	*Stereospermum chelenoides*	16	16	0.87	2.41	1.00	1051.99	2.90	0.063	6.18
18	*Albizia odoratissima*	12	4	0.65	0.60	3.00	1559.09	4.30	0.750	5.55
19	*Terminalia bellarica*	12	8	0.65	1.20	1.50	1289.73	3.56	0.188	5.41
20	*Cassia fistula*	4	4	0.22	0.60	1.00	1649.45	4.55	0.250	5.37
21	*Schleichera oleosa*	16	8	0.87	1.20	2.00	1145.45	3.16	0.250	5.23
22	*Stereospermum collais*	24	20	1.30	3.01	1.20	220.64	0.61	0.060	4.92
23	*Sapindus sp.*	16	16	0.87	2.41	1.00	286.36	0.79	0.063	4.07
24	*Holarhena pubascens*	24	16	1.30	2.41	1.50	120.99	0.33	0.094	4.04
25	*Haldinia cordifolia*	8	4	0.43	0.60	2.00	927.82	2.56	0.500	3.60
26	*Hydnocarpus pentandra*	4	4	0.22	0.60	1.00	962.50	2.66	0.250	3.47
27	*Bauhinia malabarica*	16	8	0.87	1.20	2.00	483.95	1.34	0.250	3.41
28	*Garuga pinnata*	4	4	0.22	0.60	1.00	927.82	2.56	0.250	3.38
29	*Cleistanthus sp.*	24	4	1.30	0.60	6.00	275.34	0.76	1.500	2.66
30	*Wrightia tinctoria*	4	4	0.22	0.60	1.00	459.45	1.27	0.250	2.09
31	*Caryota urens*	12	4	0.65	0.60	3.00	276.90	0.76	0.750	2.02
32	*Careya arborea*	8	8	0.43	1.20	1.00	105.97	0.29	0.125	1.93
33	*Kydia calicina*	12	4	0.65	0.60	3.00	215.09	0.59	0.750	1.85
34	*Ziziphus oenoplia*	8	4	0.43	0.60	2.00	267.59	0.74	0.500	1.77

35	*Acasia instia*	4	4	0.22	0.60	1.00	86.63	0.24	0.250	1.06
36	*Bischofia javanica*	4	4	0.22	0.60	1.00	86.63	0.24	0.250	1.06
37	*Ficus drupaceae*	4	4	0.22	0.60	1.00	86.63	0.24	0.250	1.06
38	*Olea dioica*	4	4	0.22	0.60	1.00	81.45	0.22	0.250	1.04
39	*Tabernamontana heyneana*	4	4	0.22	0.60	1.00	81.45	0.22	0.250	1.04
	Total	**1848**	**664**	**100**	**100**	**80**	**36242.8**	**100**	**10.3**	**300**

D = Density; F = Frequency; RD = Relative Density; RF = Relative Frequency; AB = Abundance; BA = Basal Area; RBA = Relative Basal Area; IVI = Importance Value Index

** Maturity index = 17.03

Table 5.2 Vegetation analysis of Kavallur

Sl.No	Species	D	F	RD (%)	RF (%)	AB	BA(cm^2)	RBA (%)	AB/F	IVI
1	*Ficus tjakela*	40	40	2.78	5.41	1.00	7943.09	21.82	0.025	30.01
2	*Macaranga peltata*	260	80	18.06	10.81	3.25	389.77	1.07	0.041	29.94
3	*Lagerstroemia microcarpa*	120	60	8.33	8.11	2.00	3469.09	9.53	0.033	25.97
4	*Terminalia paniculata*	140	40	9.72	5.41	3.50	3310.36	9.10	0.088	24.22
5	*Xylia xylocarpa*	160	40	11.11	5.41	4.00	2329.39	6.40	0.100	22.92
6	*Grewia tilifolia*	100	60	6.94	8.11	1.67	2853.48	7.84	0.028	22.89
7	*Dillenia pentagyna*	40	40	2.78	5.41	1.00	5071.52	13.93	0.025	22.12
8	*Hydnocarpus pentandra*	60	20	4.17	2.70	3.00	4159.31	11.43	0.150	18.30
9	*Erythrena indica*	80	60	5.56	8.11	1.33	1272.91	3.50	0.022	17.16
10	*Macaranga peltata*	100	40	6.94	5.41	2.50	235.40	0.65	0.063	13.00
11	*Aporusa lindleyana*	40	40	2.78	5.41	1.00	1354.68	3.72	0.025	11.91
12	*Bombax ceiba*	60	40	4.17	5.41	1.50	467.55	1.28	0.038	10.86
13	*Sterculia guttata*	20	20	1.39	2.70	1.00	1935.82	5.32	0.050	9.41
14	*Cassia fistula*	40	40	2.78	5.41	1.00	206.90	0.57	0.025	8.75
15	*Tabernamontana heyneana*	60	20	4.17	2.70	3.00	110.87	0.30	0.150	7.17
16	*careya arborea*	20	20	1.39	2.70	1.00	876.99	2.41	0.050	6.50
17	*Caryota urens*	40	20	2.78	2.70	2.00	103.09	0.28	0.100	5.76
18	*Carica pappaya*	20	20	1.39	2.70	1.00	168.32	0.46	0.050	4.55
19	*macaranga peltata*	20	20	1.39	2.70	1.00	91.95	0.25	0.050	4.34
20	*Cleistanthus collinus*	20	20	1.39	2.70	1.00	45.82	0.13	0.050	4.22
	Total	**1440**	**740**	**100**	**100**	**36.75**	**36396.31**	**100**	**1.161**	**300**

D = Density; F = Frequency; RD = Relative Density; RF = Relative Frequency; AB = Abundance; BA = Basal Area; RBA = Relative Basal Area; IVI = Importance Value Index

** Maturity index = 37.00

5.3 Sedimentation

The total rainfall in the months of July, August and October 2005 were 665,102 and 112 mm, respectively while that in June, August and September 2006 were 538, 304 and 296 mm respectively. The mean values of sediment yield estimated from the watershed are shown in Table 5.3. The nutrient contents in the sediments are presented in Table 5.4. The mean sediment production estimated by measuring the flow of water from the watershed was 1335, 4363 and 1152 g during July, August and October 2005, respectively. In the months of June, August and September 2006 corresponding mean values were 932, 2104 and 973 g. This is from an area of 1.22 km^2. This indicates that the maximum sediment yield was in the month August, 2005 (4363.2 g) and there was much variation in the months of June (133.5 g) and October, 2005 (1152 g). In the year 2006, the maximum sediment yield was in the month of August (2104 g). There was not much difference in the sediment yield during the months of June and September, 2006. The general pattern with respect to the sediment yield is same, the maximum being in the month of August in both the years 2005 and 2006.

The nutrient contents in the sediments during the above periods were 1.725, 2.081, 1.532 g/ha of nitrogen, 0.72, 1.38, 0.68 g/ha of phosphorus and 1.16, 1.89 and 1.05 g/ha of potassium in the months of July, August and October 2005 respectively. In 2006, the nutrients removed through the sediments in the months of June, August and September were 1.263, 1.642, 1.361g/ha of nitrogen, 0.54, 1.12, 0.63 g/ha of phosphorus and 0.96, 1.47 and 1.07g/ha of potassium respectively.

Converting the sediment yield/ ha basis, it was 10.90 g, 35.75 g and 9.44 g/ha in the months of June, August and October, 2005 (the weight of 1.22 km^2 soil is 268.4 million kg). In the year 2006, the sediment yield was 7.64, 17.25 and 8.0 g/ha in June, August and September, respectively. This shows that during the period 2005 to 2006, 88.98 g/ha of sediment was produced. This is from a small area where the disturbance is very low and is totally protected.

Table 5.3 Sediment yield estimated from the watershed

Year/ month	Yield	
	1.22 km² (g)	**Per ha (g)**
2005 July	1335.00	10.90
August	4363.20	35.75
October	1152.00	9.44
2006 June	932.00	7.64
August	2104.00	17.25
September	973.00	8.00

Table 5.4 Sediment yield estimated from the watershed and the nutrient contents

Year/ month	Yield per ha (g)	Nutrients g/ha		
		N	**P**	**K**
2005 July	10.90	1.725	0.72	1.16
August	35.75	2.081	1.38	1.89
October	9.44	1.532	0.68	1.05
2006 June	7.64	1.263	0.54	0.96
August	17.25	1.642	1.12	1.47
September	8.00	1.361	0.63	1.07

The relationship between sediment yield and rainfall is shown in Table 5.5. It could thus be seen that the maximum sediment yield occurred in the month of August in 2005 and 2006. This showed a pattern in which the yield is maximum, immediately after a heavy rainfall followed by a sudden decrease. Usually high sediment yield is expected where the rainfall is maximum. But, highest values were recorded immediately after the occurrence of heavy rain fall. This indicates that during heavy splash, the soil becomes loose and is transported later. When the rain recedes in the month of September in both years, the transport of materials declines.

Table 5.5. Relationship between sediment yield and rainfall

Year/ month	Sediment yield	
	g/ha	Rainfall (mm)
2005		
July	10.90	665.8
August	35.75	102.4
October	9.44	112.8
2006		
June	7.64	538.7
August	17.25	304
September	8.00	296.6

Attempt was also made to assess sedimentation in highly degraded parts of upland area. Unfortunately due to non-co-operation of the local people, data could not be gathered. Thus, to indicate the trend we depend upon a study by Suresh Kumar (2002) at Bharathamala of Peechi, which is a part of Kavallur area. The study reported high sedimentation in the area. For instance, sedimentation was found to be 9675.229 tonnes in August, followed by 7470.739 tonnes in September, but the run-off was maximum during October. This increased rate of sediment yield during August and September is due to the large quantity of soil movement together with the surface flow at the time of intercultural operations in the cultivable lands. This indicates two things; first, sedimentation is low in a good forest area and as degradation increases due to loss of vegetation and cultivation, sedimentation also increases. This underscores the need for more vegetation cover in the upland areas, which will prevent sedimentation in the reservoir.

5.4 Increase of production and productivity in agricultural sector

The traditional agricultural system in the study area was dominated by paddy-based production system, where production from cultivated crops was accounted mainly by paddy, followed by coconut, tapioca, banana, and vegetables. Crops other than paddy were not attended to intensively, which resulted in poor yields from these crops. Even for coconut, once the seedlings were planted further attention was paid to it only at the time of harvest. Mango, jack, cashew, tamarind, etc were just natural growth and no attention was given. Since cultivation was meant mainly for home consumption in the past, monetary income was not the criterion for cropping decisions. The situation has now changed and in the present scenario, cultivation is mainly for income and profit generation. Farmers therefore take special care to select crops and crop varieties with better yields and tend them carefully, to obtain better yields. For instance, the yields of coconut, banana, tapioca, and pepper doubled during the past two decades. Cashew, though an income-generating crop, had almost been replaced by rubber, which generated a more steady and higher income flow. Fruit trees like mango and jack were replaced by income-generating cash crops. The overall result was an increase in agricultural production with major shifts in composition from food items to commercial items (Table 5.6). One disadvantage of this is that the food security has been reduced significantly.

The comparison of productivity of selected crops during 1975-76 and 2005-06 revealed an increase in the productivity of major crops like paddy, coconut, rubber, and tapioca (Table 5.7). Modernization of agriculture with the adoption of high yielding varieties, mechanization, and widespread application of fertilizers, manures and pesticides had enabled the increase in the productivity of the crops.

Table 5.6 Production: A comparative analysis between 2005-06 and 1975-76 (kg)

Sl. No.	Crop	Production in (2005-06)	Productionin (1975-76)
1	Paddy	88506	85673
2	Coconut (Nos)	62457	53157
3	Areca nut	376	280
4	Pepper	2920	2206
5	Cashew	1064	2479
6	Tapioca	127069	73297
13	Pulses	1120	955
14	Banana	228673	136667
15	Ginger	3158	2751
18	Rubber	30317	18699

Table 5.7 Productivity comparison between 1975-76 and 2005-06 (Kg/ha)

SI. No.	Crop	Productivity in 2005-06	Productivity in 1975- 76
1	Paddy	2882	2185
2	Coconut (Nos)	5637	5520
3	Areca nut	217	209
4	Pepper	326	299
5	Cashew	760	740
6	Pulses	830	758
7	Banana	8190	7052
8	Ginger	3852	3620
9	Turmeric	2342	2289

5.5 Socio-economics

As mentioned earlier, conversion of forest area to agricultural land was the main land use change in the study area, which brought about changes in the socio-economic conditions of the people. Table 5.8 gives an overview of major socio-economic conditions of selected farmers

Table 5.8 Socio- economic profile of selected farmers

1	Sample size	100
2	Total population	451
3	Average Family size	4.51
4	Literacy rate	99%
5	Total work force	333(74%)
6	Work force participation rate	57%
7	Total employed person	188
8	Female work participation rate	3.55
9	Male work participation rate	95.31
10	House holds fully depended agriculture	29%
11	Employed in agriculture	58%
12	Employed in service sector	24%
13	Average annual income of family	Rs.71,296
14	Per capita income	Rs.15,809
15	Annual income from agriculture per household	49,100
16	Average savings per family	9731
17	Average debt per family	57270

The family size of the selected farmers was small (4.51). As elsewhere in the State, the literacy rate was very high (99%). The per capita income amounted to Rs. 15809 which was lower than that of state (Rs. 24053) and district average (Rs. 25933) during 2004-05 (Government of Kerala, 2005). Average savings per family amounted to Rs.9731. However, it was reported that the average debt (Rs.57270) was more than average family savings. They borrowed money for agricultural operation, house construction, marriages, etc. Low per capita income, low savings and high debt indicate their poor economic condition.

The respondent informed that about 85 per cent of the households depended fully on agriculture for their livelihood during 1975-76. In contrast, nearly 29 per cent of the households depended fully on agricultural sector either as cultivators and/or as farm labour for their livelihood during 2005-06. However, due to an increase in productivity and production in the agricultural sector and price rise, income from agriculture has been doubled, that is from Rs. 7267 to Rs. 15809 from 1975-76 to 2005-06.

Due to increase in population and the land reforms, agricultural farms got subdivided resulting predominance of very small-sized farms. Since small-sized farms are not viable and mechanization is not practical in such farms, the owners of these farms turned to other occupations for their livelihood. For such cultivators farming was only a subsidiary activity who preferred those crops which required less personal attention.

The immediate result of the change in the cropping pattern was the reduction in rice production. Rice-based farming system and cattle-rearing are inter-dependent activities. Sharp decline in the area under rice reduced the availability of straw, which, in turn, led to reduction in the number of draught animals and working bullocks in the farm sector. This caused decline in the availability of farmyard manure and break down of the traditional farming sector. Since most of the farmers preferred to keep rice lands fallow during summer, production of pulses and vegetables declined significantly.

While increase in the area under cash crops like coconut and rubber helped to increase farm income, changes in cropping pattern in favor of perennial crops have an immediate and direct impact on the employment pattern in the rural area. The shrinkage of rice cultivation and other seasonal crops has displaced agricultural labour especially women from the farm sector (The female work participation rate in the study area was only 3.55%). Although cultivation of perennial crops like coconut and rubber required only less number of workers per unit area, increase of area under agriculture was not helpful to solve unemployment problem in the farming sector.

Chapter 6

VALUATION OF WATER RESOURCES AND USE CONFLICTS

The man-made wetlands in the forest ecosystem are water storage areas and are classified into (a). Reservoirs holding water for irrigation and/or human consumption with a pattern of gradual, seasonal, draw down of water level and (b). Hydro-dams with regular fluctuations in water level on a weekly or monthly basis (Dugan, 1990). Water is often regarded as naturally existing, freely available commodity. But in reality, since its supply in most places is less than its demand, it has a value.

Conflict over natural resources, particularly water can take place at various levels: households, local, regional, societal and global. The intensity and impact of conflict over water resources also varies from time to time and place to place. For instance, intensity and impact of non-availability of irrigation or drinking water during summer and rainy season and also in rural and urban areas are different. In this chapter, the results of economic valuation of water resources in Peechi reservoir/wetland, problems relating to pricing of water and the willingness to pay expressed by the people for adequate and regular supply of water are presented. The nature and extent of water resource use conflict in the study area is also discussed.

6.1 Direct extractive benefits

The direct extractive/consumptive benefits of Peechi wetland include fish, irrigation and drinking water benefits. The estimated values of the benefits are presented in Table 6.1. The direct extractive benefits from the wetlands amount to Rs. 1110 lakhs with a value of Rs. 3, 232, and 875 lakhs for fish, irrigation, drinking water use respectively. The drinking water users appreciated the wetland benefits more than that of the irrigation users in the study area. This may be attributed to the severe scarcity of water and the burgeoning demand in the urban areas where there are no better alternatives.

Table 6.1 Value of direct extractive benefits from Peechi wetland

Particulars	Value (Rs. In lakhs)
Fish	3
Irrigation	233
Drinking water	875
Total	1111
Value per ha (Rs.)	0.88

6.2 Direct non-extractive benefits

The direct non-consumptive/extractive benefits of the wetlands were taken in the study as its ecotourism potential. The consumer surpluses of the visitors to the Peechi Dam are presented in the ensuing section.

6.3 Demand function of tourists of Peechi Dam

The demand function estimated for the Dam, presented in Table 6.2, revealed that variables income (X_4), opportunity cost of time (X_6), travel cost (X_7) distance traveled (X_8) infrastructure (X_9) were statistically significant with expected signs (Table 6.2). The positive sign of the variable, willingness to pay (X_3) indicates that tourists are willing to pay for the recreational benefits enjoyed at the Dam site and hence the present entrance fee of Rs. 2 per person under estimates the WTP of the visitor. The fee is much lower as evident from the high consumer surplus. This finding emphasizes that the present fee can be hiked and the additional revenue so generated can be utilized for site improvement. With an increase in income, the WTP of the tourist increases and vice versa.

Table 6. 2 Demand function of tourists of Peechi Dam

Variable	Coefficient	t value
Constant	0.1635 (0.2109)	0.7752
X_1	0.0056 (0.0036)	1.5555
X_2	0.9399 (0.2084)	4.5100**
X_3	0.0353 (0.0091)	4.8791**
Variable	**Coefficient**	**t value**
X_4	0.0194 (0.0078)	2.4871*
X_5	0.5939 (0.6386)	0.9299
X_6	-0.2176 (0.0790)	-2.7544*
X_7	-0.0125 (0.0029)	-4.3103**
X_8	-0.2166 (0.0515)	-4.2058**
X_9	0.0191 (0.0051)	3.7450*
X_{10}	-0.0021 (0.0015)	-1.4000
Consumer surplus = Rs. 392 per person per visit		
R^2=0.55, F=25.22 n=250 Total visitors are estimated to be 100000 per annum		

* Significant at five per cent level of significance

** Significant at one per cent level of significance

Figures in parentheses are standard errors

6.4 Total recreational value

The total recreational values of the Dam presented in Table 6.3, show that recreation value per unit area of the Dam is Rs. 3136 per hectare.

Table 6.3 Total estimated value of tourism in Peechi wetlands

Particulars	Value
Recreation benefits of Peechi Dam (Rs. in lakhs)	39.61
Total recreation value per hectare (Rs)	3136

6.5 Indirect use value

The indirect use values for the wetlands were worked out based on figures given by WWF (2004) since estimation of individual values was beyond the scope of the study. The figures have been extrapolated to the study site and are presented in Table 6. 4.

Table 6.4 Indirect use value of Peechi wetlands

Economic value	Rs in lakhs	Rs. per hectare
Flood Control	264	20880
Water Filtering	164	12960
Biodiversity	122	9630
Habitat Nursery	114	9045

6.6 Total estimated economic value

Based upon the estimates of different tangible and intangible benefits the TEV of Peechi wetlands was measured and the results are presented in Table 6.5. The estimated value per hectare of the wetlands is Rs. 1.46 lakhs with an estimated total value of Rs.1844 lakhs.

Table 6.5 Total economic value of Peechi wetlands

Wetland Benefits	Value (Rs. in lakhs)	Value (Rs. ha $^{-1}$)
Use values		
Direct use values		
• Direct consumptive use	1111	87948
• Direct non consumptive use	40	3136
Indirect use values		
Flood Control	264	20880
Water Filtering	164	12960
Biodiversity	122	9630
Habitat Nursery	115	9045
Option values	11	799
Non-use values	21	1640
TEV	1848	146039

6.7 Pricing of water: Some issues

It was beyond the scope of this study to determine the price of water supplied from Peechi Reservoir. Instead, it is attempted here to compare the price per unit of water supplied from Peechi and its costs and also to discuss issues like equity and need of fair pricing for better management of water resources in the study area. The average cost of purification of Peechi water is very low (below Rs.2 per 1000 liters). As per the estimate of Water Authority, the average cost of purification and distribution is Rs. 9 per 1000 liters. But, it collects only Rs.2 per 1000 liters. In other words, the water is supplied at a subsidized rate. It is a controversy whether water should be supplied at a subsidized rate when its supply is limited compared to its demand. If water is viewed simply as a commodity, it would be reasonable to expect that it should be priced to cover at least its cost of provision so that low value uses are discouraged and supplies are available for high value users. However, a strict application of this principle needs to be handled with some caution to ensure that the poorest people in the community are not disadvantaged (Agudelo, 2001). There are arguments that subsidy in the water supply ends up in a 'free water dilemma': a situation which ironically results in rich people getting water free or very cheaply and poor people buying water at excessive rates or drinking unsafe water (Savenije and Zaag, 2002). Our survey highlights nearly 85 per cent of the people who have water connection from Peechi Water Supply scheme belong to higher and middle income groups whose ability to pay for water is more.

One of the disadvantages of low pricing of water is that it cannot generate adequate surplus to maintain the distribution system, resulting in its frequent breakage of supply of water. The present distribution system (pipes) of Peechi drinking water supply scheme was laid about two decades back and the water supply started in 1986. Primo pipes of 700 mm diameter and 5.5 m length are used in the scheme. Although the life span of the primo pipe is said to be 15 years, it is around 20 years now, since the pipe line has been laid. During the initial period, there were no major problems reported regarding breakage of distribution line. The breakage problem which started around 8-10 years back has almost become a regular and major problem during recent years. For instance, this problem occurred about 17 times during 2005-2006 and in each occasion water supply was delayed about 2-3 days. This was mainly due to inefficient management and inadequate monitor and maintenance of pipes on a timely basis.

Since the breakage has to be repaired immediately, the cost of repairing is also high. For emergency works the labour cost will be more. According to the officials of Kerala Water Authority, the main expenditure consists of material and labour cost. It is difficult to assess cost of repair per meter length as it depends on the intensity of breakage, time (if the work is at night, labour charge will more), place, type of soil etc. An average cost of replacement of 5 m length, material cost will be around Rs.28000-30000 (includes pipe, iron brackets, transportation, etc.). The labour cost will be around Rs.12000-15000 (includes human labour, machineries etc). An average expenditure of 40000-45000 is expected per case of breaking of distribution line. According to the officials of Water Authority, about Rs. 7-7.5 lakhs is spent per annum only for the replacement of the broken pipes.

Thus, this necessities the generation of more profit through proper pricing of water which should be based on economic as well as social, environmental and technical impacts. In other words, a proper water pricing policy should be formulated aiming to recover at least a major portion of cost of providing the supply, get funds for water development, proper allocation and resolution of water resource conflict, environmental benefits and demand management (Agudelo, 2001).

6.8 Willingness to pay

The Kerala Water Authority in Thrissur district mainly provides three categories in water connection viz., domestic, non-domestic and industrial on the basis of the level of consumption and charges rates accordingly as shown in Table 6.6.

The cost of supplying water depends upon different schemes. State average is Rs.8/- to Rs.9/- per 1000 ltrs. Comparatively it is very low in Peechi as compared to the State average. There is a marginal increase of 1000 to 1500 connection per year in Thrissur Water Supply Division. There are 4976 public taps (The old municipality area is excluded) under Thrissur Water Supply Division. Out of this, approximately 80 per cent of public taps depends on Peechi as the source of water. There are 1790 public taps in old Municipality area which fully depends on Peechi water. Total supply of water through a public tap depends upon the area and the season. In some areas and seasons, there is continuous water supply.

Table 6.6 Categories of water use and the charge per 1000 ltrs

Categories	Present charge
Domestic	
Up to 10000 ltrs	Rs. 20/-+2/-
10001 to 30000	Rs. 3/- 1000 ltrs
30001 to 50000	Rs. 5/- per 1000 ltrs
Above 50000	Rs. 7.35/- per 1000 ltrs
Non-Domestic	
Minimum charge	Rs.102/-
Up to 50000	Rs. 7.35/-per 1000 ltrs
Above 50000	Rs. 10.60/- per 1000 ltrs
Industrial	
Minimum charge	Rs.202/-
Above 50000	Rs. 10.60/- per 1000 ltrs

But, in some other areas it is limited to 4 to 5 hrs. There is no metering in case of public taps and therefore no accurate measurement is possible regarding the total supply of water through public taps. Kerala Water Authority collects the charges on public taps from the local authorities-Panchayats/Muncipalities.

A survey was conducted among users of drinking water to know their willingness to pay for timely and adequate water supply. About 80 per cent of the samples, who used drinking water from Peechi, were willing to pay more for timely and adequate supply of water where as 20 per cent agreed with the existing price. In the first category, about 60 per cent were willing to pay about Rs 6-8 for 1000 litres of water and rest have agreed to pay Rs. 10-12 on condition that the supply should be regular. The first category offered a higher amount since about 50 per cent of them have no well. Peechi is the main source of drinking water for this category which suffers a lot at the time of breakage of pipes. In the second category, about 80 per cent have wells in their house compound and water from Peechi is only a supplementary one. This supports charging a fair price for water from Peechi, as it is essential to reflect its value to society as a scarce resource.

6.9 Water use conflict

The implications of the competition between agricultural use and potable/domestic/municipal/industrial use for water quantity and quality are manifold. Urban water supply utilities and most industrial concerns are always looking for low volume high quality water whereas irrigated agriculture seeks high volumes of water and is generally indifferent to quality. In addition, the trend to conserve the integrity of natural systems, particularly that of surface water bodies and wetlands and to maintain a set of *in-situ* environmental services adds another dimension to the competition and conflicts for water between multitude of users.

There are socio-ecological and economic conflicts and conflict over natural resources such as land, water, and forests is ubiquitous. Some of the natural resources provide basic goods without which people cannot survive in the world. Thus, people with varied interest and socio-economic conditions compete for natural resources to ensure their livelihood which results in conflict. A study by FAO (1998) has stated that conflict emerges when the interests of two or more parties clash and at least one of the parties seeks to assert its interests at the expense of another party's interests. A variety of factors contribute conflict over natural resources but scarcity due to increasing demand and environmental degradation is the most important. Economic theory has provided two reasons why conflicts emerge over natural resources: a) the allocation of scarce resources requires trade-offs which become increasingly difficult as the demand for and supply of resources changes and b) short-term personal gain wins out over long-term social needs or benefits (Sreelakshmi, 2005).

6.10 Sources of water in the study area

Households, agriculture, and industrial sectors are three consumers of water in the study area. Since there are only very few industrial units, the first two sectors consumed about 80 per cent of the available water. Although there are a few tanks and ponds, the major sources of water in the study area are wells and Peechi Reservoir (Manali river).

6.11 Irrigation vs. Drinking water

Before examining the conflict between irrigation and drinking water sectors, an understanding of the major features and objectives of the Reservoir will help to throw more light to this conflict. The Peechi is one of the major irrigation projects in the State. The project was started in 1947 and commissioned in 1959. Water was first let out for irrigation in 1953. One of the major objectives of the Reservoir was to supply water to the agricultural sector. The height of the Dam is 79 m and water supply inlet is at 53.34 m. Right and left bank canals for irrigation are at 56.39 m and 67.06 m. respectively. They irrigate an area of 18,623 ha. mostly in Thrissur district.

Peechi Reservoir provides drinking water to Thrissur Corporation and 9 Panchayats nearby Thrissur Corporation. The water demand of Thrissur Corporation is fully met by Peechi Reservoir. There is a water purification plant in Peechi with 50 Million litres (Ml) production capacities per day (total production in a year is 365 x 50 Ml). In 1965, 14.5 Ml. was the capacity of the plant and was used its capacity only for Thrissur Municipality. The authority maintains PH of water as 7, turbidity below 5 and does chlorination for purification.

The turbidity of water is usually normal and it creates problem only in peak days of monsoon. So, the average cost of purification of Peechi water is very low. (below Rs.2 per 1000 litres). Water level reaches below 200 ft. in summer season. As per the estimates of KWA, per capita consumption of water per day was 40 litres in 1982 and it increased to 140 litres now. If the water from Peechi is not supplied, there is no alternative arrangement for drinking water in Thrissur Corporation.

As stated earlier, one of the objectives of the Dam was to supply water to the agriculture sector, particularly to the Kole lands in Thrissur district. The water release from Peechi showed a shift in favour of drinking water since 1983 (Indira Devi, 2002). Total inflow of the water during 1983 was 155.79 Mm^3 of which 143.73 Mm^3 was released from the reservoir, accounting for 92 per cent. Of the total water released, irrigation accounted for 87 per cent and rest for drinking purpose (Table 6.7). But during 1983-2002, quantity of water released for irrigation reduced from 143.73 Mm^3 to 58.64 M m^3, while quantity released for drinking purpose increased from 10.95 Mm^3 to 20.07 Mm^3, indicating that the drinking water supply from the Reservoir doubled at the cost of irrigation. It was found that about 80 per cent of the people, having water connection in the urban areas were higher income group.

Table: 6.7 Water release data of Peechi irrigation project during 1983-2002 (Mm^3)

Year	Quantity released for drinking	Quantity released for irrigation	Total quantity released	Total inflow
1983	10.95	126.358	143.731	155.794
1984	10.98	129.37	146.773	153.13
1985	10.95	135.727	153.1	156.0481
1986	10.95	70.665	88.038	97.67
1987	10.95	70.763	88.136	181.671
1988	10.98	158.525	175.928	142.746
1989	10.95	142.108	159.481	146.643
1990	13.146	114.291	133.86	194.8455
1991	15.33	170.818	192.571	197.226
1992	15.372	140.454	162.249	130.489
1993	15.33	129.314	151.067	191.643
1994	15.33	173.795	195.548	210.175
1995	15.33	126.105	147.858	130.489
1996	19.113	102.02	127.556	68.249
1997	20.075	165.332	191.83	116.5083
1998	20.075	122.817	149.315	NA
1999	20.075	75.9708	96.046	NA
2000	20.13	111.863	105.013	NA
2001	20.075	55.139	52.585	NA
2002	20.075	71.61	58.649	NA

Source: Kerala Engineering Research Institute, Peechi, Kerala

6.12 Conflict among farmers

Side by side with decline in the irrigation water supply from the reservoir, there existed distributional inequality; that is use of water by the farmers, in the head, middle and tail end regions was not in uniform. For instance, Indira Devi (2002) estimated that water availability in head, middle and tail end regions were 14.16 m^3/day/ha, 6.93m^3/day/ha and 4.7 m^3/day/ha. Suresh (2000) estimated irrigation water use by head farmers as 38 ha cm and 4.2 ha cm by the tail end farmer. Our estimate showed that use of water by the head region was 12.98 m^3/day/ha, middle region 7.69 m^3/day/ha and tail end region 5.6 m^3/day/ha. Major reasons for the low availability of water in the tail enders were due to lack of proper maintenance of canals and decrease in the number of days water supplied.

The productivity of a crop is the result of combined effect of various inputs. Since no production function study was undertaken here, it was not easy to identify the effect of one input on productivity. However, based on the assumption that other inputs are being applied similarly by the farmers, the productivity differences of crops in head, middle and tail end of the irrigation canals in command areas of Peechi may be due to differences in the availability of water (Table 6.8). The timely supply of sufficient water assumes great significance in the critical growth stages of the crops.

Table: 6.8 Productivity differences of selected crops in head, middle and tail end regions of Peechi Irrigation Project (kg/ha) 2005-06

Crops	Head	Middle	Tail end
Rice	3068	2898	2680
Banana	5899	5641	5269
Coconut (nuts/ha)	8229	8108	8029

The average productivity of the farmers in head, middle and tail end areas shows variations; the productivity of the head region is higher than that of other two regions mainly due to timely and sufficient use of water from the canals. A change in cropping pattern has also resulted in aggravation of water shortage in the study area. For instance, paddy land has an ability to hold water for a long time, which helps to maintain water table in a particular area. This situation is no longer prevalent as paddy is being increasingly substituted with banana on a large scale, resulting in drying up of wells or drastic reduction of water tables in the down stream areas.

6.13 Local level conflicts

It is generally said that Kerala has highest density of family based open dug wells and on an average; there are more than 120 wells/km^2. More than 70 per cent of the State's population gets drinking water from the house compound's well. During the summer season, because of decline of water table, at least 10 per cent of wells will be dried up, causing acute water problems to 15-20 lakhs people (Indira Devi, 2002). In the study area about 75 per cent of the households have wells in their house compounds. As our data shows, water table in the wells declined from November to May in upland area (Olakara) and October to May in Kavallur. But the decline was more in upland areas where water shortage was more.

According to one estimate by the Panachery Panchayat, where the Peechi Irrigation Project is located, out of 10720 households in the Panchayat about 60 per cent of them were affected by water shortage during 2005-06. There were about 4426 wells in the Panchayat of which only 2639 wells (60 per cent of the total), gave water through out the year. There were 170 tube wells in the Panchayat of which only 118 wells or 70 per cent provided water through out the year. Kerala Water Authority had given water connection to 418 houses, 1049 households got water partially from public tap and about 388 households depend on public wells during the reference period. Thus, water shortage was very acute in the Panchayat whereas water problems in Thrissur Corporation have been solved (Government of Kerala, 2006). The local people have strong protest against the present state of affair. They asserted that Water Authority should solve their water problems first and then supply to other parts of the Thrissur Corporation.

Chapter 7

LINKAGES BETWEEN UPLAND AND DOWN STREAM AREAS

Watersheds are drainage or catchment areas where water gathers and flows downstream to feed rivers and lake, before running into oceans. Thus, it is evident that upland and downstream areas of a watershed are interlinked. However, the nature and extent of linkage may be different in different watersheds. This section is mainly devoted to trace out the linkage between upland and downstream areas and also linkage between watershed and marketshed which is defined as the geographical area and associated population that has real or potential relationship with a particular centre. Marketsheds are selected in areas where smallholders have at least minimal access to water and markets (ADB, 2003). An attempt is also made to examine some of the vital environmental problems in the watershed, which has implications on its future development.

7.1 Upland

Before the construction of Peechi Dam, the upland areas of this watershed were free from environmental problems. Over the last three decades, the upland areas have come under increasing threats. Pressure from population growth, deforestation, mining, unsound agricultural practices, tourism and increasing construction activities are all taking their toll in the upland areas. Initially, the settlers attempted to cultivate subsistence crops like rice and tapioca in the upland areas. As paddy was cultivated in terraced areas, the soil erosion was not severe in this area. The tapioca cultivation, however, triggered soil erosion, but it was only in limited areas initially. Due to a small population in the initial period, the area of cultivation was limited and consequently the impact of tapioca cultivation was not very high and there was not much silting in the Reservoir.

Eventually, the population increased at an exponential rate in the area with resulting competition and conflicts over land and other resources and a new system of cropping viz., mixed cropping- a combination of subsistence and horticultural crops - was introduced in the area. The market for horticultural crops expanded with an increased demand and consequently its prices also showed a boom assuring the farmers' food security and cash savings. When the price of horticultural crops showed further increase, more land was brought under these crops. This was done mainly by encroaching the nearby forested areas and partly by reducing the area under paddy. During 1970-1985 periods, this area also witnessed a massive inflow of settlers and majority of them were farmers from central Kerala. This brought about two major developments in the areas. First, the land price increased significantly which forced the farmers to encroach forest areas. Secondly, since the land became unproductive over the years due to constant and indiscriminate exploitation, the productivity showed a declining trend which in turn forced the farmers to adopt more lucrative crops like rubber and banana in place of traditional crops like paddy. This change in cropping pattern assured relatively more profit per unit area and an increased cash income. This input intensive cropping practice, eventually increased soil erosion and a decline in biodiversity followed, which led to an unsustainable farming regime. This culminated in reduced employment among agricultural workers, particularly among women in the area as the traditional cropping provided more opportunities for women folks.

A major impact due to the input intensive cropping regime was the increased use of pesticides and land management practices, which accelerated the rate of sedimentation, leading to diminish the water quality and quantity in the downstream.

7.2 Changes in downstream areas

Our survey revealed that during 1970's about 90 per cent of the people in the down stream areas of Manali watershed were farmers and agricultural workers. Ironically, over the years it was reduced to 29 per cent. Paddy cultivation and homestead farming were the major areas of agricultural operations in the downstream areas. Paddy was cultivated twice, depending on monsoon. Farmers used the water from the upland areas and channels in addition to the irrigation water supplied from Peechi Reservoir. Over the years, there have been a number of changes in the agricultural sector in the down stream areas. First, because of subdivision and fragmentation, the land size of each family was reduced significantly.

Secondly, due to low prices, the paddy cultivation was not remunerative and some people substituted farming to other jobs and some people leased out the land for banana cultivation as it provided more profit per unit area. Although banana cultivation provided higher income, it generally reduced the employment opportunity of the women workers as mentioned elsewhere. But its impact on ecology of the region was severe. Due to conversion of wetlands to banana and other horticultural crops, the period and quantum of water held in the field was considerably reduced, resulting in lower water table and water shortage. Shortage of water during summer months is a common phenomenon in the area, while such a situation was not prevalent in 30 years back.

The interaction of bio-physical factors such as soils, water, plants and animals enables the watershed to perform many vital functions like water storage, storm protection and flood mitigation (Ecological system). Similarly, the watershed provides many economic benefits like water supply, agriculture, erosion control, among others (Economic system). A change in the economic system (ill managed and over exploited watersheds) poses serious problems to ecological system of the upstream and downstream areas. The cost of damage can be seen in eroded soil, land slides, low water quality and quantity, loss of biodiversity and ecological imbalances which affect the production. A change in production will generally bring about changes in demand/supply and or prices (Market shed). In other words, there was a close linkage between bio-physical and socio-economic factors of the watershed and also between the watershed and 'marketshed' (Fig. 7.1). This interaction was one of the major underlying factors of land use changes in the selected watershed.

The land use change in a given watershed is a function of various parameters as given below.

Land use Change = f {Socio-economic drivers/Marketshed (Price of main crops, upstream/downstream, price of other crops, cost of production, price policies, other income generating activities, real estate boom, absentee landlords, adoption of innovative technology/crops, etc.) and Ecological drivers (Critical factors of production, physiography/ geographical factors, rainfall and other climatic factors, ecosystem resilience etc.).

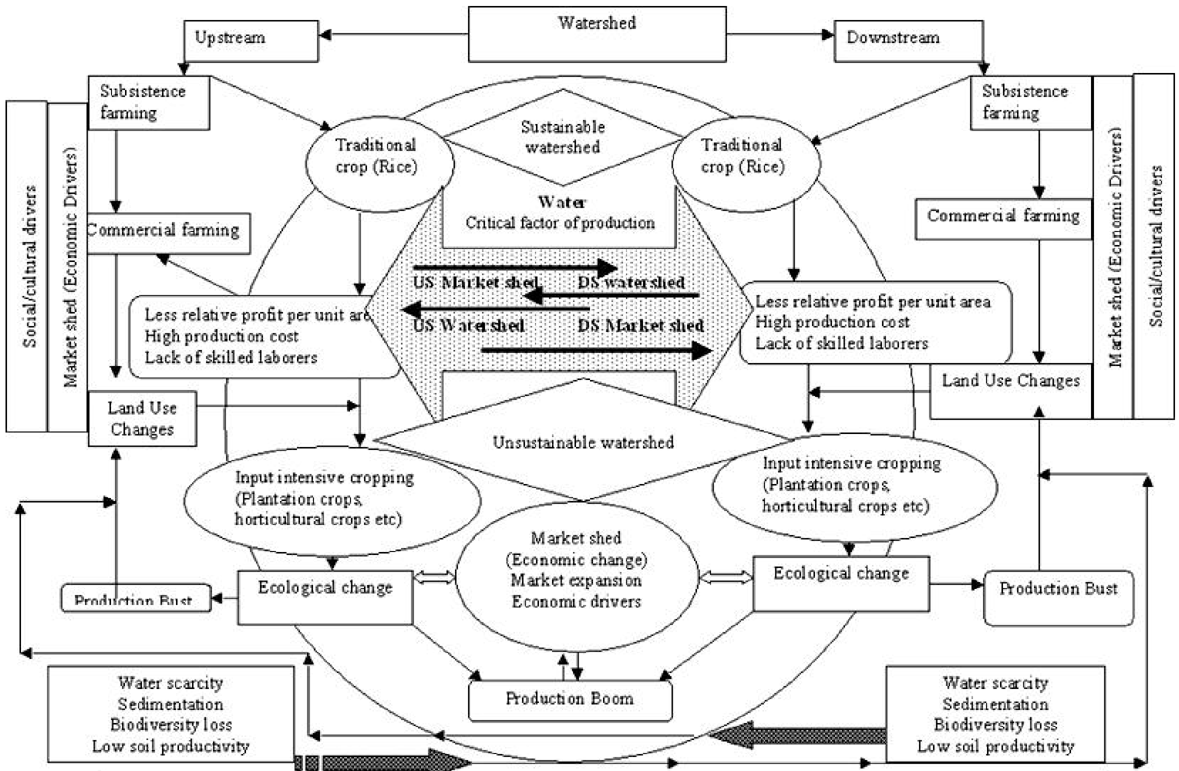


Fig. 7.1 Conceptualizing Land Use Change, Sustainable watershed and Ecological-Economic Linkages of watershed and marketshed

7.3 Environmental problems

Several environmental problems are observed in the region, of which the most important is rock mining in the upland areas and sand and clay mining in the down stream areas. With the availability of new machines, methods and transportation facilities, rock mining in the upland areas has become a productive activity and in the selected upland area, organized rock mining is very much prevalent. In the context of expansion of construction activities in the downstream areas, mining provides high profit to the miners and employment to the local people. But in the fragile upland areas its environmental effects are large; as it often effects small land slides, and enhances sedimentation, surface dumps and trenches/open pits. It also causes atmospheric pollution and health problems among people living in nearby areas.

Karuvannur river basin is one of the areas in Thrissur district where clay and sand mining is concentrated (Sreekumar and John Thomas, 2006). Majority of tile factories and brick making units in Thrissur district are located in and around this area. Clay mining is very severe in areas like Pudukad, Parpukara, Nenmanikara, Poruthussery, Madayikonam, Thottipal, Anathapuram, Amballur, Rappal, Kallor, and Thrikkur. In these places, the entire paddy lands were used for clay mining and as a result paddy fields have been converted into water logging pits. With the market expanding for sand, the contractors continued sand mining from these waterlogged pits exacerbating the damage caused on the ecosystem. A severe ecological implication due to sand mining is destruction of a thick sand horizon which lies below the clay zone that serves as a potential aquifer of the area. Its removal will lower water storage/holding capacity of wetlands significantly (Sreekumar and John Thomas, 2004). Excessive sand mining is the most serious problem that has contributed mostly to the destruction of rivers of Kerala (Gopinathan Nair, 2006). There is no official data on collection of sand from Manali river or Karuvannur river basin and hence the quantum of damage could not be estimated in the study. But a number of Panchayats through which the river flows allow people to collect sand. In addition, smuggling of sand by truck owners is a regular activity here. One of the unofficial estimates indicated that the sand extraction from the river basin exceeded more than 10 lakhs tonnes during 2005-06. This is said to be significantly higher than what is naturally deposited in the river. The sand has a major role in purification of water and also conservation of water by reducing the speed of flow of water especially during rainy season (Gopinathan Nair, 2006). The excessive sand mining results in lower water table, intrusion of saline water into the river and slumping and caving in riverbanks, leading to degradation of watershed and finally slow death of the river.

Chapter 8
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Drastic changes in landuse have occurred, particularly conversion of forest land to agricultural land in the study area during the analysis period 1960-61 to 2004-05. Encroachment and conversion of forest land to agricultural land has been a continuous activity in the study area, in spite of laws to prevent this. For instance, during 1996-2004, area under agriculture increased by 50 per cent, mostly through conversion of forests. Population increase, encroachment, agricultural expansion and construction of dam are the major socio-economic drivers that influenced land use changes in Manali watershed.

A shift from subsistence to commercial crops over a period of time was recorded both upland and down stream areas of watershed. This happened in response to price increase of commercial crops. Obviously, this change has brought about an increase in income of the farmers. However, their per capita income remained less than that of the district and State averages. Further, the low saving and high borrowing further worsened their economic condition. Moreover, the changes in cropping pattern reduced food security, employment opportunity and water availability in the study area.

As regards to climate, there was no indication for the decrease in rainfall since 1966. However, yearly variations did occur, which was not abnormal. The river flow discharge observed since 1963 also revealed that there was no tendency for its decrease during the entire period. Here also, there were some irregular fluctuations from year to year.

In the forested watershed at Olakara, the base-flow persisted till December in contrast with the Kavallur watershed, where it stopped in November itself. More sustained streamflow at Olakara as compared to Kavallur favours the idea of a forested catchment as compared to predominantly agricultural catchment. This indicates the need for undertaking conservation and afforestation measures in the degraded forest areas for better availability of water. However, it is interesting to note that there was no sustained streamflow from a moist deciduous forest, which is leafless during the dry season.

Plant diversity analysis carried out in Olakara area shows that habit wise, 122 are herbs, 33 shrubs, 54 climbers and 50 are trees. Among the 259 species enumerated only 29 are Peninsular Indian endemics. The occurrence *of Securinega virosa*, *Careya arborea*, *Catunaregam spinosa* etc. indicates that the area was prone to seasonal fire in the past.

Sedimentation was low in a forested watershed whereas in the upper reaches of downstream areas, which were highly degraded, it was high. Annual sedimentation in Peechi Reservoir was 0.9 per cent. This can be reduced further if the forest areas are properly afforested or conserved.

Total economic value of Peechi wet lands was approximately Rs. 1844 lakhs (per hectare value amounted to Rs. 146039). Willingness to pay for regular and steady supply of water from Peechi Reservoir was also assessed. About 80 per cent, who used drinking water from Peechi, were willing to pay more for timely and regular supply of water whereas 20 per did not agree for any increase in price of water.

Peechi water supply could solve the drinking water problems in Thrissur town to a great extent where as there existed water shortage in nearby panchayats where the Peechi dam is located during summer months. It was found that about 80 per cent of the people who have water connection in the urban areas belonged to rich or upper middle class. Proper strategy may be evolved to solve the water shortages in the agricultural sector and also water requirements of the poor.

In short, it was highlighted that whatever happens in upland areas has a massive impact on downstream area and *vice versa* as both the areas are interlinked. Further, the study also indicated that both watershed and 'market shed' are closely inter-connected and as a result of which a change in demand/supply/prices of commodities has its own impacts- either positive or negative - on watershed.

Recommendations

Forested upland areas have an essential role in sustaining and protecting water resources and also maintaining the quality of water yield. Upstream management of forests influences availability and uses of water in downstream areas. Thus, emphasis should be given to enrichment planting especially in degraded upland areas. While implementing enrichment planting programmes in the upstream areas, due stress may also be given to shrubby indigenous species, which play an important role in checking soil erosion.

An effective watershed management plans taking upstream and downstream and also watershed and market shed linkages into consideration, should be formulated and implemented. Separate micro planning with appropriate cropping pattern and effective water and land management practices for both upland and downstream areas in a micro watershed shall be prepared. In addition, a macro planning at river basin level, combining all micro plans at the watershed level may be formulated and implemented. A watershed management approach, focusing various aspects of forestry, agriculture, hydrology, ecology, soils, and climatology to find ways of conserving and using land resources, shall be adopted in drawing micro and macro level plans. Conservation of paddy field in downstream areas should get a top priority. The implementation of the plan shall be done through effective participation of local people, which shall prevent further ecological degradation in the study areas.

Since the users of water are willing to pay more, proper pricing of water resources in Peechi Reservoir may be fixed, considering the surplus generation and equity factors. For instance, a differential pricing based on ability to pay may be thought of. A part of the surplus generated through proper pricing may be used for the afforestation of degraded forest area, which may sustain and conserve water resources in Peechi.

The watersheds that are degraded pose serious problems to environment and people. The degradation factors such as rock mining in upland areas, sand and clay mining in downstream areas, riverbank encroachment, etc. in the study area should be controlled. River bank protection measures like planting of bamboo or other plants along riverbanks may be encouraged and encroachments may be evicted.

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APPENDIX

THE PLANTS IN THE WATERSHED AREA

1. *Abrus precatorius* L.
2. *Abutilon persicum* (Burm.f.) Merr.
3. *Acacia caesia* (L.) Willd.
4. *Acacia pennata* (L.) Willd.
5. *Acacia sinuata* (Lour.) Merr.
6. *Acacia torta* (Roxb.) Craib
7. *Acalypha racemosa* Wall. ex Baill.
8. *Achyranthes aspera* L.
9. *Achyranthes bidentata* Blume
10. *Adiantum philippinum* L.
11. *Aerides ringens* (Lindl.) C.E.C. Fisch.
12. *Ageratum conyzoides* L.
13. *Albizia odoratissima* (L. f.) Benth.
14. *Allophylus cobbe* (L.) Raeusch.
15. *Alstonia scholaris* (L.) R. Br.
16. *Andrographis alata* (Vahl) Nees
17. *Anisochilus carnosus* (L. f.) Wall. ex Benth.
18. *Anogeissus latifolia* (Roxb. ex DC.) Guill. & Perr.
19. *Antidesma acidum* Retz.
20. *Aporosa cardiosperma* (Gaertn.) Merr.
21. *Asparagus racemosus* Willd.
22. *Baliospermum montanum* (Willd.) Muell.-Arg.
23. *Bambusa bambos* (L.) Voss
24. *Barleria acuminata* Nees – Endemic to Peninsular India
25. *Barleria prattensis* Sant. – Endemic to Western Ghats
26. *Bauhinia racemosa* Lam.
27. *Bidens biternata* (Lour.) Merr. & Sheriff
28. *Bidens pilosa* L. var. *minor* (Blume) Sherff
29. *Blumea lanceolaria* (Roxb.) Druce
30. *Blumea virens* Wall. ex DC.
31. *Bolbitis appendiculata* (Willd.) K.Iwats.

32. *Bombax ceiba* L.
33. *Bombax insigne* Wall.
34. *Briedelia retusa* (L.) A. Juss.
35. *Briedelia stipularis* (L.) Blume - Endemic to Peninsular India
36. *Caesalpinia mimosoides* Lam.
37. *Cajanus scarabaeoides* (L.) Thouars
38. *Calopogonium mucunoides* Desv.
39. *Calycopteris floribunda* Lam.
40. *Canscora diffusa* (Vahl) R. Br. ex Roem. & Schult.
41. *Canthium coromandelicum* (Burm. f.) Alston
42. *Carallia brachiata* (Lour.) Merr.
43. *Careya arborea* Roxb.
44. *Caryota urens* L.
45. *Cassia fistula* L.
46. *Catunaregam spinosa* (Thunb.) Tirveng.
47. *Cayratia pedata* (Lam.) A. Juss. ex Gagnep. var. *glabra* Gamble - Endemic to Southern Western Ghats
48. *Cayratia trifolia* (L.) Domin
49. *Celastrus paniculatus* Willd.
50. *Centotheca lappacea* (L.) Desv.
51. *Centrosema molle* Benth.
52. *Ceraptopteris thalictroides* (L.) Brongn.
53. *Chassalia curviflora* (Wall. ex Kurz) Thw. var. *ophioxyloides* (Wall.) Deb & Krishna
54. *Chlorophytum nimmonii* (Graham) Dalz.
55. *Chromolaena odorata* (L.) King & Robins.
56. *Cipadessa baccifera* (Roth) Miq.
57. *Cissampelos pareira* L. var. *hirsuta* (Ham. ex DC.) Forman
58. *Cissus latifolia* Lam.
59. *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f.
60. *Clematis gouriana* Roxb. ex DC.
61. *Clerodendrum infortunatum* L.
62. *Commelina diffusa* Burm. f.
63. *Commelina maculata* Edgew.

64. *Corchorus aestuans* L.
65. *Cordia wallichii* G. Don – Endemic to Peninsular India
66. *Cosmostigma racemosum* (Roxb.) Wight
67. *Costus speciosus* (Koenig) J.E. Smith
68. *Crotalaria heyneana* Graham ex Wight & Arn. – Endemic to Southern Western Ghats
69. *Curcuma ecalcarata* Sivar. & Indu-Endemic to Southern Western Ghats
70. *Curcuma vamana* Sabu & Mangaly-Endemic to Southern Western Ghats
71. *Cyathula prostrata* (L.) Blume
72. *Cyclea peltata* (Lam.) Hook. f. & Thoms.
73. *Cymbidium aloifolium* (L.) Sw.
74. *Cynanchum callialatum* Ham. ex Wight
75. *Cyperus iria* L.
76. *Cyrtococcum oxyphyllum* (Steud.) Stapf
77. *Dalbergia lanceolaria* L. f. ssp. *lanceolaria*
78. *Dalbergia latifolia* Roxb.
79. *Dalbergia volubilis* Roxb.
80. *Dendrophthoe falcata* (L. f.) Etting.
81. *Derris canarensis* (Dalz.) Baker - Endemic to Western Ghats
82. *Desmodium gangeticum* (L.) DC.
83. *Desmodium laxiflorum* DC.
84. *Desmodium motorium* (Houtt.) Merr.
85. *Desmodium pulchellum* (L.) Benth.
86. *Desmodium triangulare* (Retz.) Merr.
87. *Desmodium triflorum* (L.) DC.
88. *Desmodium velutinum* (Willd.) DC.
89. *Dillenia pentagyna* Roxb.
90. *Dioscorea bulbifera* L.
91. *Dioscorea oppositifolia* L.
92. *Dioscorea pentaphylla* L.
93. *Dioscorea wallichii* Hook. f.
94. *Diospyros montana* Roxb.
95. *Drosera indica* L.
96. *Drosera peltata* Smith

97. *Drynaria quercifolia* J.E. Smith
98. *Ehretia canarensis* (Clarke) Gamble - Endemic to Peninsular India
99. *Elephantopus scaber* L.
100. *Embelia tsjeriam*-cottam (Roem. & Schult.) DC.
101. *Eranthemum capense* L.
102. *Eriocaulon xeranthemum* Mart.
103. *Eulophia spectabilis* (Dennst.) Suresh
104. *Ficus hispida* L. f.
105. *Ficus microcarpa* L. f.,
106. *Ficus tsjahela* Burm. f.
107. *Firmiana colorata* (Roxb.) R. Br.
108. *Flemingia macrophylla* (Willd.) Prain ex Merr.
109. *Flueggea virosa* (Roxb. ex Willd.) Voigt
110. *Globba marantina* L.
111. *Gloriosa superba* L.
112. *Gmelina arborea* Roxb.
113. *Gomphostemma heyneanum* Benth. var. *rottleri* Prain - Endemic to Southern Western Ghats
114. *Grewia abutilifolia* Vent. ex Juss.
115. *Grewia serrulata* DC.
116. *Grewia tiliifolia* Vahl
117. *Gymnopetalum tubiflorum* (Wight & Arn.) Cogn.
118. *Habenaria plantaginea* Lindl.
119. *Haldina cordifolia* (Roxb.) Ridsd.
120. *Hedyotis neesiana* Arn.
121. *Helicteres isora* L.
122. *Hemidesmus indicus* (L.) R. Br.
123. *Hibiscus hispidissimus* Griff.
124. *Hibiscus lobatus* (Murr.) O. Ktze.
125. *Hibiscus lunariifolius* Willd.
126. *Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don
127. *Holostemma ada*-kodien Schult.
128. *Hoppea fastigiata* (Griseb.) Clarke
129. *Hydnocarpus pentandra* (Buch.-Ham.) Oken - Endemic to Southern Western Ghats

130. *Hymenodictyon orixense* (Roxb.) Mabb.
131. *Hyptis capitata* Jacq.
132. *Hyptis suaveolens* (L.) Poit.
133. *Ichnocarpus frutescens* (L.) R. Br.
134. *Impatiens minor* (DC.) Bennet - Endemic to Peninsular India
135. *Indigofera astragalina* DC.
136. *Ipomoea deccana* Austin
137. *Ipomoea hederifolia* L.
138. *Ipomoea pes*-tigridis L.
139. *Ipomoea pileata* Roxb.
140. *Ischaemum indicum* (Houtt.) Merr.
141. *Jasminum multiflorum* (Burm. f.) Andr.
142. *Justicia japonica* Thunb.
143. *Justicia trinervia* Vahl
144. *Lagenandra toxicaria* Dalz.
145. *Lagerstroemia microcarpa* Wight-Endemic to Southern Western Ghats
146. *Lagerstroemia speciosa* (L.) Pers.
147. *Lannea coromandelica* (Houtt.) Merr.
148. *Leea indica* (Burm. f.) Merr.
149. *Leea macrophylla* Roxb. ex Hornem.
150. *Lepidagathis incurva* Buch.-Ham. ex D.Don
151. *Lobelia alsinoides* Lam.
152. *Lindernia caespitosa* (Blume) Panigrahi
153. *Ludwigia hyssopifolia* (G. Don) Exell
154. *Luisia evangelinae* Blatt. & McCann - Endemic to Western Ghats
155. *Lygodium flexuosum* (L.) Sw.
156. *Macaranga peltata* (Roxb.) Muell.-Arg.
157. *Mallotus philippensis* (Lam.) Muell.-Arg.
158. *Merremia umbellata* (L.) Hall. f.
159. *Merremia vitifolia* (Blume) Hall. f.
160. *Microstachys chamaelea* (L.) Muell.-Arg.
161. *Miliusa tomentosa* (Roxb.) Finet & Gagnep.
162. *Mimosa pudica* L.
163. *Mitracarpus hirtus* (L.) DC.

164. *Mitragyna parvifolia* (Roxb.) Korth.
165. *Mitreola petiolata* (Gmel.) Torr. & Gray
166. *Morinda pubescens* J. E. Smith
167. *Mucuna pruriens* (L.) DC.
168. *Murdannia japonica* (Thunb.) Faden
169. *Murdannia semiteres* (Dalz.) Sant. - Endemic to Peninsular India
170. *Murdannia spirata* (L.) Brueck.
171. *Mussaenda frondosa* L. - Endemic to Peninsular India
172. *Naregamia alata* Wight & Arn. - Endemic to Peninsular India
173. *Naringi crenulata* (Roxb.) Nicolson
174. *Nelsonia canescens* (Lam.) Spreng.
175. *Oberonia mucronata* (D. Don) Ormerod & Seidenf.
176. *Oldenlandia ovatifolia* (Cav.) DC.
177. *Olea dioica* Roxb. - Endemic to India
178. *Oplismenus compositus* (L.) P. Beauv.
179. *Ormocarpum cochinchinense* (Lour.) Merr.
180. *Oroxylum indicum* (L.) Benth. ex Kurz
181. *Oryza officinalis* Wall. ex Watt ssp. *malampuzhensis* (Krishnasw. & Chandrasek.) Tateoka - Endemic to Southern Western Ghats
182. *Passiflora foetida* L.
183. *Pavetta indica* L.
184. *Pennisetum americanum* (L.) Leeke
185. *Pennisetum pedicellatum* Trin.
186. *Peristrophe montana* Nees
187. *Persea macrantha* (Nees) Kosterm.
188. *Phyllanthus emblica* L.
189. *Phyllanthus kozhikodianus* Sivar. & Manilal
190. *Phyllanthus retculatus* Poir.
191. *Piper longum* L.
192. *Platostoma hispidum* (L.) Paton
193. *Pongamia pinnata* (L.) Pierre
194. *Porpax jerdoniana* (Wight) Rolfe-Endemic to Southern Western Ghats
195. *Pouzolzia zeylanica* (L.) Bennett
196. *Pseudarthria viscida* (L.) Wight & Arn.

197. *Pterocarpus marsupium*
198. *Pueraria tuberosa* (Roxb. ex Willd.) DC.
199. *Radermachera xylocarpa* (Roxb.) K. Schum.-Endemic to Peninsular India
200. *Rhinacanthus nasutus* (L.) Kurz
201. *Rhynchosia rufescens* (Willd.) DC.
202. *Rhynchostylis retusa* (L.) Blume
203. *Rottboellia cochinchinensis* (Lour.) W. D. Clayton
204. *Sapindus trifoliatus* L.
205. *Sauropus quadrangularis* (Willd.) Muell.-Arg.
206. *Schleichera oleosa* (Lour.) Oken
207. *Scleria rugosa* R. Br.
208. *Selaginella sp.*
209. *Setaria palmifolia* (Koenig) Stapf
210. *Sida acuta* Burm. f.
211. *Sida alnifolia* L.
212. *Sida beddomei* Jacob - Endemic to Southern Western Ghats
213. *Sida cordata* (Burm. f.) Borss.
214. *Sida mysorensis* Wight & Arn.
215. *Spatholobus parviflorus* (Roxb. ex DC.) O. Ktze.
216. *Spodiopogon rhizophorus* (Steud.) Pilger
217. *Spondias pinnata* (L. f.) Kurz
218. *Stachyphrynium spicatum* (Roxb.) Schum. - Endemic to Southern Western Ghats
219. *Staurogyne glauca* (Nees) O. Ktze.
220. *Staurogyne glutinosa* (Wall. ex Clarke) O. Ktze.
221. *Sterculia guttata* Roxb. ex DC.
222. *Sterculia urens* Roxb.
223. *Sterculia villosa* Roxb. ex Smith
224. *Stereospermum colais* (Buch.-Ham. ex Dillw.) Mabb.
225. *Streblus asper* Lour.
226. *Strychnos nux*-vomica L.
227. *Synedrella nodiflora* (L.) Gaertn.
228. *Tabernaemontana alternifolia* L.-Endemic to Southern Western Ghats
229. *Tamilnadia uliginosa* (Retz.) Tirveng. & Sastre

230. *Tectaria coadunata* (Js.Sm.) C.Chr.
231. *Tectona grandis* L. f.
232. *Tephrosia canarensis* Drumm.
233. *Teramnus labialis* (L.f.) Spreng.
234. *Teramnus mollis* Benth.
235. *Terminalia bellirica* (Gaertn.) Roxb.
236. *Terminalia crenulata* Roth
237. *Terminalia paniculata* Roth – Endemic to Peninsular India
238. *Tetrameles nudiflora* R. Br.
239. *Thespesia lampas* (Cav.) Dalz. & Gibs.
240. *Tinospora cordifolia* (Willd.) Miers.
241. *Tragia involucrata* L.
242. *Triumfetta rhomboidea* Jacq.
243. *Tylophora tetrapetala* (Dennst.) Suresh var. *tenuissima* (Roxb. ex Willd.) Swarup.
244. *Typhonium bulbiferum* Dalz. - Endemic to Western Ghats
245. *Uraria rufescens* (DC.) Schind.
246. *Urena lobata* L. ssp. *lobata*
247. *Urena lobata* L. ssp. *sinuata* (L.) Borss.
248. *Utricularia graminifolia* Vahl
249. *Vanda testacea* (Lindl.) Rchb.f.
250. *Vernonia divergens* (Roxb.) Edgew.
251. *Vigna pilosa* (Roxb.) Baker - Endemic to Peninsular India
252. *Vigna umbellata* (Thunb.) Ohwi & Ohashi
253. *Wrightia tinctoria* (Roxb.) R. Br.
254. *Xenostegia tridentata* (L.) Austin & Staples ssp. *hastata* (Desr.) Panigrahi & Murti
255. *Xylia xylocarpa* (Roxb.) Taub.
256. *Zanthoxylum rhetsa* (Roxb.) DC.
257. *Zingiber neesanum* (Graham) Ramam. - Endemic to Western Ghats
258. *Zingiber wightianum* Thw.
259. *Ziziphus oenoplia* (L.) Mill.
260. *Ziziphus rugosa* Lam.