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Economic Land Evaluation for Sustainable Land Management of Watersheds in Different Agro-Climatic Zones of Karnataka

S C Ramesh Kumar

National Bureau of Soil Survey, Bangalore

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NBSS Tech. Report No. 582

ECONOMIC LAND EVALUATION FOR SUSTAINABLE LAND MANAGEMENT OF WATERSHEDS IN DIFFERENT AGROCLIMATIC ZONES OF KARNATAKA

Volume I Summary Report

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Land Use Planning
(Indian Council of Agricultural Research)
Amravati Road, Nagpur 440 010
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RESEARCH TEAM

S.C. Ramesh Kumar
Principal Investigator

Project Associates

Contribution	Garakahalli	Nalatwad	Pettamanurahatti	Molahalli
Field review and soil interpretation	R.S. Reddy C.S. Harindranath C.R. Shivaprasad	C.R. Shivaprasad C.S. Harindranath R.S. Reddy	C.S. Harindranath R.S. Reddy C.R. Shivaprasad	C.R. Shivaprasad R.S. Reddy C.S. Harindranath
Soil suitability interpretation	L.G.K. Naidu	L.G.K. Naidu	L.G.K. Naidu	L.G.K. Naidu
Soil survey and mapping	K.V. Niranjana K. Paramesha	B.A. Dhanorkar Bhoora Prasad M. Jayaramaiah C. Bachegowda	Bhoora Prasad B.A. Dhanorkar M. Jayaramaiah C. Bachegowda	B. A. Dhanorkar Bhoora Prasad C. Bachegowda M. Jayaramaiah
Laboratory investigation	S.L. Budihal Arti Koyal	S.L. Budihal Arti Koyal	S.L. Budihal R.A. Nasre Arti Koyal	S.L. Budihal Arti Koyal
Geographic Information System analysis	S. Srinivas K.M. Nair D.H. Venkatesh Shivappa Angadi	S. Srinivas K.M. Nair D.H. Venkatesh Shivappa Angadi	S. Srinivas K.M. Nair D.H. Venkatesh Shivappa Angadi	S. Srinivas K.M. Nair D.H. Venkatesh Shivappa Angadi
Socio-economic survey and analysis	J. Nagendra M. Padmavathi G.R. Harishilpa	J. Nagendra M. Padmavathi G. R. Harishilpa	J. Nagendra M. Padmavathi G. R. Harishilpa	J. Nagendra M. Padmavathi G. R. Harishilpa
Cartography	M. Ramesh K.S. Sathyanarayana G. Venkatagiriyappa K. Sujatha K.V. Archana	M. Ramesh K. Sujatha K.S. Sathyanarayana G. Venkatagiriyappa K.V. Archana	M. Ramesh K. Sujatha G. Venkatagiriyappa K.S. Sathyanarayana K.V. Archana	M. Ramesh G. Venkatagiriyappa K. Sujatha K.V. Archana K.S. Sathyanarayana

Consultants — **V.A.K. Sarma**, **J.V. Venkataram**

Regional Coordinator — **P. Krishnan**

National Coordinators — **M. Velayutham**, **K.S. Gajbhiye**

About the NBSS&LUP

The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, a premier Institute of the Indian Council of Agricultural Research (ICAR), was set up in the year 1976 with the objective to prepare soil resource maps at state and district level and to provide research inputs in soil resource mapping, and its applications, land evaluation, land use planning, land resource management, and database management using GIS for optimising land use on different kinds of soils in the country. The Bureau has been engaged in carrying out agro-ecological and soil degradation mapping at the country, state and district level for qualitative assessment and monitoring the soil health towards viable land se planning. The research activities have resulted in identifying the soil potentials and problems, and the various applications of the soil surveys with the ultimate objective of sustainable agricultural development. The Bureau has the mandate to correlate and classify soils of the country and maintain a National Register of all the established soil series. The Institute is also imparting in-service training to staff of the soil survey agencies in the area of soil survey and land evaluation, soil survey interpretations for land use planning. The Bureau in collaboration with Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola is running post-graduate, teaching and research programme in land resource management, leading to M.Sc. & Ph.D. degrees.

The research of the Bureau has resulted in identifying various applications of soil surveys in education, planning and management. The publication "**Economic Land Evaluation for Sustainable Land Management of Watersheds in Different Agroclimatic Zones of Karnataka**" is one such example.

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TO OBTAIN COPIES OF THIS REPORT,

Please write to:

Director, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP),

Amravati Road, NAGPUR-440 010, India.

Phone : (0712) 500386, 500664, 500545 (O), 264631, 264804 (R)

Telefax : +91-0712-500534

Telegram : SOILANDBRU

E-Mail : ksgajbhiye@nbsslup.mah.nic.in; director@nbsslup.mah.nic.in

OR

Head, Regional Centre, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Hebbal, BANGALORE-560 024, India.

Phone : (080), 3412242, 3415683, 3331499 (R)

Telefax : +91-080-3412242

Telegram : SOICORE

E-Mail : nbsslup@vsnl.net

ABOUT THE PROJECT

The project was undertaken with the objective of increasing the capacity for application of economic principles and tools to environmental management in India. It was assisted by Indira Gandhi Institute of Development Research (IGIDR) by providing necessary funds for a period of 18 months with a budget outlay of Rs 14.98 lakhs. The project work was started in May 2000 and completed in June 2002.

The data was assessed, analysed, evaluated and synthesized into report form. The report has two parts. Part One consists of Chapters 1 to 5 describing the methodology followed in survey and summary results of biophysical and socio-economic accounting and evaluation. Part Two consists of the detailed database of biophysical and economic land evaluation of Garakahalli Nalatwad, Pettamanurahatti, and Molahalli. watersheds in Karnataka.

FOREWORD

Soil is one of the most important natural resources, and maintaining it in good health, is very much needed for meeting the increasing demand for food, fibre, fodder and fuel. It assumes greater significance in present situation wherein the scope of increasing the area further for cultivation is very limited. In view of this, the information on soils in respect of their extent on a particular landscape and their characteristics in terms of potentials and constraints is required so that the precious soil resource may be put to judicious use without allowing it to degrade further.

Proper identification of soil potential has been one of the key sectors in the planning and development processes. Hence, an appraisal of soil resources is a pre-requisite for planning a sustainable development. An appropriate soil resource inventorisation creates the awareness among the land users, planners, research workers and administrators in order to ensure the proper and effective utilisation of soil resource. The necessity of generating developmental plan at different level has been increasingly felt and therefore, thrust on proper land use planning through watershed management is given during the VIII Five Year Plan. The priority is being re-emphasised in X Plan formulation.

Soil has assumed multifunctionalities both as a source of livelihood gathering as well as environmental sink. Realising the needs for illustrating the soil and land resource inventories, the National Bureau of Soil Survey and Land Use Planning is generating the information on soils at the different scale (1:250,000, 1:50,000, 1:10,000 and 1:5,000). The report on "**Economic Land Evaluation for Sustainable Land Management of Watersheds in Different Agroclimatic Zones of Karnataka"** with soil maps is one of such important practical document brought out by the Regional Centre, NBSS&LUP, Bangalore. It provides information about the soils and their characteristics and potential for better use and management including agriculture and other allied aspects. At the same time, it elaborates inherent potential and problems of soil likely to be encountered while exploring potential, and needed ameliorative measures. The data have been interpreted as per capability of soils and their suitability for different crops which could form the basis for sustainable agricultural practices and protection of soil resource from being degraded. The maps and data base will be of immense use in setting developmental activities and extension work to achieve rehabilitation of inmates and as a teaching and training tool for farm level workers.

I express my appreciation to Dr. K.S. Gajbhiye, Director and Dr. P. Krishnan, Head, Regional Centre, Bangalore for their sincere efforts in bringing out this model watershed soil database for optimising land use. I believe that this publication will help the user agencies, inmates of watersheds farmers in understanding the soils potential for different crops/cropping sequences towards increasing crop production to reach to a level of self-sufficiency and generating self employment throughout the year.

(J.S. SAMRA)

Deputy Director General (NRM)

ICAR, New Delhi

PREFACE

It is estimated that nearly 50 per cent of the land in the country, is suffering from different kinds of degradation problems due to its non-scientific and indiscriminate use. In addition to this, the shrinking land resources as evidenced by the availability of land area per human head is gradually diminishing. In Indian scenario, the land to man ratio was 0.50 ha in 1950, and it came down to 0.30 ha in 2000. If the situation continues, there would be chaos and turmoil leading to a lot of confrontation to provide basic need of human being for food, fibre, fodder and fuel. Hence, the land resource assessment is considered as a pre-requisite for development and management of natural resources for sustainable use by protecting the inherent production capacity of soil. At the same time, soil based data need to be disseminated very widely through education and training to create awareness about the value of the soil to the people so that, each one may be able to use the land judiciously, thereby protecting and preserving the soils for human posterity. The child of 21st century may not ask '*Here is the land but where is the soil*.'

This publication on "**Economic Land Evaluation for Sustainable Land Management of Watersheds in Different Agroclimatic Zones of Karnataka**" deals with the aspects connected with the generation of soil resource data and their economic interpretation to evolve the system for identifying salient problems and suggesting appropriate ameliorative measures thereon in order to ensure sustainable land use. The spatial distribution of each soil mapping unit occurring in the area is depicted in soil map. The soils were mapped into different mapping units as phases of soil series. Pedons belonging to each series were characterised in laboratory to understand the physical and chemical properties affecting the land use. The collected data were quantified for the suitability and extent of soil resources for different crops and the constraints were highlighted. This project characterise that farm level sustainable land management indicators which clearly bring out the issues of poverty in relation to soils.

The efforts made by Dr. S.C. Ramesh Kumar, Senior Scientist and his team in bringing out this publication and the cooperation and help extended by other staff of the Regional Centre, Bangalore are well appreciated. The report will be useful in planning soil based developmental activities and in training the farmers and young entrepreneur to make them aware to use the soils according to its potential for sustainability in agriculture.

(**K.S. GAJBHIYE**)

Director

NBSS&LUP, Nagpur

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1. INTRODUCTION

1.1 Background

Agricultural production planning in India evolved around achieving self-sufficiency in food, fuel and fibre. Initially, production strategies started with resource-based extensive app-roach and this continued to the sixties of the last century. The emphasis then shifted to produc-tivity-based resource-intensive strategies to promote quick growth at any cost to feed the bur-geoning population. While agricultural production was increased considerably, the economic con-dition of the farming community did not significantly improve. Meanwhile there have been signs of large-scale ecological degradation of natural resources caused by deforestation, depletion of water table and erosion of topsoil.

To remedy this situation the Government of India formulated a new agricultural and land use policy to promote efficient management of land and water resources to achieve sustainable growth in agricultural production (Anonymous, 1990). The National Land Use and Waste Land Development Council framed a programme to prevent further deterioration of land resources, for which an inventory of soil resources is utmost desirable in order to allocate the resource data-base (NLUCB, 1988) for achieving sustainable production. Attempts are, therefore, made to for-mulate land-use plans of four watersheds (Garakahalli, Nalatwad, Pettamanurahatti and Molahalli) based on biophysical land evaluation considering socio-economic aspects and their effect in planning of natural resources in the state of Karnataka. It has been emphasized to relate soil productivity to socio-economic response and management aspects rather than the traditional concept of inherent capacity of the soil to produce.

Land evaluation assesses the suitability of land for specified land uses. The predictions are made about the expected performance of different land uses on each land mapping unit in a project area for rational land-use planning by individuals or society (FAO, 1993, 1995). Economic land evaluation is a method for predicting the micro-economic value of implementing a given land-use system (Rossiter, 1995). Earlier studies on land evaluation were carried out mostly by soil scientists and agronomists taking into consideration soil and climatic attributes indicating physical constraints and remedial measures therefor. Thus the land evaluation studies focussed on assessing the theoretical production potential. Little or no attention has been paid to follow up the adoption of this potential by the user agencies. Kutter *et al.* (1997) indicated that the conventional land evaluation approach has not provided relevant answers for a rapidly changing society mainly because of too much technical emphasis, lack of a multi-disciplinary approach and inability to link production goals with sustainable land use.

Hence an integrated approach to planning the use and management of land resources entails involvement of all stakeholders in the process of decision-making on the future of the land, and identification and evaluation of all the biophysical and socio-economic attributes of land units (FAO, 1995). This calls for identification and establishment of a use for each land unit that is technically appropriate, economically viable, socially acceptable and environmentally eco-friendly. This 'integrated approach' to planning and management of land resources has been identified as a separate programme area in Chapter 10 of Agenda 21 of the United Nations Conference on Environment and Development (UNCED, 1993). In the face of the rapidly chan-ging situation, there is need to move from a prescriptive approach to land evaluation to an integ-rated approach of economic land evaluation considering socio-economic and institutional dimen-sions of land management as well.

The planning of sustainable land management (SLM) is becoming an urgent necessity during the 21st century. Smyth and Dumanski (1993) defined SLM as a system that is a combi-nation of technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns to

– maintain or enhance production/services,
– reduce the level of production risk;
– protect the potential of natural resources,
– prevent degradation of soil and water;
– be economically viable and
– be socially acceptable.

1.2 Objectives

The objectives of the project were

- to survey the biophysical resources (soil, water, forest and common property resources) at 1:8000 scale in selected watersheds for natural resource accounting and quantifying physical land potential and constraints for land use and management,
- to survey the social, economic and institutional constraints and potentials in the watersheds to evaluate the impact of soil conservation measures,
- to design and organize a spatial information system for integration of socio-economic and biophysical data for economic land evaluation and land use planning at watershed level,
- to develop a methodological framework using bio-economic modelling for analysing the relationships between socio-economic and biophysical factors in planning sustainable land management and
- to develop optimum land-use plans keeping economic (benefits and costs) and environ-mental considerations for sustainable land management.

Keeping these in view, an attempt was made to integrate the socio-economic and insti-tutional dimensions with biophysical factors in economic land evaluation for planning sustainable land management of watersheds representing 4 different agroclimatic zones of Karnataka.

The watersheds are

– Garakahalli in the eastern dry zone,

– Nalatwad in the northern dry zone,

– Pettamanurahatti in the central dry zone and

– Molahalli in the coastal zone (Fig. 1.1).

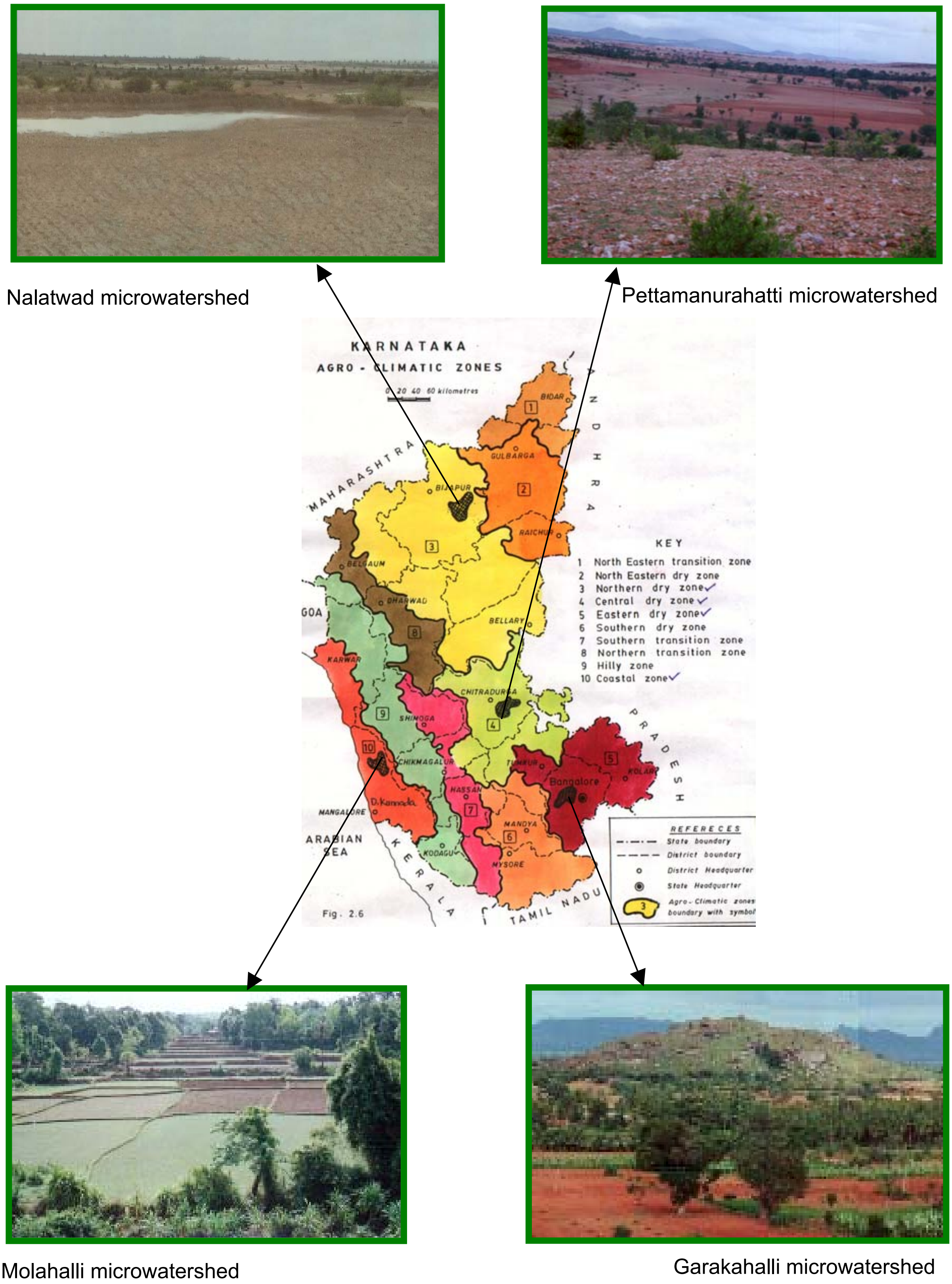

Fig. 1.1 Location of the four microwatersheds studied in Karnataka

2. METHODOLOGY FOR THE BIOPHYSICAL DATA SET

2.1 Soil Survey Method and the Biophysical Data Set

The biophysical data set was based on a detailed soil survey of the selected micro-watersheds by standard techniques (Soil Survey Staff, 1951; AIS & LUS, 1970). The aims of a soil survey are to identify the kinds of soils in an area, characterize them, delineate them and finally map them. Cadastral maps of the microwatersheds (scale 1:7920) were used as base.

The soil survey of each microwatershed was undertaken with a rapid traverse to identify the survey numbers and plots and to identify the major physiographic units such as mounds, undulating uplands and valleys by means of visible breaks-in-slope and to record the changes in landform. In the process, an understanding was gained of the geology and parent material occur-ring in the watershed. Simultaneously transects were selected for soil profile location for soil studies. Profiles were dug in the selected locations to 1.5-m depth or to the parent material and were examined for morphological characteristics. Based on variation within the soil profiles in physiographic units soil series were identified by following the criteria given in AIS & LUS (1970). The major differentiating characteristics used for identifying the soil series were parent material, soil depth, soil colour, soil texture, coarse fragments, mottling and occurrence of buried undecomposed wood material in the valleys. The soil series were classified according to the system described by Soil Survey Staff (1999).

The soil map was generated by delineating soil series at phase level by studying soil and land characteristics such as surface texture, gravelliness, slope and erosion status.

The phase boundaries identified in the field were transferred on to a base map (scale 1:7920) to generate soil maps. Two soil maps were prepared for each watershed, one for soil series and the other showing phases of soil series.

Soil samples were collected from the typifying pedons of the identified soil series for laboratory characterization by standard methods. In addition, surface soil samples were collected at grid points at 80-m interval and analysed for the macronutrients (N, P and K), and micro-nutrients (Fe, Zn, Cu and Mn). The data for each nutrient at the grid points were classified according to the limits prescribed by the Department of Agriculture, Karnataka, and maps were generated by an interpolation technique with a GIS to show the spatial distribution of nutrient levels in the watersheds.

2.2 Interpretation of the Biophysical Data Set

2.2.1 Climatic analysis

Since the four watersheds in the study followed rainfed agriculture, rainfall and potential evapotranspiration (PET) were the critical climatic factors for interpretation. Long-term weekly data on these two parameters were analysed for calculation of length of growing period (LGP). The LGP is the period in days during a year when rainfall exceeds half the potential evapo-transpiration plus a period required to evapotranspire an assured estimated stored moisture. It was assessed for each watershed using the FAO model (Higgins and Kassam, 1981). Frequency of recurrence of drought years (years with >25% deficit from normal rainfall) in each decade and onset and end of growing season were worked out using probability analysis.

2.2.2 Land capability classification

Land capability classification is an interpretative grouping of lands made to show their relative suitabilities for various crops, pasture, forestry and wildlife and recreation. The inherent characteristics, limitations and risk of damage to the soils and also their response to manage-ment are taken into consideration for classifying them under various land capability classes.

Land capability class is the broadest category in the land capability classification system. Class codes I, II, III, IV, V, VI, VII, and VIII are used to represent arable and non-arable land as defined below.

Class I lands have slight limitations that restrict their use.

Class II lands have moderate limitations that reduce the choice of plants or require moderate conservation practices.

Class III lands have severe limitations that reduce the choice of plants or require special conservation practices, or both.

Class IV lands have very severe limitations that restrict the choice of plants or require very careful management, or both.

Classes V to VII cover lands that are unsuitable for agriculture but suitable for pasture.

Class VIII lands are suitable neither for agriculture nor for forestry and are best left for wildlife and recreation.

Land capability classes are divided into land capability subclasses, groupings of soils that have the same kind of limitations for agricultural use. Subclass codes used are e, w, s and c.

‘e’ represents susceptibility to erosion by water or wind,

‘w’ represents drainage difficulties including wetness or overflow,

‘s’ represents soil limitations for plant growth and

‘c’ represents climatic limitations.

Land capability subclasses are subdivided into land capability units that are groupings of one or more individual soil map units having similar limitations or hazards. They are denoted by appending a numeral from 0 to 9 to the land capability subclass to specify the kind of limitation. The specific limitations are

– stony or rocky (0),

– erosion hazard/slope (1),

– coarse texture (2),

– fine texture (3),

– slowly permeable subsoil (4),

- coarse substratum (5),
- salinity/alkalinity (6),
- stagnation/overflow (7),
- effective rooting depth (8) and
- fertility (9).

The soil map units in each microwatershed were grouped to the level of land capability unit and the corresponding land capability maps were prepared.

2.2.3 Land irrigability classification

Land irrigability classification is a grouping of soil map units into classes based on the degree of limitations of soils for sustained use under irrigation and on physical and socio-economic factors. Lands suitable for irrigation are grouped under classes 1 to 4 according to their limitations. Lands not suitable for irrigation are grouped under classes 5 and 6.

Land irrigability classes have subclasses to indicate dominant limitations for irrigation purposes. Three subclasses are based on limitations and are denoted by 's' for soil limitations such as heavy clay or sandy texture, soil depth and gravel/stones, 'd' for drainage problems and 't' for limitations of topography.

The soil map units in each microwatershed were grouped to the level of land irrigability subclass and the corresponding land irrigability maps were prepared.

2.2.4 Fertility capability classification

Fertility capability classification (FCC) was developed to bridge the gap between soil classification and soil fertility (Sanchez *et al*., 1982). It is a system for grouping soils according to their fertility constraints in a quantitative manner. The surface soil layer has been given more consideration as up to 70 per cent of variability in crop yield is due to soil properties in the plough layer (Sopher and McCracken, 1973) and most management practices are largely limited to the plough layer. The system has three category levels, viz., type, substrata type and modifiers. Topsoil texture, namely, sandy, loamy, clayey and organic matter represents type. The substrata type denotes subsoil texture and includes sandy, loamy, clayey and rock or other root-restricting layer. There are 15 modifiers, namely, g (gley), d (dry), e (low CEC), a (Al-toxicity), h (acid), i (high P fixation capacity), x (X-ray amorphous), v (Vertisol), k (low K reserves), b (basic reaction), s (salinity), n (natric), c (cat clay), ′ (gravel), and % (slope).

The soil map units were grouped first by type, then substrata type (if different from type) and finally by modifiers. Types and substrata types were represented in upper case, modifiers in lower case, gravel by a prime.

2.2.5 Problems and potentials

Soil units were interpreted and grouped with respect to major soil characteristics such as soil depth, surface soil texture, surface gravelliness and/or stoniness, soil available water capacity, soil drainage, slope, soil erosion, soil reaction and/or calcareousness, salinity, macronutrient status, micronutrient status. Such grouping of soils helps in identifying areas that have specific problems and areas that have high potential for sustained agriculture.

Soil depth. Depth of the soil determines effective rooting depth for plants and, in accordance with texture, mineralogy and gravel content, the capacity of the soil column to hold water and supply nutrients. There are seven depth classes (Sehgal, 1990)

– extremely shallow (<10 cm),

– very shallow (10–25 cm),

– shallow (26–50 cm),

– moderately shallow (51–75 cm),

– moderately deep (76–100 cm),

– deep (101–150 cm) and

– very deep (>150 cm).

Maps were prepared for each watershed to depict the spatial distribution of soil-depth classes.

Surface soil texture. The surface layer of soil to a depth of about 25 cm is the layer most used by crops and plants. The surface soil textural class provides a guide to understanding soil water retention and availability, workability of soil, infiltration and drainage conditions, and suitability for specific crops. The 11 surface soil textural classes used for grouping the soil map units were sand, loamy sand, sandy loam, loam, silt loam, clay loam, silty clay loam, sandy clay loam, sandy clay, silty clay and clay. The surface soil texture map was generated for each watershed.

Available water capacity. Classes of soil available water capacity (AWC) are based on the ability of the soil column to retain water between the tensions of 0.33 and 15 bar in the top 100 cm or the entire solum if the soil is shallower. The AWC of soils depends on soil properties such as soil texture, depth, kind of clay minerals and gravel content. The AWC of soils of the microwatersheds was estimated in mm from these characteristics (Sehgal, 1990).

Surface gravelliness and/or stoniness. *Gravel is the term used for coarse fragments between 2 mm and 7.5 cm diameter; stones have a diameter of 7.5 cm to 25 cm. The presence of gravel and stones in the topsoil or on the surface influences moisture storage, infiltration and runoff and hinders plant growth by impeding root growth and seedling emergence. The soil map units of each watershed were grouped into three surface gravelliness and/or stoniness classes based on content by volume of coarse fragments, namely, g1 (<15%), g2 (15–35%) and g3 (>35 %). Where appropriate, thematic maps depicting surface gravelliness/stoniness in the watershed were prepared.*

Soil erosion. The term soil erosion is used to denote accelerated soil losses through the action of wind or water resulting from disturbance of the natural landscape by excessive grazing, forest cutting, burning and tillage, usually by human and bovine populations. The four classes of ero-sion status used for grouping the soil map units are

– e1: no erosion or slight erosion where <25 per cent of the A horizon has been lost,

– e2: moderate erosion with loss of 50–75 per cent of the A horizon,

– e3: severe erosion with loss of entire A horizon and with incipient gullies,

– e4: very severe erosion with a few shallow gullies and occasional deep gullies.

The approximate annual soil loss under each of the erosion classes has been estimated to be e1, < 5 t ha^{-1} y^{-1}; e2, 5–15 t ha^{-1} y^{-1}; e3, >15–40 t ha^{-1} y^{-1}; e4: >40 t ha^{-1} y^{-1} (Dr M.S. Ramamohan Rao, pers. communication).

Soil calcareousness. Calcareousness is the term used to denote the content of calcium carbo-nate in the soil. It is estimated in the field by observing effervescence given by the soil when it is moistened with dilute hydrochloric acid. Effervescence is classified into slight, strong and violent. The equivalent calcareousness classes are slightly calcareous, moderately calcareous and strongly calcareous. Where appropriate, the soil map units of the watershed were grouped into calcareousness classes to show the extent of the problem of calcareousness.

Slope. Slope was determined during the traverse and is an important characteristic of the soil map unit. The slope classes used in this study for grouping soil map units were A (nearly level, 0–1% slope), B (very gently sloping, 1–3% slope), C (gently sloping, 3–5% slope), D (mode-rately sloping, 5–10% slope), E (strongly sloping, 10–15% slope) and F (moderately steep to steep, 15–30%). The soil map units were grouped into these slope classes and the slope map was prepared for each watershed to depict the spatial distribution.

Nutrient status. The standards prescribed for available levels of the macronutrients N, P and K and the micronutrients Fe, Zn, Cu and Mn as used by the Department of Agriculture, Karnataka, were applied to assess the fertility status of the soil samples from the grid points. The fertility status point data were used to generate nutrient status maps of each watershed through computerized linear interpolation technique.

2.2.6 Land suitability evaluation for specific crops

The suitability of soil map units for growing specific crops, restricted to the major crops grown in each watershed, was evaluated using the guidelines given by FAO

(1983). In this procedure the land-use requirements for each major crop grown were matched with land qualities or characteristics. The land-use requirements for each crop were obtained from publi-cations and reports of research projects; the land characteristics were obtained from the bio-physical data set.

The land suitability assessment was qualitative, each land quality being assessed by the ratings s1 (highly suitable), s2 (moderately suitable), s3 (marginally suitable) and n (not suitable) that refer to the effects of the *individual* land qualities on production of the crop. These factor ratings are defined in terms of expected yield without inputs to ameliorate the particular land quality, as a percentage of yields under optimal conditions. Thus s1 signifies that yield is expec-ted to be >80 per cent of the optimum, s2 indicates that the yield is expected to be 40–80 per cent, and s3 that the expected yield is 20–40 per cent of the optimum yield. The rating n shows that yield is expected to be 20 per cent or less, and the limitation can rarely or never be overcome by inputs or management. The land-use requirements and land qualities were matched for each of the soil map units in the watersheds and the final land-suitability assessment in classes S1, S2, S3 and N arrived at by taking the *least favourable* of the individual factor ratings as limiting.

Sorghum. Sorghum is a warm-climate crop and withstands drought better than any other cereal. High rainfall at heading reduces pollination and results in poor yield. The crop is tolerant to waterlogging. The optimum temperature range for growth is 25–30 °C. Temperatures <15 °C adversely affect crop growth. Humus-rich soils with good water holding capacity are best suited. Black cotton soils of central India are considered the best soils for sorghum. The crop is grown in the pH range of 6.0-8.5 (Rathore, 1999a). The land use requirements and factor ratings are col-lated in Table 2.1.

Sunflower. Sunflower is basically a temperate-zone crop. It is commercially grown in the warm temperate regions. It grows well in the temperature range 20–25 °C (27–28 °C is the optimum range). Prolonged high temperatures reduce maturation time. In general, temperatures >25 °C at flowering reduce seed yield and oil content, temperatures <16 °C reduce seed set and oil content. A frost-free period of about 120 days is required for commercial cultivation of the crop (Weiss, 1983). Sunflower is considered to be drought-resistant, but oil yield is substantially reduced if plants are stressed at flowering and peak growth period. Evenly distributed rainfall of 500–700 mm over the growing period is ideal. Diseases and lodging can be severe in areas of high rainfall (1000 mm). The plant is susceptible to lodging with high winds and is highly vulnerable to hailstorms at seedling stage (Gajendra Giri, 1999). Irrespective of soil type, soils with free drainage are best suited. It grows well on neutral to moderately alkaline (pH 6.5–8.0) soils, but acid soils are not suitable (Weiss, 1983). High soil salinity affects plant growth and development. Exchangeable sodium percentage >15 delays germination and development of flower heads (Gajendra Giri, 1999). The land use requirements and factor ratings are presented in Table 2.2.

Table 2.1 Land suitability criteria for sorghum

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	Not suitable, N
Temperature regime	Mean temperature in growing season (°C)	26–30	30–34; 24–26	34–40; 20–24	>40; <20
Moisture availability	Length of growing period (days)	105–150	90–104	<90	
Oxygen availability to roots	Soil drainage (class)	welldrained–mod. well drained	imperfectly drained; somewhat excess. drained	poorly drained; excessively drained	
	Waterlogging in growing season (days)	<3	3–4	>4	
Nutrient availability	Soil reaction (pH)	5.5–8.2	5.0–5.4; 8.3–8.5	<5.0; 8.6–9.5	
	$CaCO_3$ in root zone (%)	<10	10–25	>25	
Nutrient retention	Texture (class)	l, cl, sicl, sc, sic, c	sil, scl	sl, ls, c >60%	
Rooting conditions	Effective soil depth (cm)	>75	51–75	25–50	
	Gravel content (% by vol.)	<15	15–35	>35	
Soil toxicity	Salinity (EC satn extract, dS m^{-1})	<4	4–8	8–10	
	Sodicity (ESP, %)	<10	10–15	>15	
Erosion hazard	Slope (%)	<3	3–5	>5–15	

Source: NBSS & LUP (1994)

Bengal gram. Bengal gram requires cool climate for growth and development and high temp-erature for maturity. The optimum temperature range is 15–25 °C. Severe cold and frost are deleterious to growth and development. Frost at the time of flowering causes flower drop. Low temperature affects germination percentage. Heavy rains at germination and flowering, and hail-storms at and after flowering severely damage the crop. The plant requires cloud-free days for normal growth. It can be grown in areas receiving annual rainfall of 600–1000 mm. Waterlogging at any stage of growth may destroy the crop. However, it responds to light irrigation at flowering and grain-filling stages (Ahlawat, 1999). It is a hardy crop and can be grown on a wide range of soils. It thrives best on deep loams or silty clay loams, free from excessive salts, with about 200 mm available water capacity. Very light and very heavy soils are not suitable. The soil should be welldrained with pH in the range 6.0–8.0 (Ahlawat, 1999). The land use requirements and factor ratings are given in Table 2.3.

Table 2.2 Land suitability criteria for sunflower

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	24–30	30–34; 20–24	34–38; 16–20	>38; <16
Moisture availability	Length of growing period (days)	>90	80-	70–80	<70
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained	imperfectly drained	poorly drained
Nutrient availability	Soil reaction (pH)	6.5–8.0	8.1–8.5; 5.5–6.4	8.6–9.0; 4.5–5.4	>9.0; <4.5
Nutrient retention	Texture (class)	l, cl, sil, sc	scl, sic, c	c >60%, sl	ls, s
Rooting conditions	Soil depth (cm)	>100	76–100	50–75	<50
	Gravel content (% by vol.)	<15	15–35	>35	
Soil toxicity	Salinity (EC satn extract, dS m^{-1}))	<1.0	1.0–2.0	2.0–4.0	>4.0
	Sodicity (ESP, %)	<10	10–15	>15	
Erosion hazard	Slope (%)	<3	3–5	5–10	>10

Wheat. A climate with cool weather during vegetative development and warm weather for maturity are deemed ideal for wheat. Optimum grain development takes place with mean maxi-mum temperature of 25 °C and mean minimum temperature of 12 °C. Day temperatures >25 °C depress grain formation (Asana and Saini, 1962).

Fertile, welldrained medium-textured (loam to clay loam) soils are considered best. The crop can also be grown on clay or fine sandy loam. Very sandy or poorly drained soils are unsatisfactory. Wheat is tolerant to salinity/sodicity, but grows best in the pH range 6–8 (ICAR, 1997). The land use requirements and factor ratings are assembled in Table 2.4.

Mulberry. Mulberry is a deep-rooted perennial plant and can be grown under a wide range of climatic conditions of humid, tropical and temperate regions receiving 600–2500 mm rainfall. It is a hardy and drought resistant crop. If there is uniform monthly rainfall of 100–150 mm, mulberry requires no supplementary irrigation. Elevation of 600–700 m above MSL is optimal for growth of the plant. It grows well on level lands with slope <15 per cent (Rangaswamy et al., 1988). A temperature between 20 and 30 °C is favourable for growth and development. Temperatures below 13 °C and >38 °C affect sprouting of buds and growth of the plant; best growth is seen around 23.9–26.6 °C (Madan Mohan Rao, 1998; Bongale, 1994). Relative humidity of 65–80 per cent is considered ideal for leaf growth. Ideal soils for mulberry cultivation are deep (>75 cm depth), fertile, welldrained, friable, porous, non-saline, acid (pH 6.2 to 6.8) clay loam to loam soils with good water-holding capacity and aeration.. Saline, alkaline and peaty soils are not suitable (Bongale, 1994; Madan Mohan Rao, 1998). The land use requirements and factor ratings are presented in Table 2.5.

Table 2.3 Land suitability criteria for bengal gram

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	20–25	25–30; 18–20	30–35; 15–18	>35; <15
Moisture availability	Length of growing period (days)				
	short-duration variety	>100	90–100	70–90	<70
	long-duration variety	>150	120–150	90–120	<90
Oxygen availability to roots	Soil drainage	welldrained	mod. well drained; imperfectly drained	poorly drained; excessively drained	very poorly drained
Nutrient availability	Soil reaction	6.0–7.5	7.6–8.0; 5.5–5.9	8.1–9.0; 4.5–5.4	>9.0
Nutrient retention	Texture	l, sil, cl, scl	sic, sicl, c	sl, c >60%	s, ls

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Rooting conditions	Effective soil depth	>75	51–75	25–50	<25
	Gravel content	<15	15–35	>35	
Soil toxicity	Salinity (EC saturation extract)	<1.0	1.0–2.0	>2.0	
	Sodicity (ESP)	<10	10–15	>15	
Erosion hazard	Slope	<3	3–5	5–10	

Banana. Banana is a predominantly tropical crop. The optimum temperature for foliar growth is 26–28 °C and for fruit growth 29–30 °C. Leaf area production is highest at 33 °C day and 26 °C night temperatures, pseudostem growth at 21–24 °C. Temperatures <20 °C reduce growth and rate of fruit maturation. Temperatures below 16 °C in subtropics can cause fruit deformation and temperatures of 37 °C or higher may cause leaf scorch (Turner and Lahav, 1983). The girth of banana fruits increases up to a temperature of 29 °C. All growth stops when the temperature falls below 10 °C or goes above 38 °C (Aubert, 1971). Wind velocity of 40 km per hour or above causes breakage or uprooting of pseudostems and is a major reason for loss of fruit. Five cm rain per month represents a level below which the plant is seriously short of water, while ten cm inches per month may be taken as 'satisfactory' (Manshard, 1974). Banana can be cultivated from sea level to 1500 m and under rainfed conditions at elevation of 500–1500 m (Ganry, 1980). It can be grown on a wide range of soils provided there is good internal drainage and adequate fertility, and moisture is sufficient. Ideal soils for banana cultivation are level (0–1% slope), silt loam or fine sandy loam soils that have gravel content of 5 per cent or less, are >120 cm deep, have angular blocky structure and pH 5.5–7.0. The clay content should be <40 per cent and the water table deeper than 120 cm (Stover, 1972). Banana tolerates a pH range of 4.5–8.0, but excellent growth can be obtained in very slightly acid to mildly alkaline soils. A soil that is not too acid, rich in organic matter, has high nitrogen content, adequate phosphorus and plenty of potash is preferable. Soils derived from limestone are ideal. Coarse sands, heavy compact clays, silts, poorly drained soils with compact subsoils and saline soils with salt percentage

>0.05 are unsuitable. Acid soils predispose banana to Panama disease (Stover and Simmonds, 1959). Land use requirements and factor ratings are given in Table 2.6.

Table 2.4 Land suitability criteria for wheat

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable' S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	22–25	25–28; 20–22	28–34; 18–20	
Moisture availability	Length of growing period (days)	>150	120–150	90–120	<90
Oxygen availability to roots	Soil drainage (class)	welldrained; moderately well drained	imperfectly drained	poorly drained	very poorly drained; excessively drained
Nutrient availability	Soil reaction (pH)	6.0–8.0	8.1–9.0; 5.5–5.9	>9.0; 4.5–5.4	<4.5
Nutrient retention	Texture (class)	l, cl, sil, scl	sc, sic, sl, c	c >60%	ls, s
Rooting conditions	Effective soil depth (cm)	>75	51–75	25–50	<25
	Gravel content (% by vol.)	<15	15–35	>35	
Soil toxicity	Salinity (EC saturation extract, dS m^{-1}))		<4.0	4.0–6.0	
	Sodicity (ESP, %))	<15	15–20	20–25	
Erosion hazard	Slope (%)	<3	3–<5	5–10	>10

Coconut. Coconut can be successfully grown up to elevations of 600–900 m above MSL in areas near the equator, with 27 °C mean annual temperature and 1000–2250 mm average annual rainfall evenly distributed throughout the year. Temperatures <21 °C and extreme fluctuations harm vigorous growth. In addition the coconut palm also requires plenty of sunlight and does not grow well under shade or in cloudy weather (Menon and Pandalai, 1958). It comes up well on a wide range of soils including coastal sandy soils, lateritic soils, coastal deltaic and river alluvia, forest loams, medium black soils, reclaimed marshy soils and coral soils (Cecil and Khan, 1993). Presence of water within 3 m, good water-holding capacity, proper drainage and absence of rock or hard substratum within 1 m of the surface are desirable (Thampan, 1981). Land use requirements and factor ratings for coconut are given in Table 2.7.

Table 2.5 Land suitability criteria for mulberry

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	24–28	22–24; 28–32	32–38; 22–18	>38; <18
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained, imperfectly drained	poorly drained, excessively drained	very poorly drained
Nutrient availability	Soil reaction (pH)	6.5–7.5	5.5–6.4; 7.6–8.5	4.5–5.4; 8.6–9.0	<4.5; >9.0
Nutrient retention	Texture (class)	cl, l, scl, sc, sil	scl, sc, c (non-swelling)	c (swelling), sl	c (swelling >60), ls, s
Rooting conditions	Soil depth (cm)	>150	101–150	50 to 100	<50
	Gravel content (% by vol.)	<15	15–35	>35	
Soil toxicity	Salinity (EC satn extract, dS m^{-1}))	<1.0	1.0 to 2.0	2.0 to 4.0	>4.0
	Sodicity (ESP)	<10	10 to 15	>15	
Erosion hazard	Slope (%)	<3	3 to 5	5 to 10	>10

Table 2.6 Land suitability criteria for banana

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	26 to 33	33 to 36; 24 to 26	36 to 38	>38
Moisture availability	Months with rainfall >75 mm	>8	6 to 7	<6	
Oxygen availability to roots	Depth to water table (m)	>1.25	1.25–0.75	0.5–0.75	<.5
	Soil drainage (class)	welldrained	moderately drained; imperfectly drained	poorly drained	very poorly drained
Nutrient availability	Soil reaction (pH)	6.5–7.0	7.1–8.5; 5.5–6.4	>8.5; <5.5	
Nutrient retention	Texture	l, cl, scl, sil	sicl, sc, c(<45%)	c (>45%), sic, sl	ls, s
Rooting conditions	Effective soil depth	>125	76 to 125	50 to 75	<50
	Gravel content	<10	10 to 15	15 to 35	>35
Soil toxicity	Salinity (EC saturation extract)	<1.0	1.0–2.0	>2.0	
	Sodicity (ESP)	<5	5 to 10	10 to 15	>15
Erosion hazard	Slope	<3	3 to 5	5 to 15	>15

Source: Simmonds (1962)

Rice. Rice is a heat- and water-loving plant requiring high temperature and water supply (Matsuo, 1955). Rice lands are classified according to water regimes into upland with no standing water, lowland with 5–50 cm standing water, and deep-water land with >50 cm standing water (De Datta, 1981). Low temperature (13–21 °C) at early growth stages, namely, seedling, tillering, panicle initiation and anthesis is most detrimental to grain yields. High temperatures (35–40 °C) during the vegetative stage can result in reduced tillering and degradation of young leaf tips. The average temperature required throughout the life period of the crop ranges from 21 to 35 °C. Temperatures <30 °C retard absorption of nitrogen, phosphorus, potassium and silica without significantly affecting that of calcium and magnesium (Matsuo, 1955). Spikelet sterility is high at temperatures > 35 °C (Balasubramanyan and Palaniappan, 2001).

The water requirement of rice under lowland conditions is 1110–1250 mm. The water requirement for land preparation ranges from 200 to 400 mm depending on the soil. Nursery requires about 50 mm and the growth period 1000 mm (Balasubramanyan and Palaniappan, 2001). Under rainfed conditions, rice is cultivated in places receiving annual rainfall of 1000 mm or more (Ghose *et al*., 1960). Rice is also grown on flat terrain subject to natural floods. In such situations duration and depth of flooding decides the land suitability (Sys *et al.*, 1991).

Rice is grown on a variety of soils ranging from waterlogged and poorly drained soils to welldrained soils (Murthy, 1978). In India, rice is grown under diverse soil conditions and over a wide range of soil reaction from pH 4.5 to 8.0. The soils most suited to cultivation of the crop are heavy soils (clay or clay loam and loam soils). The broad soil types under rice cultivation are alluvial soils, red soils, mixed red and brown hill soils, laterite and lateritic soils, black soils, sub-montane soils, saline and alkali soils and peaty and marshy soils (Ghose *et al*., 1960; Jha *et al*., 1999). The land suitability criteria and factor ratings for rice are presented in Table 2.8.

Table 2.7 Land suitability criteria for coconut

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature	Mean annual soil temperature (°C)	26–29	23–25; 30–32	20–22; 32–34	
Moisture availability	Annual rainfall (mm)	>1500	1000 to 1500	500 to <1000	
	Months with rainfall <50 mm	3	4–5	6–7	
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained	imperf. drained, excessively drained	poorly drained
	Depth to water table (m)	2–3	1 to 2	0.5 to 1	
Nutrient availability	Soil reaction (pH)	5.1–7.5	7.6–8.0; 4.5–5.0	8.1–8.5; 4.0–4.4	
Nutrient retention	Texture (class)	cl, scl, sc, sicl, sil	sl, c (non–swelling), sic	c (swelling), ls, s	
Rooting conditions	Effective soil depth (cm)	>150	101 to 150	75 to 100	<75
	Gravel content (% by vol.)	<15	15 to 35	35 to 50	>50
Erosion hazard	Slope (%)	<8	8 to 15	15 to 30	

Source: Naidu *et al.* (1997)

Table 2.8 Land suitability criteria for rice

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	30–34	34–38	38–40	
Oxygen availability to roots	Soil drainage (class)	imperfectly drained	moderately well drained	well drained; somewhat excessively drained	excessively drained
	Flooding (months)*	3–4	≥4	2–3	
	Depth of water (cm)	<10	10–20	>20–40	>40
Nutrient availability	$CaCO_3$ in root zone (%)	<15	15 to 25	25 to 30	>30
Nutrient retention	Texture (class)	c, sic, cl, sicl, sc	scl, sil, l	sl, ls	s
Rooting conditions	Effective soil depth (cm)	>75	51 to 75	25 to 50	<25
Soil toxicity	Salinity (EC saturation extract, dS m^{-1})	<3	3 to 10	10 to 20	>20
	Sodicity (ESP)	<10	10 to 15	15 to 25	
Erosion hazard	Slope (%)	0 to 3	3 to <5	5 to 10	>10

* Flooding is considered for rainfed rice.
Source: Dr A. Natarajan (pers. communication)

Groundnut. Groundnut is predominantly a crop of tropical and subtropical climates. It comes up well in tracts receiving 625–1250 mm of fairly well distributed rainfall. Even so, well-distributed rainfall of 575–625 mm is adequate for good yield. Heavy rains offer no advantage (Cheema *et al*., 1974). The crop requires intermittent light showers for profuse flowering coupled with sunshine for further development of flowers. Thus, alternate spells of dry and wet weather are ideal for flowering; excessive rains are also not desirable for the development of pods since they induce vegetative growth of the plant at the cost of pod formation (Kanwar *et al.*, 1983). Reproductive growth is highest between 24 and 27 °C; temperatures constantly higher than 33 °C affect pollen viability (De Beer, 1963). Temperatures <20 °C affect flowering and proportion of fertilized flowers. A temperature range of 25–30 °C appears to be optimum; flower production is adversely affected above 35 °C (Kanwar *et al.*, 1983). Loose/friable soils facilitate good pod development. Therefore, sandy and loamy soils, fair to rich in organic matter are extremely suitable. Groundnut is grown on many soil types such as black cotton soil and gravelly red soils. Red soils that harden on drying are not suitable, Pods produced in soils subject to waterlogging, alkali soils and soils poor in lime are not filled properly (Subbaiah Mudaliar, 1960). Table 2.9 gives the suitability criteria and factor ratings for groundnut.

Pearl millet (bajra). Pearl millet is one of the most drought tolerant crops amongst cereals and millets. It is a warm weather crop, mostly grown in semi-arid and arid climate of tropical and subtropical regions. The crop is more suited to regions of low (425–500 mm) rainfall (Yegna Narayan Aiyer, 1958). It can be grown rainfed in regions where annual rainfall is between 400 and 650 mm. A temperature range of 28–32 °C is considered optimum for full vegetative growth. High humidity and low temperature at the time of flowering increase incidence of ergot disease, which reduces grain yield (Gill, 1991). The crop can be grown on almost all types of soils, but ideal soils are sandy loam to loam soils that are welldrained and free from toxicity such as salinity or sodicity. It is grown on sandy soils, shallow, light gravelly soils, light red soils, black soils, red and grey sandy soils free from stones.

The crop performs well on soils with alkaline reaction but not on highly saline soils; acid soils are unsuitable (Yegna Narayan Aiyer, 1958; Gill, 1991; Gautam, 1999). Land use requirements for pearl millet are summarized in Table 2.10.

Table 2.9 Land suitability criteria for groundnut

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	24–33	22–24; 33–35	20–22; 35–40	<20; >40
Moisture availability	LGP (days)				
	bunch variety	105–120	90–105	<90	
	spreading variety	120–135	105–120	90–105	
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained	imperfectly drained	poorly drained
Nutrient availability	Soil reaction (pH)	6.0–8.0	8.1–8.5; 5.5–5.9	>8.5; <5.5	
Rooting conditions	Effective soil depth (cm)	>75	51–75	25–50	<25
	Surface soil texture (class)	ls, sl	cl, sicl, scl	c, sic	
	Subsoil texture (class)	sil, l, scl, cl, sicl	sc, sic, c	s, ls, sl, c>60	
	Gravel content (% by vol.)	<35	35–50	>50	
Soil toxicity	Salinity (EC saturation extract, dS m^{-1}))	<2.0	2.0–4.0	>4.0	
	Sodicity (ESP)	<5	5–10	10–15	>15
Erosion hazard	Slope (%)	<3	3–5	5–10	>10
Soil degradation	Crusting (degree)	none	slight	moderate	

Source: NBSS & LUP (1994)

Finger millet *(ragi)*. Finger millet can be grown throughout the year if temperature is >15 °C. The minimum annual rainfall requirement for successful cultivation is 460 mm, but the crop can be grown in higher rainfall areas also. The plant is suitable from sea level to an altitude of 1000 m (Hegde and Lingegowda, 1986) .It can be grown on all types of soils ranging from poor to fertile soils. It performs well on rich loam soils, sandy loams, red, light red, and laterite soils. Alluvial and black soils are also suitable if welldrained (Hegde and Lingegowda, 1986; Yegna Narayan Aiyer, 1958). Welldrained loams or clay loam soils are best (Rathore, 1999b). The crop tolerates alkalinity better than many others (Yegna Narayan Aiyer, 1958; Subbaiah Mudaliar, 1960). Land use requirements and factor ratings are given in Table 2.11.

Table 2.10 Land suitability criteria for pearl millet

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	28–34	>34–38; 24–28	>38–40; 20–<24	
Moisture availability	Length of growing period (days)	>90	70–<90	50–<70	
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained	imperf. drained; poorly drained	
Nutrient availability	Soil reaction (pH)	6.0–8.0	5.0–5.9; 8.1–8.5	4.5–4.9; 8.6–9.5	
Nutrient retention	Texture (class)	sl, l, scl, sil, cl	ls, c, sicl, sc	c >45%, s	
Rooting conditions	Effective soil depth (cm)	>75	51–75	25–50	
	Gravel content (% by vol.)	<15	15–35	>35–50	>50
	$CaCO_3$ in root zone (%)	<5	5–10	10–25	>25
Soil toxicity	Salinity (EC saturation extract, dS m^{-1})	<1.0	1.0–2.0	2.0–4.0	
	Sodicity (ESP)	<15	15–20	20–35	
Erosion hazard	Slope (%)	<3	3–5	5–10	>10

Table 2.11 Land suitability criteria for finger millet

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean temperature in growing season (°C)	28–34	25–28; 34–38	38–40; 20–25	>40; <20
Moisture availability	Length of growing period (days)	>110	90–110	60–90	<60
Oxygen availability to roots	Soil drainage (class)	welldrained; moderately well drained	imperfectly drained; somewhat excessively drained	poorly drained; excessively drained	
Nutrient availability	Soil reaction (pH)	5.5–7.5	7.6–8.5; 4.5–5.4	8.6–9.5; 4.0–4.4	<4.0
Nutrient retention	Texture (class)	l, sil, sl, cl, sicl, scl	sic, c, sc	ls, s, c >60%	
Rooting conditions	Effective soil depth (cm)	>75	51–75	26–50	<25
	Gravel content (% by vol.)	<15	15–35	35–50	>50
Soil toxicity	Salinity (EC saturation extract, dS m^{-1})	<1.0	1.0–2.0	2.0–4.0	
	Sodicity (ESP)	<10	10–15	15–25	>25
Erosion hazard	Slope (%)	<3	3–5	5–10	>10

Source: C.R. Shivaprasad (pers. communication)

Arecanut. The arecanut palm is mostly grown in plains of humid areas; at higher elevations the minimum temperature will be a limitation for the crop. At altitudes >850 m MSL, per cent germi-nation of nut and ratio of dry weight of kernel to that of whole fruit are less than at lower altitudes (Nambiar, 1949). The palm flourishes well in the temperature range 14–36 °C. Extremes of temperature and wide diurnal variations are not conducive for healthy growth. Low humidity can cause severe foliar damage. The palm is delicate and cannot withstand exposure to direct sun. When young the stem gets scorched resulting in permanent damage to the palm, so it is essential that the site selected for raising the garden have protection from direct sunlight from the south and west by way of hillocks or tall evergreen trees. Arecanut comes up well in areas with high rainfall (>4500 mm) as well as in low rainfall areas (<750 mm), but in the latter case it has to be irrigated during long dry spells (Nambiar, 1949). Drainage should be adequate as the plant does not tolerate water stagnation (Shama Bhat and Abdul Khader, 1982). The plant performs well in acid to neutral pH range (Yegna Narayan Aiyer, 1966). The land use requirements and factor ratings are presented in Table 2.12.

Table 2.12 Land suitability criteria for arecanut

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature	Mean annual soil temperature (°C)	25–30	22–25; 30–32	20–22; 32–36	
Moisture availability	Annual rainfall (mm)	>1500	1000 to 1500	500 to <1000	
	Months with rainfall <50 mm	3	4–5	6–7	
Oxygen availability to roots	Soil drainage (class	welldrained	moderately well drained	imperfectly drained, excessively drained	poorly drained
	Depth to water table (m)	2–3	1 to 2	0.5 to 1	
Nutrient availability	Soil reaction (pH)	5.0–7.5	7.6–8.0; 4.5–4.9	8.1–8.5; 4.0–4.4	
Nutrient retention	Texture (class)	cl, scl, sc, sicl, sil	sl, c (non-swelling), sic	c (swelling), ls, s	
Rooting conditions	Effective soil depth (cm)	>100	76 to 100	50 to 75	<50
	Gravel content (% by vol.)	<15	15 to 35	35 to 50	>50
Erosion hazard	Slope (%)	<3	3 to 5	5 to 10	

Cashew. Cashew is a tropical plantation crop. The optimum monthly temperature is around 27 °C. The most important cashew-producing regions have daily minimum temperatures between 15 and 25 °C and mean daily maximum temperatures of 25–35 °C. Heavy rains during flowering affect yields adversely. Extremely dry air during flowering causes withering of flowers resulting in considerable yield loss. However, excessive relative humidity is unfavorable as it promotes growth of fungi and insect pests. The tree needs a well-defined dry season of at least 4 months, preferably longer, to produce best yields. A climate with 4–6 dry months and rainfall ranging from 1000 to 2000 mm will be suitable for commercial cultivation. The best soils for cashew are deep, friable, welldrained, sandy loams with water table below 5–10 m. Cashew cannot withstand flooding or poor drainage. Compacted subsoil or hard pan impedes root penetration (Ohler, 1979). The land use requirements and factor ratings for cashew are given in Table 2.13.

Table 2.13 Land suitability criteria for cashew

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	**Not suitable,** N
Temperature regime	Mean annual temperature (°C)	32 to 34	28 to 32; 34 to 38	24 to 28; 38 to 40	>20; >40
Moisture availability	Annual rainfall (mm)	1500–2500	1300–1500	900–1300	
	Length of growing period (days)	>210	150 to 210	90 to 150	
	Relative humidity (%)	70–80	65 to 70; 80 to 85	50 to 65; 85 to 90	<50; >90
Oxygen availability to roots	Soil drainage (class)	welldrained	moderately well drained	imperfectly drained	poorly drained
	Depth to water table (m)	>2	1.5 to 2	0.75 to 1.5	
Nutrient availability	Soil reaction (pH)	6.3–7.3	5.6–7.2; 4.5–5.0	5.1–5.5; 7.4–8.0	
Nutrient retention	Texture (class)	l, sl, scl, cl, sil	ls, s (coastal)	sic, c (non-swelling)	c (swelling)
Rooting conditions	Effective soil depth (cm)	>150	76 to 150	50 to 75	<50
	Gravel content (% by vol.)	<15	15 to 35	35–50	>50
Situation	Elevation (m)	<20	20 to 450	450 to 750	
	Distance from coast (km)	<80	80 to 240	240 to 320	
Erosion hazard	Slope (%)	<5	5 to 15	15 to 30	

Sources: Mahapatra and Bhujan (1974); Nambiar and Thankamma Pillai (1985)

Land suitability evaluation in the watersheds

The following evaluations of land suitability for crops were done in the specified micro-watersheds.

Garakahalli — mulberry, banana, coconut, finger millet, groundnut;
Nalatwad — sorghum, sunflower, bengal gram, wheat;
Pettamanurahatti — groundnut, sorghum, pearl millet, finger millet;
Molahalli — rice, arecanut, cashew, coconut.

3. DATA ANALYSIS

3.1 Socio-economic Survey

The base map for collection of socio-economic data for each microwatershed was generated from the village cadastral maps. The lists of farmers owning land and the corres-ponding survey numbers were obtained from the village accountant/mandal panchayat office. The list of farmers who had benefited under components of the watershed programmes and details of investment made in the watershed were collected from the watershed development agency. Socio-economic survey of all the farmers in the watershed was carried out by personal interview with the help of a questionnaire.

3.2 Impact Assessment of Watershed Development Programme

The data on investment made on different components of watershed development were collected from state watershed department and Assistant Director of Agriculture who imple-mented the programme. The changes in terms of land use, cropping pattern, productivity, emp-loyment and income were collected from farm households for assessing the impact of project implementation.

3.3. Economic Analysis of Crop Enterprises

The cost of inputs such as seed, manure and fertilizers, plant-protection chemicals, pay-ment towards human and bullock labour and interest on working capital were included under variable costs. In the case of perennial crops, the cost of establishment was estimated by using actual physical requirements and prevailing market prices. Establishment cost included main-tenance cost up to bearing period. The value of main product and by-product from the crop enterprise at the market rates were the gross returns of the crop. Net returns were worked out by deducting establishment and maintenance cost from gross returns.

3.4 Economic Evaluation of Soil Conservation Measures

The investments made by the watershed project on various soil- and water-conservation practices were evaluated using the techniques presented below. These techniques have been advocated as aids in arriving at viable solutions to capital investments, by bringing the cash flow to a common time by discounting. This procedure facilitates comparisons among different alter-natives with varying lengths of project time. Project-evaluation criteria help in according prio-rities when a number of possible investment alternatives exist.

Four criteria used in the project evaluation in the study were: Pay-Back Period, Benefit-Cost ratio (B:C), Net Present Worth (NPW) or Net Present Value (NPV) and Internal Rate of Return (IRR).

3.4.1 Pay-back period

Pay-back period is the length of time from the beginning of the project until the stage when net value of incremental production stream equals the total amount of the capital invest-ments. The pay-back period is a common and rough means of choosing among investments especially when projects entail a high degree of risk. However, as a measure of investment worth, the payback period has two important weaknesses—it fails to consider cash flows after the payback period and it does not adequately take into account the timing of cash flows (Gittinger, 1982). Pay-back period is represented in mathematical form as

$$P = I/Y,$$

where P = pay-back period in pre-defined time units,

I = capital investment on the project in rupees,

Y = net income realized after meeting production expenses.

3.4.2 Benefit-cost ratio (B:C ratio)

The B:C ratio is obtained by dividing present worth of benefits by present worth of costs. It should be greater than unity for any project to be considered economically viable. However, the absolute value of B:C ratio will vary depending on the discount rate chosen—the higher the discount rate, the smaller the resultant benefit-cost ratio, *ceteris paribus* (Gittinger, 1982). All independent investments with a discounted benefit-cost ratio of 1 or greater are acceptable. However, the greater the positive value of B:C ratio, the higher the priority assigned to the selection. In the present study 12 per cent discount rate was used as it closely represented the opportunity cost of capital in the study area. The mathematical form of benefit-cost ratio is

$$\text{B:C ratio} = \frac{\sum_{t=1}^{n} R_t \, (1+i)^{-n}}{I_0}$$

where R_t = net incremental income in each year (Rs)

I_0 = initial investment (Rs),

i = discount rate (%),

t = number of years of economic life of the investment project (t = 1…..n).

3.4.3 Net present worth (NPW)

Net present worth is the most straightforward method of evaluation of a project. It is simply the present worth of the incremental net benefit or incremental cash flow stream. The net present worth represents the discounted value of all annual margins (the difference between incomes and costs) over the complete project life. Net present worth for each watershed may be interpreted as the present worth of the incremental net income stream generated over years by an investment. The net present worth for each watershed was computed by determining the net benefit gains and by discounting gains. For a project to be economically feasible the NPW should be positive and as high as possible. The mathematical form of net present worth is

$$NPW = \sum_{t=1}^{n} R_t \ (1+i)^{-n} - I_0$$

where

R_t = incremental net income realized after meeting production cost in each time period,

I_0 = initial investment on the project,

i = discount rate,

t = economic life span of the project in predetermined time units (t = 1…..n).

3.4.4 Internal rate of return (IRR)

The internal rate of return is defined as the rate that makes the present net worth of costs equal to the net benefits. It is the maximum interest that a project could pay for the resources used if the project were to recover its investment and operating costs. It also represents the rate of return on capital employed of the project. Thus IRR indicates 'yield' or marginal efficiency of project capital. Projects with highest internal rate of return should, *ceteris paribus,* get priority in selection. The IRR was estimated by trial and error through interpolation as indicated below.

The estimation of IRR is primarily a search process to find out a particular discount rate that makes the NPW of a project zero. The net cash flows from the project were discounted with a rate that closely represented the true value of IRR, and NPW was estimated. If the NPW was positive with such a discount rate, it indicated under-estimation of the true value of IRR. Hence, a higher discount rate was used and the

NPW of cash flow was estimated to be zero or negative and the IRR was worked out using the following interpolation method:

IPR= (lower dis count rate)- (difference between lower and higher discount rates)* (NPW at LDR

Abs. diff. between the two NPWs

where lower discount rate represented the discount rate with positive NPW and higher discount rate that with negative NPW. The estimated IRR would invariably result in zero NPW.

3.5 Geographic Information System Modelling

The data collected in biophysical survey (on climate, soils, water resources, present land use, land suitability, etc.) and socio-economic survey (on social and economic aspects) were used for this analysis. The Geographic Information System (GIS) software SPANS was used to create a georeferenced database for sorting and retrieving information based on geographic location. After completion of both biophysical and socio-economic survey and laboratory analysis a basic decision support system (Fig. 3.1) was created and an evaluation procedure that provi-ded information for each land use option developed to select the best option for each land unit.

The data incorporated in the database were available in the form of maps and statistical tables and often these might be compiled at different formats and scales. The delineation of an area can be made either on the basis of village or plot boundaries or of natural boundaries—soil series or phases, watersheds, etc., or a combination of these.

3.6 Integration of Biophysical and Socio-economic Data

Decisions on land use are rooted in the physical suitability of land, but they are driven by socio-economic needs. Hence resource problems generally have at least a socio-economic and a biophysical dimension; but when analysing land-use decisions policy makers often focus on only one of them. Despite recognition of its importance in land-use planning and policy analysis, integration of socio-economic and biophysical factors has not been satisfactorily achieved, and thus remains a major challenge.

The need for integration of socio-economic and agroecological analysis in land-use plan-ning and policy analysis is well recognized (Fresco *et al*., 1992; Stomph *et al*., 1994; Alfaro *et al*., 1994). In the realm of agricultural planning, many of these conceptual and methodological constraints to integration have been discussed by many authors (Malingreau and Mangun-sukardjo, 1978; Luning, 1986; Braat and van Lierop, 1987; van Diepen *et al*., 1991; Fresco *et al*., 1992; Hengsdijk and Kruseman, 1993; Sharifi and van Keulen, 1994).

An attempt was made in the present study to integrate socio-economic and biophysical data at microwatershed level in the following steps.

1. The data on biophysical and socioeconomic aspects were organized in a spatial database for easy retrieval in required sequences.

2. The farm households were classified by size into marginal (<1 ha), small (1–2 ha) and large (>2 ha). To assess the variation among size groups and to identify the association among their characteristics, statistical analysis was done using SYSTAT-9 statistical software. Plot boundaries of households were given unique identity as Farm Types (FTs) for integration.

3. The soils were delineated as soil series and phases and mapped and given unique identity as Land Mapping Units (LMUs) for spatial integration.

4. The maps of Farm Types and of Land Mapping Units were integrated through overlaying (Fig. 3.2) using SPANS software, giving a map with a new unit, Farm Type Land Mapping Unit (FTLMU) or, simply, Integrated Land Unit (ILU).

This concept was based on the argument of Stomph *et al*. (1994) that land-use systems, irrespective of the level at which they are defined, are integrated systems and should include bio-physical and socio-economic characteristics. In accordance with the definition of system (Fresco, 1986), inputs and outputs were defined, and the transformation processes from inputs to outputs in the system were identified and quantitatively described. The diagram in Fig. 3.3 illustrates the integrated land use system.

3.7 Bio-economic Modelling Methods

Bio-economic models enable integration of agroecological and socio-economic information to analyse the impact of agricultural policies on sustainable land use. Such models were tested under various agroecological conditions by Ruben *et al.* (1998).

In a given set of agroecological and socio-economic circumstances, farm households make agricultural-production choices based on their objectives and access to resources. These decisions determine household income, type and quantity of products available for society, resources required for production and consequences for sustainability of the resource base. Agro-ecology defines input requirements and output levels for cropping under different soil and weather conditions. This approach to production activities enables us deal with a range of activities with differences in input-use efficiency when complementary factors are constrained.

Linear programming technique is the most appropriate to determine the optimal suita-bility of different production activities under different soil and weather conditions. A Multiple-Goal Linear Programming (MGLP) model was used as a tool to integrate different types of information and to generate land-use scenarios.

3.7.1 Linear Programming

Linear programming is the basis for multiobjective programming and has been widely used for its several advantages over functional analysis. Programmes involving changes in resource levels cannot be easily handled by functional analysis and determination of normative plans with resource inequalities appears to be impossible through functional analysis. Hence, linear programming technique was chosen for analysis.

The mathematical form of linear programming used in this study can be written as

$$\text{Maximize} \quad Z_j = \sum_{j=1}^{n} C_{jk} X_{jk} \tag{1}$$

subject to

1. $$\sum_{j=1}^{n} a_{ijk} X_{jk} > b_i \quad (i = 1.....l) \tag{2}$$

2. $$\sum_{j=1}^{n} a_{ij\,k} X_{jk} < b_i \quad (i = m......n) \tag{3}$$

3. $$\sum_{j=1}^{n} a_{ij\,k} X_{jk} = b_i \quad (i = p.......r) \tag{4}$$

4. $$X_{jk} \geq 0 \tag{5}$$

where

Z_j = objective function to be maximized,

C_{jk} = value of the jk^{th} activity in Rs/ha,

K = kind of soil,

X_{jk} = level of jk^{th} activity per hectare,

a_{ijk} = coefficient that reflects either absorption of ($a > 0$) or contribution to ($a < 0$) a constrained resource,

b_i = available quantity of i^{th} resource or the requirement to be met.

3.7.2 Objective function

The objective function represents maximization of the 'annual net returns' per hectare from crop enterprises subject to the resource constraints specified in the model. The general basic economic objective is maximization of welfare of the watershed. This concept is subjective and difficult to quantify. Hence the annual net returns in the watershed for the resources committed to the farming system were used as a proxy for maximizing welfare of the farmers.

The net returns per hectare were calculated by deducting total variable costs of seeds, human and bullock labour, fertilizer, FYM and plant protection chemicals from gross returns.

3.7.3 Input coefficients (a_{ijk})

Input coefficient is the average quantity of the i^{th} input used per unit of the j^{th} activity on the k^{th} type of soil (soil series). It was calculated per hectare for each crop. The input coefficients for men, women and bullock labour, FYM, fertilizers (N, P, K), plant-protection chemicals and seed for different crops on different soil series were derived by totalling and averaging the corresponding input-output coefficients of different soil series and crops. These coefficients formed elements of the matrix.

3.7.4 Constraints and requirements

These are the elements in the matrix. The activities (row vectors), which were the impor-tant constraints considered in the study, were land, labour, manure (FYM). fertilizers (N, P, K), plant-protection chemicals, available own funds, borrowing and non-resource constraints such as food requirements. A constraining resource was specified as maximum resource available with a relation $\leq$, while $\geq$ referred to the requirement. They are generally found as RHS values in the linear programming model.

Land. The kinds of soil mapped at series level were considered for each crop season (*kharif, rabi* and summer). The area under perennial crops and soils not suitable for certain crops were exc-luded from the model. All the resource requirements were considered at macrolevel to reflect the total watershed area.

Labour. The availability of family labour was estimated taking into consideration the number of persons aged >15 years and <60 years (both male and female) fully or partially engaged in farm business. Men labour and women labour, expressed in days, were treated as separate activities since there was gender segmentation in the various activities. The wages of own labour and hired labour were considered in calculating the total cost and returns per hectare. The availability was indicated in days for each category in a year or season and the hiring facility was accommodated in the model. Availability of bullock labour in bullock-pair days was also estimated.

Manures (FYM). Available FYM among the farm households in the watershed was estimated and considered in the model along with a provision for purchase.

Fertilizers and plant-protection chemicals. The fertilizer inputs were converted to nutrient units and the requirements for different crop activities were worked out. The level of plant-protection chemicals used was also incorporated in the model as input coefficient. The availa-bility of fertilizers (N, P, K) was assumed to be unlimited (≥0).

Working capital. The working capital available with the farmers sometimes might not be suffi-cient to meet the requirements of the different agricultural operations. Capital thus acted as a constraint in the study area, and farmers had taken to subsistence agriculture owing to inade-quacy of working capital. Working capital includes funds required to meet the cost of seeds, FYM, fertilizers, plant-protection chemicals and wages of human and bullock labour. Family savings were estimated for available capital in the model, the constraint being specified by the '≤' relation.

Borrowing. Borrowing activity was provided to encompass only short-term credit needs. Interest rate was reflected as the cost of borrowing in the objective function. The amount borrowed was to supplement the cash available with the farmers during the crop season.

Non-resource constraints. These constraints arise not because of lack of resources but from customs and psycho-ogical reasons affecting the decisions of the farmers.

Minimum cereal requirement of family. This constraint ensures that the minimum cereal needs of the households are met from the farm itself. The area required to meet the requirement of the commonly consumed cereal of the watershed population was incorporated as a constraint.

Maximum area constraint. Factors such as risk, uncertainties, high input costs, self-dependence on farm-grown food, supervision and marketing problems, and environmental deg-radation associated with crops might prevent farmers from growing them beyond certain limits. In allocating resources it is important to see that resources allocated to these crops do not cross the limits set by the farmers.

3.7.5 Activities in the model

These activities (column vectors) specify the crop and/or livestock activities that could be put to various alternative uses. The various activities incorporated in the model, namely, crop-production activities, livestock activities, labour-hiring activities, borrowing activities, and pur-chase of FYM and fertilizers were categorized according to soil (soil series) in each watershed.

3.7.6 Generation and evaluation of land-use plans

To represent the multiple and partially conflicting views of different stake-holders, vari-ous socio-economic and biophysical (environmental) objectives were identified for evaluation as given below.

Parameters	Objectives
Socio-economic	Maximization of net farm income
	Minimization of total variable cost
	Minimization of total seasonal employment of men labour
	Minimization of total seasonal employment of women labour
	Minimization of total seasonal employment of bullock labour
Biophysical (environmental)	Maximization of FYM application
	Minimization of N fertilizer application
	Minimization of P fertilizer application
	Minimization of K fertilizer application

To achieve policy objectives, instruments that influence farmers' decision on land use and allocation of other resources need to be identified. These measures or instruments are repre-sented in the model in accordance with relevance of the measures.

3.8 Methods for Environmental Valuation of Land Resources

Depletion and damage of natural resources through the goods and services they provide to society are rarely valued. Thus, low priority has been assigned in the past to environmental protection actions in government programmes related to agricultural development. A problem in analysis of projects with impacts on the environment is the difficulty of identifying the complete range of costs/benefits and then placing a monetary value on those that are not marketed.

3.8.1 Functions of land

For valuation of any natural resource, it is essential to define its various functions and the ways it could be used. Functions of land have been defined by FAO (1995) as follows.

- Land is the basis for many life support systems through the production of biomass that provides food, fodder, fibre, fuel, timber and other biotic materials for human use, either directly or through animal husbandry including aquaculture and inland and coastal fishery (the *production function*).

- Land is the basis of terrestrial biodiversity by providing the biological habitats and gene reserves for plants, animals and microorganisms both above the ground and below it (the *biotic environmental function*).

- Land and its use are a source and sink of greenhouse gases and constitute a co-determinant of the global energy balance (reflection, absorption and transformation of radiation energy of the sun) and of the global hydrological cycle (the *climate regulative function*).

- Land regulates the storage and glow of surface and ground water resources, and influences their quality (the *hydrologic function*).

- Land is a storehouse of raw materials and minerals for human use (the *storage function*).

- Land has a receptive, filtering, buffering and transforming function of hazardous compounds (the *waste and pollution control function*).

- Land provides the physical basis for human settlements, industrial plants and social activities such as sports and recreation (the *living space function*).

- Land is a medium to store and protect the evidence of the cultural history of mankind and a source of information on past climatic conditions and past land use (the *archive or heritage function*).

- Land provides space for the transport of people, inputs and produce, and for the movement of plants and animals between discrete areas of natural ecosystems (the *connective space function*).

Total economic value of land is the sum of use value and non-use value of the resource. Use values are defined as those benefits that derive from actual use of the land. Non-use values are also termed existence values.

Total economic value = use value + non-use value

Use value = non-perceived values (in terms of soil fertility) + primary goods (crop main product + by-product).

In the present project an attempt was made to quantify the value of agricultural land use and to estimate the extent of land-resource degradation in the four watersheds studied.

3.8.2 Econometric approach to land valuation using physical linkage method

The econometric approach using physical linkage method measures the influence of environmental features (land characteristics such as soil depth, soil fertility, soil water holding capacity, degree of soil erosion), crop management (factors like quantity of seeds and fertilizer used, labour) and socio-economic features (population pressure, farm size, land tenure) on land productivity measured in terms of value per hectare of land.

The contribution of independent variables was quantified by fitting the data into the fol-lowing regression model (Cobb-Douglas function)

$Y= f\ (x_1+ x_2 + x_3+ \ldots\ldots\ldots\ x_n)$

where Y= value of land per hectare,

$x_1, x_2, x_3, \ldots\ldots\ldots\ x_n$ are independent variables.

3.8.3 Replacement-cost approach for estimation of cost of soil erosion

Replacement cost approach provides an alternative method for estimating the cost of soil erosion. The replacement cost method assumes that the productivity of a soil can be maintained if the lost nutrients and organic matter are replaced artificially (Hufschmidt *et al*., 1983; Dixon and Hufschmidt, 1986; Dixon *et al*., 1994). The basic premise of the replacement cost method is that the cost incurred in replacing productive assets damaged by an economic activity can be mea-sured and interpreted as benefits if the damage were prevented.

The data requirements for this method are estimates of soil erosion rates, nutrient ana-lysis of eroded soil, and nutrient prices. The soil nutrients (N, P, K and micronutrients) and organic matter lost through erosion were quantified using erosion rate and soil nutrient level. These quantities were then valued using the market prices.

In mathematical form the approach is

$$RC_i = (S_t - S_{t+1}) \sum_{j=1}^{k} N_{ij}P_j + C_{il}$$

where i = 1.....n, j = 1.....k,

RC_i = replacement cost of nutrients in i^{th} category soil unit (Rs/ha),

$S_t - S_{t+1}$ = soil loss from year t to year t+1 in i^{th} category soil unit (t/ha),

N_{ij} = quantity of j^{th} nutrient in the i^{th} category soil unit (kg/ha),

P_j= price of j^{th} nutrient (Rs/kg),

C_{il} = cost of labour in spreading fertilizers in i^{th} category soil erosion unit (Rs/ha).

3.8.4 Estimation of misapplication of fertilizer nutrients

Calculation of nutrient requirement for specific yields. The present general fertilizer recom-mendations were compared with soil test based recommendation for specific yield target (balanced fertilizer application). A linear relationship between grain yield and nutrient uptake by a crop was assumed, that is, for a particular yield, a definite amount of nutrients is taken up by the plant. This requirement minus the contribution of soil nutrients gives the amount of fertilizer nutrient needed.

Type I misapplication. This type of misapplication is the potential loss if farmers follow the Agriculture Depart-ment's blanket regional recommendations of nutrients for optimum yields ins-tead of the dose calculated by applying the STCR formula for those yields. The cost of such misapplication was calculated from the excess or deficit of nutrient applied.

Type II misapplication. Taking into account the nutrients available in each soil unit, fertilizer nutrients needed to produce the yield obtained by each category of farmer (marginal, small and large) were com-puted using the fertilizer-response equations for targeted yields given by Veerabhadraiah *et al.* (2001) for the various agroclimatic zones of Karnataka. The nutrient dose actually applied by farmers was compared with the calculated dose to quantify type II misapp-lication of fertilizer nutrient. Positive and negative differences were both considered harmful, for excess nutrient is wasted in the former, and the shortfall in nutrient in the latter leads to depletion of the soil. The cost of the misapplication was calculated from the market value of the nutrients N, P and K.

3.8.5 Evaluating agricultural land using soil potential rating (SPR)

Soil potential ratings are classes that indicate the relative quality of a soil for a particular use compared with other soils in a given area. Field performance level, the relative cost of app-lying modern technology to minimize the effect of any soil limitations and adverse effects of continuing limitation (like soil degradation) if any, and social, economic and environmental values are considered. Such rating helps in deciding the relative suitability of a soil for a given use. It is used in conjunction with other resource information as a guide for land-use decisions. The rating is derived by working out soil potential index (SPI).

SPI = P – (CM + CL)

where P = index of performance or yield as locally established standard,

CM = index of cost of corrective measures to overcome or minimize the effect of soil limitations,

CL = index of social, economic and environmental costs resulting from continuing limitations.

For developing SPI, the following details are required:

a) performance level of crop on the particular soil;

b) measures for overcoming soil limitations;

c) limitations continuing after corrective measures have been applied.

The soil potential index was estimated for each soil unit of the watersheds.

3.8.6 Valuation of agricultural land using income approach

The income approach to valuation requires estimates of income and cost to obtain net income. The net income can then be capitalized to get an income value. The capitalization pro-cess, by which value is estimated from annual income, requires two factors, namely, an estimated annual income and a capitalization rate. Thus the capitalization value, which represents the pre-sent worth of future incomes, is obtained by the following equation:

$$\text{Capitalization value} = \frac{\text{Annual net income}}{\text{Capitalization rate}}$$

The present worth of future incomes may also be computed by using the formula

Present value = $(1 + \text{interest rate})^{-n}$ x future income.

Analysis of present worth of future incomes provides a useful method for computing land value that is appreciating through drainage and erosion control practices, horticulture, etc. Depre-ciation is reflected by decline in net incomes because of erosion, fall in fertility status, etc.

3.9 Characterization of Farm-level Sustainable Land Management (SLM) Indicators

Sustainability and sustainable farming have been widely used and defined differently to suit the situation and purpose for which they were used. The biggest problem faced by every attempt was to measure this concept as a variable based on some standard indicators. However, there is unanimity in the concept that sustainability of a farming system is a composite of three dimensions, namely, ecological, economic and social.

3.9.1 Scale values through Guilford Rank Order method

Twenty components purported to be the indicators of sustainable farming were listed from the literature and discussion with experts. The components were then scrutinized for their amenability to operationalization, measurement and possibility of eliciting data from farmers. Six components were retained as essentials of sustainable farming. The six components were nutrient management, land productivity, input self-sufficiency, input productivity, crop yield security, and family food sufficiency.

The six components were presented to 25 experts, who were asked to rank them in order of importance. Ranks were converted into rank values, percentile values and ‘C’ values. Scale values were finally worked out using the Guilford (1954) formula

$R_c = 2.357R_1 – 7.01$

Scale value obtained for each of the components is given in the following table. These scale values were then used to arrive at the index of sustainability for each farm.

Component	Scale value
Nutrient management	6.85
Land productivity	5.53
Input self-sufficiency	4.68
Crop yield security	4.49
Input productivity	4.02
Family food sufficiency	3.08
Total scale value	28.65

3.9.2 Measurement of the components of sustainability of farming

Nutrient management index (NMI). Nutrient management was operationalized based on the score for timely application of right quantity of organic and inorganic fertilizers and amendments to soil using proper method and combination aimed at deriving maximum benefits and causing minimum damage to the resource base.

Keeping the operational definition in mind, a list of questions related to nutrient manage-ment was prepared. Maximum care was taken to cover all the aspects of nutrient management. Minimum possible score was zero and maximum possible was 15.

The index for each individual farmer was worked out by using the formula

$$NMI = \frac{\text{Actual score}}{\text{Possible score}} \times 100$$

Land productivity. Land productivity was operationalized as yield per unit area, expressed in qtl/ha and was calculated by

$$\text{Land productivity} = \frac{\text{Total quantity of crop produced (qtl)}}{\text{Total area under the crop (ha)}}$$

Input productivity. Input productivity was considered as output per unit of input used and was expressed as the ratio of gross value of output to the total variable cost.

$$\text{Input productivity} = \frac{\text{Total value of the output}}{\text{Total variable cost}}$$

Crop yield security index (CYSI). Crop yield security was operationalized as the extent to which farmers managed the crop so as to withstand external crises due to excess or shortage of rainfall, outbreak of pest attack, non-availability of inputs and inability of the farmers to take up timely operations.

The index was computed as the ratio of yield obtained to yield expected, expressed in per cent. Expected yield was the value given in the package of practices.

$$CYSI = \frac{\text{yield obtained}}{\text{expected yield}} \times 100$$

The minimum and maximum possible scores were 0 and 100 respectively.

Input self-sufficiency index (ISSI). Input self-sufficiency was operationalized as the extent to which the farmer was able to meet the input requirement from own resources rather than by purchase. It was taken as the ratio of value of owned inputs to the total value of inputs used in the farming. Value of inputs was worked out at the prevailing rates in the area at the time of data collection. The index was calculated by the formula

$$ISSI = \frac{\text{Value of owned input}}{\text{Total value of input used}} \times 100$$

Theoretically, an ISSI value of '0' would indicate that the farmer was completely depen-dent on external inputs while a value of 100 would indicate the farmer's complete dependence on owned inputs.

food sufficiency (FFS). Family food sufficiency was operationalized as the extent to which the farm family possessed sufficient food grain required for family consumption. It was calculated as the ratio (multiplied by 100) of the quantity of food available for consumption to that required for the entire year:

$$FFS = \frac{\text{Quantity of food available for consumption}}{\text{Quantity of food required for consumption}} \times 100$$

A value <100 indicated food insufficiency and one of 100 or more sufficiency or surplus.

Calculation of unit values. The six components measured were expressed in different units. Hence, all values were converted into unit values by using simple range and variability as given below.

$$U_{ij} = \frac{Y_{ij} - \text{Min } Y_j}{\text{Max } Y_j - \text{Min } Y_j}$$

where Y_{ij} = value of the i^{th} farmer on j^{th} component,

Min Y_j = minimum score on the j^{th} component,

Max Y_j = maximum score on the j^{th} component,

U_{ij} = unit value of the i^{th} farmer on the j^{th} component.

These unit values ranged from 0 to 1. When Y_{ij} is minimum, unit value is 0 and when Y_{ij} is maximum, unit value is 1.

3.9.3 Grouping the components into dimensions of sustainability

Principal component analysis was further utilized to group these six components into some well-defined dimensions (groups of variables). The groupings supported by the latent vec-tors of the first three principal components denote variables that go together. Economic indi-cators like input productivity, crop yield security and land productivity dominated the first prin-cipal component. The second principal component was characterized by ecological indicators such as nutrient management. The other two components fall in between these two principal components and have been conveniently grouped under the social dimension.

COMPONENTS	PRIN 1	PRIN 2	PRIN 3
Input productivity	0.409	–0.283	0.172
Crop yield security	0.402	–0.119	–0.386
Land productivity	0.393	–0.367	0.010
Family food sufficiency	0.356	–0.224	0.235
Input self sufficiency	–0.154	0.238	0.795
Nutrient management	0.309	0.444	0.107

After grouping the components into three dimensions, the respective indices of the dimensions were obtained.

$$\text{Ecological Safety index for the } i^{th} \text{ farmer} = \frac{UNMI_i \times SV}{\text{scale value of particular component (6.85)}} \times 100$$

where $UNMI_i$ = Nutrient Management Index for i^{th} farmer converted into its unit value

SV = Scale Value

$$\text{Economic Security index for the } i^{th} \text{ farmer} = \frac{UCYSI_i \times SV + ULPI_i \times SV + UIPI_i \times SV}{\text{Total scale value of these components (14.04)}} \times 100$$

where $UCYSI_i$ = Crop Yield Security Index for i^{th} farmer converted into its unit value,

$ULPI_i$ = Land Productivity of i^{th} farmer converted into its unit value,

$UIPI_i$ = Input Productivity of i^{th} farmer converted into its unit value,

SV = Scale Value.

$$\text{Social Stability Index for } i^{th} \text{ farmer} = \frac{ISSI_i \times SV + FFS_i \times SV}{\text{Total scale value of these components}} \times 100 \qquad (7.70)$$

where $ISSI_i$ = Input Self Sufficiency Index of i^{th} farmer converted into its unit value,

$FFSI_i$ = Family Food Sufficiency Index of i^{th} farmer converted into its unit value,

SV = Scale Value.

3. 9.4 Composite index of sustainability

The unit values for each farmer were then multiplied by respective component scale values, summed, divided by total scale value and multiplied by 100 to get sustainability index.

$$SI_i = \frac{\sum U_{ij} \cdot S_j}{\text{Total scale value}} \times 100 \qquad j = 1.....6$$

where SI_i = sustainability index of i^{th} farmer,

U_{ij} = unit value of i^{th} farmer on j^{th} component,

S_j = scale value of j^{th} component,

Total scale value = 28.65.

Individual maps of the ten sustainability indicators for each watershed were prepared from the data with the help of a Geographic Information System.

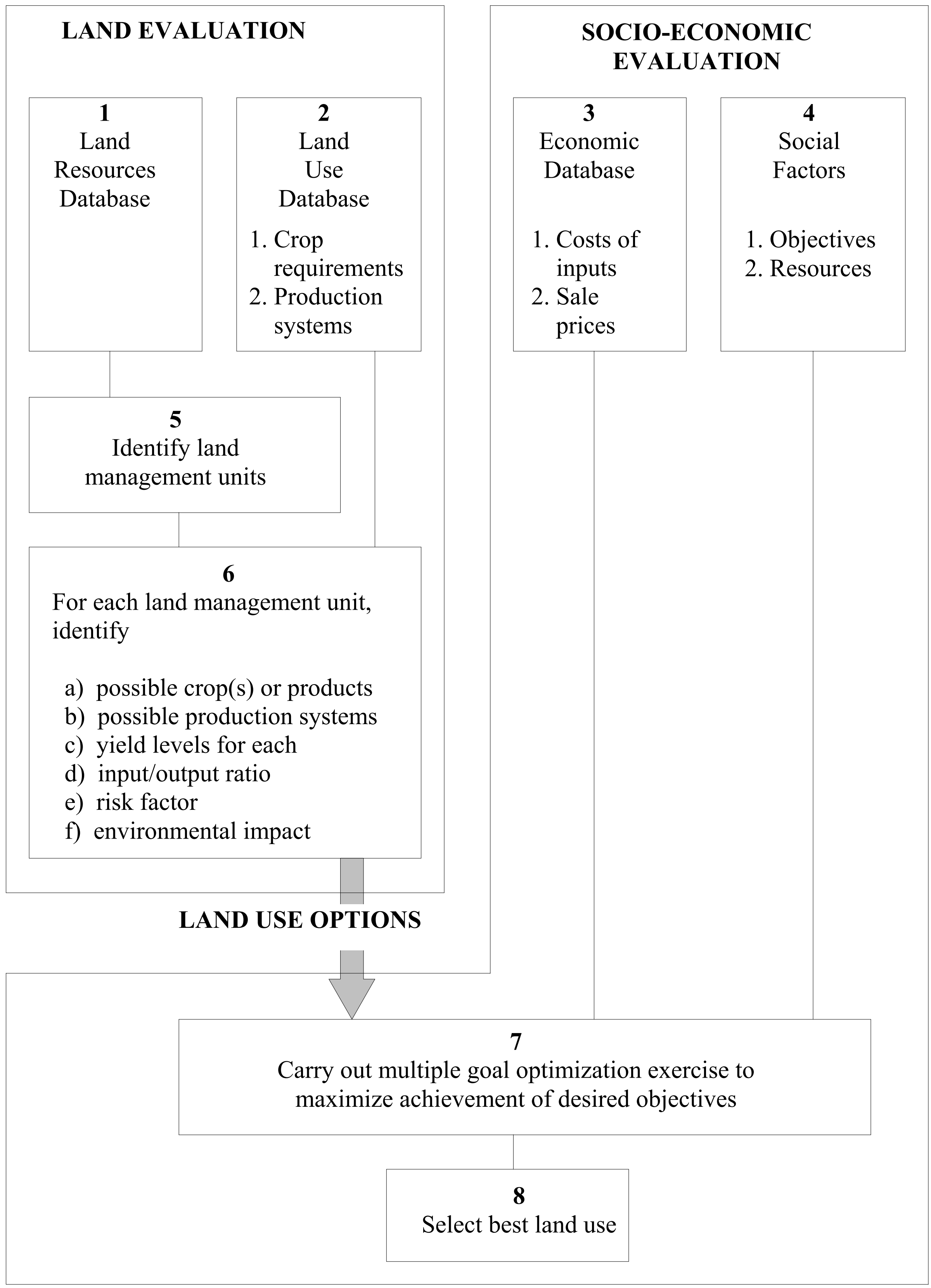

Fig. 3.1 Decision support system for land-use planning.

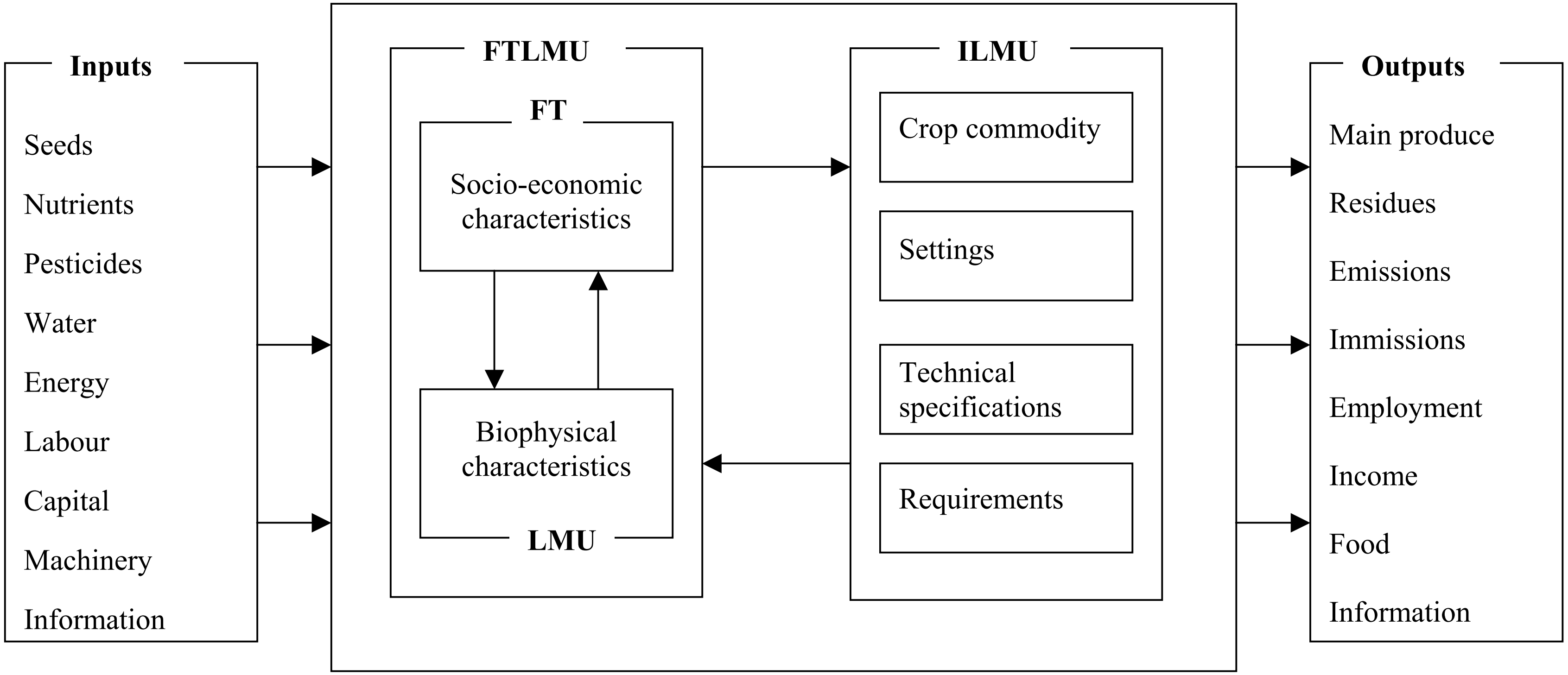

Fig. 3.3 Schematic diagram of an integrated land-use system.

4. RESULTS AND DISCUSSION

4.1 Biophysical Accounting of Garakahalli Microwatershed

4.1.1 Generalities

Garakahalli microwatershed is located in Garakahalli village, Channapatna taluk of Ban-galore rural district, Karnataka and is 25 km east of Channapatna town. It is situated between 12°31′15″ to 12°31′36″ N latitude and 77°7′05″ to 77°7′54″ E longitude. The area of the water-shed is 527 ha.

The watershed falls in agroclimatic zone 5 (eastern dry zone) of Karnataka. Garakahalli area receives a mean annual rainfall of 821.0 mm with bimodal distribution. May and September are the two peak rainy months. The frequency of drought is 1 to 2 in a decade. The length of the main growing season is 120 to 150 days during August to November. The mean maximum temp-erature during July to November ranges from 26.3 to 27.6 °C and mean minimum temperature remains between 17.2 and 19.2 °C so that there is no limitation for most of the crops grown.

The watershed is on granite and granite-gneiss over which residual soils have formed. The area consists of very gently sloping and gently sloping lands with elevation ranging from 895 m to 900 m above MSL. The slope ranges from <1 per cent to about 8 per cent. The area is drained to a stream, which joins the Garakahalli tank.

Most of the area is under cultivation; hence there is very little natural vegetation. *Ficus* spp., *jali*, neem, *Lantana* spp., eucalyptus, tamarind, and pongamia are found along the streams and on bunds.

The area of the microwatershed is presently under rainfed agriculture. The important crops grown are mulberry, groundnut, finger millet, horsegram, and sorghum. Irrigation from tubewells has enabled cultivation of irrigated mulberry, banana and rice.

4.1.2 The soils

Fourteen soil series were identified in Garakahalli watershed. From detailed survey, 85 phases of these series were mapped on the basis of variations in surface soil texture, slope and erosion status. The soil series map of the microwatershed is presented in Fig. 4.1 and the detailed soil map of phases in Fig. 4.2.

Series A (area 2.08 ha, 0.39%). Soils of series A are very shallow (<25 cm deep), welldrained to somewhat excessively drained, dark brown to dark reddish brown, gravelly sandy loam soils with 60 to 70 per cent gravel and stones. They are formed on weathered granite, occur on moderately sloping and moderately steeply sloping (10–25% slope) mounds and are moderately eroded. They are mostly under grasses and scrub forest. One phase of series A was mapped in the watershed.

Series B (area 7.35 ha, 1.39%)*.* Soils of series B are moderately shallow (50–75 cm deep), welldrained soils with dark red to red sandy clay loam to sandy loam surface soils and dark red to dark reddish brown sandy clay to sandy clay loam subsoils with 5–30 per cent quartz gravel and are formed on weathered granite. They occur on very gently sloping (1–3% slope) uplands, are slightly eroded and are generally cultivated to rainfed crops such as finger millet, *Dolichos lablab,* niger and fodder sorghum.. Two phases of series B were mapped in the watershed.

Series C (area 50.61 ha, 9.61%). Soils of series C are moderately deep (75–100 cm deep), welldrained soils with yellowish red to dark reddish brown, sandy loam to loamy sand and sandy clay loam surface soils and dark brown to dark red, sandy clay to clay subsoils with 0–30 per cent quartz gravel and are formed on weathered granite. They occur on very gently sloping and gently sloping (1–5% slope) uplands. These soils are slightly or moderately eroded and are mostly cultivated to rainfed *kharif* crops. Eight phases of series C were mapped in the watershed.

Series D (area 8.61 ha, 1.64%). Soils of series D are moderately deep (75–100 cm) and well-drained, and have dark red to red, loamy sand or sandy loam surface soils and dark red, gravelly clay or clay subsoils with 10–70 per cent quartz gravel between 15 and 60 cm depth. They occur on very gently sloping and gently sloping (1–8% slope) uplands and are formed on weathered granite. These soils are slightly eroded and are mostly cultivated to rainfed *kharif* crops. Four phases of series D were mapped in the watershed.

Series E (area 21.87 ha, 4.14%). Soils of series E are moderately deep (75–100 cm) and well-drained, and have reddish brown to red and dark red, sandy loam or sandy clay loam surface soils and strong brown to dark red gravelly sandy clay loam subsoils with 15–35 per cent quartz gravel in the subsoil. They occur on very gently sloping and gently sloping (1–8% slope) uplands and are formed on weathered granite. These soils are slightly eroded or moderately eroded and are generally cultivated to rainfed *kharif* crops. Six phases of series E were mapped in the watershed.

Series F (area 38.00 ha, 7.21%). Soils of series F are deep (100–150 cm) and welldrained, and have strong brown to red, loamy sand, sandy loam or sandy clay loam surface soils and brown to yellowish red and dark red sandy clay or gravelly sandy clay subsoils with more than 35 per cent quartz gravel. They are formed on weathered granite and occur on very gently sloping (1–3% slope) uplands. These soils are slightly eroded. They are generally cultivated to rainfed *kharif* crops, but at places are irrigated from borewells for banana and coconut, and vegetables such as brinjal. Four phases of series F were mapped in the watershed.

Series G (area 27.03 ha, 5.13%). Soils of series G are deep (100–150 cm) and welldrained, and have dark reddish brown to yellowish red, loamy sand, sandy loam or sandy clay loam surface soils and reddish brown to dark red, gravelly sandy clay loam subsoils with 15–40 per cent quartz gravel. They occur on very gently sloping to moderately steeply sloping (1–30% slope) uplands. They are formed on weathered granite and are slightly eroded or moderately eroded. These soils are under grass and scrub forest, but at places are cultivated to rainfed *kharif* crops. Ten phases of series G were mapped in the watershed.

Series H (area 48.59 ha, 9.22%). Soils of series H are deep (100–150 cm) and welldrained, and have dark brown to red, loamy sand, sandy loam or sandy clay loam surface soils and dark red to dark reddish brown, gravelly sandy clay loam or gravelly sandy clay subsoils with 15–60 per cent quartz gravel. They occur on very gently sloping to moderately sloping (1–15% slope) uplands, are formed on weathered granite and are slightly eroded or moderately eroded. These soils are generally cultivated to rainfed crops, but at places are under grass. Fifteen phases of series H were mapped in the watershed.

Series I (area 29.96 ha, 5.68%). Soils of series I are deep (100–150 cm) and welldrained, and have dark brown to dark reddish brown, sandy loam, sandy clay loam or sandy clay surface soils and dark reddish brown, sandy clay loam subsoils. They occur on very gently sloping or on gently sloping (1–8% slope) uplands, are formed on weathered granite, and are slightly eroded or moderately eroded. These soils are cultivated to rainfed *kharif* crops. Ten phases of series I were mapped in the watershed.

Series J (area 10.66 ha, 2.02%). Soils of series J are deep (100–150 cm) and welldrained, and have dark brown to dark reddish brown, sandy loam, sandy clay loam or sandy clay surface soils and reddish brown to dark brown, sandy clay loam and sandy clay subsoils. They occur on very gently sloping to moderately sloping (1–15% slope) lands, are formed on weathered granite and are slightly or moderately eroded. These soils are cultivated to rainfed *kharif* crops. Three phases of series J were mapped in the watershed.

Series K (area 146.38 ha, 27.76%). Soils of series K are very deep (>150 cm) and welldrained, and have dark brown to red and reddish brown, loamy sand, sandy loam or sandy clay loam surface soils and dark red to dark reddish brown, sandy clay loam, sandy clay and gravelly sandy clay loam subsoils. They occur on very gently sloping to moderately sloping (1–15% slope) uplands, are formed on weathered granite and are slightly or moderately eroded. These soils are mostly cultivated to rainfed *kharif* crops. Fourteen phases of Series K were mapped in the watershed.

Series L (area 8.10 ha, 1.53%). Soils of series L are very deep (>150 cm)) and welldrained, and have strong brown to reddish brown, loamy sand or sandy loam surface soils and dark red to dark reddish brown, gravelly sandy clay loam or gravelly sandy clay subsoils. They occur on gently sloping or moderately sloping (3–15% slope) uplands, are developed on granite and are moderately eroded. These soils are mostly cultivated to rainfed *kharif* crops. Two phases of series L were mapped in the watershed.

Series M (area 11.38 ha 2.16%). Soils of series M are very deep (>150 cm) and welldrained or moderately well drained, and have strong brown to dark brown, sandy loam surface soils and dark brown to dark reddish brown, sandy loam and sandy clay loam subsoils. They occur on very gently sloping (1–3% slope) uplands, are formed on weathered granite and are slightly eroded. These soils are cultivated to rainfed *kharif* crops and at places to crops irrigated from borewells. Two phases of series M were mapped in the watershed.

Series N (area 30.07 ha, 5.71%). Soils of series N are very deep (>150 cm) and moderately well drained or welldrained, and have reddish brown to dark reddish brown, loamy sand to sandy loam and sandy clay loam surface soils and yellowish red to dark reddish brown and dark red, gravelly sandy loam to sand and sandy loam to sandy clay loam stratified subsoils. They are formed on weathered granite, occur on very gently sloping uplands and fringes of valleys with slopes of 1–3 per cent and are slightly eroded. They are cultivated to rainfed as well as irrigated crops. Four phases of series N were mapped in the watershed.

4.1.3 Current soil fertility

The available-nitrogen status was low in 78 per cent of the area of the watershed. Avail-able phosphorus level was low in 37.9 per cent and medium in 36.89 per cent of the area. Avail-able potash levels were also mostly medium (46.55%) and low (23.55%). More than half the area (51.81%) had soils deficient in available zinc, but the soils were mostly adequate in avail-able iron, manganese and copper.

4.1.4 Land capability

The soil map units in the watershed were grouped under five land capability classes, nine land capability subclasses and 13 land capability units. Of the total area of 482.7 ha in the watershed, about 430 ha (81.6%) was suitable for agriculture and about 53 ha (10%) was not suitable for agriculture but well suited to forestry, pasture, agri-horti-silvipastoral system, quarry-ing, as habitat for wild life and for recreation. Of the area suitable for agriculture, about 342 ha (65%) area had good cultivable lands (class II) with minor soil and topography (slope) problems, about 46 ha (8.8%) area had moderately good cultivable lands with moderate problems of soil and erosion, and about 42 ha (8%) area had fairly good cultivable lands with severe problems of erosion, gravelliness, stoniness and moderate slopes.

4.1.5 Interpretation of suitability of soil map units for different crops

The major crops grown in Garakahalli watershed in order of area were horsegram (24.19%), groundnut (20.05%) and finger millet (7.57%) under rainfed conditions and, under irrigated conditions, finger millet (19.7%), rice (18.4%), banana (13.53%), mulberry (7.5%) and coconut (2.2%). The land suitability assessment of soil units for groundnut, finger millet, banana, mulberry and coconut is presented below.

Finger millet. The suitability evaluation (Fig. 4.3) grouped the soils into highly suitable (4.7%), moderately suitable (76.22%), marginally suitable (1.53%) and not suitable (1.0%).

Groundnut*.* The evaluation grouped the soils into highly suitable (6.4% area), moderately suitable (66.2%), marginally suitable (9.96%) and not suitable (1.0%).

Mulberry*.* The soils were grouped into moderately suitable (69.40%), marginally suitable (1.39%) and not suitable (12.78%). The area grouped as not suitable had very severe limitations of depth (<50 cm) or gravelliness (>35%).

Banana*.* Slightly more than 80 per cent area was moderately suitable, 7.09 per cent area mar-ginally suitable and 12.78 per cent area was not suitable due to severe limitations of subsoil gravelliness (>35% gravel) or depth (<50 cm).

Coconut*.* Nearly 55 per cent area was highly suitable, 41.55 per cent moderately suitable, 16.77 per cent marginally suitable and about 2.07 ha (0.39%) not suitable due to depth limitation.

4.2 Biophysical Accounting of Nalatwad Microwatershed

4.2.1 Generalities

Nalatwad microwatershed is located in Nalatwad village, Muddebihal taluk of Bijapur dis-trict, Karnataka and is about 20 km south east of Muddebihal town. It is situated between 16°13′30″ to 16°13′45″ N latitude and 76°16′05″ to 76°16′15″ E longitude. The area is 560 ha.

The microwatershed falls in agroclimatic zone 3 (northern dry zone) of Karnataka State. Nalatwad area receives a mean annual rainfall of 616.5 mm. Most of the rainfall is received during the southwest monsoon in June–October. The length of growing period is 115–120 days.

The microwatershed is on granite bedrock on which alluvial black soils derived from basalt have formed. The area consists of gently sloping plain lands with elevation ranging from 515 m to 530 m above MSL. The slope ranges from less than 1 per cent to about 5 per cent and is generally up to 3 per cent. The general slope is north to south. The area is drained by the Arehalla stream, which joins the Krishna River further south..

Most of the area was under cultivation; hence there was very little natural vegetation. Along the streams and on the bunds most of the vegetation was xerophytic trees and dry deci-duous plants. Acacia species, cactus, agave and grasses were found. The cultivated area of the microwatershed was all under rainfed agriculture. The important crops grown were sorghum, sunflower, bengal gram and wheat.

4.2.2 The soils

Six soil series were identified in the watershed These series were mapped as 19 phases on the basis of variations of slope and erosion status The soil series map of the microwatershed is presented in Fig. 4.4 and the detailed soil map showing phases in Fig. 4.5.

Soil series A (area 56.93 ha, 10.18%). Soils of series A are shallow (25–50 cm) and have very dark greyish brown, slightly calcareous, clay surface and subsoil horizons with many calcium carbonate concretions. These are alluvial soils of basalt origin, occur on very gently to gently sloping uplands with 1–5 per cent slope and undergo moderate to severe sheet erosion. They are under cultivation to *rabi* sorghum, *tur* and pearl millet. These soils have moderate to severe sheet erosion. Three phases of A series were mapped in the watershed:

Soil series B (area 56.13 ha, 10.03%). Soils of series B are moderately shallow (50–75 cm) and have very dark greyish brown, slightly calcareous, clay surface and subsoil horizons with calcium carbonate concretions. They occur on very gently to gently sloping uplands with 1–5 per cent slope and are moderately or severely eroded. These soils are cultivated to *rabi* sorghum, *tur*, pearl millet, green gram and sunflower. Three phases of series B were mapped in the watershed.

Soil series C (area 81.61 ha, 14.58%). Soils of series C are moderately deep (75–100 cm), strongly calcareous soils and have very dark greyish brown, clay surface horizons and very dark greyish brown to brown, clay subsoil horizons with well-developed angular blocky structure and slickensides. They occur on very gently to gently sloping uplands with 3–5 per cent slope, are moderately to severely eroded and are under cultivation to *rabi* sorghum, *tur*, pearl millet, green gram and sunflower. Three phases of series C were mapped in the watershed:

Soil series D (area 79.14 ha, 14.15%)*.* Soils of series D are deep (100–150 cm) and have very dark greyish brown, clay surface horizon followed by very dark greyish brown to brown, calcareous, clay subsoil horizons with intersecting slickensides. They occur on nearly level to gently sloping uplands with up to 5 per cent slope and are slightly to severely eroded. Crops grown are *rabi* sorghum, *tur,* pearl millet*,* pulses and sunflower. Four phases of series D were mapped in the watershed.

Soil series E (area 37.16 ha, 6.65 %). Soils of series E are deep (100–150 cm) and have very dark greyish brown, clay surface horizon followed by very dark greyish brown to brown, very dark grey and dark brown, calcareous, clay subsoil horizons with intersecting slickensides. They occur on nearly level to gently sloping(1–5% slope) uplands, are moderately eroded or severely eroded and are cultivated to *rabi* sorghum, *tur* and sunflower. Two phases of series E were mapped in the watershed:

Soil series F (area 241.70 ha, 43.17%). Soils of series F are very deep (>150 cm) and have very dark greyish brown, clay surface horizon followed by very dark greyish brown and dark brown calcareous, clay subsoil horizons with intersecting slickensides. They occur on nearly level to gently sloping (1–5% slope) uplands, are slightly to severely eroded and are cultivated to *rabi* sorghum, pulses and sunflower. Four phases of series F were mapped in the watershed.

4.2.3 Current soil fertility status

The entire area of the watershed showed low levels of nitrogen (<280 kg ha^{-1}). Phos-phorus levels were low to medium (<57 kg P_2O_5 ha^{-1}) in about 74 per cent and potassium levels high (>337 kg K ha^{-1}) in almost 94 per cent of the area. The soils of the watershed were almost all deficient in available zinc (< 0.6 ppm). The levels of available iron were deficient (<4.5 ppm) in about 57 per cent of the area.

4.2.4 Land capability

The soils of the watershed were classified into three land capability classes. Class II land covered nearly 387 ha, class III land 43.51 ha and class IV land 122 ha.

4.2.5 Interpretation of soil units for land suitability for crops

Land suitability of the 19 soil map units of the watershed was assessed for the four main crops grown in the watershed.

Sorghum. Almost 99 per cent of the area was marginally suitable for sorghum. The spatial distri-bution of the suitability units is presented in Fig. 4.6.

Sunflower*.* Nearly 60 per cent of the area was marginally suitable for sunflower and about 40 per cent not suitable

Bengal gram*.* About 70 per cent was marginally suitable for bengal gram and 29 per cent not suitable.

Wheat*.* Lands marginally suitable for wheat covered 99 per cent of the area.

4.3 Biophysical Accounting of Pettamanurahatti Microwatershed

4.3.1 Generalities

Pettamanurahatti microwatershed is located in Challakere taluk in Chitradurga district, Karnataka. It is situated between 14°19′15″ and 14°20′39″ North latitude and 76°34′22″ and 76°36′20″ East longitude and has an area of 592.37 hectares.

The microwatershed falls in agroclimatic zone 4 (central dry zone) of Karnataka. Annual rainfall ranges from 350 mm to 525 mm (average 466 mm) spread over about 30 rainy days. About 54 per cent of the rainfall is received during the southwest monsoon (June–September) and 32 per cent during the northeast monsoon.

Major rock formations in the microwatershed are Archaean Peninsular Gneiss and undif-ferentiated crystalline granites. The area consists of undulating to gently sloping uplands and lowlands.

Natural vegetation is of dry deciduous xerophytic and scrub types (*Acacia* spp., *Cassia* spp., *Lantana camera* and *Prosopis juliflora*) with stunted growth and open canopy. The natural vegetation is degraded.

The most widespread rainfed crop grown was groundnut (434 ha), followed by pearl millet. The prominent irrigated crops were finger millet, rice and sorghum.

4.3.2 The soils

Sixteen soil series were identified in the watershed. These series were mapped as 92 phases on the basis of variations of surface-soil texture, slope and erosion status. The soil series map of the watershed is presented in Fig. 4.7 and the detailed map showing phases in Fig. 4.8.

Soil series A (area 12.22 ha 2.06%). Soils of series A are very shallow and welldrained, and have strong brown, gravelly loamy sand and gravelly sandy loam surface soil followed by strong brown, gravelly sandy clay loam subsoil developed on weathered granite gneiss. The gravel content ranges from 40 to 75 per cent. These soils occur on gently sloping and very gently sloping uplands. Four phases of series A were mapped in the watershed.

Soil series B (area 34.73 ha, 5.86%). Soils of series B are shallow and welldrained, and have dark brown, gravelly sandy loam, (gravelly loamy sand, sandy loam and sandy clay loam) calcareous surface soil with 15–20 per cent quartz gravel followed by dark brown and strong brown, gravelly sandy clay loam calcareous subsoil with 40–60 per cent quartz gravel. They are formed on weathered granite-gneiss mixed with calcium carbonate and occur on very gently sloping uplands. Nine phases of series B were mapped in the watershed.

Soil series C (area 20.01 ha, 3.38%). Soils of series C are shallow and welldrained, and have strong brown, gravelly loamy sand/loamy sand surface soil generally with 40–75 per cent quartz gravel, occasionally with <15 per cent gravel, followed by dark yellowish brown to reddish brown, gravelly sandy loam subsoil developed on weathered granite-gneiss. They occur on very gently sloping uplands. Four phases of series C were mapped in the watershed.

Soil series D: area 47.68 ha (6.64%). Soils of series D are shallow and welldrained, and have strong brown, gravelly loamy sand (loamy sand, gravelly sandy loam and gravelly sandy clay loam) surface soil with 15–35 per cent gravel (rarely <15%) and yellowish red to dark red, gravel-ly sandy loam to gravelly sandy clay loam subsoil with 35–50 per cent gravel formed on weath-ered granite-gneiss. They occur on very gently sloping to gently sloping (1–5% slope) uplands. Eight phases of series D were mapped in the watershed.

Soil series E: area 17.14 ha (2.89%). Soils of series E are shallow and welldrained, and have dark red, gravelly sandy clay loam (gravelly loamy sand, gravelly sandy loam) surface soil with 15 to 35 per cent gravel followed by dark reddish brown to dark red gravelly sandy clay loam subsoil with 50–75 per cent gravel formed on weathered granite-gneiss. They occur on very gently sloping and gently sloping (1–3% slope) uplands. Seven phases of series E were mapped in the watershed.

Soil series F(area 24.83 ha, 4.19%). Soils of series F are moderately shallow and welldrained, and have yellowish red, gravelly loamy sand (loamy sand, gravelly sandy loam and gravelly sandy clay loam) surface with up to 35 per cent gravel followed by dark red , gravelly sandy clay loam subsoil with 40–75 per cent gravel. They are formed on weathered granite-gneiss and occur on very gently sloping and gently sloping (1–5% slope) uplands. Five phases of series F were mapped in the watershed.

Soil series G (area 196.55 ha, 33.18%). Soils of G series are moderately shallow and well-drained, and have dark brown, gravelly sandy loam (loamy sand, gravelly sandy loam, sandy clay loam) surface soil with up to 35 per cent gravel followed by dark red, gravelly sandy clay loam subsoil with 35–75 per cent gravel. They are formed on weathered granite-gneiss and occur on rolling to undulating uplands with slopes ranging from 1 to 10 per cent. Thirteen phases of series G were mapped in the watershed.

Soil series H (area 6.18 ha, 0.88%). Soils of series H are moderately shallow and well drained, and have dark brown, gravelly loamy sand (sandy loam) surface soil with up to 35 per cent gravel followed by reddish brown and dark reddish brown, gravelly sandy clay loam subsoil. They are formed on weathered granite-gneiss and occur on undulating uplands. Two phases of series H were mapped in the watershed.

Soil series I (area 30.55 ha, 5.16%). Soils of I series are moderately shallow and welldrained, and have dark yellowish brown calcareous gravelly sandy loam (gravelly loamy sand, loamy sand, gravelly sandy clay loam and sandy clay loam) surface soil with 15–20 per cent gravel followed by yellowish brown to dark reddish brown, calcareous gravelly sandy clay loam subsoil with 35–65 per cent gravel underlain by a calcareous C horizon. They occur on gently sloping and very gently sloping uplands. Nine phases of series I were mapped in the watershed.

Soil series J (area 67.49 ha, 11.4%). Soils of series J are moderately deep and welldrained, and have dark brown to dark reddish brown, gravelly sandy loam (gravelly loamy sand and gravelly sandy clay loam) surface soil with 15–40 per cent gravel followed by dark reddish brown to dark red, gravelly sandy clay loam subsoil with 35–60 per cent gravel. They are formed on granite-gneiss and occur on undulating lands and gently sloping to very gently sloping uplands. Eleven phases of series J were mapped in the watershed.

Soil series K (area 31.51 ha, 5.32%). Soils of series K are moderately deep and welldrained, and have dark brown, gravelly sandy loam (gravelly loamy sand, sandy loam or sandy clay loam) surface soil with up to 40 per cent gravel followed by dark reddish brown to red, gravelly or non-gravelly sandy clay loam subsoil with up to 40 per cent gravel underlain by a cemented calcareous C horizon. They occur on undulating and gently sloping lands. Six phases of series K were mapped in the watershed.

Soil series L (area 29.09 ha, 4.9%). Soils of series L are deep and welldrained, and have dark yellowish brown, loamy sand (sandy loam or sandy clay loam) surface soil followed by reddish brown to red, calcareous sandy clay loam subsoil layers. They are formed in colluvio-alluvium and occur on nearly level to very gently sloping (up to 3% slope) lower portions of uplands. Four phases of series L were mapped in the watershed.

Soil series M (area 9.82 ha, 1.66%). Soils of series M are deep and welldrained, and have dark brown, gravelly loamy sand surface (gravelly sandy clay loam) with 15–35 per cent gravel fol-lowed by reddish brown to dark red, gravelly sandy clay loam subsoil with 45–55 per cent gravel. They are formed on granite-gneiss and occur on very gently sloping and gently sloping lands. Two phases of series M were mapped in the watershed.

Soil series N (area 13.33 ha, 2.25%). Soils of series N are deep and welldrained, and have dark reddish brown, sandy loam (sandy clay loam) surface soil followed by dark reddish brown, sandy clay loam to gravelly sandy clay subsoil. They are formed on weathered granite-gneiss and occur on nearly level and very gently sloping lands. Three phases of series N were mapped in the watershed.

Soil series O (area 9.03 ha, 1.53%). Soils of series O are deep and somewhat excessively drained or welldrained, and have yellowish brown to strong brown loamy sand surface soil followed by stratified, yellowish brown to yellowish red loamy sand to sandy clay loam subsoil. They occur on nearly level and very gently sloping lowlands. Four phases of series O were mapped in the watershed.

Soil series P (area 39.99 ha, 6.75%). Soils of P series are very deep and welldrained, and have reddish brown to dark yellowish brown, calcareous loamy sand to sandy loam surface soils followed by stratified layers of yellowish brown to dark reddish brown, loamy sand to sandy clay loam subsoil underlain by saline patches. They are formed in alluvium on nearly level to very gently sloping lowlands. The series was mapped as one unit.

4.3.3 Current soil fertility

Available nitrogen status was low in nearly 98 per cent of the area of the watershed. Phosphorus levels were low to medium in about 45 per cent and potassium levels high in almost 74 per cent of the area. The soils of the watershed showed deficiency of zinc in 86 per cent of the area and of iron in 69 per cent of the watershed.

4.3.4 Land capability

The soils of the watershed were grouped into five land-capability classes. About 92 per cent of the area was suitable for agriculture, the remaining 8 per cent well suited to forestry, pasture, silvi-pastoral system, quarrying, and wildlife and recreation.

4.3.5 Interpretation of soil units for land suitability for crops

Based on the existing cropping pattern in the watershed, land suitability assessment was carried out for groundnut, pearl millet *(bajra)*, finger millet *(ragi)* and sorghum *(jowar)*.

Groundnut. But for an area of 12.22 ha (2.06%) that was not suitable, the entire watershed was marginally suitable for groundnut cultivation (Fig. 4.9). The chief limitation was climate (aridity).

Pearl millet. Barring 12.22 ha of land that was unsuitable for growing pearl millet the remainder of the cultivable area was moderately or marginally suitable for the crop.

Finger millet. All the area of the watershed (except for 12.22 ha) was marginally suitable for growing finger millet.

Sorghum. As for the other crops above, 12.22 ha was unsuitable for sorghum. The remainder of the watershed was marginally suitable for the crop.

4.4 Biophysical Accounting of Molahalli Microwatershed

4.4.1 Generalities

Molahalli microwatershed, covering Molahalli, Halasinakatte, Manayadibail, Korala, Bit-teri and Mavinakatte villages of Molahalli panchayat, is located 20 km west of Kundapur in Kun-dapur taluk, Udupi district, Karnataka. It is situated between 13°55′20″ to 13°36′55″ N latitude and 74°47′30″ to 74°4910′15″ E longitude. The area is 463 ha.

The watershed falls in agroclimatic zone 10 (coastal zone) of Karnataka. Molahalli receives a mean annual rainfall of 3787 mm. Most of the rainfall is received during the southwest monsoon in June–August. Considerable flooding and runoff occurs in this season. The length of growing period is 210 to 236 days.

The rock types in the microwatershed are granite-gneiss, sandstone, laterite and recent alluvium. Granite-gneiss occurs in the eastern uplands of the watershed and sandstone in the western uplands. Laterite is found in the lower uplands adjoining valleys. Valley soils are formed in recent alluvium. The watershed has an elevation of 10 to 20 m above MSL and consists of one major valley with branches. The watershed is drained by the Dasanakattehole stream that joins the Haladi river at the northern border of the watershed.

The valley lands were all under cultivation and almost devoid of natural vegetation. The uplands had mixed semi-evergreen forest with dense canopy and impoverished under-storey because of continual fuelwood collection. The species were *Hopea parviflora (kiralu bogi),* teak *(Tectona grandis)*, jack *(Artocarpus hirsuta, Artocarpus heterophyllus)*), *Terminalia tomentosa (mathi), Terminalia benicula (marva),* sandalwood *(Santalum album)*, *Acacia catechu (kachu), Azadirachta indica (bevu), Eugenia jambulana (nerale), Sapindus marginatur (auntwala), Ficus indica (arali), Terminalia arjuna (holemathi), Bombax malabaricum (buruga), Terminalia catapa (badami)* and mango *(Mangifera indica).*

Forest land covered 162 ha and cultivated (irrigated) area about 39 ha. Fallow/pasture lands covered about 9 ha. The major field crop grown was rice. The important plantation crops were arecanut, cashew and coconut.

4.4.2 The soils

Sixteen soil series were identified in the watershed. These series were mapped as 71 phases on the basis of variations of slope and erosion status. The soil series map of the water-shed is presented in Fig. 4.10 and the detailed soil map showing phases in Fig. 4.11.

Series A (area 2.44 ha, 0.53%). The soils of series A are very shallow (10–25 cm) and have yellowish red, gravelly sandy clay loam surface horizon followed by yellowish red and reddish brown, gravelly sandy clay loam Bt horizon developed on granite. They occur on gently and moderately sloping uplands with 3–10 per cent slope and have undergone severe erosion. The land use is forest. Two phases of series A were mapped in the watershed.

Series B (area 8.34 ha, 1.80%). Soils of series B are moderately shallow (50–75 cm) and have yellowish brown, clay loam, sandy loam, sandy clay loam or sandy clay surface horizon followed by yellowish red and dark red gravelly clay loam and gravelly clay subsoil layers. These soils are formed on granite and occur on nearly level to gently sloping uplands with slopes of 1–5 per cent with slight to moderate erosion. These lands are used for rainfed rice, after cutting and levelling. Otherwise, these lands are under forest. Four phases of series B were mapped in the watershed.

Series C (area 59.44 ha, 12.84%). Soils of series C are deep (100-150 cm) and have yellowish brown and brown, sandy clay loam, clay loam or sandy clay surface horizon followed by yellow-ish red to reddish brown, gravelly sandy clay loam to gravelly clay and clay subsoil layers. They are formed on granite and occur on very gently sloping to strongly sloping uplands with slight to severe soil erosion. Where adjoining valley lands, these lands are cultivated to rice. Rest of the area is under forest. Ten phases of series C were mapped in the watershed.

Series D (area 46.48 ha, 10.04%). Soils of series D are deep (100–150 cm) and have brown sandy loam, sandy clay loam and sandy clay surface horizon followed by yellowish red gravelly clay subsoil layers. These soils are formed on granite and occur on nearly level to strongly sloping uplands with slight to severe erosion. These lands are mostly under forest. Twelve phases of series D were mapped in the watershed.

Series E (area 3.61 ha, 0.78%). Soils of series E are very shallow (10–25 cm) and have yellowish red sandy loam to sandy clay loam surface horizon and yellowish red sandy clay loam subsoil. They are formed on sandstone and occur on nearly level to moderately sloping uplands with slight to severe erosion. These lands are under forest, cashew and fallow. Two phases of series E were mapped in the watershed.

Series F (area 2.21 ha, 0.48%). Soils of series F are moderately shallow (50–75 cm) and have yellowish red, gravelly sandy clay loam and sandy clay surface horizon followed by dark red, gravelly sandy clay sub-soil. They are formed on sandstone and occur on very gently sloping to gently sloping uplands with moderate to severe erosion. These lands are under forest. Two phases of series F were mapped in the watershed.

Series G (area 5.04 ha, 1.09%). Soils of series G are moderately shallow (50–75 cm) and have yellowish red sandy clay loam, clay loam and sandy clay surface horizon followed by dark red, clay subsoil. They are formed on sandstone and occur on very gently sloping to gently sloping uplands with moderate or severe erosion. These lands are under forest and cashew plantation. Three phases of series G were mapped in the watershed.

Series H (area 78.43 ha, 16.94%). The soils of series H are deep (100–150 cm) and have brown sandy loam or sandy clay loam surface horizon followed by dark red, sandy clay loam subsoil. They occur on nearly level to moderately sloping uplands with slight to severe erosion. These lands are under forest. Eight phases of series H were mapped in the watershed:

Series I (area 25.41 ha, 5.49%). Soils of series I are deep and have dark yellowish brown clay loam to sandy clay surface horizon and yellowish brown clay loam and clay subsoil layers. They are formed on granite and occur on nearly level and very gently sloping valleys with slight or moderate erosion and are under rice. Two phases of series I were mapped in the watershed.

Series J (area 26.02 ha, 5.62%). Soils of series J are very deep and have brown loam to sandy clay surface horizon followed by yellowish brown loam, sandy loam and clay loam subsoil. They are alluvial soils on nearly level to very gently sloping valley lands. These lands are cultivated to rice. Three phases of series J were mapped in the watershed.

Series K (area 9.86 ha, 2.13%). Soils of series K are very deep and have yellowish brown loamy sand to clay loam surface horizon followed by yellowish brown loamy sand subsoil layers. They occur on nearly level to very gently sloping valley lands and are cultivated to rice. Four phases of series K were mapped in the watershed.

Series L (area 61.03 ha, 13.18%). Soils of series L are very deep and have dark yellowish brown clay loam, sandy clay loam and sandy clay surface horizon and yellowish brown to dark yellowish brown, loam, sandy loam and clay loam subsoil layers. They are alluvial soils on nearly level to gently sloping valley lands with slight to moderate erosion. These lands are cultivated to rice. Five phases of series L were mapped in the watershed.

Series M (area 34.17 ha, 7.38%). Soils of series M are deep and have yellowish brown loam, sandy clay loam, clay loam and clay surface horizon followed by light yellowish brown to yellowish brown, sandy loam, loamy sand and sandy subsoil horizons. They are alluvial soils occurring on nearly level valley lands with slight erosion. These lands are cultivated to rice. Four phases of series M were mapped in the watershed.

Series N (area 6.46 ha, 1.40%). Soils of series N are very deep and have yellowish brown sandy clay loam to loam surface horizon followed by dark yellowish brown to yellowish brown and grey-ish brown sandy loam to clay loam and clay (with loamy sand) subsoil horizons. They occur on nearly level valley lands with slight erosion and are cultivated to rice. Three phases of soil series N were mapped in the watershed.

Series O (area 6.73 ha, 1.45%). Soils of series O are very deep and have dark yellowish brown loam surface soil and dark yellowish brown to dark brown, loam and clay loam subsoil horizons. They occur on nearly level valley lands with slight erosion, have high water table and are culti-vated to rice. Three phases of series O were mapped in the watershed.

Series P (area 62.67 ha, 13.54%). Soils of series P are very deep and have strong brown gra-velly sandy clay loam or gravelly clay surface horizon and yellowish red to dark red gravelly clay subsoil horizons. They are formed on laterite, occur on nearly level to gently sloping uplands with slight to severe erosion and are under forest. Four phases of series P were mapped in the watershed.

4.4.3 Current soil fertility

The available nitrogen status was medium in about 63 per cent, low in about 26 per cent and high in about 6 per cent of the area of the watershed. Phosphorus levels were low to medium in about 56 per cent and potassium levels low in almost 71 per cent of the area. The soils of the watershed showed deficiency of zinc in 52 per cent and adequacy in 43 per cent of the area. The levels of available iron, manganese and copper were adequate in most of the watershed.

4.4.4 Land capability

The soils of the watershed were classified into four land capability classes, three of them suitable for agriculture with varying degrees of limitations. Class II land covered 42 per cent, class III land 20 per cent and class IV 31 per cent area.

4.4.5 Interpretation of soil map units for land suitability for crops

Based on the existing cropping pattern in the watershed under irrigated conditions (rice 63% of the area; arecanut 18%) and rainfed conditions (cashew 12%), land suitability assess-ment of the soil map units of the watershed was carried out for irrigated rice and arecanut, and rainfed cashew.

Rice. Out of 463 ha total area of the watershed only 346.66 ha was assessed for land suitability for rice. Nearly 22 per cent area was moderately suitable, 35 per cent marginally suitable and 18 per cent not suitable (Fig. 4.12).

Arecanut. Out of 463 ha total area of the watershed 184.32 ha was assessed for land suitability for arecanut since cultivation of arecanut is confined to very gently sloping or nearly level valley fringes and terraced midlands. Nearly 94 ha (20.26% of the area) was highly suitable, 76 ha (16.48%) moderately suitable, 10 ha (2.13%) marginally suitable and 4 ha (0.95%) not suitable.

4.5 Socio-economic Features of Farm Households in the Watersheds

The socio-economic profile of farmers indicates their overall development. Variables such as age, composition of families, educational status, land holdings, assets, social mobility, etc., control the quality and nature of the farm households and the economic activities. The socio-economic status of the farm households in different watersheds is presented in Table 4.1. The total number of farm households was 251 in Garakahalli, 135 in Nalatwad, 231 in Petta-manurahatti and 147 in Molahalli microwatershed.

Age has immense relationship with adoption of new practices, the greater the age the less the flexibility and readiness to adopt new practices due to conservatism. The farmers were classified into 3 groupings based on age, namely, young (<30 years), middle-aged (30–50 years) and old (>50 years). Considering the age of the heads of the farm households, 150, 70, 139 and 69 farmers were middle-aged accounting for 60, 52, 60 and 47 per cent, respectively, in Garakahalli, Nalatwad, Pettamanurahatti and Molahalli watersheds. Ninety (36%), 59 (44%), 75 (32%) and 73 (50%) of the farmers were old and 11 (4%), 6 (4%), 17 (7%) and 5 (3%) of the farmers were young in the four watersheds. Majority of the farmers were middle-aged in all the watersheds and their adoption level may be lower compared to that of young aged farmers.

The farm households were categorized into small (<5 members), medium (5–10 mem-bers) and large (>10 members). Family size was small among 115 (46%), 24 (18%), 67 (29%) and 35 (24%) households in Garakahalli, Nalatwad, Pettamanurahatti and Molahalli watersheds, respectively, while 113 (45%), 92 (68%), 141 (61%) and 91 (62%) had medium family size and 23 (9%), 19 (14%), 23 (10%) and 21 (14%) were of large size, respectively, in Garakahalli, Nalat-wad, Pettamanurahatti and Molahalli microwatersheds. Most households had medium-sized family, indirectly reflecting the demand for labour. The larger the family size the greater the con-tribution of family labour in farming resulting in reduced demand for hired labour.

The educational status of the head of the family of the households in the watersheds was categorized into five groups, namely, illiterate, primary school literate, secondary school literate, high school literate and college literate. It was observed that most of the farmers were illiterate.

Table 4.1 Demographic characteristics of farm households in the watersheds

Particulars	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Age (years)								
Young (<30)	11	4.38	6	4.44	17	7.36	5	3.40
Middle aged (30–50)	150	59.76	70	51.85	139	60.17	69	46.94
Old (>50)	90	35.86	59	43.70	75	32.47	73	49.66
Family size (members)								
Small (<5)	115	45.82	24	17.78	67	29.00	35	23.81
Medium (5–10)	113	45.02	92	68.15	141	61.04	91	61.90
Large (>10)	23	9.16	19	14.07	23	9.96	21	14.29
Educational status								
Illiterate	174	69.32	54	40.00	161	69.70	69	46.94
Primary school	22	8.76	12	8.89	43	18.61	39	26.53
Secondary school	25	9.96	32	23.70	11	4.76	23	15.65
High school	20	7.97	14	10.37	12	5.19	11	7.48
College	10	3.98	23	17.04	5	2.16	5	3.40
Institutional membership								
Panchayat	6	2.39	2	1.48	12	5.19	7	4.76
Cooperative society	38	15.14	42	31.11	28	12.12	29	19.73
Non-governmental organization	—	—	—	—	29	12.55	0	0.00
Taluk development board	—	—	—	—	—	—	0	0.00
Youth club	—	—	—	—	—	—	0	0.00
Non-members	207	82.47	91	67.41	161	69.70	111	75.51
Social groups								

Particulars	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Scheduled Caste	5	1.99	4	2.96	—	—	5	3.40
Scheduled Tribe	6	2.39	7	5.19	180	77.92	1	0.68
Other Backward Classes	237	94.42	124	91.85	51	22.08	41	27.89
General	3	1.20	—	—	—	—	100	68.03
Total	251	100.00	135	100.00	231	100.00	147	100.00

Institutional membership reflects an individual's social mobility and status. But hardly one-fourth of the farmers in all the four watersheds were members of organizations. Only 6 (2%), 2 (1%), 12 (5%) and 7 (5%) were members of the panchayat in Garakahalli, Nalatwad, Petta-manurahatti and Molahalli watersheds, respectively, whereas 38 (15%, 42 (31%), 28 (12%) and 29 (20%) were members of the cooperative society. However, 29 (13%) farmers in Pettamanura-hatti watershed were members of an NGO. Farmers with no institutional membership were 207 (82%), 91 (67%), 161 (70%) and 111 (76%) in Garakahalli, Nalatwad, Pettamanurahatti and Molahalli watersheds. Such low institutional membership indicates low social mobility and social participation and limited interaction among the farmers.

Social groupings decide the social status of the farmers' households and such groupings are prominent in rural areas. In Garakahalli watershed, most households (237, 94%) belonged to OBCs, while Scheduled Caste households were 5 (2%), Scheduled Tribe households 6 (2%) and General category households 3 (1%). Among Nalatwad farm households, 124 (92%) belonged to OBCs, 7 (5%) belonged to Scheduled Tribes and 4 (3%) to Scheduled Castes. In Pettamanura-hatti watershed, 180 (78%) households belonged to Scheduled Tribes and 51 (22%) to Other Backward Classes. In Molahalli, nearly 100 households (68%) belonged to General category, 41 (28%) to OBCs, 5 (3%) to Other Backward Classes and just one belonged to Scheduled Tribes.

The average family size of the households and working population in the watersheds are presented in Table 4.2. In Garakahalli watershed, the average family size was 5.79, with 1.97 working males, 1.66 working females and 1.97 dependent children. In

Nalatwad, the average family size was 7.36, with 2.69 working males, 2.05 working females, 2 dependent children and 0.62 non-working member. For Pettamanurahatti watershed, the size was 6.45, with 1.71 working males, 1.54 working females, 3 09 dependent children and 0.11 non-working member. In Molahalli, the average family size was 6.94, with 2.04 working males, 2.05 working females, 2.24 dependent children and 0.6 non-working member. Thus the non-working population per household was smallest in Pettamanurahatti, followed by Garakahalli, Molahalli and Nalatwad.

Table 4.2 Family size and composition among farm households in the watersheds

Particulars	Garakahalli	Nalatwad	Pettamanurahatti	Molahalli
Average family size	5.79	7.36	6.45	6.94
Average working population				
Adult male	1.97	2.69	1.71	2.04
Adult female	1.66	2.05	1.54	2.05
Total	3.63	4.74	3.25	4.10
Dependents				
Children	1.97	2.00	3.09	2.24

The working population was engaged in different activities/occupations as seen in the data on occupational pattern presented in Table 4.3. Of the farm households (113) in Garaka-halli, 113 (45%) were engaged in crop production and sericulture; no household in the other watersheds was practising sericulture. In Nalatwad and Molahalli, around 4 and 34 per cent, respectively, of the farm households (5 and 50) did not have any subsidiary occupation and were dependent on crop production as their main source of income. The combination of crop production and agricultural labour accounted for 14, 10, 13 and 38 per cent of households in Garakahalli, Nalatwad, Pettamanurahatti and Molahalli watersheds, respectively.

Table 4.3 Farm household occupational pattern in the watersheds

Occupation		Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
Main	Subsidiary	Num.	%	Num.	%	Num.	%	Num.	%
Crop production	—	0	0.00	5	3.70	0	0.00	50	34.01
Crop production	Sericulture	113	45.02	0	0.00	0	0.00	0	0.00
Crop production	Agric. labour	35	13.94	14	10.37	29	12.55	56	38.10
Crop production	Sheep, goat rearing	14	5.58	2	1.48	78	33.77	0	0.00
Agric. labour	Crop production	32	12.75	0	0.00	24	10.39	0	0.00
Sheep, goat rearing	Crop production	0	0.00	0	0.00	13	5.63	0	0.00
Crop production	Dairy enterprise	46	18.33	38	28.15	60	25.97	18	12.24
Rural artisans	Crop production	1	0.40	1	0.74	23	9.96	2	1.36
Business	Crop production	6	2.39	61	45.19	2	0.87	14	9.52
Govt. service	Crop production	4	1.59	14	10.37	2	0.87	7	4.76
Total		**251**	**100.00**	**135**	**100.00**	**231**	**100.00**	**147**	**100.00**

Crop production as main and sheep and goat rearing as subsidiary occupation was prominent among Pettamanurahatti households (78, 34%). The number of households with this combination of occupations was 14 in Garakahalli and 2 in Nalatwad. Only in Pettamanurahatti was sheep and goat rearing a main occupation (13 households, 5.63%).

The combination of agricultural labour as main and crop production as subsidiary occu-pation was practised by 32 (13%) households in Garakahalli and 24 (10%) in Pettamanurahatti, but in Nalatwad and Molahalli agricultural labour was not a main occupation.

Crop production and dairy enterprise as main and subsidiary occupations were practised by 46 (18%) households in Garakahalli, 38 (28%) in Nalatwad, 60 (26%) in Pettamanurahatti and 18 (12%) in Molahalli. Business and crop production as main and subsidiary occupations were followed by 61 (45%) Nalatwad households and 14 (10%) households in Molahalli. This combi-nation was not common in Garakahalli and Pettamanurahatti. Rural artisanship and crop produc-tion as main and subsidiary occupations accounted for 0.4, 0.7, 10 and 1 per cent of the house-hold income in Garakahalli, Nalatwad, Pettamanurahatti and Molahalli watersheds, respectively. Government service and crop production as main and subsidiary occupations were practised by 10 per cent or less of the households in the four watersheds.

Data on occupational pattern presented in Table 4.4 shows that the population in the watersheds was as follows: 1454 in Garakahalli, 993 in Nalatwad, 1489 in Pettamanurahatti and 1020 in Molahalli watershed. Males engaged in farming were 459 (32%) in Garakahalli, 287 (20%) in Nalatwad, 360 (90%) in Pettamanurahatti and 207 (20%) in Molahalli watershed. The corresponding figures for females were 404 (28%), 267 (18%), 347 (92%) and 245 (24%). The number of male agricultural labourers was 23 (2%), 15 (1%), 22 (6%) and 79 (8%), while female agricultural labourers numbered 11 (1%), 14 (1%), 8 (2%) and 56 (5%) in the same order. The number of salaried workers among females was very small in all watersheds.

Table 4.4 Gender wise occupational pattern of farmers in the watersheds

Particulars	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Total male	531	36.52	363	36.56	398	26.73	331	32.45
Farming	459	31.57	287	28.90	360	24.18	207	20.29
Agricultural labour	23	1.58	15	1.51	22	1.48	79	7.75
Salaried	2	0.14	14	1.41	4	0.27	14	1.37
Business/trade	6	0.41	195	19.64	10	0.67	0	0
Studying	4	0.28	-	-	0	0	1	0.10
Non-working	36	2.48	-	-	2	0.13	30	2.94
Total female	428	29.44	360	36.25	378	25.39	358	35.10
Farming	404	27.79	267	26.89	347	23.30	245	24.02
Agricultural labour	11	0.76	14	1.41	8	0.54	56	5.49
Salaried	3	0.21	-	-	0	0	0	0
Business/trade	0	0	-	-	0	0	0	0
Studying	0	0	-	-	0	0	3	0.29
Non-working	11	0.76	83	8.36	23	1.54	54	5.29
Total children	495	34.04	270	27.19	713	47.88	330	32.35
Studying	311	21.39	137	13.80	294	19.74	205	20.10
Non-studying	184	12.65	133	13.39	419	28.14	125	12.25
Total population	1454	100.00	993	100.00	1489	100.00	1020	100.00

Business was strictly a man's profession and kept busy 6 (0.41%) in Garakahalli,, 195 (20%) in Nalatwad, 10 (2.5%) in Pettamanurahatti and 14 (1.3%) in Molahalli. The number of adults studying was small in all watersheds. At the same time, non-working population, both male and female, was very small in all the 4 watersheds.

About one-fifth of the population of each watershed was composed of studying children (311 or 21% in Garakahalli, 137 or 14% in Nalatwad, 294 or 20% in Pettamanurahatti and 205 or 20% in Molahalli).

The average annual household income (Table 4.5) was highest at Rs 44243 in Garaka-halli followed by Molahalli (Rs 39533), Nalatwad (Rs 31842) and Pettamanurahatti (Rs 30038). In Garakahalli, crop production and sericulture contributed 43 per cent each to total average income. Other professions each contributed less than 7 per cent.

Table 4.5 Average annual household income of farmers in the watersheds

Source	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Rs	%	Rs	%	Rs	%	Rs	%
Crop production	19111.10	43.20	6770.81	21.26	6099.54	20.31	32232.78	81.53
Agric. labour	450.22	1.02	1750	5.50	1366.67	4.55	983.33	2.49
Sheep & goat rearing	1450.46	3.28	1011.95	3.18	13650.93	45.45	0	0
Dairy enterprise	3018.95	6.82	4041.85	12.69	5943.62	19.79	4225.70	10.69
Sericulture	18867.01	42.64	0	0	0	0	0	0
Business	903.73	2.04	15975.39	50.17	550.83	1.83	1116.67	2.82
Govt. service	441.87	1.00	2083.33	6.54	343.33	1.14	791.67	2.00
Rural artisanship	441.87	1.00	2083.33	6.54	343.33	1.14	791.67	2.00
Total	151.95	0.34	208.33	0.65	2082.97	6.93	183.33	0.46

Among Nalatwad farmers, contribution of business to total income was more than half, of crop production 21 per cent, and of dairy enterprise 13 per cent. In Pettamanurahatti, the major contribution was from sheep and goat rearing (45%), followed by crop production (21%) and dairy enterprise (20%). In Molahalli, contribution of crop production (82%) was the major com-ponent of total income. Other sources each contributed one-tenth or less.

Crop production was the major source of income of Molahalli and Garakahalli farmers, with sericulture also contributing equally in Garakahalli. Sheep and goat rearing was the major source in Pettamanurahatti.

The landholding pattern of the farmers in the watersheds is presented in Table 4.6. In Garakahalli 220.92 ha and 2.04 ha respectively were owned and leased-in rainfed land account-ing for 72 and 0.67 per cent of the total operational area respectively. About 83.04 ha (27%) was owned and 0.65 ha (0.2%) leased-in irrigated land. In Nalatwad watershed there was no irrigated area, and owned and leased-in rainfed land were 96 and 4 per cent of the total area of the watershed, respectively. In Pettamanurahatti watershed, 473.65 ha (91%) was owned and 0.8 ha (0.15%) leased-in rainfed land. Irrigated owned land (45 12 ha) accounted for less than one-tenth of the total operational area. Among Molahalli farmers, 261.46 ha (87%) was owned rainfed land and 39.49 ha (13%) owned irrigated land. there was no leased-in land among the households.

Table 4.6 Distribution of landholdings in the watersheds

Particulars	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	ha	%	ha	%	ha	%	ha	%
Owned cultivable land								
Rainfed	220.92	72.04	536.17	95.81	473.65	91.16	261.46	86.88
Irrigated	83.04	27.08	0	0	45.12	8.68	39.49	13.12
Leased in land								
Rainfed	2.04	0.67	23.43	4.19	0.80	0.15	0	0
Irrigated	0.65	0.21	0	0	0	0	0	0
Total operational area	306.65	100.00	559.60	100.00	519.57	100.00	300.95	100.00

Data on the livestock population of the farm households in the watersheds are presented in Table 4.7. The total livestock population was highest in Pettamanurahatti watershed (3318) fol-lowed by Garakahalli with 927, Molahalli with 858 and Nalatwad with 361.

Table 4.7 Livestock population among farm households in the watersheds

Livestock	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Bullock	46	4.96	136	37.67	288	8.68	58	6.76
Dual-purpose cows	212	22.87	84	23.27	76	2.29	242	28.21
Crossbred cows	69	7.44	13	3.60	14	0.42	43	5.01
Buffaloes	110	11.87	97	26.87	136	4.10	148	17.25
Poultry	26	2.80	0	0	535	16.12	363	42.31
Sheep	282	30.42	26	7.20	2104	63.41	4	0.47
Goats	182	19.63	5	1.39	165	4.97	0	0
TOTAL	**927**	**100**	**361**	**100**	**3318**	**100**	**858**	**100**

The composition of livestock in Garakahalli watershed was 282 sheep (30%), 212 dual-purpose cows (23%), 182 goats (20%), 110 buffaloes (12%) and smaller numbers of crossbred cows, bullocks and poultry birds. Nalatwad farmers had 136 bullocks (38%), 97 buffaloes (27%), 84 dual purpose cows (23%) and smaller numbers of sheep, crossbred cows and goats. In Pettamanurahatti watershed, the livestock consisted of 2104 sheep (63%), 535 poultry birds (16%), 288 bullocks (9%), 165 goats (5%) and a few other animals. In Molahalli watershed, live-stock composition of the farm households was 363 poultry birds (42%), 242 dual-purpose cows (28%), 148 buffaloes (17%), 58 bullocks (7%), 43 crossbred cows (5%) and 4 sheep (0.47%). Sheep and goats were most numerous in Pettamanurahatti watershed and so were poultry birds. The population of crossbred and dual-purpose cows was highest in Garakahalli watershed.

Population pressure in the four watersheds is presented in Table 4.8. The average size of land holding was 4.15 ha in Nalatwad, 2.25 ha in Pettamanurahatti, 2.05 ha in Molahalli and 1.22 ha in Garakahalli. The availability of land per person in Nalatwad was 0.56 ha, in Pettamanurahatti 0.35 ha, in Molahalli 0.3 ha and in Garakahalli 0.21 ha. On the other hand, the availability of land per animal was 1.55 ha, 0.35 ha, 0.33 ha and 0.16 ha in Nalatwad, Molahalli, Garakahalli and Pettamanurahatti watersheds, respectively. Nalatwad ranked first in terms of availability of land per person and also per animal. Garakahalli ranked first in density of human population and Pettamanurahatti in density of animal population.

Table 4.8 Population pressure in the watersheds

Item	Garakahalli	Nalatwad	Pettamanurahatti	Molahalli
Number of farm households	251	135	231	147
Cultivable land (ha)				
Rainfed	222.96	559.60	474.45	261.46
Irrigated	83.69	0	45.12	39.49
Human population	1454	993	1489	1020
Animal population	927	361	3318	858
Density (per hectare)				
Human	4.74	1.77	2.87	3.39
Animal	0.60	0.65	6.39	0.81
Average size of land holding	1.22	4.15	2.25	2.05
Cultivable land available (ha)				
Per person	0.21	0.56	0.35	0.30
Per animal	0.33	1.55	0.16	0.35

Data on the tenurial status of the farmers in the watersheds are presented in Table 4.9. In Garakahalli, 202 (80%) of the farmers had land records in their names. The corresponding figures for Nalatwad were 132 (57%), for Pettamanurahatti 158 (68%) and for Molahalli 126 (86%). The possible perceived reasons for possessing land records were security, self-satisfaction and for taking bank loan. Farmers not having land records in their names accounted for 20, 1, 32, and 14 per cent, respectively, in Garakahalli, Nalatwad, Pettamanurahatti and Mola-halli watersheds. Reasons quoted for not having land records in individual names were family dispute, litigation and high cost of registration. Negligence was the reason given by 6 farmers in Pettamanurahatti watershed. Property rights are very important as they may have psychological effect on production and management of agricultural activities. Furthermore land records are essential for taking bank loan, which in turn improves the socio-economic viability of the farmers.

Table 4.9 Tenurial status of farmers in the watersheds

Particulars	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Farmers having land records and rights in their names	202	80.48	132	57.14	158	68.40	126	85.71
Farmers not having land records in their name	49	19.52	3	1.30	73	31.60	21	14.29
Reasons for possessing land records								
Security	166	66.14	119	51.52	136	58.87	91	61.90
Prestige	23	9.16	32	13.85	34	14.72	18	12.24
Self-satisfaction	72	28.69	3	1.30	38	16.45	104	70.75
For taking bank loan	25	9.96	11	4.76	31	13.42	28	19.05
Reasons for not having land records								
Family dispute	40	15.94	3	1.30	13	5.63	3	2.04
Litigation	6	2.39	0	0	2	0.87	3	2.04
High cost of registration	4	1.59	0	0	69	29.87	3	2.04
Negligence	0	0	0	0	6	2.60	0	0

Data on crops grown by the farmers in the watersheds are presented in Table 4.10. The chief crops grown under in Garakahalli under rainfed conditions were finger millet (145.22 ha, 65% of the total rainfed land), groundnut (37 ha, 17%) and horsegram (22.63 ha, 10%). The principal crops grown under irrigation were banana (17.54 ha, 21% of total irrigated land), coconut (19.11 ha, 23%), mulberry (22.12 ha, 26%) and finger millet (10.34 ha, 12%). The fallow left in rainfed land was 8.75 ha (4%) and in irrigated land 4.92 ha (6%). Only rainfed crops were grown in Nalatwad watershed. Major area was under sorghum (413.55 ha, 74%), followed by sunflower (88.12 ha, 16%)), bengal gram (28.55 ha, 5%) and wheat (17.5 ha, 3%). Fallow land (5.76 ha) accounted for just 1 per cent of the total area.

Table 4.10 Cropping pattern (area) among farmers of the watersheds

Crop	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	ha	%	ha	%	ha	%	ha	%
RAINFED								
Arecanut	0	0	0	0	0	0	11.71	4.48
Pearl millet	0	0	4.92	0.88	31.95	6.74	0	0
Bengal gram	0	0	28.55	5.10	0	0	0	0
Cashew	0	0	0	0	0	0	64.04	24.49
Coconut	9.33	4.18	0	0	0	0	6.67	2.55
Green gram	0	0	1.20	0.21	0	0	0	0
Groundnut	37	16.60	0	0	434.10	91.51	0	0
Horsegram	22.63	10.15	0	0	0	0	0	0
Rice	0	0	0	0	0	0	171.30	65.52
Finger millet	145.22	65.14	0	0	0	0	0	0
Sorghum	0	0	413.55	73.90	0.60	0.13	0	0
Sunflower	0	0	88.12	15.75	0	0	0	0
Sweet potato	0	0	0	0	0	0	0.40	0.15
Wheat	0	0	17.50	3.13	0	0	0	0
Fallow	8.75	3.92	5.76	1.03	7.70	1.62	7.34	2.81
Total rainfed	222.94	100	559.60	100	474.36	100	261.46	100
IRRIGATED								
Arecanut	0	0	0	0	0	0	7.85	19.88
Banana	17.54	20.96	0	0	0	0	0	0
Coconut	19.11	22.84	0	0	0	0	0	0
Groundnut	0.40	0.48	0	0	4.40	9.75	0	0
Mango	1.40	1.67	0	0	0	0	0	0
Mulberry	22.12	26.44	0	0	0	0	0	0
Onion	0	0	0	0	1.20	2.66	0	0
Rice	7.45	8.90	0	0	12.41	27.51	29.78	75.41
Finger millet	10.34	12.36	0	0	15.07	33.40	0	0
Sorghum	0	0	0	0	9.10	20.17	0	0
Sugarcane	0.40	0.48	0	0	0	0	0	0
Fallow	4.92	5.88	0	0	2.94	6.52	1.86	4.71
Total irrigated	83.69	100	0	0	45.12	100	39.49	100
TOTAL	**306.63**		**559.60**		**519.48**		**300.95**	

In Pettamanurahatti both rainfed and irrigated crops were grown. Under rainfed conditions, groundnut covered 434.1 ha (92% of total rainfed area) and pearl millet 31.95 ha (7%). Crops grown under irrigation were chiefly groundnut (4.4 ha, 10% of total irrigated area), rice (12.41 ha, 28%), finger millet (15.07 ha, 33%) and sorghum (9.1 ha, 20%). Fallow land was 7.7 ha (2%) of rainfed land and 2.9 ha (7%) of irrigated land. Molahalli watershed also had both rain-fed and irrigated land. The major area under rainfed conditions was cultivated to rice (171.3 ha, 66% of rainfed area). The rest was devoted to plantation crops such as cashew (64.04 ha, 24%), arecanut (11.71 ha, 4.5%) and coconut (6.67 ha, 2.5%). The irrigated crops were rice (29.78 ha, 75% of irrigated area) and arecanut (7.85 ha, 20%). The land left fallow was 7.34 ha (3%) of rainfed and 1.86 ha (5%) of irrigated land.

4.6 Assessment of Impact of the Watershed Development Programme

Component-wise investment under watershed-development programmes. As can be seen from Table 4.11, total investment was highest in Nalatwad (Rs 20,96,811) and lowest in Molahalli (Rs 6,15,746). The largest proportion of investment in the watersheds was on soil- and water-conservation measures except in Pettamanurahatti where it was on basic activities, with conservation measures taking second place. The other investments were on crop demonstration in Garakahalli, Nalatwad and Pettamanurahatti and household production system in all except Nalatwad. Investment on livestock development, horticulture and agroforestry was seen only in Garakahalli and Pettamanurahatti watersheds.

Table 4.11 Component-wise investment in the watersheds under NWDPRA

Component-wise investment	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Rs	%	Rs	%	Rs	%	Rs	%
Basic activities	469180	28.75	45000	2.15	768598	46.35	29986	4.87
Soil and water conser-vation measures	795760	48.76	2049411	97.74	557500	33.62	582172	94.55
Crop demonstration	80000	4.90	2400	0.11	52400	3.16	0	0.00
Household production system	186000	11.40	0	0.00	126075	7.60	3588	0.58
Livestock develop-ment	26000	1.59	0	0.00	121098	7.30	0	0.00
Horticulture	40000	2.45	0	0.00	20000	1.21	0	0.00
Agroforestry	35000	2.14	0	0.00	12500	0.75	0	0.00
TOTAL	1631940	100.00	2096811	100.00	1658171	100.00	615746	100.00

Beneficiaries under different components. Since a major investment in watershed develop-ment was on soil- and water-conservation measures a large percentage of farmers had the benefit of soil and water conservation. However, in Garakahalli around 50 per cent of the farmers reported having been benefited from agroforestry. The least benefited component in the watersheds was crop demonstration. Though horticulture seems to be a better component not many farmers reported benefit from it. Around 20 per cent farmers said they had not derived any benefit from investments made through watershed development programmes (Table 4.12).

Table 4.12 Beneficiaries under different components of watershed development

Components	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Soil and water conservation measures	80	31.87	103	76.30	157	67.97	96	41.56
Crop demonstration	11	4.38	2	1.48	120	51.95	0	0.00
Household production system	13	5.18	0	0.00	63	27.27	53	22.94
Livestock development	42	16.73	0	0.00	97	41.99	0	0.00
Horticulture	20	7.97	0	0.00	38	16.45	0	0.00
Agroforestry	126	50.20	0	0.00	38	16.45	0	0.00
Not benefited	48	19.12	30	22.22	59	25.54	48	20.78

Impact on land use pattern and land value. There was negligible change or none in owned land and/or leased-in land area brought under cultivation following watershed development (Table 4.13). The increase in leased-in land was 1.20 ha in Garakahalli and 7.26 ha in Nalatwad. Increase in average land value ranging from Rs 382/ha to Rs 38541/ha was reported in Garakahalli and Nalatwad watersheds.

Change in cropping pattern. In Garakahalli watershed, there was an increase of cultivated area (rainfed and irrigated) at the expense of fallow land consequent on watershed development. The increase in cropped area in Nalatwad was 9.38 ha distributed between sorghum and sunflower, the area being transferred from fallow land. The situation in the other two watersheds was similar, with fallow land being converted to cultivated land. The decrease in the fallow land ranged from a minimum of 50 per cent to a maximum of 71 per cent.

Livestock population. The change in livestock population due to investment in watershed was assessed through change in number and average value of different kinds of animal as well as in number of house-holds having livestock. Decrease in the number of households having no livestock ranged from 1 in Garakahalli to 6 in Molahalli. The decreases in number of households having no draft animals were 8 in Garakahalli, 1 each in Nalatwad and Pettamanurahatti and 2 in Molahalli.

Change in agro-biodiversity. The total number of different species of trees was 27 (Table 4.14). Included were fruit, fuelwood and commercial trees. The largest increase in number was in mango (1111) and coconut (539) in Garakahalli; the third highest increase was reported for man-gium (119) in Molahalli. Most of the changes in number of trees were reported in Garakahalli watershed (mango, teak, coconut, silver oak, pongamia, pomegranate, jack, eucalyptus, *bersey, ankole, baghe,* acacia and sapota), while the lowest number came from Nalatwad (lemon, acacia and *banni*). In Pettamanurahatti, the change in number of trees was observed under 7 species, while 9 species increased in population in Molahalli watershed.

Table 4.13 Impact of watershed development on land use pattern

Particulars	Before development		After development		Change	
	Area, ha	Value, Rs/ha	Area, ha	Value, Rs/ha	Area, ha	Value, Rs/ha
			Garakahalli			
Owned cultivable land						
Rainfed	220.92	84266.67	220.92	85235.83	0.00	969.17
Irrigated	83.04	146966.67	83.04	147641.67	0.00	675.00
Leased-in land						
Rainfed	0.84	89475	2.04	89475	1.20	0.00
Irrigated	0.20	148100	0.65	150968.75	0.45	2868.75
			Nalatwad			
Owned cultivable land						
Rainfed	536.17	67516.67	536.17	67898.33	0.00	381.67
Irrigated	0.00	0.00	0.00	0.00	0.00	0.00
Leased-in land						
Rainfed	16.17	34375.00	23.43	72916.25	7.26	38541.25
Irrigated	0.00	0.00	0.00	0.00	0.00	0.00
			Pettamanurahatti			
Owned cultivable land						
Rainfed	473.65	48192.50	473.65	48192.50	0.00	0.00
Irrigated	45.12	91410.00	45.12	91410.00	0.00	0.00
Leased-in land						
Rainfed	0.80	50000.00	0.80	50000.00	0.00	0.00
Irrigated	0	0	0	0	0	0
			Molahalli			
Owned cultivable land						
Rainfed	261.46	161666.67	261.46	161666.67	0.00	0.00
Irrigated	39.49	231250.00	39.49	231250.00	0.00	0.00
Leased-in land						
Rainfed	0	0	0	0	0	0
Irrigated	0	0	0	0	0	0

Table 4.14 Impact of watershed development on agro-biodiversity

Species	Number before development				Number before development				Change			
	G'halli	N'wad	P'hatti	M'halli	G'halli	N'wad	P'hatti	M'halli	G'halli	N'wad	P'hatti	M'halli
Acacia	5	20	489	1	10	25	520	21	5	5	31	20
Ankole	28	0	0	0	37	0	0	0	9	0	0	0
Baghe	2	0	0	0	7	0	0	0	5	0	0	0
Banni	0	128	0	0	0	132	0	0	0	4	0	0
Banana	0	0	0	174	0	0	0	228	0	0	0	54
Bersy	0	0	0	0	9	0	0	0	9	0	0	0
Bogi	0	0	0	63	0	0	0	63	0	0	0	0
Casuarina	0	0	150	0	0	0	170	1	0	0	20	1
Citrus	0	0	0	1	0	0	0	2	0	0	0	1
Coconut	28	0	193	0	567	0	250	0	539	0	57	0
Curry leaf tree	0	0	0	0	0	0	0	1	0	0	0	1
Doopa	0	0	0	14	0	0	0	14	0	0	0	0
Eucalyptus	7	0	19	0	16	0	19	0	9	0	0	0
Jack	4	0	0	74	10	0	0	74	6	0	0	0
Lemon	0	0	0	0	0	100	0	0	0	100	0	0
Mangium	0	0	0	68	0	0	0	187	0	0	0	119
Mango	116	0	7	98	1227	0	8	99	1111	0	1	1
Neem	168	10	200	0	270	10	226	1	102	0	26	1
Pome-granate	0	0	0	0	4	0	20	0	4	0	20	0
Pongamia	32	0	568	0	71	0	628	0	39	0	60	0
Saguvani	0	0	0	69	0	0	0	69	0	0	0	0
Sapota	0	0	0	0	8	0	0	0	8	0	0	0
Silver oak	0	0	0	0	77	0	0	0	77	0	0	0
Seethaphal	0	1	0	0	0	1	0	0	0	0	0	0
Syzygium	0	2	0	0	0	2	0	0	0	0	0	0
Tamarind	0	1	84	1	6	1	86	1	6	0	2	0
Teak	33	0	0	16	465	0	0	28	432	0	0	12
Richness	**10**	**6**	**8**	**11**	**15**	**7**	**9**	**14**	**15**	**3**	**8**	**9**
Index of diversity	**0.72**	**0.32**	**0.72**	**0.82**	**0.70**	**0.49**	**0.74**	**0.84**	**0.64**	**0.15**	**0.76**	**0.52**

Change in annual household income. Farmers of Garakahalli watershed increased their annual household income consequent on watershed development chiefly from sericulture and crop production, with smaller contributions from dairy and sheep and goat rearing. In Nalatwad watershed, however, business was the main source of increase in annual income, with crop production making a sizeable contribution. Other sources of increase were dairy enterprise, agri-cultural labour and sheep and goat rearing. In Pettamanurahatti, the sources of increases in income were chiefly sheep and goat rearing, crop production and dairy enterprise in that order. The increase in Molahalli watershed was greatest from crop production followed by dairy enter-prise and agricultural labour. In general, crop production was a major source of increase in income common to all the watersheds.

Change in value of farm assets. The farm assets considered were land, livestock, dwelling house, cattleshed, tubewell and pumpset, bullock cart, tractor/power tiller), farm implements and farm house. In Garakahalli watershed, the number of farmers reporting acquisition of assets con-sequent on watershed development was 4 for cattleshed, 2 for tubewell, 2 for bullock cart, 10 for farm implements and 3 for farm house. The greatest increase in average value was Rs 11,667 for cattleshed, while the least (Rs 0) was for bullock cart. Farmers in Nalatwad with increase in assets numbered only 2, for farm implements. The change in average value was Rs 147. In Molahalli watershed, the number of farmers with gain in assets was 1 for farm house and 5 for livestock. However, the change in value was negligible. There was no increase in Pettamanura-hatti. However, the change in average value was Rs 4,697 for tubewell/pumpset and about Rs 200 for farm implements and livestock. Thus the number of farmers with increase in assets and increase in average value of farm assets in the four watersheds were not significant.

Impact on calorie intake of farmers. The individuals of the four watersheds were consuming more than 2100 kcal/day but less than 2500 kcal/day before watershed development (Table 4.15). There was not much difference in intake of farmers among the watersheds. The mean daily intake increased by 37 kcal in Nalatwad, 51 in Pettamanurahatti, 79 in Molahalli and 109 kcal in Garakahalli. The increases came from non-cereal foods in Pettamanurahatti and Molahalli. The amount spent daily per person was Rs 5.79 to Rs 7.83 before development, and showed a marginal increase of Rs 0.38 to Rs 0.66 per person after development.

Awareness of soil problems. The farmers were aware of several soil problems resulting in crop loss (Table 4.16). The Rank Based Quotient (RBQ) reflects the perception of crop loss caused by each problem. It was highest for perennial weeds (95.69) followed by moisture loss (92.52), nut-rient loss (63.04), topsoil loss (61.45) and slope (52.83) in Pettamanurahatti. In Garakahalli, the RBQ was highest for loss of moisture (63.25) followed by perennial weeds (56.54) and crusting (48.22). In Nalatwad watershed, the highest RBQ was for declining land value (37.76) followed by slope (34.51) and loss of nutrients (33.26). In Molahalli, however, the RBQ was highest for slope (21.09) followed by rill and gully formation (18.82) and loss of nutrients (18.59).

Adoption of soil- and water-conservation practices. Soil- and water-conservation practices such as summer ploughing, contour bunding, opening furrows, forming ridges, sowing across the slope, small section bunds, compartment bunds, application of FYM, scooping, mulching and silt/ soil addition were commonly followed by farmers in the watersheds (Table 4.17). All farmers per-ceived that non-adoption of most of the measures (except mulching and silt/soil addition) would result in crop losses. The expected crop loss due to non-adoption ranged from a minimum of 0.23 per cent (scooping) to a maximum of 45 per cent (application of FYM). The application of FYM was adopted by the highest number of farmers in all the watersheds. The least adopted practice was contour bunding in Molahalli (only one farmer). Summer ploughing, sowing across the slope and application of FYM were the most popular practices followed by the farmers in the four watersheds. In general, the least preferred practice appeared to be mulching, which was adopted by six farmers in Garakahalli watershed only. The second least preferred practice was scooping (4 in Garakahalli only).

Table 4.15 Impact of watershed development on food intake of farmers in the watersheds

Item	Intake/person before development, kcal d^{-1}				Intake/per person after development, kcal d^{-1}				Change/person, kcal d^{-1}			
	G'halli	N'wad	P'hatti	M'halli	G'halli	N'wad	P'hatti	M'halli	G'halli	N'wad	P'hatti	M'halli
Cereals	2043.31	1936.15	1831.63	2132.04	2074.16	1942.59	1831.63	2132.04	30.84	6.44	0.00	0.00
Pulses	131.06	212.06	144.12	125.09	146.91	222.79	155.68	157.03	15.86	10.73	11.56	31.95
Veg. & fruits	98.84	82.31	124.83	108.55	102.11	94.67	143.51	135.47	3.27	12.36	18.68	26.93
Meat & eggs	31.67	28.15	20.84	20.84	41.67	31.33	31.94	31.94	10.00	3.19	11.10	11.10
Veg. oil	156.77	18.17	47.00	47.00	206.18	22.33	56.45	56.45	49.41	4.17	9.45	9.45
Total	**2461.64**	**2276.83**	**2168.42**	**2433.51**	**2571.02**	**2313.72**	**2219.22**	**2512.93**	109.37	36.89	50.80	79.42
	Cost/person before development, Rs/day				Cost/person after development, Rs/day				Change/person ,Rs/day			
Cereals	4.07	4.78	3.03	4.86	4.39	4.78	3.03	4.82	0.32	0.00	0.00	–0.04
Pulses	1.20	1.59	0.89	0.70	1.43	1.66	1.00	0.77	0.23	0.07	0.11	0.08
Veg. & fruits	0.50	0.56	0.84	0.49	0.52	0.56	0.89	0.55	0.02	0.00	0.05	0.06
Meat & eggs	0.59	0.50	0.39	0.88	0.84	0.56	0.64	1.04	0.25	0.06	0.25	0.16
Veg. oil	0.37	0.41	0.64	0.33	0.61	0.50	0.75	0.51	0.24	0.10	0.11	0.18
Total	**6.72**	**7.83**	**5.79**	**7.26**	**7.48**	**8.06**	**6.31**	**7.70**	0.76	0.23	0.52	0.44

Table 4.16 Awareness of soil problems among the farmers of the watersheds

Soil problem	Garakahalli			Nalatwad			Pettamanurahatti			Molahalli		
	RBQ	Crop loss (%)*		RBQ	Crop loss (%)*		RBQ	Crop loss (%)*		RBQ	Crop loss (%)*	
		Min.	Max.		Min.	Max.		Min.	Max.		Min.	Max.
Gravelliness/Stones	31.46	11.33	17.33	0.37	3.89	5.56	33.33	18.09	22.97	1.81	12.67	17.00
Crusting	48.22	17.67	24.67	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00
Sandy soil	6.83	3.00	5.00	0.00	0.00	0.00	15.65	12.03	16.74	16.33	10.54	13.77
Clayey soil	0.60	0.23	0.47	23.93	7.01	10.75	0.68	14.17	17.50	0.68	0.00	0.00
Sloping land	30.03	13.00	17.67	34.51	13.74	18.80	52.83	14.73	19.60	21.09	12.38	13.88
Shallow soil	3.56	0.83	1.50	12.59	5.48	7.14	0.00	0.00	0.00	1.13	5.00	8.33
Perennial weeds	56.54	34.00	45.67	27.05	15.28	19.53	95.69	37.33	43.04	5.90	16.79	20.07
Uneven land shape	17.61	7.00	10.33	19.45	14.20	19.65	45.80	10.21	15.09	5.90	9.94	14.83
Poor infiltration	0.57	0.06	0.13	2.22	5.28	6.94	0.00	0.00	0.00	0.91	11.67	15.00
Loss of topsoil	33.43	14.00	22.00	21.41	10.74	14.74	61.45	28.27	33.95	17.69	12.72	17.51
Loss of nutrients	33.19	15.00	21.00	33.26	14.24	19.59	63.04	24.85	30.08	18.59	10.41	14.94
Rooting depth loss	9.47	1.67	5.00	12.10	6.61	9.94	0.00	0.00	0.00	1.59	10.89	10.78
Loss of moisture	63.23	21.67	24.00	0.00	0.00	0.00	92.52	35.27	41.13	1.13	4.44	7.78
Rill, gully formation	20.32	4.00	7.33	21.27	7.58	11.11	42.63	7.50	12.40	18.82	10.91	15.66
Siltation of tanks	0.20	0.03	0.06	6.67	2.44	3.98	0.00	0.00	0.00	0.68	0.00	0.00
Declining land value	32.45	-	-	37.76	-	-	58.28	0.00	0.00	10.88	-	-

* Farmers' perception

Table 4.17 Adoption of soil- and water-conservation practices by the farmers of the watersheds

Practice	Garakahalli			Nalatwad			Pettamanurahatti			Molahalli		
	Adop-ters	Expected crop loss by non-adoption (%)*		Adop-ters	Expected crop loss by non-adoption (%)*		Adop-ters	Expected crop loss by non-adoption (%)*		Adop-ters	Expected loss by non-adoption (%)*	
		Min	Max		Min	Max		Min	Max		Min	Max
Summer ploughing	237	11.67	16.67	17	11.62	16.80	181	7.40	12.85	103	9.49	13.57
Opening furrows, ridges	104	4.00	6.00	0	0.00	0.00	137	7.70	12.63	54	9.98	14.60
Contour bunding	50	1.33	2.33	8	5.11	8.44	5	4.00	6.78	1	3.33	5.00
Sowing across slope	225	15.33	20.00	129	24.20	29.63	220	21.30	35.61	89	15.07	19.67
Small-section bunds	54	2.00	3.00	76	9.22	13.44	4	12.22	15.56	27	23.87	28.77
Compartment bunds	52	1.67	2.67	56	10.77	15.10	12	16.94	21.94	137	20.34	25.18
Scooping	21	0.23	0.50	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
FYM application	246	34.67	45.00	129	31.07	37.97	223	36.97	43.60	140	33.27	38.73
Mulching	6	0.06	0.10	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Silt/soil addition	119	7.67	12.00	0	0.00	0.00	0	0.00	0.00	4	5.50	10.00

* Farmers' perception

Reasons for non-adoption of soil- and water-conservation practices. Small size of holdings, uneconomical nature of the practices, lack of funds and interference in farm operations were the reasons cited by farmers of the watersheds for not adopting conservation practices (Table 4.18). The largest number of farmers (107) in Garakahalli averred that the practices were unecono-mical, while the smallest number of farmers (9) in Nalatwad indicated this reason. The next common reasons were lack of funds and small size of holdings.

Table 4.18 Reasons for non-adoption of conservation practices by farmers of the watersheds

Reasons for non-adoption	Garakahalli		Nalatwad		Pettamanurahatti		Molahalli	
	Num.	%	Num.	%	Num.	%	Num.	%
Small holding	64	25.50	2	1.48	5	2.16	28	19.05
Practice is uneconomical	107	42.63	9	5.19	19	8.23	18	12.24
Practices interfere with farm operations	0	0.00	8	5.93	10	4.33	9	6.12
Lack of funds	80	31.87	13	9.63	5	2.16	6	4.08

Impact of watershed development on net income of the farmers. The pooled net income of the farmers in the watershed before watershed development was lowest in Nalatwad watershed (Rs 15,67,855) and highest in Garakahalli (Rs 100,16,315), while it was about 46 lakhs in Molahalli and Rs 55 lakhs in Pettamanurahatti (Table 4.19). After the implementation of the watershed programme, the net income improved by less than Rs 1 lakh in Molahalli to nearly Rs 3 lakhs in Nalatwad. The change in income was a function of the area under cultivation, type of crops and fertility of the soil.

Table 4.19 Impact of watershed programme on pooled net income of farmers of the watersheds

Item	Garakahalli	Nalatwad	Pettamanurhatti	Molahalli
Net income before development, Rs	10016314.80	1567855.00	5522793.42	4574472.42
Net income after development, Rs	10255289.39	1860698.00	5742835.00	4667169.00
Incremental income, Rs	238974.59	292843.00	220041.37	92696.73

Economic evaluation of investment in the watersheds. The worthiness of the investment was evaluated using four criteria namely pay-back period, net present worth, B:C ratio and IRR (Table 4.20). All the four criteria revealed the economic feasibility and commercial viability of the investment of about 20 lakhs in each watershed for various soil- and water-conservation measures including land development activities.

Table 4.20 Economic evaluation of investment in the watersheds

Criterion	Garakahalli	Nalatwad	Pettamanurahatti	Molahalli
Pay-back period, y	6.42	7.00	7.25	6.5
NPW @ 12%, Rs	195379	288441	24375.34	93060
NPW @ 15%, Rs	–85225	–102285	–233997.24	–15785
B:C ratio	1.146	1.13	1.132	1.151
IRR, %	13.39	14.2	12.19	13.71

In general, it would be possible to recover the entire macroinvestment made in the watershed programme in 6 to 7 years. The benefit:cost ratio indicated that every rupee of invest-ment in the watershed yielded an incremental net return of at least Rs 1.13. The internal rate of return was greater than the opportunity cost or the present lending rate and hence the investment in the four watersheds was economically viable, commercially feasible and financially sound.

Cost of cultivation. The cost/ha of cultivation of annual crops in the watersheds (Table 4.21) took into account the amount of money spent on human and bullock labour, machinery charges, seed material, manures and fertilizers, plant protection chemicals, irrigation charges if any and interest on working capital (12.5% annually). The cost of cultivation of finger millet was Rs 8585/ha in Pettamanurahatti and Rs 8014/ha in Garakahalli, and of rice Rs 12,325/ha in Petta-manurahatti Rs 17,072/ha in Garakahalli and Rs 16,398/ha in Molahalli. The cost of cultivation of sorghum was Rs 4703/ha in Nalatwad and Rs 7241/ha in Pettamanurahatti. Horsegram was grown only in Garakahalli and the cost of cultivation was Rs 2613/ha. Wheat costing Rs 3134/ha and bengal gram costing Rs 4748/ha were cultivated only by farmers of Nalatwad watershed.

Table 4.21 Cost of cultivation of different crops in the watersheds

Crop	Item	Garakahalli	Nalatwad	P'hatti	Molahalli
Groundnut	Cost of cultivation (Rs)	6579.00	—	6126.00	—
	Yield (qtl)	7.43	—	6.40	—
	Gross return (Rs)	9637.92	—	9217.00	—
	Net return (Rs)	3058.92	—	3091.00	—
	B:C ratio	1.46	—	1.50	—
Sorghum	Cost of cultivation (Rs)	—	4702.70	7241.00	—
	Yield (qtl)	—	10.08	20.00	—
	Gross return (Rs)	—	7402.70	10480.00	—
	Net return (Rs)	—	2700.00	3238.00	—
	B:C ratio	—	1.57	1.45	—
Pearl millet	Cost of cultivation (Rs)	—	—	2904.00	—
	Yield (qtl)	—	—	7.00	—
	Gross return (Rs)	—	—	3397.00	—
	Net return (Rs)	—	—	492.00	—
	B:C ratio	—	—	1.17	—
Finger millet	Cost of cultivation (Rs)	8014.34	—	8585.00	—
	Yield (qtl)	19.80	—	16.00	—
	Gross return (Rs)	9900.00	—	9719.00	—
	Net return (Rs)	1885.66	—	1134.00	—
	B:C ratio	1.24	—	1.13	—
Rice	Cost of cultivation (Rs)	17072.75	—	12325.00	16398.10
	Yield (qtl)	29.29	—	26.00	27.49
	Gross return (Rs)	21505.02	—	15353.00	21593.90
	Net return (Rs)	4432.27	—	3028.00	5195.65
	B:C ratio	1.26	—	1.25	1.32
Banana	Cost of cultivation (Rs)	52776.44	—		—
	Yield (qtl)	181.85	—		—
	Gross return (Rs)	127294.20	—		—
	Net return (Rs)	74517.76	—		—
	B:C ratio	2.41	—		—
Horsegram	Cost of cultivation (Rs)	2612.84	—	—	—
	Yield (qtl)	4.37	—	—	—
	Gross return (Rs)	3125.32	—	—	—
	Net return (Rs)	512.48	—	—	—
	B:C ratio	1.20	—	—	—
Sunflower	Cost of cultivation (Rs)	—	3709.85	—	—
	Yield (qtl)	—	5.87	—	—
	Gross return (Rs)	—	7042.47	—	—
	Net return (Rs)	—	3332.63	—	—
	B:C ratio	—	1.90	—	—
Wheat	Cost of cultivation (Rs)	—	3133.66	—	—
	Yield (qtl)	—	4.69	—	—
	Gross return (Rs)	—	7394.93	—	—
	Net return (Rs)	—	4261.28	—	—
Bengal gram	B:C ratio	—	2.36	—	—
	Cost of cultivation (Rs)	—	4747.96	—	—
	Yield (qtl)	—	5.82	—	—
	Gross return (Rs)	—	9321.62	—	—
	Net return (Rs)	—	4573.66	—	—
	B:C ratio	—	1.96	—	—

In Pettamanurahatti watershed, groundnut was the most popular commercial crop with a cultivation cost of Rs 6126/ha while it cost Rs 8429/ha in Garakahalli. The crop was not culti-vated in Nalatwad and Garakahalli. The annual fruit crop banana was cultivated only in Garaka-halli and had a cost of cultivation of Rs 52,776/ha. The oilseed crop sunflower was grown only in Nalatwad watershed. The cost of cultivation was Rs 3710/ha.

Crops get their importance through the net returns rather than cost of cultivation and/or gross returns. Examination of the crops grown in the watersheds revealed the lowest net return in pearl millet (Rs 492/ha in Pettamanurahatti) and the highest for banana (Rs 74,518/ha in Garakahalli watershed). Net returns per hectare ranged from Rs 1209 to Rs 3091 for groundnut, Rs 2700 to Rs 3438 for sorghum, Rs 1016 to Rs 1134 for pearl millet and from Rs 3028 to Rs 5196 for rice. The yield of crops ranged from the lowest of 4.37 qtl/ha in horsegram to the highest of 181.85 qtl/ha in banana.

Input use and yield gap analysis. Yield gap analysis was done only for annual crops grown in the watersheds. The present level of FYM use was generally lower than the recommended quan-tity for almost all the crops in all the four watersheds except in rice in Garakahalli, where an excess of about 10 per cent was used. Biofertilizers, a recent important input recommended for groundnut, finger millet and bengal gram, was not at all being used. Nitrogen had an input use gap of 1.82 per cent in rice and 97 per cent in horsegram (Garakahalli). In general, nitrogen use was lower than the recommended level in all the watersheds except in case of finger millet in Garakahalli (44% excess) and bengal gram in Nalatwad (33% excess). Phosphorus use was lower than recommended for all the crops except bengal gram in Nalatwad (3% excess) and groundnut (18% excess) and finger millet (31% excess) in Garakahalli. Potash had an input use gap from 66 to 100 per cent. Apparently the importance of potash in crop production has not been realized by the farmers of the watersheds. Gypsum, an important input for groundnut was not being used by any of the farmers.

None of the farmers of the watersheds obtained yields greater than the recommended levels. The yield gap ranged from a minimum of about 17 per cent for groundnut in Garakahalli to a maximum of 85 per cent for wheat in Nalatwad watershed. The low yields may be attributed to imbalance in fertilizer use, poor crop management practices and deficiency in plant protection.

4.7 Environmental And Economic Valuation Of Land Resources of Garakahalli Watershed

4.7.1 Production function analysis

Finger millet. The resource productivity for finger millet calculated through production function analysis showed that the regression coefficients were positive and significant for soil depth (0.311), farmyard manure applied (0.120), seed (0.053) nitrogen (0.028) and potash (0.150).

The regression coefficients resulting from this type of production function directly reflect the elasticity. Hence, positive and significant coefficients indicate the additional yield of finger millet per hectare that may be realized by using an additional unit of those resources over and above their present geometric mean levels. For example, for one unit increase in level of potash above the present level, the yield of finger millet would increase by 1.009 qtl/ha.

Marginal productivity refers to the contribution of a specific unit of input to the output and helps determination of the optimum level of input use. The data for finger millet reveal that, for every 1-cm increase in soil depth from the geometric mean depth (101.66 cm), yield would increase by 0.037 qtl/ha and the gross returns by Rs.18.63. However, for every one per cent increase in erosion from the geometric mean level (5.17 t ha^{-1} y^{-1}), yield would decrease by 0.035 qtl/ha resulting in Rs 17.67 decrease in gross returns. An increase of one kg of potassium application would yield an additional return of Rs 504.7.

Groundnut. Data from production function analysis for groundnut showed that the regression coefficients were positive and statistically significant for soil depth (0.64), farmyard manure (0.063) and phosphorus (0.116). Thus these variables contributed significantly to groundnut yield. How-ever, the coefficient for size of land holding was negative (–0.073) and significant.

The marginal productivity of the inputs used in cultivation of groundnut showed that for every unit increase in soil gravel content above the present geometric mean (15.61), groundnut yield would increase by 0.096 qtl, *ceteris paribus*. This also meant that the marginal productivity of soil gravel was 0.115 qtl, which would add Rs 137.63 to the gross income. Similarly, the addi-tional contributions from unit increases in application of farmyard manure, phosphorus and potash were 0.063, 0.116, and 0.034 qtl/ha, respectively. The marginal productivity of these inputs revealed that 0.136 qtl from farmyard manure, 0.41 qtl from phosphorus and 0.604 qtl from potash would be the yield for each unit increase of these inputs over and above their present geometric mean levels. Their contribution to gross income would be Rs 163.38, Rs 49.56 and Rs 724.69, respectively.

4.7.2 Replacement cost approach for estimation of cost of soil erosion

Soil erosion is an indicator of land degradation. Soil erosion status was assessed in the watershed during detailed survey and mapping. Quantification of soil losses and erosion status was given by slight (<5 t ha^{-1} y^{-1}), moderate (5–15 t ha^{-1} y^{-1}) and severe (15–40 t ha^{-1} y^{-1}).

Loss of soil by erosion also includes loss of soil organic matter. The loss per year was estimated in terms of the equivalent weight of farmyard manure. Nutrient losses due to soil erosion were estimated and the value worked out at prevailing market prices of the nutrients.

Soil organic matter. Annual soil organic matter loss from the soils ranged from a minimum of 16.38 kg/ha to a maximum of 524.10 kg/ha with a mean value of 69.62 kg/ha. Total annual soil organic matter loss for the watershed was 23143.28 kg, worth Rs.11571.64.

Nitrogen. Nitrogen loss ranged from 0.33 kg/ha to 3.51 kg/ha per year. The average annual loss worked out to 0.79 kg/ha. The total annual loss of nitrogen from the watershed was 302.77 kg, worth Rs.3157.94.

Phosphorus. Phosphorus loss ranged from 0.01 kg/ha to 0.36 kg/ha, and the average loss was 0.09 kg/ha. Total annual loss of phosphorus was 39.99 kg, worth Rs.639.92.

Potash. The annual potash loss ranged from 0.13 kg/ha to 2.71 kg/ha with an average loss of 0.71 kg/ha. The total annual potash loss estimated was 302.83 kg worth Rs. 2422.63.

Iron. The annual iron loss varied from 0.017 kg/ha to 0.655 kg/ha, with a mean of 0.078 kg/ha. The total annual loss of iron was 30.13 kg worth Rs.998.95.

Manganese. Annual manganese loss due to soil erosion ranged from 0.052 kg/ha to 0.873 kg/ha with a mean of 0.196 kg/ha. The total loss from the watershed was 73.93 kg, worth Rs.1091.25.

Copper. Loss of copper ranged from 0.00 kg/ha to 0.02 kg/ha per year with a mean of 0.01 kg/ha. About 2.45 kg of copper was lost annually from the watershed by soil erosion; its worth was Rs.36.13.

Zinc. Zinc loss was 0.00 kg/ha to 0.04 kg/ha per year. The total annual loss from the watershed was estimated at 2.35 kg, worth Rs.246.62.

The aggregate annual loss of soil organic matter and nutrients from the watershed as a whole was 23897.75 kg, with a value of Rs.20155.09.

4.7.3 Estimation of cost of misapplication of nutrients

Misapplication of nutrients is grouped into Types I and II. Type I misapplication is the absolute difference between the regional blanket recommendation of nutrients and the balanced dose of nutrients for obtaining the potential yield as per soil test values (STCR). Type II misapp-lication is the difference between the levels actually added by the farmers and the nutrients required for the farmers' yield level (STCR).

Finger millet. The recommended fertilizer dose is 50–40–25 kg NPK/ha against 46.06–14.35–19.76 kg NPK required for the regional targeted yield. The rate of misapplication was 3.94–25.62–5.24 kg NPK/ha amounting to Rs. 492.94 misuse. In Type II misapplication farmers in general were app-lying more N and P than required and less K, resulting in depletion of soil nutrient reserve. The levels of nutrient applied (kg NPK/ha) in the watershed for finger millet were 57.91–54.52–1.30, 81.23–53.63–0.47, and 76.63–49.15–1.51 kg NPK/ha by marginal, small and large farmers, respectively, against 34.29–8.19–14.65, 27.45–6..26–12.65 and 25.73–

4.60–10.38 kg NPK required for getting the present yields. Misapplication of nutrients (NPK) was highest (57.12 kg/ha) in marginal farmers followed by small (46.36 kg/ha) and large farmers (40.71 kg/ha), valued at Rs. 880.94/ha, Rs. 1172.78/ha and Rs. 122.49/ha, respectively. Estimated loss in the watershed due to misapplication of nitrogen to finger millet was Rs 65771 (6.31 t), of phosphorus Rs 115622 (7.23 t) and of potassium Rs 15074 (–1.88 t), giving a total of Rs 166318 (11.65 t).

Groundnut. The data on level of nutrient application (excess or less) and the cost of misappli-cation practised by farmers for groundnut showed that the recommended nutrient dose is 25–50–25 kg NPK/ha as against (–)39.63–(–)216.43–(–115.58) kg NPK required for the regional targeted yield. The rate of misapplication found was 64.63–266.43–140.58 kg NPK/ha amounting to Rs. 6061.54 misuse. On the other hand Type II misapplication showed that farmers in general were applying more N, P and K than required, resulting in degradation of soil. Type II misapplication varied with size group of farmers. The levels of nutrient application (kg NPK/ha) in the watershed for groundnut crop were 22.58–56.12–0.60, 28.84–72.87–0.00, and 18.78–47.45–0.00 kg NPK/ha by marginal, small and large farmers, as against (–)48.67–(–)248.98–(–)129.79, (–)52.23–(–)232.49–(–)118.95, (–)46.75–(–)236.11–(–)137.04 kg NPK, respectively, required for getting the present yields. The misapplication of nutrients (NPK) was highest (540.21 kg/ha) in large farmers followed by marginal farmers (506.74 kg/ha) and small farmers (505.38 kg/ha). Estimated loss in the watershed due to misapplication of nitrogen to groundnut was Rs 36083.93 (3.46 t), of phosphorus Rs 178190.42 (11.14 t) and of potassium Rs38116.63 (4.76t), giving a total of Rs 252390.98 (19.36 t).

4.7.4 Estimation of soil potential index

The Soil Potential Index (SPI) is a numerical rating of a soil's relative suitability or quality and is expressed by

SPI = P – (CM+CL)

where, P = index of performance or yield as a locally established standard,

CM = index of costs of corrective measures to overcome or minimize the effect of soil limitations,

CL = index of costs resulting from continuing limitations.

Finger millet. Soil unit ImB1 with 23.40 qtl/ha grain yield was considered the performance standard and served as basis for recognizing sub-standard soil performance in terms of both yield and additional costs required for correcting soil limitations. The level of crop management in achieving yield was measured in terms of cost, since consideration of cost is the most deciding factor in selection of any crop enterprise by farm households.

The only corrective measure required in the watershed was contour bunding to fight soil erosion. The cost incurred by the watershed development department worked out to Rs 3095/ha. The expected life span of contour bunds is 20 y. Thus the annual cost was Rs 154.75/ha. Where slope was 1–3 and 3–5 per cent the cost was twice and four times.

The continuing limitation amenable to improvement in Garakahalli watershed was low soil fertility. The share of fertilizer inputs was the major annual investment. Fertile soils needed lower level of inputs (Rs 798.84 on Kg1hB1) than poor soils (Rs 177 on Gg1hE3St4).

The SPR approach grouped the watershed soils into 3 categories low, medium and high, which appeared realistic and matching the ground reality.

Groundnut. Soil unit NiB1 with 10.40 qtl/ha groundnut yield was taken as performance standard.

The annual cost of contour bunding was Rs 154.75/ha. Where slope was 1–3 and 3–5 per cent the cost was twice or four times.

The share of fertilizer inputs was the major annual investment. Fertile soils needed lower level of inputs (Rs 630.38 on NiB1) than poor soils (Rs 2833.86 on Hg1bB1).

The soil potential rating assessment grouped the soils of the watershed into three cate-gories, namely, medium, high and very high potential for growing groundnut based on current crop yield and management costs.

4.7.5 Valuation of land using income approach

Finger millet production system. The economic valuation of finger millet system on different soil units showed that the cost of cultivation per hectare ranged from a minimum of Rs 4691 on soil unit CbB1 to a maximum of Rs 7466 on NbB1 with a mean of Rs 5744. Net returns ranged from Rs 2000/ha on soil unit Lg1bC2St3 (very deep soil on 3–5% slope, with moderate erosion) to Rs 6277/ha on soil unit ImB1 (moderately deep soil on 1–3% slope with slight erosion). Net returns from finger millet cultivation and soil depth were positively correlated. Shallow soils (BcB1) fetched net returns of Rs 2746/ha compared to Rs 5455/ha on very deep soil (KbB1).

Groundnut production system. Cost of cultivation per hectare ranged from Rs 6150 on soil unit Eg1hB1-R to Rs 10809 on HcB1 with a mean of Rs 8345. Net returns per hectare ranged from a low of Rs 1054.74 on soil unit Fcb1 (deep soil on 1–3% slope, with slight erosion) to a high of Rs 5087 on KmB1 (very deep soil on 1–3% slope with slight erosion). Net returns from groundnut cultivation and soil depth were positively correlated. Moderately shallow soils (CbB1) fetched net returns of Rs 2610/ha compared to Rs 3222/ha on very deep soil (KbB1).

Horsegram production system. Cost of cultivation per hectare ranged from Rs 1931 on soil unit FcB1 to Rs 2760 on CiC1 with a mean of Rs 2233. Net returns ranged from Rs 632/ha on soil unit CcB1 (moderately shallow soil on 1–3% slope, with slight erosion) to Rs 1576/ha on soil unit KbB1 (very deep soil on 1–3% slope with slight erosion). Net returns from horsegram cultivation and soil depth were positively correlated. Moderately shallow soils (CbB1) fetched net returns of Rs 1026/ha against Rs 1527/ha on very deep soil (KbB1). The land value ranged from Rs 5745/ha to Rs 14335/ha.

Mulberry production system. Cost of cultivation per hectare ranged from Rs 10185 on soil unit KbB1 to Rs 15936 on NcB1 with a mean of Rs 11523. Net returns ranged from a low of Rs 9837/ha on soil unit Lg1bC2St3 (very deep soil on 3–5% slope, with moderate erosion) to Rs 48334/ha on soil unit NbB1 (very deep soil on 1–3% slope with slight erosion). Net returns from mulberry and soil depth were positively correlated. Moderately shallow soils (CbB1) fetched net returns of Rs 25929/ha compared to Rs 35708/ha on very deep soil (KbB1). Soil gravel and net returns had inverse relationship. Net returns from mulberry on non-gravelly soils were Rs 30034/ha against Rs 11292/ha on gravelly (>35%) soils. Land value per hectare ranged from Rs 89434 to Rs 439401.

Banana production system. Cost of cultivation per hectare ranged from Rs 25128 on soil unit Kg1hB1 to Rs 36516 on NcB1 with a mean of Rs 29776. Net returns ranged from a low of Rs 70872/ha on soil unit CbB1 (moderately deep soil on 1–3% slope, with slight erosion) to Rs 92483/ha on soil unit NcB1 (very deep soil on 1–3% slope with slight erosion). Net returns from banana cultivation and soil depth were positively correlated. Moderately shallow soils (CbB1) fetched net returns of Rs 70872/ha compared to Rs 83770/ha on very deep soil (KbB1).

Coconut production system. Cost of cultivation per hectare ranged from Rs 11293 on soil unit JhB1 to Rs 16637 on Hg2iC1 with a mean of Rs 14248. Net returns ranged from a low of Rs 8472/ha on soil unit CbB1 (moderately deep soil on 1–3% slope, with slight erosion) to Rs 25060 on NhA1 (very deep soil on 1–3% slope with slight erosion). Net returns from coconut cultivation and soil depth were positively correlated. Moderately deep soils (CbB1) fetched net returns of Rs 8472/ha compared to Rs 25060/ha on very deep soil (NhB1) with a difference of Rs 16588/ha.

4.8 Environmental And Economic Valuation Of Land Resources of Nalatwad Watershed

4.8.1 Production function analysis

Sorghum. The resource productivity for sorghum calculated through production function analysis showed that the regression coefficients were positive and significant for depth of the soil (0.536), potassium applied (0.004) and men labour used (0.006).

The regression coefficient for slope of the land (–0.428) was negative and statistically significant and hence indicated that as slope increased sorghum yield decreased.

Data on marginal productivity revealed that, for every 1-cm increase in soil depth from the geometric mean (151.94 cm), yield increased by 0.03 quintal and gross returns by Rs 18. However, for every one per cent increase in slope from the geometric mean (1.93 %), yield decreased by 2.2 qtl resulting in Rs 1320 decrease in gross returns. An increase of one kg of potash application would yield an additional return of Rs 22.46/ha and use of one additional men-labour day would provide an additional return of Rs 4.97/ha.

Sunflower. The regression coefficients were positive and statistically significant for seed (0.631), men labour (0.082) and bullock labour used (0.184). However, the coefficient for women labour used was negative (-0.128) and statistically significant, indicating over-use of the input or under-valuation of the input. The coefficient for tenurial status was not significant.

Every kg/ha of seed used beyond the present geometric mean (7.29 kg/ha) would increase yield by 0.631 qtl/ha, adding Rs 638.79/ha to the gross income. Women labour used above the present geometric mean would decrease output by 0.04 qtl/ha (Rs 43.09/ha).

Bengal gram. The regression coefficients for depth of the soil (0.184), men labour (0.839) and women labour used (0.856) were positive and statistically significant.

The regression coefficients for nitrogen (–1.273), potash (–0.468) and PPC (–0.202) were negative and statistically significant and, therefore, indicative of their over-use.

Marginal productivity of soil depth was 0.01 qtl/ha yielding an income of Rs 16. Increase of erosion of the soil by one t ha^{-1} y^{-1} from the present geometric mean level would decrease yield by 1.1 qtl, resulting in reduction in gross returns by Rs 1760. An additional increase of one unit use of nitrogen, potassium and plant protection chemicals from the current mean level would result in decrease in gross income by Rs 743.85, Rs 1525.23 and Rs 5866.67 respectively. The additional use of men and women labour would result in increased gross income by Rs 2754.93 and Rs 346.65 respectively. The coefficient of multiple determination was very high at 0.984.

The use of men labour over and above the existing mean level contributed significantly to the increase in yield of all the three crops. Other resources, additional use of which could increase the yield and gross income, are potash application in sorghum, seed and bullock labour for sunflower and women labour in bengal gram.

4.8.2 Replacement cost approach for estimation of cost of soil erosion

Soil organic matter. Soil organic matter loss from the soils ranged from a low of 46.55 kg/ha to a maximum of 462 kg/ha with average value of 127 kg/ha. The annual soil organic matter loss for the watershed was 70302 kg, worth Rs 35151.

Nitrogen. Nitrogen loss ranged from 0.36 kg/ha to 3.29 kg/ha per year. The average annual loss worked out to 0.69 kg/ha valued at Rs 7.25. The total annual loss of nitrogen from the watershed was 384 kg, worth Rs 4005.37.

Phosphorus. **P**hosphorus loss ranged from 0.02 kg/ha to 0.78 kg/ha, and the average loss 0.11 kg/ha. Total annual loss of phosphorus estimated was 61.49 kg, worth Rs 984.

Potash. The annual potash loss ranged from 1.3 kg/ha to 11.96 kg/ha with an average loss of 3.42 kg/ha worth Rs 27.35. The total annual potash loss estimated was 1890.55 kg worth Rs 15124.40.

Iron. The annual loss of iron ranged from 0.05 kg/ha to 0.83 kg/ha. The total annual loss of iron estimated was 63.39 kg worth Rs 2080.50.

Manganese. Annual manganese loss due to soil erosion ranged from 0.09 kg/ha to 5.09 kg/ha. The total loss from the watershed was 220.38 kg, worth Rs 3251.26.

Copper. Loss of copper ranged from 0.01 kg/ha to 0.70 kg/ha per year. About 19 kg of copper was lost annually from the watershed by soil erosion; its worth was Rs 278.

Zinc. Zinc loss was 0.01 kg/ha to 0.03 kg/ha per year. The total annual loss from the watershed was estimated at 4 kg, worth Rs 419.30.

The total annual soil-nutrient loss due to erosion from the watershed as a whole was 72.944.78 kg, with a value of Rs 61293.57.

4.8.3 Estimation of cost of misapplication of nutrients

Sorghum. The recommended fertilizer dose is 90–50–65 kg NPK/ha as against 60–25–32.5 kg NPK required for the farmers' yield. The rate of misapplication was 30–25–32.5 kg NPK/ha accounting for Rs 1945.80 misuse. In Type II misapplication farmers in general were applying more N and P than required and less K, resulting in depletion of soil nutrient reserve. Levels of nutrient application (kg NPK/ha) in the watershed for sorghum were 30.5–31.0–11.5, 35.5–27.5–11.0 and 36.0–27.5–11.5 kg NPK/ha by marginal, small and large farmers, respectively, compared to 14.0–8.0–32.5, 7.0–25.0–32.5 and 4.0–25.0–32.5 kg NPK required for getting the present yields. Misapplication of nutrients (NPK) was highest (60.5 kg/ha) in marginal farmers followed by large farmers (55.5 kg/ha) and small farmers (52.5 kg/ha), valued at Rs 708.10/ha, Rs 541.76/ha) and Rs 504.04/ha, respectively. Estimated loss in the watershed due to misappli-cation in sorghum of nitrogen was Rs 133989.76 (12.87 t), of phosphorus Rs 20169.68 (1.26 t) and of potassium Rs 69692 (8.71 tons), giving a total of Rs 223851.41 (22.84 t).

Sunflower. The recommended fertilizer dose (NPK) is 75.5–65.0–75.5 kg/ha as against 17.0–76.0–38.0 kg NPK required for getting the regional yield. The present trend of fertilizer use showed application of excessive N and K and less P. The rate of misapplication of nutrients (NPK) was 58.5–11.0–37.5 kg/ha, worth Rs 1945.80/ha. On the other hand, Type-II misappli-cation was 29.0–25.0–34.0 kg/ha by marginal and 10.5–9.2–24.5 kg/ha by large farmers. The rate of Type-II misapplication of nutrients was the highest (88 kg NPK/ha) in marginal farmers and the lowest (44.20 kg NPK/ha) in large farmers, valued at Rs 974.47/ha and Rs 452.74/ha, respectively. The total annual estimated cost of misapplication (nutrient loss) of nitrogen in sun-flower cultivation in the watershed was Rs 12898.31 (1.24 t), of phosphorus Rs 17264.26 (1.1 t), of potash Rs 20105.40 (2.5 t), adding up to Rs 50267.97 (4.8 t).

Wheat. The recommended nutrient dose (NPK) is 137.5–90.0–87.5 kg/ha against 69.0–135.0–44.0 kg required for getting the potential yield. The rate of Type-1 misapplication was 68.5–45.0–43.5 kg NPK/ha, costing Rs 1782.46/ha. The current level of nutrient addition (NPK) by small farmers was 36.0–26.0–4.0 kg/ha and by large farmers 21.0–24.0–13.0 kg NPK/ha as against 69.0–4.0–44.0 and 69.0–45.0–

44.0 kg NPK, respectively, required for getting the present yields. Generally less nutrient was being applied, except for P in case of small farmers, where there was surplus use. The rate of Type-II misapplication was 33.0–22.0–40.0 kg/ha (Rs1069.19/ha) for small and 48.0–22.0–31.0 kg/ha (Rs 1084.19/ha) for large farmers The estimated annual cost of misapplication of nitrogen in wheat cultivation in the watershed was Rs 8682.98 (0.83 t), of phos-phorus Rs 5536.00 (0.35 t) and of potash Rs 4376.00 (0.55 t), aggregating to Rs 18594.98.

4.8.4 Estimation of Soil Potential Index

Finger millet. Soil unit EmB2 with 13.5 q/ha grain yield was considered the performance stan-dard and served as basis for recognizing substandard soil performance in both yield and addi-tional costs required for correcting soil limitations. The only corrective measure required in the watershed was contour bunding to fight soil erosion. The cost incurred worked out to Rs 2890/ha. As the expected life span of contour bunds is 20 y, the annual cost was Rs 144.50/ha; where slope was 3–5 per cent, the cost was doubled.

The continuing limitations in Nalatwad watershed were low soil fertility (N, P, Zn) and sodicity. Costs involved in correcting nutrient status and sodicity in the soil units were calculated for each soil unit. The share of fertilizer inputs was the major annual investment. Fertile soils needed lower level of fertilizer (Rs 2421.25 on AmC3) than poor soils (Rs 4545.25 on CmC3).

The SPR approach grouped the soil units of the watershed into 3 categories (very low, low, medium potential), which appeared to realistic and matching the ground reality.

4.8.5 Valuation of Land Using Income Approach

Sorghum-production system. The economic valuation of sorghum on different soil units ranged from a minimum of Rs 3363 in CmB2 to a maximum of Rs 4376 in BmB2 with a mean cost of cul-tivation of Rs 3783.12/ha. Net returns ranged from a low of Rs 3066.76/ha on soil unit AmC2 (shallow soil on 3–5% slope, with moderate erosion) to a high of Rs 5810.16/ha on soil unit EmB2 (deep soil on 1–3% slope, moderate erosion). Shallow soils (AmB2) fetched net returns of Rs 3369.24 /ha compared to a maximum of Rs 5810.16/ha on deep soils (EmB2). Erosion and net returns had inverse relationship. Net returns from slightly eroded soils (soil loss <5 t ha^{-1} y^{-1}) were Rs 5287/ha compared to Rs 3161/ha on severely eroded soils (soil loss 15–40 t ha^{-1} y^{-1}). The land value ranged from Rs 27879.63/ha to Rs 52819.62/ha; the average being about Rs 403491/ha.

Sunflower-production system. The cost of cultivation of sunflower ranged from a minimum of Rs 3967.27/ha on soil unit CmC2 to a maximum of Rs 4921.27/ha on soil unit BmB2, with mean of Rs 4365.21/ha. Soil depth and sunflower net returns were positively correlated. The difference in net returns between shallow soil (AmB2) and deep soil (EmB2) was Rs 4249.77/ha. The land value under sunflower ranged from Rs 10979.18/ha (AmB2) to Rs 63337.66/ha (FmA1). On average, the land value under sunflower production system in Nalatwad watershed was about Rs 43596/ha.

Wheat-production system. Cost of wheat cultivation ranged from Rs 3291.28/ha (CmB2) to Rs 3808.25/ha (FmA1) the mean being Rs 3595.23/ha. Soil depth and net returns were positively correlated. The difference in net returns between shallow soil (CmB2) and deep soil (FmA1) was Rs 516.37/ha. Net returns and soil erosion were inversely correlated. Net returns on slightly eroded soil (FmA1) and moderately eroded soil (EmB2) differed by Rs 762.69/ha. Land value under wheat ranged from Rs 8090.25/ha (AmC2) to Rs 40425.02/ha (FmA1), with a mean of Rs 21968.45.

Bengal gram production system. The cost of cultivation ranged from Rs 4078.23/ha (CmB2) to Rs 4854.98/ha (FmB2) with a mean of Rs 4325.39/ha. Soil depth and bengal gram net returns were positively correlated. Net returns from shallow soil (CmB2) and were Rs 2836.25/ha less than from deep soil (FmA1). The relationship between net returns and soil erosion was inverse. The difference in net returns between slightly eroded (FmA1) and moderately eroded soil (FmB2) was Rs 868.99/ha. The land value under bengal gram ranged from Rs 18416.09/ha (CmB2) to Rs 44200.19/ha (FmA1), with a mean of Rs 32884.29/ha.

4.9 Environmental and Economic Valuation of Land Resources of Pettamanurahatti

4.9.1 Production function analysis

Rainfed groundnut. The regression coefficients were positive and significant for soil depth (0.980), farmyard manure (0.024), nitrogen (0.140), phosphorus (0.156), women labour (0.092) and bullock labour (0.100). The coefficient for soil erosion (–0.052) was negative and significant. The marginal productivity of the inputs used in cultivation of groundnut showed that for every unit increase in soil depth above the present geometric mean (85.36 cm), groundnut yield would increase by 0.094 qtl/ha, adding Rs 112.80/ha to the gross income. Similarly, the additional cont-ributions from unit increases in nitrogen, phosphorus and potash were 0.083, 0.037, and 0.104 qtl/ha, respectively. Contributions to gross income would be Rs 99.60, Rs 44.40 and Rs 125.80, respectively.

Rainfed pearl millet. The regression coefficients were positive and statistically significant for soil depth (0.310), farmyard manure (0.047), nitrogen (0.069), phosphorus (0.110) and potash (0.082). Thus these variables contribute significantly to yield However, coefficients for soil erosion (–0.024) and soil gravel (–0.037) were negative and non-significant. The marginal productivity of the inputs used in cultivation of pearl millet showed that for every unit increase in soil depth above the present geometric mean (68.93 cm), yield would increase by 0.041 qtl/ha. This increase in yield would add Rs16.40/ha to the gross income.

The marginal productivity of other inputs revealed that 0.127 qtl from farmyard manure, 0.072 qtl from nitrogen, 0.053 qtl from phosphorus and 0.494 qtl from potash would be the yield increase for each unit increase of these inputs beyond their present geometric mean levels. Their respective contributions to gross income would be Rs 50.80, Rs 28.80, Rs 21.20 and Rs 197.60.

Irrigated finger millet. Regression coefficients were positive and statistically significant for soil depth (0.244), farmyard manure (0.063), nitrogen (0.077), phosphorus (0.034) and bullock labour (0.142). The marginal productivity of the inputs used in cultivation of finger millet showed that for every unit increase in soil depth above the present geometric mean (85.72 cm), yield would inc-rease by 0.062

qtl/ha. Additions from unit increases in farmyard manure, nitrogen, phosphorus and bullock labour would 0.178, 0.036, 0.041 and 0.227 qtl/ha, respectively. Their contributions to gross income would be Rs 80.10, Rs 16.20, Rs 18.45 and Rs 102.15, respectively.

Irrigated sorghum. The regression coefficients were positive and statistically significant for farmyard manure (0.159), seed rate (0.077), phosphorus (0.201), potassium (0.190) and size of holding (0.125). The coefficients for erosion (–0.195) and bullock labour (–0.508) were significant but negative. The marginal productivity of the inputs used in cultivation of sorghum showed that additional contributions from unit increases in farmyard manure, seed, phosphorus and potash were 0.363, 0.254, 0.242 and 0.225 qtl/ha, respectively. Their contribution to gross income would be Rs 163.35, Rs 114.30, Rs 108.90 and Rs 101.25, respectively. For every unit increase in soil erosion above the present geometric mean (11.85 t ha^{-1} y^{-1}), sorghum yield would decrease by 0.352 qtl *ceteris paribus*, resulting in a loss of Rs 158.40 from the gross income.

Rice. The resource productivity for rice calculated through production function analysis showed that regression coefficients were positive and significant for applied farmyard manure (0.028), nitrogen (0.039) and phosphorus (0.049). The data on marginal productivity showed that an increase of one kg nitrogen and one kg phosphorus would yield additional returns of Rs 10.92 and Rs 39.42, respectively.

4.9.2 Replacement cost approach for estimation of cost of soil erosion

Soil organic matter. Annual soil organic matter loss from the soils ranged from a minimum of 2.59 kg/ha to a maximum of 482.72 kg/ha with a mean value of 143.91 kg/ha. Total annual soil organic matter loss for the watershed was 65945.78 kg, worth Rs 32972.89.

Nitrogen. Nitrogen loss ranged from 0.36 kg/ha to 3.76 kg/ha per year. The mean annual loss worked out to 1.38 kg/ha. The total annual loss of nitrogen from the watershed was 705.73 kg, worth Rs 7360.73.

Phosphorus. Phosphorus loss ranged from 0.04 kg/ha to 0.87 kg/ha with the mean loss at 0.24 kg/ha. Total annual loss of phosphorus was 127.60 kg, worth Rs 2041.62.

Potash. The annual potash loss ranged from 0.43 kg/ha to7.09 kg/ha with an average loss of 2.04 kg/ha. The total annual potash loss estimated was 1040.84 kg worth Rs 8326.68.

Iron. The annual iron loss varied from 0.007 kg/ha to 0.360 kg/ha, with a mean of 0.070 kg/ha. The total annual loss of iron was 37.01 kg worth Rs 1217.33.

Manganese. Annual manganese loss due to soil erosion ranged from 0.028 kg/ha to 1.179 kg/ha with a mean of 0.237 kg/ha. The total loss from the watershed was 129.47 kg, worth Rs 1910.98.

Copper. Loss of copper ranged from 0.002 kg/ha to 0.023 kg/ha per year with a mean of 0.07 kg/ha. Annual loss of copper from the watershed by soil erosion was 3.39 kg worth Rs 50.10.

Zinc. Zinc loss was 0.001kg/ha to 0.024 kg/ha per year. The total annual loss from the water-shed was estimated at 3.73 kg, worth Rs 390.83.

Total annual loss of organic matter and nutrients was 67993.63 kg, worth Rs 54271.16.

4.9.3 Estimation of cost of misapplication of nutrients

Groundnut. The recommended nutrient dose is 25–50–25 kg NPK against (–)29.74–(–)196.64–(–)144.6 0) kg NPK per hectare required for the regional yield. Type I misapplication was 54.74–246.64–169.60 kg NPK/ha costing Rs 5873.94/ha. With regard to Type II misapplication farmers in general were applying more nutrient than required. Application by marginal, small and large farmers was 16.32–41.44–0.00, 15.15–38.48–0.00 and 12.90–32.3–0.00 kg NPK/ha as against (–)53.40–(–)260.23–(–) 136.22, (–)57.92–(–) 246.02–(–)126.68, (–)56.53–(–)259.36–(–)150.32 kg NPK/ha, respectively, required for getting the present yields. Misapplication of nutrients (NPK) was highest (536.99 kg/ha) by large farmers followed by marginal farmers (507.60 kg/ha) and small farmers (484.24 kg/ha). Estimated loss in the entire watershed due to misapplication of nitrogen to groundnut was Rs 387047.37 (37.11 t), of phosphorus Rs 2037852.91 (127.37 t) and of potassium Rs 493812.01 (61.73 t), giving a total of Rs 2918712.29 (226.2 t).

Pearl millet. The recommended fertilizer dose is 50–25–0 kg NPK/ha against (–)12.71–9.17–19.94 kg NPK required for the regional yield. Type I misapplication was 62.71–15.83–(–)19.94 kg NPK/ha amounting to Rs 1066.80. In regard to Type II misapplication the farmers were applying more nutrient than required, except for small farmers who were applying less N and K, and marginal farmers who were applying less K. The levels of nutrient application in the watershed were 8.86–22.50–0.00, 7.03–17.85–0.00, and 6.34–15.84–0.00 kg NPK/ha by marginal, small and large farmers, respectively, in contrast to (–)56.56–(–)33.92–(–) 3.89, (–)14.26–(–) 43.21–0.50 and (–)420.50–(–)57.53–(–)5.64 kg NPK required for getting the present yields. Type II misapplication of nutrients (NPK) was highest (505.84 kg/ha) by large farmers followed by mar-ginal farmers (125.73 kg/ha) and small farmers (68.80 kg/ha). Estimated loss in the watershed due to misapplication of N was Rs 89427.05 (8.57 t), of phosphorus Rs 34.994.10 (2.19 t) and of potassium Rs 796.72 (0.09 t), aggregating to Rs 125217.9 (10.86 t).

Irrigated finger millet. The recommended fertilizer dose is 100–50–50 kg NPK/ha against 194.31–115.82–117.25 kg NPK for the regional yield. Type I misapplication was (–)94.31–(–) 65.82–(–)67.25 kg NPK/ha amounting to Rs 2574.69. In Type II misapplication, farmers in general were applying less nutrient than required, except for marginal farmers who applied just the required rate of nitrogen. The levels of nutrient application were 68.29–22.23–18.48, 58.41–23.05–14.51, and 41.31–24.73–2.13 kg NPK/ha by marginal, small and large farmers instead of 68.22–46.96–36.66, 78.04–52.68–43.34 and 55.73–41.08–28.05 kg NPK, respectively, required for getting the present yields. Misapplication (NPK) was highest (78.09 kg/ha) with small farmers followed by large farmers (56.69 kg/ha) and marginal farmers (41.96 kg/ha). Total estimated loss by misapplication of nitrogen was Rs 1589 [(–)152.35 kg], of phosphorus Rs 5518.33 [(–)344.9 kg] and of potassium Rs 2804.38 [(–)350.55 kg), adding up to Rs 9911.72 [(–)847.79 kg].

Irrigated sorghum. The rate of Type I misapplication was (–)36.16–(–) 28.24–(–)24.04 kg NPK per hectare costing Rs 1021.37/ha. In Type II misapplication, farmers in general were applying excess N and less P than required. Large farmers were applying less K, while small and marginal farmers were applying excess. Levels of application to sorghum were 62.64–22.71–22.71, 42.92–17.36–17.36, and 28.60–6.00–0.00 kg NPK/ha by marginal, small and large farmers, respectively, against 35.19–39.27–18.91, 28.64–35.79–17.01 and 12.48–26.57–9.44 kg NPK required for getting the present yields. The misapplication of nutrients (NPK) was highest (47.80 kg/ha) in marginal farmers followed by large farmers (46.14 kg/ha) and small farmers (33.07 kg/ha). Estimated loss in the watershed due to misapplication of nitrogen to irrigated sorghum was Rs 1883.95 (180.63 kg), of phosphorus Rs 2983.73 [(–)186.48 kg] and of potassium Rs 353.12 [(–)44.14 kg], giving a total of Rs 5220.81 (411.25 kg).

Rice. The rate of Type I misapplication was (–)52.72–(–)58.59–(–) 21.41 kg NPK/ha amounting to Rs 1658.63. In Type II misapplication (Fig. 28.5) the farmers were applying less N and more P than required. Marginal farmers were applying excess K. Nutrient application to rice was 93.22–26.03–26.03, 69.32–24.76–19.76, and 29.14–18.06–4.72 kg NPK/ha by marginal, small and large farmers, respectively, as against 35.19–39.27–18.91, 28.64–35.79–17.01 and 12.48–26.57–9.44 kg NPK required for getting the present yields. Estimated loss due to misapplication of nitrogen to rice was Rs 5300.62 (508.21 kg), of phosphorus Rs 2221.45 [(–)138.84 kg) and of potassium Rs 248.02 (31 kg), giving a total of Rs 7770.08 (678.05 kg) in the watershed.

4.9.4 Estimation of soil potential index

Groundnut. Soil unit NcA1 (very deep soils on <1% slope) with farmers' level of management, yielding 8.98 qtl/ha groundnut was considered the performance standard. The only corrective measure required in the watershed was contour bunding to fight soil erosion. The cost incurred by the watershed development department was Rs 3200/ha. The expected life span of contour bunds is 20 y. Thus the annual cost was Rs 160/ha. Where slope was 1–3 or 3–5 per cent the cost was doubled or quadrupled. The continuing limitation in Pettamanurahatti watershed was low soil fertility. The cost of improving fertility was lower for fertile soil (Rs 2289.87/ha for unit NcA1) than for poor soils (Rs 2369.38/ha for unit Kg3bD3).

In general, the soil potential rating assessment grouped the soils of the watershed into three categories medium, high and very high potential for growing groundnut based on current crop yield and management costs.

Pearl millet. Soil unit NcA1 (very deep soils on <1% slope) with farmers' level of management, yielding 12.10 qtl/ha pearl millet was considered the performance standard. Fertile soils needed lower level of inputs (Rs 238.72 on Bg3bB2) than poor soils (Rs 1409.25 on Kg3bD3).

Irrigated finger millet. Soil unit NcA1 (very deep soils on <1% slope) with farmers' level of management, yielding 23.88 qtl/ha was considered the performance standard. The data on cost of corrective measures, continuing limitations of different soil units and corresponding soil potential ratings indicated that fertile soils needed lower level of inputs (Rs 2561.02 on NcA1) than poor soils (Rs 3347.59 on IbC2).

Irrigated sorghum. Soil unit NcA1 yielding 23.33 qtl/ha was considered the performance stan-dard. Fertile soils needed lower level of inputs (Rs 762 on NcA1) than poor soils (Rs 1713.51 on Bg2bC2).

4.9.5 Valuation of land using income approach

The net income was capitalized at 11% to arrive at the land value of each soil unit.

Rainfed groundnut production system. The economic valuation of groundnut system on dif-ferent soil units showed that cost of cultivation ranged from a low of Rs 5845.99/ha on NcA1 to a high of Rs 8357.80/ha on Dg2bB2 with a mean of Rs 6950.55/ha. Net returns ranged from a high of Rs 1664.74/ha on unit BcB2 (shallow soil on 1–3% slope, with moderate erosion) to a high of Rs 8357.80/ha on unit Dg2bB2 (shallow soil on 0–1% slope with moderate erosion). Shallow soils (Bg2hB2) fetched net returns of Rs 2493.55/ha compared to a maximum of Rs 3503.22/ha on very deep soil (LbA1) with a difference of Rs 1243.38/ha.

Soil gravel and net returns had inverse relationship. The net returns from groundnut on non-gravelly (<15%) soil were Rs 2793/ha against Rs 1664.74/ha on highly gravelly (>35%) soil, the difference being Rs 18742/ha. The net returns from groundnut on slightly eroded soils(<5 t ha^{-1} y^{-1}) were Rs 3503.22/ha compared to Rs

1091.00/ha on severely eroded soil (>40 t ha^{-1} y^{-1}) the difference being Rs 2412.22/ha. The land value was Rs 15134/ha to Rs 38986.48/ha.

Rainfed pearl millet production system. The cost of cultivation ranged from a minimum of Rs 2538.63/ha on soil unit Cg3bB2 to a maximum of Rs 3307.15/ha on Dg2bB2 with a mean of Rs 2981.36/ha. Net returns ranged from a low of Rs 185.65/ha on soil unit Dg2cB2 (shallow soil on 1–3% slope, with moderate erosion) to a high of Rs 1814.54/ha on soil unit LcA1 (deep soil on 1–3% slope with slight erosion). Shallow soils (Cg2bB2) fetched net returns of Rs 338.03/ha against the highest of Rs 1814/ha on deep soil (LcA1) with difference of Rs 1476.51/ha. Land value ranged from Rs 1687.73/ha to Rs 16495.82/ha.

Irrigated finger millet production system. Cost of cultivation ranged from a minimum of Rs 5973.73/ha on Ig2cB2 to a high of Rs 8325.06/ha on NcA1 with a mean of Rs 7093.78/ha. Net returns were Rs 1303.77/ha on soil unit Dg2cB2 (shallow soil on 1–3% slope, with moderate erosion) to Rs 4421.27/ha on Ig2cB2 (moderately shallow soil on 1–3% slope with moderate erosion). Shallow soils (BhA2) fetched net returns of Rs 1380.76/ha compared to a maximum of Rs 3316.88/ha on deep soil (LcA1) with a difference in net returns of Rs 1936.12/ha. The land value ranged from Rs 11852.45/ha to Rs 40193.38/ha.

Irrigated sorghum production system. The economic valuation of sorghum system on different soil units showed that the cost of cultivation ranged from a minimum of Rs 5453.93/ha on Kg2cB2 to a maximum of Rs 7618.01/ha on NcA1 with a mean cost of Rs 6310.09/ha. Net returns ranged from a low of Rs 1467.38/ha on soil unit Cg2bB2 (shallow soil on 1–3% slope, with moderate erosion) to Rs 4725.93/ha on soil unit LcA1 (deep soil on 0–1% slope with slight erosion). Net returns from sorghum cultivation and soil depth were positively correlated. Shallow soils (Cg2bB2) fetched net returns of Rs 1467.37/ha compared to a maximum of Rs 4725.92/ha from deep soil (LcA1) with a difference of Rs 3258.55/ha. Land value ranged from Rs 13339.77/ha to Rs 42962.95/ha.

Rice-production system. The economic valuation of rice system on different soil units showed that cost of cultivation ranged from a minimum of Rs 7067.75/ha on Cg2bB2 to Rs 11450.86/ha on OhB2 with a mean of Rs 8936.71/ha. Net returns ranged from a low of Rs 3121/ha from unit Cg2bB2 (shallow soil on 1–3% slope, with moderate erosion) to a high of Rs 8269.96/ha from unit Jg2cB2 (moderately deep soil on 1–3% slope with moderate erosion). Net returns from rice cultivation and soil depth were positively correlated. Shallow soils (Cg2bB2) fetched net returns of Rs 3121/ha compared to a maximum of Rs 8269.96/ha on deep soil (Jg2cB2) with a difference of Rs 3027.32/ha. Land value ranged from Rs 28372/ha to Rs 75181/ha.

4.10 Environmental and Economic Valuation of Land Resources of Molahalli Watershed

4.10.1 Production function analysis for rice

The resource productivities for *kharif* and *rabi* rice were calculated through production function analysis. The regression coefficients were positive and significant for soil reaction (0.671), farmyard manure applied (0.044), nitrogen (0.037), phosphorus (0.080), potash (0.370) and women labour used (0.413) in *rabi*. The intercepts for *kharif* (0.432) and *rabi* (3.669) were positive and significant and may be attributed to inherent capacity of the soil. The coefficients for soil erosion (–0.015) and size of holding (–0.306) were negative and statistically significant.

Marginal productivity data for *kharif* rice revealed that for every 1-cm increase in soil depth from the geometric mean depth (167.35 cm), yield would increase by 0.026 qtl and the gross returns by Rs 15.48. However, for every one unit increase in erosion from the geometric mean level (6.27 t ha^{-1} y^{-1}), yield would decrease by 2.87 qtl/ha resulting in Rs 1723 decrease in gross returns. An increase of one kg of phosphorus application would yield an additional return of Rs 171.71, of one kg of potash a return of Rs 690.81 and use of one additional women-labour day would provide an additional return of Rs 95.37.

The regression coefficients for *rabi* rice were positive and statistically significant for soil depth (0.202), soil reaction (0.685), phosphorus (0.021) and potash (0.012). Thus these variables contribute significantly to *rabi* rice yield and encourage use of additional quantity of these inputs over and above their present geometric mean levels. However, the coefficient for women labour used was negative (–0.0176) and not significant. The marginal productivity of the inputs used in cultivation of *rabi* rice showed that for every unit increase in soil reaction above the present geometric mean (4.86), rice yield would increase by 0.685 qtl. This also means that the marginal productivity of soil reaction is 3.81 qtl, which adds Rs 2287.78 to the gross income.

Similarly, the additional contributions from unit increases in phosphorus and potash would be 0.021 and 0.012 qtl/ha, respectively. The marginal productivity of these inputs revealed that 0.074 qtl from phosphorus and 0.088 qtl from potash would be the yield for each unit increase of these inputs over and above their present geometric mean levels. Their contribution to gross income would be Rs 44.36 and Rs 52.58 respectively.

4.10.2 Replacement cost approach for estimation of cost of soil erosion

Soil organic matter. Soil organic matter loss from the soils ranged from a minimum of 96.54 kg/ha to a maximum of 1737.79 kg/ha with an average value of 432.68 kg/ha. Total annual soil organic matter loss for the watershed was 215622.49 kg, worth Rs 107811.25.

Nitrogen. Nitrogen loss ranged from 0.50 kg/ha to 7.87 kg/ha per year. The average annual loss worked out to 2.28 kg/ha. The total annual loss of nitrogen from the watershed was 1094.69 kg, worth Rs 11417.61.

Phosphorus. Phosphorus loss ranged from 0.02 kg/ha to 1.09 kg/ha, and the average loss was 0.19 kg/ha. Total annual loss of phosphorus was 91.97 kg, worth Rs 1471.54.

Potash. The annual potash loss ranged from 0.09 kg/ha to 3.10 kg/ha with an average loss of 0.84 kg/ha. The total annual potash loss estimated was 397.8 kg worth Rs 3182.42.

Iron. The annual iron loss varied from 0.06 kg/ha to 3.62 kg/ha, with a mean of 0.84 kg/ha. The total annual loss of iron was 403.21 kg worth Rs 13233.37.

Manganese. Annual manganese loss due to soil erosion ranged from 0.01 kg/ha to 2.03 kg/ha with a mean of 0.25 kg/ha. The total loss from the watershed was 114.42 kg, worth Rs1668.82.

Copper. Loss of copper ranged from 0.00 kg/ha to 0.09 kg/ha per year with a mean of 0.02 kg/ha. About 6.29 kg copper; worth Rs 92.85, was lost annually from the watershed by erosion.

Zinc. Zinc loss was 0.00 kg/ha to 0.05 kg/ha per year. The total annual loss from the watershed was estimated at 4.19 kg, worth Rs 438.7.

The aggregate annual loss of soil organic matter and nutrients from the watershed as a whole was 217335.06 kg, with a value of Rs 139336.55.

4.10.3 Estimation of cost of misapplication of nutrients in rice

The recommended fertilizer dose is 60–30–45 kg NPK/ha as against 23.42–33.41–74.85 kg NPK required for the regional yield. Type I misapplication was 36.58–(–)3.41–(–)29.85 kg NPK/ha amounting to Rs 674.78 misuse. With regard to Type II misapplication farmers in general were applying more N and P and less K than required. Levels of nutrient application (kg NPK/ha) for rice were 49.80–19.16–14.37, 20.87–7.75–5.81, and 36.76–19.07–14.30 kg NPK/ha by mar-ginal, small and large farmers against (–)36.16–8.46–34.03, (–) 41.05–6.03–28.63 and (–)32.50–9.19–31.86 kg NPK, respectively, required for getting the present yields. The misapplication of nutrients (NPK) was highest (130.69 kg/ha) in marginal farmers followed by large farmers (111.01 kg/ha) and small farmers (92.26 kg/ha), valued at Rs 1340.03/ha (marginal), Rs 1135.42/ha (large) and Rs 902.28/ha (small farmers). Estimated loss in the watershed due to misapplication of nitrogen was Rs 150242.04 (14.40 t), of phosphorus Rs 25085.99 (1.56 t) and of potassium Rs 31758.86 [(–)3.67 t], giving a total of Rs 226380.51 (22.35 t).

4.10.4 Estimation of soil potential index

Soil unit NdA1 with 30.83 qtl/ha grain yield was considered the performance standard and served as basis for recognizing sub-standard soil performance in terms of both yield and additional costs required for correcting soil limitations.

The only corrective measure required in the watershed was contour bunding to fight soil erosion. The cost incurred by the watershed development department was Rs 1542/ha. The expected life span of contour bunds is 20 y. Thus the annual cost was Rs 77.12/ha. Where slope was 1–3 and 3–5 per cent the cost was doubled and quadrupled.

The continuing limitations in Molahalli watershed were low soil fertility and acidity. Fertile soils needed lower level of inputs (Rs 11.87 on IfA1) than poor soils (Rs 1161.35 on DiD3).

In general, the soil potential rating assessment grouped the soils of the watershed into three categories medium, high and very high potential for growing rice based on current crop yield and management costs.

4.10.5 Valuation of land using income approach for rice production system

The net income was capitalized at 11% (interest on fixed deposit) to arrive at the land value of each soil phase.

The land value ranged from a minimum of Rs 19521 on HhC3 to a maximum of Rs 66011 on BfA1. The mean cost of cultivation was Rs 10488.79/ha. Net returns ranged from a low of Rs 2147.32 per hectare on soil unit HhC3 (deep soil on 3–5% slope, with severe erosion) to a high of Rs 7829.12 on soil unit JiB1 (very deep soil on 1–3% slope with slight erosion). Mode-rately shallow soils (BfA1) fetched net returns of Rs 4496.23/ha compared to a maximum of Rs 7261.21/ha on very deep soil (LfA12) with a difference in net returns of Rs 2764.98/ha. Soil erosion and net returns had inverse relationship. Net returns from rice on slightly eroded (soil loss <5 t ha^{-1} y^{-1}) soils were Rs 6825.76/ha against Rs 2147.32/ha on severely eroded (soil loss 15–40 t ha^{-1} y^{-1}) soils, the difference being Rs 4678.44/ha.

Soil reaction (pH) and net returns had a positive relationship. The net returns from rice on very strongly acid soil (pH <5.0) were Rs 4058/ha on unit JiB1 compared to Rs 6242/ha on the medium acid (pH 5.5–6.0) LhA1 with a difference of Rs 2184/ha.

4.11 Bioeconomic Modelling of the Cropping Systems in the Watersheds

4.11.1 Optimum land-use plans for Garakahalli watershed

Present cropping and input-use pattern

In the existing cropping pattern in Garakahalli watershed farm households were growing finger millet (145.22 ha rainfed and 10.34 ha irrigated), groundnut (37.40 ha), horsegram (22.63 ha) coconut (28.4 ha), rice (7.45 ha), banana (17.54 ha) and mulberry (22.12 ha).

The various inputs used under the existing cropping pattern were 13580 qtl FYM, 3089 pair-days bullock labour, 12111 days men labour, 18849 days women labour, 22028 kg nitrogen, 17745 kg phosphorus and 6977 kg potash. Cash expenses incurred for these inputs amounted to Rs 2860781. The net income realized was Rs 3980494. Based on data on availability of own funds (cash) it was estimated that around Rs 28.61 lakhs short-term loan was used.

Analysis of the data by linear programming technique

The information collected from the watershed farmers was tabulated and analysed using linear programming technique to draw inferences on the nine objectives set forth in the study, and to draw up land-use plans.

Model I: maximization of net income. The optimum plan under maximization of net income as objective recommended cultivation of finger millet on a larger area of 200 ha to be distributed on different soil series against the current 155.56 ha. The minimum finger millet area (200 ha) was specified for meeting the food requirement in all the models. The area under mulberry, which was 22.12 ha under existing cropping pattern, increased to 145.11 ha. The area under banana increased from 17.54 ha under existing cropping pattern to 65.03 ha. The coconut area remained unchanged at 28.44 ha .The other annual crops, namely, groundnut and horsegram were not recommended in the plan. The total area recommended for cultivation was 438.58 ha to realize a net income of Rs. 94,91,343.53. This would require costs of Rs 4,08,666.65 for the purpose of 7710.79 bullock-pair days, 28,689 men labour days, 30,296.62 women labour days, 5444.69 qtl FYM, 23,608.17 kg nitrogen, 1648.53 kg phosphorus and 13541.34 kg potash. This model suggests the necessity of Rs 10.4 lakhs of crop loan over and above the availability of Rs 30.45 lakhs of owned funds. There was no recommendation of fallow land in this model.

Model II: minimization of cost. The optimum plan with minimization of cost as objective recom-mended changes in area under finger millet on soil series E, F, G, J and K, but did not change area on soil series B, C, I and L. However there was decrease in area on series H from 51.47 to 38.96 ha. The optimization model with cost minimization as main focus allocated 200 ha under finger millet, 22.12 ha under mulberry (8.61 on soil series D, 2.13 on H and 11.38 on N) and 28.44 ha of coconut on soil series N. This model recommended the entire coconut area to be on soil series N unlike in Model I where it was on series D, M and N. The mulberry area had been reduced to a minimum of 22.12 ha from 145.11 ha of model I and the entire area (65.03 ha) under banana in model I was removed to minimize cost. It can be observed that the reduced area under mulberry and banana has been recommended to be left fallow (188.02 ha). The cropping pattern in this model would provide a net income of Rs 19,07,833.27 (lower than that under maximization of net income and also under the existing pattern) with cost of Rs 13,16,168.99. All the inputs were lower than in Model I. This model indicated a surplus of Rs 17.3 lakhs of owned funds.

Model III: minimization of bullock labour. The cropping pattern obtained when the model for minimization of bullock labour was applied did not show any change in the total area under finger millet, mulberry and coconut from the pattern under Model II. However there were small changes in the area under individual soil series. These marginal changes would be reflected in the net income and cost. The area under finger millet on soil series K increased to 123.95 ha from the 19.99 ha of model I and 0 ha under model II. Mulberry crop was recommended for 22.12 ha by this model (14.92 ha on series C and 7.2 ha on series D). The area under coconut, which was on series N in model II, has been shifted to series D (1.41 ha) and series G (27.03 ha).

Net income under this model would be Rs 18,03,622.96, and the costs incurred would be Rs 13,86,386.74. This model also recommended 188.02 ha be left fallow on different soil series

Model IV: minimization of men-labour. The cropping pattern obtained with the model for mini-mization of men-labour compared to that with Model III calls for adjustments in area under finger millet on series B, C, F, H, J, L, M, and N, while coconut area (28.44 ha) is allocated on series C (1.41 ha) and G (27.03 ha). The mulberry area (22.12 ha) is suggested on soil series D (8.16 ha) and H (13.51ha). Fallowing is recommended for 188.02 ha, as in the previous two models. Under this cropping pattern the farmers of the watershed would realize a net income of Rs 15,72,060.49 with a total cost of Rs 13,32,427.74.

Model V: minimization of women-labour. The optimum cropping pattern under Model V (mini-mization of women-labour) showed net income of Rs 17,24,317.00 with the cost incurred at Rs 1477429.45. The model suggested finger millet, mulberry and coconut to be on 200 ha, 22.12 ha and 28.44 ha, respectively. In order to reduce the employment of women-labour the model suggested 188.02 ha to be left fallow.

Model VI: maximization of FYM use. The cropping pattern with maximization of FYM use suggested the largest area (388.02 ha) under finger millet, allocated among soil series B (7.35 ha), C (50.61 ha), D (98.31 ha), E (21.87 ha), F (33.95 ha), H 951.47 ha), I (29.95 ha), J (10.66 ha), K (143.48 ha) and N (30.07 ha). Mulberry was recommended on soil series G (2.64 ha), L (98.10 ha) and M (11.38 ha), and coconut on F (4.05 ha), and G (24.39 ha). The entire cultivable area of 438.58 ha has been allocated for cropping, without suggesting any fallow land. The net income would be Rs 2106058.91 with a cost of Rs 24,21,505.68. The FYM to be purchased would be the highest (6879.54 t).

Model VII: minimization of nitrogen use. The optimization model for reducing the level of use of nitrogen recommended finger millet , mulberry and coconut to be on an area of 200, 22.12 and 28.44 ha, respectively. Finger millet was allocated to soil series B (7.3 ha), C (50.61 ha), D (8.61 ha), E (21.87 ha), F (15.88 ha), G (27.03 ha), H (51.47 ha) and I (17.18 ha), all of the mulberry to soil F and coconut to soil J (10.66 ha), K (6.40 ha) and M (11.38 ha). The cost was Rs 1392418.60 and the net income Rs1881937.76.

Model VIII: minimization of phosphorus use. Application of the model for minimization of phosphorus use resulted in the same area under finger millet (200 ha) as in the other minimization models. This area was distributed on series B (7.3 ha), C (50.61 ha), D (8.61 ha), E (21.87 ha), F (38 ha), G (27.03 ha), H (40.73 ha) and L (5.80 ha). Mulberry was allocated to series H (10.74 ha) and M (11.38 ha) and coconut to series J (10.66 ha) and K (17.78ha). The uniqueness of this optimization is that it recommended horsegram on 125.70 ha of soil series K. No other model recommended horsegram to be cultivated, though in the existing pattern it is being grown on 23.63 ha in the watershed. The net income realizable would be Rs 1949285.90 with a cost of Rs 1674124.12. The FYM purchased was the highest (6879.54 t) of the models. The fallow land recommended was 62.32 ha.

Model IX: minimization of potash use. The optimization model for reducing the level of use of potash recommended finger millet on all soil series from B to N excepting series E, H and K. Groundnut has been allocated to 143.48 ha of soil series K, mulberry to series E (21.87 ha) and series F (0.25 ha). All the area for coconut (24.44 ha) was allocated to series H. The net income calculated was Rs 2114128.61 and the cost of Rs 2372415.28. The model suggested a smaller area under fallow (44.54 ha) than the other models.

All nine optimization models clearly recommended larger area under finger millet, as far-mers of Garakahalli watershed are presently following subsistence agriculture, that is, depen-dence for food requirement on their own farm land. The areas under mulberry remained unal-tered in all the models except under that for maximization of net income where the area recommended for this crop was 145.11 ha.

Pay-off matrix for different objectives in Garakahalli watershed

The results of the models concerned with the nine objectives for the cultivable land under different soil series of Garakahalli watershed when one objective is optimized at a time were drawn up in matrix form (Table 4.22). The elements of the matrix were derived by optimizing one objective at a time and then computing the corresponding magnitude of the rest of the objectives.

The value elements in each column of the table (pay-off matrix and the ideal points) indi-cate the level of achievement of the other objectives when one objective was optimized (maxi-mized or minimized as the case may be). For example, the first column shows that the maximum net income of Rs 94,91,343.53 was associated with a cost of Rs 40,86,667.65 for 7710.79 bullock-pair days, 28,689.17 men-labour days, 30,296.02 women-labour days, 5455.09 t FYM, 23,608.49 kg N, 16,489.53 kg P and 13,541 kg K plus seed costs, etc. Finger millet is to be grown on 200 ha, mulberry on 145.11 ha, banana on 65.03 ha and coconut on 28.44 ha to realize an optimum (maximum) income of Rs 94,91,343.53.

Similarly, the data in the pay off matrix of each row shows the optimization of one objective and the related levels of other objectives. To illustrate, the minimization of cost in row 2, column 2 reflects the optimum (minimum) costs of Rs 13,16,168.99 that would bring under cultivation 250.56 ha out of a cultivable area of 438.58 ha in Garakahalli watershed with different crops such as finger millet on 200 ha distributed on series B (7.35 ha), C (50.61 ha), F (38 ha), G (27.03 ha), H (38.46 ha), I (29.95 ha) and L (8.10 ha), mulberry on 22.12 ha (8.61 ha of D, 2.13 ha of H and 11.38 ha of M) and coconut on 28.44 ha of series N, and allow 188.02 ha of fallow land. Although this cropping pattern minimized the costs, the net income was Rs 19,07,833.27, very much lower than that under the maximization of income model (Model I).

It is seen that when one objective was optimized, the other objectives were either under-achieved or exceeded. For example, when the net income was maximized (optimized), the costs were higher at Rs 40,86,667.65 (Model I) than what would have been with minimization of cost as sole objective (Rs 13,16,168.99). Similarly, when minimization (optimization) of cost was achieved, the net income concomitantly reduced to Rs 19,07,833.27 (from Rs 94,91,343.53 of maximization of income model).

The elements in the main diagonal of the pay-off matrix are termed ideal points (object-ive functional value of each plan) or an ideal plan combining all the nine objectives for the Garakahalli watershed as a whole. All the nine objectives are optimized and ideal points listed in the last row of the table, which provides Rs 94,91,343.63 net income and Rs 13,16,168.99 cost to cover 3626.52 bullock-pair, 4652.63 men-labour and 11,083 women-labour days, application of 6878.54 t FYM

(5,489.54 tons of FYM to be purchased from outside over and above their own quantity of 1,389 tons), 8,063.04 kg N, 5109.88 kg P and 9.07 kg K plus seed cost.

4.11.2 Optimum land-use plans for Nalatwad watershed

Present cropping and input-use pattern

In the existing cropping pattern in Nalatwad watershed the farm households were grow-ing sorghum (413.55 ha), sunflower (88.12 ha), wheat (17.5 ha), bengal gram (28.55 ha) and pearl millet (4.96 ha), which accounted for 74, 16, 3, 5 and <1 per cent, respectively, of the culti-vated area of the watershed.

Analysis of the data by linear programming technique

The total cultivated land under different categories of soil and crop under rainfed culti-vation was 552.68 ha. The farmers realized a total net income of Rs 1891668.31. They incurred cash expense of Rs 2171584.19, employed 3732.31 men- and 12666.37 women-labour days and 5201.89 bullock-pair days. The quantity of FYM used was 10741.47 qtl, of N 12022.69 kg, of P 13093.68 kg and of K 390.66 kg. Plant-protection chemicals were used for bengal gram grown by large farmers only. The data collected from the watershed farmers were analysed using linear programming technique to draw inferences on the nine objectives set forth in the study.

Model I: maximization of net income. The optimum plan under maximization of net income as objective recommended cultivation of sorghum on a larger area of 490.68 ha, on different soil units of all the series. The area recommended for sorghum on series A was 56.93 ha, on B 56.12 ha, on C 81.61 ha, on D 79.15 ha, on E 37.16 ha and on F 179.17 ha.

The area under sunflower was reduced from 88.12 ha under the existing pattern to 55 ha because of the specification of maximum area of 55 ha in the model, despite its profitability. The area under wheat was also reduced from 17.50 ha to 7 ha, specified in the model as the mini-mum area for the cereal requirement of the family. Maximum area specification was given in the model for sunflower and wheat mainly to avoid soil nutrient depletion, keeping in mind sustain-ability of nutrient status in the soils of the watershed.

The recommended cropping pattern under this optimization model would enable the farmers to realize a net income of Rs 2497048.60, at a cost of Rs 2136851.00 for the purpose of 63420.07 bullock-pair days, 5028.76 men-labour days, 14054.37 women-labour days and the use of 10663.98 qtl (8743 qtl to be purchased from outside) of FYM, 13253.43 kg N, 13368.57 kg P and 207.34 kg K. This model reflects the necessity of Rs 2069351.00 crop loan (over and above the own-funds availability of Rs 67500.00).

Model II: minimization of cost. The optimum plan with minimization of cost as objective did not recommend changes in the area under sorghum on soil series A, B, D and E. However, decrease was recommended on soil series C by 7 ha, which was transferred to wheat, while the entire area of 55 ha under sunflower on series F has been recommended for sorghum. This model allotted 545.68 ha for sorghum and 7 ha for wheat with no area for sunflower or bengal gram. This cropping pattern under cost-minimization objective would provide a net income of Rs 1986669.63 (lower than that under maximization of income) with a cost of Rs 1991026.67). The loan requirement would be Rs 1923707.00. There is a reduction in bullock-pair and men-labour days, and quantities of FYM, N and P used. However, women-labour days and quantity of K are higher.

Models III, IV, V: minimization of bullock, men or women labour. When the objective is mini-mization of bullock, men or women labour, the optimum land-use plans call for significant changes in the crops and area on the six soil series. Obviously, these will be reflected in the level of net income and cost associated with the types of crop grown. The area under sorghum, which was larger in the minimization of cost and maximization of net income models and the existing cropping pattern among the farmers, has been reduced under the minimization of human labour models to the minimum of 220 ha estimated for meeting the family cereal requirement of sorghum. This 220 ha is distributed as 79.15 ha on series D, 37.16 ha on series E and 103.69 ha on series F. In comparison, under the bullock-pair minimization model the area under sorghum on series F is recommended to be

140.85 ha, taking away the 37.16 ha recommended for series A in the human-labour minimization models.

Wheat crop, which was on the smallest area in the existing plan and in the maximization of net income and minimization of cost models, has been suggested for 81.61 ha on series C when the objective is minimization of bullock-pair or men labour; model IV suggested an additional 56.12 ha on series B. Bengal gram has been recommended for 213.91 ha (56.93 ha on series A, 56.12 ha on series B and 100.86 ha on soil F) in model III, but for only 139.95 ha (56.93 ha on series A and 83.02 ha on series F) in model IV. No area has been recommended under bengal gram in the minimization of women-labour model.

Sunflower has been eliminated in the models with the objectives of minimization of bullock-pair labour and of women labour, while 55 ha has been retained in the minimization of men labour model.

The net incomes in the optimization models for minimization of bullock-pair, and men and women labour would be Rs 2150155.26, Rs 2194293.14 and Rs 2370183.00, respectively, and the corresponding costs, Rs 2193020.40, Rs 2162024.00 and Rs 2106336.00.

Model VI: maximization of FYM use. The optimization model for maximization of FYM use as objective suggested sorghum on 220 ha allocated among soil series C, D, E and F, sunflower on 55 ha on series B, wheat on 56.93 ha of series A and 1.12 ha of series B, and bengal gram on 219.63 ha of F series. This pattern would enable the farmers of Nalatwad watershed to realize Rs 2175762.00 net income at a cost of Rs 2289191.00). The cost of FYM would be Rs 11923.93, which happens to be the highest as compared to the existing pattern and other optimization models. There are no significant changes in the men and women labour employed as well as N and P applied com-pared to other optimization models.

Model VII: minimization of nitrogen use. The optimization model for reducing the level of nitrogen use recommended the largest area (277.68 ha) for wheat distributed on series A (56.93 ha), series B (1.12 ha) and series F (219.63 ha). The total area under sorghum (220 ha) is similar to that obtained with the models designed for minimization of bullock-pair labour and of men labour, and for maximization of FYM, but is much lower than that with the existing pattern and the models related to maximization of net income, minimization of cost and minimization of women-labour use. With this type of cropping pattern no dramatic changes are seen in bullock-pair and men- and women-labour, and quantities of FYM, phosphorus and potash used compared to those in other optimization models. The total cost of cultivating this recommended cropping pattern on 552.68 ha of different soils in Nalatwad watershed is estimated to be Rs 2079436.00. The net returns for the entire watershed would be Rs 2179935.00.

Model VIII: minimization of phosphorus use. The results of the optimization model for minimi-zation of phosphorus use also suggest the area under sorghum to be 220 ha distributed on soil series A (56.93 ha), series C (46.76 ha), series D (79.15 ha) and series E (37.16 ha). No area is allocated for sunflower and bengal gram, while a maximum of 332.68 ha is assigned to wheat distributed on soil series B (56.12 ha), series C (34.85 ha) and series F (241.71 ha). The net income predicted with this model is Rs 2111994.00 for a cost of Rs 1997875.00.

Model IX: minimization of potash use. The optimization model for minimization of potash use similarly recommends the two cereals leaving out sunflower and bengal gram, as was noted with the model for minimization of phosphorus use. Thus, sorghum is recommended on 515.52 ha. Wheat is recommended on 37.16 ha. The net income would be Rs 2309367.00 for a total cost of Rs 2095746.00.

All nine optimization models clearly recommended larger area under cereals, particularly sorghum, as farmers of Nalatwad watershed are presently following subsistence agriculture, that is, self-dependence for food requirement from their own farm land. The shifts in the magnitude of area from wheat to sorghum (both cereals) have occurred on soil series A and B, and from sorghum to wheat and sunflower on series B, when the objective was to minimize N use or maximize FYM use. Bengal gram became significant when the objective was minimization of bullock-pair labour and/or men labour, particularly on soil series A, B and F. Wheat was the most preferred and recommended crop on larger area, to be grown on soil series C and F in order to minimize N and P use. However the optimization models for minimization of costs and of potash use recommended the largest areas under sorghum (545.68 ha and 515.52 ha, respectively).

The optimum land-use patterns clearly recommend the need for making available at least Rs 19,00,000.00 short-term loan facilities for the farming community of Nalatwad water-shed, over and above their own funds of Rs 67500.00. Similarly, the requirement of FYM from outside the watershed is estimated to be about 10,000 quintals.

Pay-off matrix for different objectives in Nalatwad watershed

Data on the land-use plans according to the models concerned with the nine objectives for the cultivable land under different soil series, when one objective was optimized at a time, were drawn up in the form of a matrix (Table 4.23).

The value elements in each column of the table indicate the level of achievement of the other objectives when one objective was optimized. For example, the first column indicates that the maximum net income of Rs 2497048 was associated with a cost of Rs 2136851 to cover 6342 bullock-pair, 5028 men-labour and 14054 women-labour days, use of 10663 quintals of FYM, and application of 13253 kg N, 13368 kg P and 207 kg K, plus seed cost.

It is envisaged that sorghum should be grown on 56.93 ha of A, 56.12 ha of B, 81.61 ha of C, 79.15 ha of D, 37.16 ha of E and 179.71 ha of F series, respectively, to give a total of 490.68 ha under the crop, while sunflower and wheat should be grown on 55 ha and 7 ha, respectively, of F series to realize an optimum income of Rs 2497048.

In the same way, the data in each row of the matrix show the optimization of one objec-tive and the corresponding levels of other objectives. To illustrate, the minimization of cost in Row 2, Column 2 reflects the optimum minimum costs (Rs 1991026) that can bring 552.68 ha of land under cultivation in the watershed with different crops such as sorghum on 545.68 ha distri-buted on different soil series, and 7 ha under wheat on series F, without cultivation of sunflower and bengal gram.

It can be seen from the table that when one objective was optimized, the other objectives were either underachieved or exceeded. For example, when net income was maximized, the cost was higher at Rs 2136851 than what would have been with minimization of cost as objective (Rs 1991026). When minimization of cost was achieved, net returns concomitantly dropped to Rs 1986669.

The elements in the main diagonal of the pay-off matrix are referred to as the ideal points or an ideal plan for the watershed. All the nine objectives are optimized and the ideal points are listed in the last row of the table, which gives Rs 2497048 net income and Rs 1991026 cost to cover 4531 bullock-pair, 3543 men-labour and 13163 women-labour days, with application of 11923 quintals of FYM, 8609 kg N, 11660 kg P and 27 kg K.

4.11.3 Optimum land-use plans for Pettamanurahatti watershed

Present cropping and input-use pattern

In the existing cropping pattern, the farmers were growing groundnut (438.50 ha), pearl millet (31.95 ha), sorghum (9.70 ha), finger millet (15.17 ha) and rice (12.41 ha), accounting for 84.40, 6.15, 1.87, 2.92 and 2.39 per cent, respectively, of the total cultivated area (519.57 ha).

The farmers had left 11.84 ha of land fallow. This cropping pattern on different soils enabled the farmers of the watershed to realize a total net income of Rs 10,94,983.48. For this they incurred cash expenses of Rs 34,94,841.54, employing per hectare 74.65 man and 267.56 woman days and 34.40 pair days. The manure and fertilizer inputs per hectare were 77.56 qtl FYM, 186.80 kg N, 117.40 kg P and 42.03 kg K.

The commercial crop groundnut took preference over cereal crops.

Analysis of the data by linear programming technique

The information collected from the farmers of watershed was tabulated and analysed by linear programming to develop normative plans.

Model I: maximization of net income. The optimum plan with maximization of net income as objective recommended cultivation of groundnut on a total of 309.82 ha. The areas recom-mended were 34.73 ha on soil series B, 20.01 ha on C, 39.36 ha on D, 17.14 ha on E, on F 24.83 ha, 2.55 ha on G, 5.18 ha on H, 30.55 ha on I, 63.30 ha on J, 9.82 ha on M, 13.33 ha on N, 9.03 ha on O and 39.99 ha on series P.

The area under finger millet was increased from 15.17 ha under existing pattern to 194 ha, all on soil series G. The area under rice, which increased from 12.41 ha under existing plan to 45.12 ha was distributed on soil series J (4.19 ha), K(31.51 ha) and L (9.42 ha). However, in the case of sorghum there was a small increase in the area from 9.70 ha under existing plan to 19.67 ha, all on soil series L. No fallow land was recommended. It is interesting to observe that pearl millet, which covered the second largest area (31.95 ha) in the existing pattern, was found uneconomical to cultivate and hence was not recommended under any of the nine normative plans. The results reflect excess availability of bullock labour, men and women labour. But this model also brings out the necessity of Rs 25,89,79.22 crop loan (over and above the existing own funds availability of Rs 14,13,061).

Model II: minimization of cost. The optimum plan with minimization of cost as objective also recommended an area of 309.82 ha under groundnut on soil series B (34.73 ha), D (39.36 ha), E (17.14 ha), on F (5.16 ha), G (2.55 ha), H (5.18 ha), I (5.44 ha), J (67.49 ha), K (31.51 ha), L (39.07 ha), M (9.82 ha), N (13.33 ha), O (9.03 ha) and P (39.99 ha). The crop, which was not recommended on soil series K and L under maximization of net income plan, has been considered under Model II except in case of series C. Sorghum, which was on 9.67 ha on soil series L has been completely eliminated. In this model as well as in the subsequent seven models as already indicated pearl millet has not been recommended. The cereal finger millet is again recommended on 194 ha on soil series G only. However rice area of 45.12 ha has been allocated to soil series C (20.01 ha) and I (25.11 ha), unlike in Model I where this crop was recommended on soil series J, K and L.

The major change in the crops in this plan from that under model I is total elimination of sorghum and recommendation of fallow land of 19.67 ha (series F). This optimization model having cost minimization as main focus would provide a net income of Rs 18,34,182.89 (lower than that under maximization of net income but higher than in the existing plan) with a cost of Rs 38,32,933.99. There is reduction in the magnitude of all inputs used compared to Model I except P. Since the model has been programmed for the entire watershed the changes in the quantities of inputs used are not large enough to cause concern. However minimization of cost requires 19.67 ha to be left fallow. The loan requirement is estimated to be Rs 24,19,872 and the FYM requirement to be purchased is 403 qtl (both are lower than in Model I). The cost of cultivation of 548.94 ha is the lowest among the nine models but a little higher than in the existing cropping pattern followed by the watershed farmers.

Model III: minimization of bullock pair days. The optimum plan under minimization of bullock pair days used did not reflect any change in the total groundnut, finger millet and rice areas, though allocation to different series had changed. For example, areas under groundnut in Model I on soil series D (39.36 ha), soil series E (17.14 ha) and series I (30.55 ha) were totally eliminated and shifted to series G. Similarly finger millet, which was on soil G (194 ha) in Models I and II was allocated to soil D (39.36 ha), G (95 ha), I (30.55 ha) and L (29.09 ha). Rice (45.12 ha) has been recommended on series G (36.09 ha) and O (9.03 ha). This model has also recommended 19.67 ha to be left fallow.

The net income in this model would be Rs 17,31,812.64 for a cost of Rs 39,29,622.78. The model recommends a crop loan facility of Rs 25,15,148.17 and purchase of 1,584 qtl of FYM from outside for the purpose of adopting the recommendations.

Model IV: minimization of men labour. The cropping pattern with minimization of men labour use as objective also suggested groundnut (309.82 ha), finger millet (194 ha) and rice (45.12 ha). However the areas allocated to different soil series were different from those under models I, II and III. For instance, 34.73 ha of groundnut on soil B and 20.01 ha on soil C have been transferred to finger millet. Minor changes can be observed for rice also (30.55 ha on soil I and 14.57 ha on soil J). Pearl millet and sorghum were again not found economical and were elimi-nated. This pattern would enable the farmers of the watershed to realize Rs 17,24,648.00 net income at a cost of Rs 39,33,377.65. The men labour employed, though the lowest of all models, would still be higher than under the existing plan followed by farmers. There were no significant changes in the bullock and women labour employed and applied N and P compared to other models. Fallow land was 19.67 ha.

Model V: minimization of women labour use. The optimization model for minimizing women labour days recommended the same cropping pattern of groundnut (309.82 ha), finger millet (194 ha) and rice (45.12 ha). However, allocation of areas to different soil series changed. Groundnut, which had the highest area on series J, was shifted to series G (145.31 ha) followed by series J (67.49 ha). Finger millet, which was mostly on soil G in the earlier models was allocated to series C (20.01 ha) and series K (25.11 ha). Fallow land was again 19.67 ha.

The net income in this cropping pattern would be Rs 16,71,473.67. The cost would be Rs 39,24,410.57 for 7601.31 bullock pair days, 8057.09 men and 26908.65 women labour days and 4,676.45 qtl FYM, 15155.87 kg N, 15117.91 kg P and 4,389.92 kg K. The crop loan required is estimated to be Rs 25,11,394.57. The FYM to be purchased from outside is 1716 qtl. The results reflect surplus availability of bullock pair, men and women labour in the watershed.

Model VI: maximization of FYM use. The optimization model for maximizing FYM use sug-gested the same cropping pattern as Model I (groundnut, finger millet, rice and sorghum). Groundnut has been recommended on soil series G (196.55 ha), P (39.99 ha), F (24.83 ha), E (17.14 ha), J (16.31 ha), M (9.82 ha) and H (5.18 ha), and finger millet on series B (34.73 ha), C (20.71 ha) and D (9.03 ha). Sorghum has been allotted to soil I (13.61 ha) and J (6.06 ha). The rice area of 45.12 ha is to be on series J. No fallow land has been recommended. This cropping pattern would enable the farmers of the water-shed to realize a net income of Rs 16,53,023.07 with cost of Rs 41,89,828.50, the highest. The quantities of bullock labour, men and women labour as well as N, P and K use are almost similar to those in Models IV,VII and IX. The level of FYM use recommended is 5548.06 qtl (the quantity available being 2,960 qtl). The crop loan facilities required would be Rs 27,76,767.50.

Models VII: minimization of nitrogen use. The model for minimizing use of nitrogen recom-mended 309.82 ha for groundnut [on series G (165.04 ha), P (39.99 ha), E (17.14 ha), F (24.83 ha) and J (53.0 ha)], 194 ha for finger millet [on series B (34.73 ha), D (39.36 ha), G (31.51 ha), I (5.44 ha), K (31.51 ha), L (29.09 ha), N (13.33 ha) and O (9.03 ha)] and 45.12 ha for rice [on series I (25.11 ha) and C (20.01 ha)]. Fallowing of 19.67 ha has also been recommended.

The total cost for this pattern would be Rs 39,86,642.75 for bullock labour (7736.20 pair days), men (7960.20 days) and women labour (28,211.36 days) and application of 4747.32 qtl FYM, 14,209.56 kg N, 16,093.81 kg P and 4,074.89 kg K. Net returns would be Rs 15,61,959.52 and the crop loan facility required would be Rs 25,73,581.75.

Model VIII: minimization of phosphorus use. Application of optimization model for minimi-zation of phosphorus use also suggested the same cropping pattern of groundnut, finger millet and rice. Groundnut was recommended on the entire area of soil series B, C, D, E, F, M, N and P and 102.73 ha of series G and 7.88 ha of series J. Finger millet has been allocated to all of series I, K, L and O and 93.82 ha of series G, while rice (45.12 ha) has been put to series J. No area was allocated for pearl millet and sorghum. The area of fallow land was 19.67 ha.

The net income predicted with adoption of this cropping pattern is Rs 18,29,098.17 for a cost of Rs 39,63,585.95 for inputs. The crop loan facility required would be Rs 25,50,524.95.

Models IX: minimization of potash use. The optimization model for minimization of potash use also recommended the same three crops. The area under groundnut (309.82 ha) on different soil series was 34.73 ha on series B, 5.44 ha on C, 39.36 ha on D, 17.14 ha on E, 24.83 ha on F, 56.81 ha on G, 5.18 ha H, 67.49 ha on J, 9.82 ha on M, 9.03 ha on O and 39.99 ha on series P. The area (194 ha) under finger millet has been distributed on series G (120.07 ha), K (31.51 ha), L (29.09 ha) and N(13.33 ha). The rice area (45.12 ha) has been allotted on series C (14.57 ha) and I (30.55 ha). Fallowing has been recommended for 19.67 ha.

The net income would be Rs 17,37,271.61 for a total cost of Rs 39,29,538.51 for using bullock labour (7552.28 pair days), men labour (7956.26 days) and women labour (29714.14 days) and applying 4033.45 qtl FYM, 16590.26 kg N, 16377.95 kg P and 3,814.51 kg K.

All the nine optimization models very clearly recommend a commercial crop, groundnut, on the largest area, followed by the cereal crops finger millet and paddy. There is a shift in area from groundnut and pearl millet to finger millet and paddy in the optimization plans compared to the existing pattern. Area under groundnut has been reduced by a little more than 100 ha while pearl millet was uneconomical with all the nine objectives visualized, and was eliminated in all the models. Sorghum was recommended only under maximization of income and maximization of FYM use. The optimum land use patterns clearly reflect the need for Rs 25–27 lakhs short term loan facility for the farming community of Petta-manurahatti watershed, over and above their own funds of Rs 14,13,061. Similarly the require-ment of FYM over and above the existing level of production has been estimated to be a mini-mum of 342 qtl (Model II) and a maximum of 2527 qtl (Model VI). In general, an area of 19.67 ha has been recommended to be left fallow except when the objectives are maximization of income and maximization of FYM use.

The results clearly reveal the surplus availability of men and women labour and bullock labour in the watershed. All models showed the possibility of higher net income than the present.

Pay-off matrix for different objectives in Pettamanurahatti watershed

The elements of the matrix (Table. 4.24) were derived by optimizing one objective at a time and computing the corresponding magnitude of the rest of the items of the objectives in that plan.

The value elements in each column of the table indicate the level of achievement of the other objectives, when one objective was optimized. For example, the first column shows that the maximum net income of Rs 20,35,085.44 was associated with a cost of Rs 40,02,852.22 for 7747.28 bullock-pair days, 8398.06 men-labour days, 30138 women-labour days, 4003.40 qtl FYM, 19586.01 kg N, 15,701.79 kg P and 4,568.57 kg K plus seed cost to cultivate 568.61 ha.

It is envisaged that groundnut should be grown on 309.82 ha distributed on soil series B (34.73 ha), C (20.01 ha), D (39.36 ha), E (17.14 ha), F (24.83 ha), G (2.55 ha), H (5.18 ha), I (30.55 ha), J (63.3 ha), M (9.82 ha), N (13.33 ha), O (9.03 ha) and P (39.99 ha), with sorghum on 19.67 ha of series L, finger millet on 194 ha of series G and rice on 4.19 ha of series J and 31.51 ha of series L. No fallow was allocated.

In the same way, the data in the matrix in each row shows the optimization of one objec-tive and the corresponding levels of other objectives. To illustrate, the minimization of cost in row 2, column 2 reflects the minimum costs (optimum) of Rs 38,32,933.99 that can bring 548.94 ha of land under cultivation of groundnut on 309.8 ha, finger millet on 194 ha and rice on 45.12 ha, with pearl millet and sorghum eliminated, and 29.49 ha fallowed.

Thus when one objective was optimized, the other objectives were either underachieved or exceeded. For instance, when the net income was maximized, the cost was higher at Rs 40,02,852.22 (Model I) than what would have been with minimization of cost as objective (Rs 38,32,933.99) (Model II). Likewise when minimization of the cost was achieved, the net income was reduced to Rs 18,34,182.89 (Model II).

The elements in the main diagonal of the pay-off matrix are known as the ideal points. The nine objectives were optimized and the ideal points of each row are listed in the last column, to give an ideal plan that would give Rs 20,35,085.14 net income at a cost of Rs 38,32,933.99 to cover 7208.41 bullock-pair days, 7689.22 men-labour days, 26,908.65 women-labour days, 5548.06 qtl FYM, 14,209 kg N, 14,713.34 kg P and 3,814.51 kg K plus seed costs.

4.11.4 Optimum land-use plans for Molahalli watershed

Present cropping and input-use pattern

In the existing cropping pattern in Molahalli watershed the farm households were grow-ing rice (218.12 ha), arecanut (11.71 ha), coconut (6.67 ha) and cashew (64.05 ha), which accounted for approximately 65, 3.5, 2 and 19 per cent, respectively, of the total cultivated area of the watershed.

The quantities of various inputs used the existing cropping pattern were 863 t FYM, 4520 pair-days bullock labour, 8717 days men labour, 18,736 days women labour, 10,677 kg N, 4796 kg P and 4399 kg K. The cash expenses incurred for these inputs amounted to Rs 35,92,314, while the gross returns were Rs 58,76,137. The net income realized was Rs 22,83,823. Based on data on availability of own funds (cash) it was estimated that around Rs 33.64 lakhs short-term loan was used.

Analysis of the data by linear programming technique

The information collected from the watershed farmers was tabulated and analysed using linear programming technique to draw inferences on the multiple objectives (nine) set forth in the study. The results are presented in the form of normative land-use plans for the watershed.

Model I: maximization of net income. The optimum plan under maximization of net income as objective recommended cultivation of rice on a larger area of 254.11 ha on different soil units, against the current area of 218 ha. The area recommended for rice on series B was 8.36 ha, on C 59.44 ha, on D 35 ha, on I 25.41 ha, on J 26.02 ha, on L 61.03 ha, on M 15.79 ha, on N 6.46 ha and on series O 6.74 ha.

The area recommended for arecanut was 11.71 ha on series M, for cashew 11.48 ha on series D and 52.67 ha on series P. The area recommended for coconut was 6.67 ha on series M. There was no allocation for fallow. Thus the entire cultivable land of 336.64 ha has been recom-mended for cultivation unlike in the current pattern where 36.09 ha is fallow. In all the minimi-zation models (II–V and VII–IX), about 95 ha was recommended for fallow. The other maximi-zation model (VI—maximization of FYM use) gave a cropping plan similar to that in this model.

The recommended cropping pattern under this optimization model would enable the farmers to realize a net income of Rs 25,77,687, at a cost of Rs 40,51,180 for 5116.82 bullock-pair days, 10559.31 men-labour days and 20927.38 women-labour days, and use of 1681.57 t FYM, 11967.33 kg N, 5671.24 kg P and 5891.33 kg K. This model reflects the necessity of about Rs 27.27 lakhs crop loan (over and above the own-funds availability of Rs 2,28,144).

The crop loan requirement is lowest in this model and Model II (minimization of cost), and highest (Rs 35.58 lakhs) in Model VI (maximization of FYM use) and in the current cropping pattern.

Model II: minimization of cost. The optimum plan with minimization of cost as objective did not recommend changes in area under perennial crops, but called for reduction of area under rice to 159 ha, specified as the minimum area required to meet the food-grain requirements of the popu-lation of the watershed. The reduction of area from that recommended under Model I was on series C (58.93 ha), I (25.41 ha), M (15.79 ha) and N (6.46 ha). The area on series C taken away from rice was recommended for cashew and thus the area under cashew on series P was reduced from 52.67 ha to 5.12 ha. Apart from this transfer to cashew on series C, all the area removed from rice in this model was recommended to be left fallow (95.21 ha).

This pattern would provide a net income of Rs 20,63,161 (lower than that under maximi-zation of net income and the current pattern) with cost of Rs 29,55,211. Loan facilities needed would be Rs 27.27 lakhs, over and above the own funds of Rs 2,28,144 available among the farmers of the watershed.

Model III: minimization of bullock labour. The cropping pattern obtained with the model for minimization of bullock labour did not show any change in the total area under any of the crops from the pattern under model II. However there were small changes in the area under rice on series B, K and O, and drastic changes on series C, I and L. In this model only 1.79 ha of series B is advocated for fallow.

The net income under this model would be Rs 20,70,913, and the costs incurred Rs 29,81,968. The net returns and costs were lower that in Model I but higher than in Model II. The input use and loan facilities needed are slightly different from those under Model II, but signi-ficantly lower than in Model I.

Models IV and V: minimization of men- and women-labour. The cropping pattern obtained with Model IV (minimization of men-labour) compared to that with Model III calls for adjustments in area under rice on series B, D, K and N and major change on series L (from 0 to 54.25 ha). Changes are seen for area under plantation crops as well. A notable change is fallowing of series C (59.44 ha). M (22.57 ha), N (6.46 ha) and O (6.74 ha).

The net income under this model (IV) would be Rs 20,68,804 with a total cost of Rs 29,74,515. There were no significant changes in the magnitude of the various inputs used and loan facilities needed.

While the optimum cropping pattern under model V (minimization of women-labour) showed the lowest net income (Rs 20,47,125) of all the nine models, the cost to be incurred was the third highest (Rs 30,166,039). Again there was not much change in the level of input use from that under models II, III and IV except in women-labour. Under model V, the cropping pattern called for 159 ha under rice, 11.71 ha under arecanut, 6.67 ha under coconut and 64.05 ha under cashew. In order to reduce the employment of women-labour the entire area of series C was recommended for rice, while no rice was allocated to series D, I, K, M and N.

Model VI: maximization of FYM use. The cropping pattern with maximization of FYM use was close to that under model I (maximization of net income), though there were small changes in area under rice, arecanut and coconut on soil series D and M.

The net income to be realized was Rs 25,67,879 with a cost of Rs 40,86,588. The FYM purchased was the highest (693 t) over that available on the farms (1005 t). The input use level was also similar to that under Model I except for quantity of FYM (1698.39 t against 1681.57 t). Loan facilities needed were highest under this model (Rs 38,58,444).

Models VII and IX: minimization of nitrogen and potash use. The optimization model for reducing the level of use of nitrogen (Model VII) recommended total rice area of 159 ha to be distributed on series B (8.36 ha), C (0.51 ha), D (46.45 ha), J (26.02 ha), K (9.86 ha), L (61.03 ha) and O (6.74 ha). The largest area of cashew (58.93 ha) was recommended on series C and the least (5.12 ha) on series P, thus leaving 47.55 ha of series O fallow. In addition, the entire area of series I (25.41) was to be left fallow. On series M, 6.67 ha has been recommended for coconut and 11.71 ha for arecanut under this model.

The cropping pattern, inputs, cost and net income calculated under both the models for minimization of nitrogen use and minimization of potash use were the same. The cost was Rs 29,55,211 and the net income Rs 20,63,161 (again similar to the values obtained under model II). The fallow land recommended was 95.2 ha. The loan facilities needed were also the same (Rs 27,27,067).

Model VIII: minimization of phosphorus use. The results of application of the model for mini-mization of phosphorus use suggested the least area under rice (159 ha) just as in all the other minimization models. This area is distributed on series B (8.36 ha), D (46.48 ha), I (0.51 ha), J (26.02 ha), K (9.86 ha), L (61.03 ha) and O 6.74 ha). The recommendations for plantation crops were arecanut (11.71 ha) and coconut (6.67 ha) on series M. The land recommended to be left fallow was 95.21 ha.

All nine optimization models clearly recommended larger area under rice, as farmers of Molahalli watershed are presently following subsistence agriculture, that is, self-dependence for food requirement from their own farm land. The areas under plantation crops remained unaltered in all the models, as these were the maximum areas possible in the watershed. However the areas on specific soil series varied between models.

The maximum area under rice (254.11 ha) was recommended under the models for maximization of net income (I) and maximization of FYM use (VI). This resulted in removal of land from fallow. In all the other models (minimization models), the area under rice was 159 ha, the minimum required to meet the food-grain requirements of the farmers, and the fallow area was about 95 ha.

Pay-off matrix for different objectives in Molahalli watershed

The elements of the matrix (Table 4.25) were derived by optimizing one objective at a time and then computing the corresponding magnitude of the rest of the objectives in that plan.

The value elements in each column of the table indicate the level of achievement of the other objectives when one objective was optimized. For example the first column indicates that the maximum net income of Rs 25,77,687 was associated with a cost of Rs 40,51,180 to cover 5116.8 bullock-pair days, 10559.31 men-labour days, 20927.38 women-labour days, 1681.57 t FYM, 11967.37 kg N, 5671.24 kg P and 5891.33 kg K plus the necessary seed costs.

It is envisaged that rice (254.11 ha) should be grown on 8.36 ha of series B, 59.44 ha of series C, 36 ha of series I, 26.02 ha of series J, 9.86 ha of series K, 61.03 ha of series L, 15.79 ha of series M and 6.46 ha of series O, arecanut on 11.71 ha of series M, coconut on 6.67 ha of series M, and cashew on 11.48 ha of series D and 52.67 ha of series P to realize the optimum income of Rs 25,77,687.

Similarly the data in each row of the matrix shows the optimized level of one objective and the corresponding level of the other objectives. For instance, the minimization of cost in row 2, column 2 reflects the optimum minimum costs (Rs 29,55,211) that can bring 241.43 ha of land under cultivation with rice on 159 ha distributed on soil series B (8.36 ha), C (0.51 ha), D (46.48 ha), J (26.02 ha), K (9.86 ha), L (61.03 ha) and O (6.74 ha), arecanut on 11.71 ha and coconut on 6.67 ha of series M, and cashew on 58.93 ha of series C and 5.12 ha of series P.

It can be seen from the pay-off matrix that when one objective is optimized, the others are either underachieved or exceeded. For example, when net income was maximized, the cost was higher (Rs 40,51,180) than what it would have been had minimization of cost been the objective (Rs 29,55,211). Similarly, when minimization of cost was the objective, the net returns concomitantly dropped to Rs 20,63,161.

The elements in the main diagonal of the pay-off matrix are referred to as the ideal points or an ideal plan for Molahalli watershed. All the nine objectives are optimized and the ideal points are listed in the last row of the table, which gives Rs 25,77,687 net income and Rs 40,51,180 cost to cover 5117 bullock-pair, 10559 men-labour and 20927 women-labour days, with application of 1681 t FYM, 11967 kg N, 5671 kg P and 336 kg K.

4.12 Characterization of Farm-level Sustainability Indicators in the Watersheds

Ten farm-level sustainability indicators were computed for one major crop-production system in each of the four microwatersheds studied.

4.12.1 Finger millet production system in Garakahalli microwatershed

Nutrient management index. The minimum nutrient management index was 0 and the maxi-mum 60.0 with a mean of 28.48. The recommended N:P:K dose (kg/ha) for rainfed finger millet is 50:40:25, while marginal farmers applied 58:55:1, small farmers 81:54:0.5 and large farmers 77:49:2. Nitrogen and P were applied in higher quantities and K was applied in negligible quan-tities. Biofertilizers and crop-residue application were neglected by all. This resulted in poor nutri-ent management. Non-availability of livestock, non-awareness and non-availability of bioferti-lizers, utilization of crop residues for cattle feed, use of complex fertilizers due to lower price than single-nutrient fertilizers and use of lesser doses of fertilizer than recommended were the major reasons for overall low mean nutrient management index among all categories of farmers.

Land productivity index. The minimum yield recorded was 2.86 qtl/ha and the maximum 20.0 qtl/ha. The mean yield was 13.98 qtl/ha, which is a good yield compared to the potential yield (17.5 qtl/ha). All categories of farmers could obtain good yields of finger millet in Garakahalli watershed. This can be attributed to timely rainfall, low pest and disease attack and suitable soil.

Input productivity index. The minimum input productivity index obtained was 0.53 and the maxi-mum 3.49, with a mean of 1.36. Though the yield of the crop was good, its medium to high cost of cultivation and poor market price of Rs 480–500/qtl diminished the net returns to Rs 870–1200/ha, which were, on the whole, low. The reason might be greater use of inputs and conse-quent higher cost invested for higher yields when rains were timely.

Crop yield security index. Crop yield security index ranged from a low of 14.29 to a high of 100.0, with mean of 69.9. Interestingly, despite the small land holdings farmers could get secure yields using local varieties and avoiding plant protection chemicals. Farmers would be encou-raged to attain higher yields if the produce were to fetch good price in the market.

Input self-sufficiency index. The farmers obtained minimum input-self sufficiency index of 6.3 and maximum of 90. The mean was 62. Use of higher owned women and bullock labour and owned manure resulted in higher input self sufficiency.

Family food sufficiency index. The farmers of the watershed obtained minimum family food sufficiency index of 15.56 and maximum of 87.04, the mean being 54.36. Thus the crop could meet only part of the cereal needs of the family but rice, vegetables, pulses and other items would have to be purchased from the market. Small and marginal farmers because of their small land holdings and lack of irrigation facilities tended to grow the crop under rainfed conditions. Though large farmers could meet the cereal needs from their own land, their higher usage of pulses, vegetables and meat/eggs from purchased sources brought them on par with marginal and small farmers with respect to family food sufficiency.

Ecological safety index. The minimum ecological safety index was 0 and the maximum 100.0. The mean index was 47.14. These results accorded with the nutrient management index values of the farmers. Organic mode of cultivation in addition to recommended dose of inorganic fertilizers would have improve ecological safety of finger millet growers.

Economic security index. The farmers obtained minimum economic security index of 0 and maximum of 82.06, with mean of 55.72. The need for higher economic security could be fulfilled by remunerative market prices and providing favourable conditions for the crop to achieve its maximum potential.

Social stability index. The social stability index had a minimum of 10.9 and maximum of 93.97. The mean index was 60.39. Utilization of own resources for farm activities and consumption of farm-produced food could result in higher social stability among the farmers.

Sustainability index. The farmers had minimum sustainability index of 25.38 and maximum of 78.25 with mean of 54.55 (Fig. 4.13). The remaining 45 per cent could be obtained by improving nutrient management, input productivity and family food sufficiency. Nutrient management can be improved by using more farmyard manure, biofertilizers and crop residues. Use of these inputs would also reduce the cost of cultivation and improve input productivity. Simple chemical fertilizers should be used at recommended doses. Family food sufficiency needs to be greatly improved among all categories of farmers. Need to purchase vegetables and meat/eggs has contributed to low family food sufficiency. Adoption of kitchen garden and small-scale poultry farming would meet the food and health needs of the family and sustainability of the farmers could be improved.

4.12.2 Sorghum-production system in Nalatwad microwatershed

Nutrient management index. The nutrient management index ranged from 26.67 to 46.67. The mean index was 34.95. Not much difference was observed among the categories of the farmers in the index values. All farmers applied less farmyard manure (20 qtl/ha) than recommended (50 qtl/ha). Major nutrients (N, P and K) were also applied in far less quantities than recommended. No farmers used bio-fertilizers and very few went for crop residues. These practices have resulted in poor nutrient management index among sorghum-growing farmers in Nalatwad.

Land productivity index. The minimum land productivity index obtained was 2 qtl/ha and maximum 13.74 qtl/ha. The mean index was 9.74 qtl/ha. All categories of farmers obtained only 66 to 70 per cent of the potential yield. Application of less farmyard manure and nutrients than recommended and use of local/same seed for years contributed to poor performance of the crop.

Input productivity index. The input productivity index had minimum of 0.46 and maximum was 4.49 with mean of 1.95, proving that higher returns are achievable with judicious use of available inputs. The crop has the ability to give high return per rupee invested.

Crop yield security index. The farmers obtained crop yield security index ranging from 12.22 to 76.35 with mean value of 54.14. The lower values could be improved by use of organic manures, improved varieties and recommended dose of fertilizers and adhering to the package of practices.

Input self sufficiency index. The residents of the watershed had minimum input self-sufficiency index of 6.99 and maximum of 76.35 with mean of 54.14. Marginal farmers used more owned men and women labour and seed than others, which enabled them to achieve higher index. Greater dependence on hired women labour, purchased seed and chemical fertilizers by small and large farmers has contributed to medium input self-sufficiency. A farm could be termed sus-tainable only when it is able to meet its requirements from its own assets.

Family food sufficiency index. The minimum family food sufficiency index was 0 and the maximum 75.71 with mean of 57.13. A family's major food needs include cereals, pulses, vegetables, oil, meat/eggs. Of these, cereals and vegetables have to be grown under irrigated conditions for assured yields. Large farmers, by virtue of their irrigation facilities could meet these needs, but marginal farmers' low irrigation capacity forced them to depend on open market/public distribution system for family food needs. Raising drought-tolerant cereal varieties that could meet food requirements of the family would enhance food sufficiency. Farmers should be educated and such varieties made available by the State Department of Agriculture through cooperative societies.

Ecological safety index. The ecological safety index of sorghum-cultivation system had a mini-mum of 0 and maximum of 99.98 with a mean of 35.85. Ecological safety index is a function of nutrient management index, which was low. To enhance it, farmers should concentrate on organic manures, biofertilizers, crop residues and recommended dose of chemical fertilizers.

Economic security index. The minimum economic security index obtained was 0.87 and the maximum 94.06, with mean of 58.32. Economic security is a function of yield and price of the produce. Farmers in the watershed could get only 50–70 percent of potential yield of the crop. This, accompanied by low market price, resulted in medium economic security among the far-mers. Higher economic security is achievable by maximizing returns and minimizing costs. This involves judicious use of inputs, timely operations and good market price.

Social stability index. The social stability index ranged from a minimum of 25.06 and maximum of 89.64 with mean of 51.96. Higher social stability is attainable with use of own inputs on the farm and trying to produce all family food requirements on one's own field. Sorghum crop met only 40 to 50 per cent of the family food requirements. For other food items, the farmer had to depend on open market for cereals and vegetables, which form the major chunk of the family's food basket.

Sustainability index. The data show that the minimum and maximum sustainability index values in the watershed were 24.88 and 84.35, respectively, with a range of 50.25 (Fig. 4.14). Large far-mers achieved higher sustainability by virtue of their higher ecological safety, economic security and social stability. Sustainability of marginal and small farmers needs to be increased by encou-raging use of organic manures, biofertilizers, crop residues, own inputs and growing crops that could meet food needs of the family. To be sustainable as a whole a farm should achieve higher values on all these individual indices. Recommendations would be use of large quantities of organic manure coupled with biofertilizers and crop residues, use of location-specific varieties tolerant to moisture stress and making the farm input-sufficient and the family food sufficient.

4.12.3 Groundnut-production system in Pettamanurahatti microwatershed

Nutrient management index. The minimum nutrient management index was 26.67 and the maximum 66.67 with mean of 42.4. High addition of organic manure and green-leaf manure, and mixing in crop residues could have resulted in medium nutrient management index, but in actua-lity increased reliance on chemical fertilizers, low livestock possession and non-availability of green leaves to make compost might have forced the farmers to purchase farmyard manure. Replenishment of micronutrients and addition of soil amendments was attended to, which might be other reasons for medium mean nutrient management index among the farmers.

Land productivity index. The minimum land productivity was 2.08 qtl/ha and maximum 8.33 qtl/ha with mean value of 6.46 qtl/ha. Use of more inputs per unit area, timeliness of operations by family labour, less cost of cultivation through reliance on own inputs and fuller care and atten-tion to the crop could have helped the farmers to achieve higher yields. Groundnut yields have become low because of lack of serious attempts at increasing productivity and maintaining soil health on drylands with all care and attention being given to irrigated land and cultivating dry-lands only because they should not be left fallow.

Input productivity index. Expressed as output per rupee invested, the minimum input produc-tivity was 0.63 and maximum 2.99 with mean input productivity of 1.83. Groundnut farming was generally profitable for the farmers. Value of total output was more than double the cost of inputs among the farmers. Adequate use of purchased inputs like chemicals and fertilizers would prevent rise in cost of cultivation. If most operations are done by family labour, work would be more efficiently done than by outside labour. It is clear from the results that even when produc-tivity levels are low, low-external-input (LEI) system can still maintain profitability.

Crop yield security index. The minimum yield security index was 24.45 and maximum 98.04 with mean of 75.98. All the farmers had problems in getting the expected yield owing to external threats that could not be anticipated. However it is reassuring that the farmers had fair yield security. Less area under the crop and minimum dependence on purchased inputs would enable the farmers get relatively stable yields. Reliance on local varieties that are less prone to pest/ disease-induced setbacks, could add to stabilized yields without much fluctuation.

Input self sufficiency index. Input self-sufficiency index ranged from 0 to 80.34 with mean of 26.77. The farmers depended greatly on purchased inputs to cultivate groundnut. Support from good herd, own seeds and family labour would enable farmers become labour-adequate for most operations on the farms. Marginal farmers with low livestock possession could not provide organic manures to their farms. Farmers might also have purchased seeds because the seeds produced in the previous season might have been sold to meet economic needs. For the large farmers, small family size, no family labour and exceedingly large holdings might have led to severe dependence on hired labour to perform almost all the operations. And it is natural for these farmers to depend on chemicals and fertilizers to get economic returns. If development were to substitute machines and chemicals for human labour and thereby destroy the environ-ment, no system could be sustainable.

Family food sufficiency index. Not even 20 per cent of the family food consumption needs were met by farm produce among the farmers. Family food sufficiency is the direct result of small family size and surplus production from larger holdings and higher productivity. Slightly higher family food sufficiency index was obtained by large farmers because of having irrigated lands, larger farms and surplus stocks but on the whole the situation needs to be remedied.

Ecological safety index. The minimum ecological safety index was 0 and the maximum 99.99, with mean of 39.33. Use of organic manures and crop residues coupled with lesser use of inor-ganic fertilizers has led to medium mean ecological index among the farmers. Use of bioferti-lizers, crop residues, crop rotation, farmyard manure, and correct dosage of inorganic fertilizers could improve soil health and enhance the ecological safety of the farmers.

Economic security index. The minimum value of this index was 5.97, maximum 94.09 and mean 65.2, showing that the farmers were economically fairly secure. Higher land productivity (qtl/ha) and crop yield security have contributed to this. Marginal farmers with small holdings are known to apply best inputs, best interest and care for crop growth. It is a well-established fact that a given amount of input is more equitably distributed over a small area than a large area. Economic security can be further increased with due care to crop yields and market price.

Social stability index. Social stability of groundnut farming was low as indicated by minimum index of 3.0, maximum of 93.05 and mean of 26.81. Farming profession makes people depen-dent on others for inputs and food when inadequately possessed. This is true in groundnut farming also. When farmers become self-sufficient in these aspects, that particular farming system could well be taken as socially stable. Present study revealed that marginal farmers were relatively more stable than small and large farmers. A major contributor was high input self-sufficiency. Most of the marginal-farmer families were self-dependent for human and animal power, prepared most of the compost with the help of available green leaves and forest plants, thus reducing external fertilizer purchase, and rarely used to purchase seed material. All these might have given better social stability to this group of farmers. Large farmers were least stable in social considerations because of their excessive dependence on external agencies for inputs. Slightly better food sufficiency had salvaged a little pride but not to the extent of overcoming the social instability.

Sustainability index. The sustainability index of the farmers ranged from a minimum of 14.08 to a maximum of 77.22 with a mean of 48.08 (Fig. 4.15). The moderate levels of sustainability of majority of the farmers has kept the mean sustainability at a high level. Maximum sustainability indices among the three farmer categories ranged form 63.72 to 79.25 thus indicating that high sustainability is not hard to achieve. Still, the disturbing fact is that the mean sustainability index was no higher than 48.08, leaving a lot to be desired.

4.12.4 Rice-production system in Molahalli Microwatershed

Nutrient management index. Rice-growing farmers obtained nutrient management index rang-ing from 20.0 to 66.7 with a mean of 41.4. All the farmers had applied higher levels of organic manure than recommended, but chemical fertilizer application was low. Recommended N:P:K dose was 60:30:45 whereas the applied dose was 50:19:0 for marginal farmers, 66:31:0 for small farmers and 21:8:0 for large farmers. Farmers rarely applied potash fertilizers and crop residues.

Land productivity index. Land productivity index had a minimum of 8.0 qtl/ha and maximum of 50.0 qtl/ha with a mean of 21.3 qtl/ha. This was only 50 per cent of the potential yield. The low mean value might be because of poor nutrition, pests and diseases, micronutrient deficiencies, excessive irrigation and labour shortage.

Input productivity index. Rice-growing farmers obtained minimum input productivity index of 0.7 and maximum of 2.4 with a mean of 1.6. This is in fact low, and might be because of high cost of cultivation of rice and low market price. Improvement in the index could be achieved only by increasing yields and fixing a remunerative price.

Crop yield security index. Crop yield security index had a minimum of 16.8, maximum of 100.0 and mean of 61.4. Increasing crop yield would raise the index. Attaining higher yield through integrated nutrient, water and pest management would result in higher crop yield security.

Input self-sufficiency index. The minimum input self sufficiency index was 25.4, the maximum 100.0 and the mean 75.4. Higher usage of owned men and women and bullock labour, owned seed and owned farmyard manure have resulted in fairly high input self-sufficiency among the farmers. Other crops in the watershed were plantation crops, which did not need exhaustive resource use. Thus all resources and inputs were directed to rice.

Family food sufficiency index. Rice farmers of Molahalli obtained minimum family food suffi-ciency index of 38.6, maximum of 86.36 and mean of 67.88. The farmers were able to meet 75 per cent of their cereal and pulse needs from the farm, but depended on the open market for vegetables and oil.

Ecological safety index. The minimum ecological safety index was 0, the maximum 100.0 and mean 48.36. Medium nutrient management index values have resulted in medium ecological safety indices. Non-application of biofertilizers and crop residues and lower application of P and K fertilizers need to be corrected to achieve higher ecological safety index.

Economic security index. The economic security index ranged from a minimum of 0 to maxi-mum of 84.8 with a mean of 48.53. Two major reasons for medium economic security might be the market glut and consequent low price resulting from all the farmers growing rice and deple-tion of soil health, loss of crop yield potential and building-up of pests and diseases because of continuous growing of rice without crop rotation and use of the same seed year after year. Use of integrated management practices and judicious use of irrigation will not only increase economic security but also ameliorate soil health.

Social stability index. The minimum social stability index was 20.01, maximum 89.46 and mean 64.76. These slightly higher social stability index values were the outcome of higher input self-sufficiency and medium family food sufficiency indices among the farmers. Diversifying the farm to produce other food needs of the family such as vegetables and oil would not only improve their social stability but also enhance the health of the rice ecosystem.

Sustainability index. The farmers obtained a minimum sustainability index of 25.54, maximum of 76.25 and mean of 51.9 (Fig. 4.16). High land productivity, crop yield security and input self-sufficiency have resulted in medium sustainability index of the farmers. Use of organic fertilizers, checking micronutrient deficiencies, using integrated pest management methods and diversifying farms would further enhance the sustainability of rice-growing farmers in Molahalli watershed.

Table 4.22 Pay-off matrix for the nine objectives and the ideal points — Garakahalli watershed

Corresponding value of the objectives	Objectives optimized									Ideal point
	MAXNI	MINCAH	MINBP	MINML	MINWL	MAXFYM	MIN_N	MIN_P	MIN_K	
Net income	9491343.53	1907833.27	1803622.96	1572060.49	1724317.57	2106058.91	1881937.76	1949285.90	2114128.61	9491343.53
Cost	4086667.65	1316168.99	1386386.74	1332427.74	1477429.45	2421505.68	1392418.60	1674124.13	2372415.28	1316168.99
Bullock labour	7710.79	4336.94	3626.52	3908.34	4521.58	7223.81	4319.93	4977.49	6661.97	3626.52
Men labour	28689.17	5146.28	5336.23	4652.63	8116.74	9004.07	7371.71	7717.37	9296.20	4652.63
Women labour	30296.62	13063.67	14253.94	13767.74	11083.88	25377.53	11763.95	21259.39	22875.32	11083.88
Farmyard manure	5455.09	3299.91	3287.14	3302.65	3612.75	6878.54	3790.96	3881.88	4145.19	6878.54
Nitrogen	23608.49	9088.68	10922.08	10049.86	9725.82	19266.17	8063.04	8239.19	13618.96	8063.04
Phosphorus	16489.53	5654.61	7979.30	6524.21	7471.41	12951.46	5801.02	5109.88	19048.28	5109.88
Potash	13541.34	707.04	1138.32	570.28	112.39	1007.25	195.56	594.95	9.07	9.07

Table 4.23 Pay-off matrix for the nine objectives and the ideal points — Nalatwad watershed

Corresponding value of the objectives	Objectives optimized									Ideal point
	MAXNI	MINCAH	MINBP	MINML	MINWL	MAXFYM	MIN_N	MIN_P	MIN_K	
Net income	2497048.60	1986669.63	2150155.26	2194293.14	2370183.60	2175761.64	2179934.61	2111993.51	2309367.44	2497048.60
Cost	2136851.00	1991026.67	2193020.40	2162024.65	2106336.53	2289191.14	2079435.70	1997874.94	2095745.63	1991026.67
Bullock labour	6342.07	5195.50	4531.51	4814.03	6295.52	4864.41	5198.25	5304.84	6336.67	4531.51
Men labour	5028.76	4421.06	3935.70	3543.46	5188.97	4151.07	4511.26	4303.42	5248.58	3543.46
Women labour	14054.37	16415.48	18285.71	18128.26	13163.91	18326.98	17551.69	16981.33	13939.88	13163.91
Farmyard manure	10663.38	9795.70	11062.82	11444.48	10728.14	11923.73	10665.25	9703.86	10373.59	11923.73
Nitrogen	13252.43	9250.54	12146.86	11746.75	13652.89	11341.74	8609.55	9255.90	13317.24	8609.55
Phosphorus	13368.58	12220.86	13540.24	12403.50	13401.91	11923.73	11996.98	11660.33	13493.46	11660.33
Potash	207.34	957.13	819.90	1000.62	107.10	1250.75	758.78	884.86	27.56	27.56

Table 4.24 Pay-off matrix for the nine objectives and the ideal points — Pettamanurahatti watershed

Corresponding value of the objectives	Objectives optimized									Ideal point
	MAXNI	MINCAH	MINBP	MINML	MINWL	MAXFYM	MIN_N	MIN_P	MIN_K	
Net income	2035085.44	1834182.89	1731812.64	1724648.00	1671473.67	1653023.07	1561959.52	1829098.17	1737271.61	2035085.44
Cost	4002852.22	3832933.99	3929622.78	3933377.65	3924410.57	4189828.50	3986642.75	3963585.95	3929538.51	3832933.99
Bullock labour	7747.28	7489.13	7208.41	7671.72	7606.31	7969.97	7736.20	7398.15	7552.28	7208.41
Men labour	8398.06	8128.73	8183.70	7689.22	8057.09	8183.72	7960.20	7917.53	7956.26	7689.22
Women labour	30138.00	28727.81	28253.46	29961.90	26908.65	29559.74	28211.36	29848.12	29714.14	26908.65
Farmyard manure	4003.40	3363.28	4605.14	4084.92	4676.45	5548.06	4747.72	4580.44	4037.45	26908.65
Nitrogen	19586.01	17893.50	18172.65	15654.85	15155.87	15948.56	14209.56	16867.85	16590.26	14209.56
Phosphorus	15701.79	16960.65	15479.25	16198.24	15117.91	15516.64	16093.81	14713.34	16377.95	14713.34
Potash	4568.57	4235.14	4440.87	4078.95	4389.92	4561.14	4074.89	4019.04	3814.51	3814.51

Table 4.25 Pay-off matrix for the nine objectives and the ideal points — Molahalli watershed

Corresponding value of the objectives	Objectives optimized									Ideal point
	MAXNI	MINCAH	MINBP	MINML	MINWL	MAXFYM	MIN_N	MIN_P	MIN_K	
Net income	2577687.10	2063161.21	2070913.35	2068803.95	2047125.53	2615322.62	2063161.21	2063174.98	2063161.21	2577687.10
Cost	4051180.28	2955210.69	2981968.47	2974514.83	3016638.85	4235862.83	2955210.69	2955218.34	2955210.69	2955210.69
Bullock labour	5116.82	3472.78	3405.84	3472.21	3525.55	5164.47	3472.78	3472.94	3472.78	3405.84
Men labour	10559.31	7876.35	8133.09	7862.39	8465.13	10417.42	7862.39	7859.12	7862.39	7862.39
Women labour	20927.38	14306.55	14369.51	14322.43	13861.02	20716.44	14306.55	14308.96	14306.55	13861.02
Farmyard manure	1681.57	1408.88	1403.49	1425.35	1422.54	1698.39	1408.88	1409.07	1408.88	1698.39
Nitrogen	11967.33	8360.09	8904.71	8867.33	9592.84	13297.10	8360.09	8363.47	8360.09	8360.09
Phosphorus	5671.24	3967.91	4410.88	4104.21	4528.36	6152.92	3967.91	3966.48	3967.91	3966.48
Potash	5891.33	4017.16	4570.57	4283.16	4581.38	6403.15	4017.16	4018.27	4017.16	4017.16

5. SUMMARY AND IMPLICATIONS

Biophysical accounting of land resources

The results of the detailed soil survey investigations on the soil and land resources of the microwatersheds highlighted the main constraints that threaten the sustainability of rainfed farming.

Soil depth. Of the four watersheds, Pettamanurahatti had the largest extent (130 ha) of shallow (<50 cm depth) soils, followed by Nalatwad (57 ha), Garakahalli (10 ha) and Molahalli (6 ha). Only a limited range of crops can be grown on these shallow soils, particularly short-duration crops. These soils are best suited to pasture, silvipasture and agroforestry. Moderately shallow and moderately deep (50–100 cm depth) soils covered a large extent in Pettamanurahatti (350 ha), followed by 138 ha in Nalatwad, 96 ha in Garakahalli and least in Molahalli watershed (16 ha). Some short and medium duration crops can be grown successfully on these soils. Deep soils (>150 cm depth) occurred to the largest extent in Molahalli (415 ha), with Nalatwad (358 ha) and Garakahalli (350 ha) close behind. Pettamanurahatti watershed had about 100 ha. All types of agricultural and horticultural crops can be grown successfully on these soils.

Surface soil texture. Pettamanurahatti watershed had the largest area of soils with sandy (loamy sand) surface texture. Of the other three, only Garakahalli watershed had a much smaller area (90 ha) of such soils. These soils are very poor in respect of available water and available nutrients. Loamy (sandy loam, loam, sandy clay loam and clay loam) soils were predominant in Molahalli (330 ha), Garakahalli (265 ha) and Pettamanurahatti watersheds. Nalatwad watershed had no soils with surface texture coarser than clay. Loamy soils have the advantages of high potential for available water and are medium in available nutrient capacity. They are greatly amenable to seedbed preparation and seedling emergence. Clayey soils covered the entire area of Nalatwad watershed. About 107 ha in Molahalli and about 86 ha in Garakahalli have surface texture of clay. These clayey soils have high potential for available nutrients and available water, but drainage and management are major problems in black clay soils.

Surface gravelliness/stoniness. The problem of surface gravelliness and/or stoniness was not encountered in Nalatwad and Molahalli watersheds. It was a major problem in Pettamanurahatti, where soils with >35 per cent gravel covered about 158 ha, with 15–35 per cent gravel about 278 ha and with <15 per cent gravel 145 ha. Most of the area (340 ha) in Garakahalli had no problem of gravel. Only about 71 ha had <15 per cent gravel and about 29 ha had 15–35 per cent gravel. High surface gravel content posed a problem in seedbed preparation and seedling emergence.

Soil slope. Nalatwad and Pettamanurahatti watersheds had no serious problem with slope. In Nalatwad, most of the area was covered by very gently sloping (1–3% slope) or nearly level (<1% slope) lands. Only a very small area had gently sloping (3–5% slope) lands. In Pettamanurahatti, about 350 ha had very gently sloping lands about 129 ha gently sloping lands and 94 ha nearly level lands. Only about 8 ha had moderately sloping (5–8% slope) lands. Most of the area of Molahalli had nearly level and gently sloping lands. About 60 ha was covered by moderately sloping and strongly sloping lands (5–10% slope) lands. Most of the area of Garakahalli watershed had very gently sloping and gently sloping lands. About 45 ha had major problems with slope and were hence unsuitable for agriculture.

Soil erosion. Soil erosion was lowest in Garakahalli watershed where an area of about 362 ha had no erosion or slight erosion and about 75 ha moderate erosion. Only 3 ha suffered from severe erosion. Nalatwad and Pettamanurahatti watersheds had large areas with moderate erosion and small areas under severe erosion. Erosion was rampant in Molahalli watershed with about 120 ha under severe erosion and about 125 ha with moderate erosion. About 192 ha had no erosion or slight erosion as most of this area was under rice cultivation with the land well protected by bunds and terraces.

Land capability. Three watersheds, namely, Nalatwad, Molahalli and Garakahalli had maximum area under good cultivable lands (class II), a small area under moderately good cultivable lands (class III) and very negligible area under fairly good cultivable lands (class IV) suited for occasional cultivation (Molahalli and Garakahalli). Most of the area of Pettamanurahatti watershed had fairly good cultivable lands suitable for occasional cultivation because of dry climate. About 145 ha had moderately good cultivable lands and about 63 ha was not suitable for cultivation but well suited for pasture or forestry.

Land irrigability. Molahalli and Garakahalli watersheds had about 170 ha and 323 ha, res-pectively, under lands with moderate limitations for sustained use under irrigation. The latter had about 42 ha of lands with severe limitations and about 70 ha of lands that were marginal for sustained use under irrigation. Molahalli had 268 ha not suitable for irrigation. Nalatwad had mostly lands marginal for sustained use under irrigation because of shrink-swell clay soils. Pettamanurhatti had a large area under lands that were marginal for sustained use under irrigation, and about 52 ha not suitable for irrigation.

Soil fertility status. Nitrogen status was predominantly low in Nalatwad (99%), Garakahalli (78%) and Pettamanurahatti (98%), whereas it was medium in 63 per cent of the area of Molahalli watershed. Available phosphorus level was mostly low in Nalatwad (74%) and Molahalli (51%) watersheds. In the other two, low and medium levels were fairly equally distributed (38% and 37%, respectively, in Garakahalli; 44% for both in Pettamanurahatti). Available potash levels were mostly high in Nalatwad (94%), medium in Pettamanurahatti (72%) and Garakahalli (47%), and low in Molahalli (71%). Among the available micronutrients, zinc was deficient in very large areas (52–98%) of all the watersheds. In Nalatwad, 56 per cent of the area was deficient in available iron, while in Pettamanurahatti, the figure was 69 per cent of the area. Most of Molahalli (95%) and Garakahalli (72%) had adequate levels of available iron. Most areas of all the watersheds had adequate levels of available manganese (84–99%) and copper (84–99%). Generally speaking, nitrogen, phosphorus and zinc were the common limiting nutrients in all the watersheds.

Land suitability for crops. Land suitability in each watershed was highly variable from crop to crop. In Garakahalli watershed, the lands were mostly moderately suitable or better for coconut, finger millet and groundnut, unlike for banana for which no land was highly suitable, although 76 per cent of the area was moderately suitable. Nalatwad watershed was only marginally suitable for sorghum and wheat, while large areas were not suitable for sunflower (39%) and bengal gram (29%), with the rest being marginally suitable. Almost the entire area of Pettamanurahatti watershed (98%) was marginally suitable for groundnut, finger millet and sorghum, whereas 70 percent was moderately suitable and 27 per cent marginally suitable for rainfed pearl millet. In Molahalli watershed the 162 ha under forest was not evaluated but was included in the area not suitable. For rice, the marginally suitable area (37%) and moderately suitable area (23%) add up to 60 per cent of the area of the watershed. Plantation crops that were compatible with land qualities in the watershed were arecanut (21% highly suitable, 17% moderately suitable) and coconut (14% highly suitable, 20% moderately suitable). Evaluation of the lands for cashew gave 14 per cent area moderately suitable and 24 per cent marginally suitable.

Socio economic features of farm households

Most of the farm households had marginal and small holdings (<2 hectares) accounting for 80 per cent. About 85 per cent of the farmers possessed land records in their name, mainly for security and for availing of crop loans.

Illiteracy was widely prevalent among marginal and small farmers; institutional participation was very low among these households. Large farmers had better institutional part-cipation. Crop production was the main occupation for 72 per cent farm households along with business, dairy enterprise, agricultural labour, sheep (and goat) rearing as subsidiary occu-pations. Average annual household income was highest among large farmers followed by small and marginal farmers.

The use of inputs in crop production by all the farmers was lower than the package-of-practice recommendations and so was the output obtained which may be attributed to non-availability of inputs, financial position, untimely application and poor crop management practices.

The wide gap in inputs adopted in cultivation of all the crops in the watershed reflects the farmers' inability to use the inputs due to financial constraint and availability, and poor manage-ment practices. Furthermore, climatic and soil conditions have a major role in the quantity of output realized.

Crop production was the main source of income of Molahalli and Garakahalli farmers. Sheep and goat rearing was major source for Pettamanurahatti and petty business was among Nalatwad watershed farmers.

Impact of watershed development programme

Soil and water conservation measures were given greatest importance under watershed programme by investing minimum of 98 per cent of the total outlay on them. About 80 per cent of the farm households received benefits. Fallow area decreased after the watershed programme.

There was a marginal increase in agro-biodiversity. The watershed programme increased the average annual household income through crop production and dairy enterprise among farm households. Among marginal farmers, the increase in income was more in crop production while for small farmers it was in dairy enterprise followed by crop production. The overall food consumption and calorific intake increased in farm households.

Farmers' perception of soil constraints was that soil slope, loss of topsoil and nutrients due to soil erosion, perennial weeds reduced the crop yield by 18-19 per cent, which in turn decreased the land value in the watershed. All the farmers practiced soil and water conservation practices like sowing across the slope, application of farmyard manure, small section bunds and contour bounding. The perception among the farmers was that non-adoption of these measures would result in crop loss between 5 and 38 per cent.

Bio-economic modelling

The methodology for integration of environmental and economic aspects into bio-economic modeling develops a framework for environmental-economic decision making that includes environmental and economic sustainability criteria, and local people's preferences in the context of a rainfed agriculture system using multiple objective programming.

Derivation of sustainability criteria at the watershed level may range from defining a concept as maintenance of resource productivity over time to a socially acceptable agricultural system. The criteria may include (a) maintenance of soil health and soil qualities of the resource base, (b) low dependence on external inputs, (c) economic viability and (d) local farmer-acceptability.

The land capability and suitability analysis is considered as a governing criterion for maintaining the resource base in the long term. Input-output ratios with consideration of environmental costs (soil nutrient depletion) are considered to be environmental and economic indicators reflecting criteria (b) and (c) above. Local people's preferences and choices from various available alternatives are considered farmer-acceptability criteria.

Land capability/suitability criteria. This criterion was related to maintenance of the soil resource base and agricultural productivity. However, it was rather difficult to measure the same over time and provide its value in economic terms. The spatial-sustainability analysis using land capability and suitability provides a sound basis as governing criteria for maintaining the soil resource productivity over the long run, and integration of ecological sustainability criteria into the cost-benefit analysis valuation of soil phases.

Hence maximization of the total net income resulting from optimum cropping area based on land suitability analysis was considered as an objective.

Input-output ratio. One main concern for achieving sustainability is to increase resource-use efficiency. Minimization of labour (both manual and animal) use for crop provides a basis for selection of the most efficient area allocation for increasing resource use efficiency. This was accommodated through minimization of manual and animal labour requirement in farming as objectives.

Environmental criteria. Selection of mix of crops that utilize the maximum farmyard manure and minimum of chemical fertilizers is the main concern for sustainable land use. Hence, the objectives were set as maximization of farmyard manure and minimum use of chemical fertilizer (NPK) for cultivation of crops.

Farmer acceptability. Another major concern of agricultural sustainability is local farmer-acceptability. Farmers' preferences play a very significant role both in planning and in imple-mentation of alternatives aimed at sustainable use of resources. The households' food needs were estimated and incorporated in the model as minimum area under food crops to reflect their minimum food needs and self-sufficiency.

The results of linear programming models using multiple objectives suggested different sustainable land use alternatives for four microwatersheds. These models are normative plans which reveals what ought to be the cropping pattern and land use as well as net income as per each objective. It is interesting to note that all the nine optimization models in all the four watersheds, clearly recommended larger areas under cereals like finger millets, sorghum, paddy depending on the soil suitability for maximization of net income of the farmers except in Pettamanurahatti where ground nut is grown in larger area.

The normative plans showed better use of land and other inputs, which reflected in terms of high net income and lower cost than the existing levels. The least increase in net income (over the existing level) was 12. 87 per cent in Molahalli, while the highest was at 138.45 per cent in Garakahalli. The efficiency in cash expenses through reduced costs varied from minimum of 17.74 per cent in Molahalli to maximum of 53.99 per cent in Garakahalli.

Similarly the total use and use/ha of men and women labour days, nitrogen, phosphorus and potash were lower in normative plans than the existing patterns in all the watersheds. The recommended total use and use/ha of farmyard manure was higher in consonance with the objective set forth in the model.

An examination of net income realized and the cost incurred per hectare between existing and normative plans in all the watersheds revealed that the possibility exists of inc-reasing the net income by at least Rs 873/ha in Molahalli, Rs 1575/ha in Nalatwad, Rs 1762/ha in Pettamanurahatti and the highest of Rs 17971/ha in Garakahalli watershed.

The increase in net income in percentage and per hectare through adoption of the normative plans in all the watersheds definitely shows the possibility of improvement in the land productivity through resource allocation in accordance with land capability and suitability.

Economic land evaluation

Evaluation of the cost of soil erosion and benefits from productivity depends on how the soil is valued. As a natural resource, soil may be viewed in different ways. It has a direct-use value as a medium for plant growth, and an indirect-use value in terms of absorbing rainfall and mitigating floods. Other kinds of value are bequest value (to future generations that will rely upon it) and existence value in global terms for biodiversity and habitat for plants and animals. The total economic value of soil is the sum of all these values. The direct-use value expressed in this watershed was based on soil productivity, which is of most immediate concern to land users.

The replacement cost approach. The replacement cost approach looks at the cost of restoring a damaged resource asset. This approach focuses on the loss of nutrients and its costs, which are valued at the market price of organic and inorganic chemical fertilizer containing the same quantity of nutrients depending upon the degree and extent of soil erosion in each watershed. The annual soil nutrient loss due to soil erosion was maximum in Molahalli (Rs 139336) followed by Nalatwad (Rs 61294), Pettamanurahatti (Rs 54271) and minimum in Garakahalli (Rs 20155).

Cost of soil nutrient misapplication. The cost of misapplication of soil nutrients was estimated taking the absolute difference between the level of nutrients actually added by the farmers and the nutrients required for achieving the farmer's yield based on soil test. The results indicated the per hectare misapplication cost for NPK was maximum in Pettamanurahatti (Rs 5903), followed by Garakahalli (Rs 1365), Molahalli (Rs 752) and minimum in Nalatwad (Rs 523)

Soil potential rating approach. Soil potential rating is a numerical rating of a soil’s relative suitability by considering the performance yield standard that is locally established minus the cost of corrective measures and continuing limitations. It was found that the land evaluation by soil potential ratings proved more rational than that by the FAO framework using qualitative suitability ratings.

Production function approach. The production-function analysis done separately for each crop revealed that the soil depth had a significant influence in increasing the crop yield and with increase in soil erosion would cause a corresponding decrease in yield.

Defensive expenditure approach. This approach considers costs of measures undertaken to avoid or reduce the unwanted resource damage. In the context of erosion-productivity, this implies the costs of conservation measures undertaken for erosion control. This approach is particularly useful when information on environmental damage is difficult to obtain or assess, while information on recommended conservation measures is available. This approach assumes that individual farmers or the government judge the resultant benefits to be greater than the costs.

The economic evaluation of investment on soil and water conservation in all the watersheds showed that it would be possible to recover the entire investment made in the watersheds programme in 6 to 7 years. The benefit: cost ratio indicated that every rupee of investment in the watershed yielded an incremental net return of at least Rs.1.13. The internal rate of returns was greater than the opportunity cost or present lending rate and hence the investment in all the four watersheds on soil and water conservation under the watershed programme was economically viable, commercially feasible and financially sound.

Characterization of farm-level sustainable land-management indicators

Sustainable farming is the process by which farmer manages soil and water relying on on-farm resources to enhance productivity and maintain it to meet farm and family needs without affecting the production environment. The farm-level analysis of sustainability involves identification of components that reflect sustainability, and can be operationalized and measured spatially. There is unanimity in the understanding that sustainability of a farming system has three dimensions, namely, ecological, economic and social. The ecological dimension consists of nutrient management. The economic dimension includes land productivity; input productivity and crop yield security. The social dimension contains input self-sufficiency and family food sufficiency.

The mean value sustainability index was high in Garakahalli (54.55) followed by Molahalli (51.90), Nalatwad (50.25) and low in Pettamanurahatti (48.08). The low sustainability in Pettamanurahatti watershed was mainly due to low ecological safety, as their nutrient management index was poor and low family food sufficiency as they are not growing their food requirement and are purchasing food grains, which resulted in low sustainability of farming.

Sustainability is not limited to maximizing production but includes ecological sustaina-bility, which is essential for long-term viable crop and animal production. Major problems that hindered Pettamanurahatti farmers from attaining high sustainability were, non-application of biofertilizers and crop residues, mono cropping, untimely farming operations, dependence on external inputs and large family size.

Organic farming, which includes usage of farmyard manure, green manure, crop residue and biofertilizers, enhances soil health, provides required nutrients for crop growth, improving productivity. Other possible recommendations for minimizing long-term damage to the soil could be improvement of livestock possession, crop rotation with leguminous crops, making the farm self-sufficient with own inputs and bringing about awareness of the benefits of soil and water conservation, especially in dryland agriculture.

IMPLICATIONS

The land resources are limited in all the four watersheds as almost all-arable land is already under cultivation. Rainfed agriculture in these watersheds characterized by low level of productivity and low quantity of input use. Being dependent on rainfall, crop production is subjected to considerable instability from year to year. The food security issues therefore need to be addressed through sustainable intensification and more efficient use and management of land.

Degradation processes are driven by socio-economic factors such as those below, which lead to mismanagement of land.

- Resource poor farmers
- Decline in man:land ratio
- Over grazing of livestock
- Deforestation
- Less adoption of high yielding and improved varieties
- Pests and diseases attack
- Unbalanced nutrient management practices
- The gap between yield potential and actual yield is very high
- Use of inorganic fertilizers
- Decline in soil organic matter
- Nutrient mining/ depletion.

The available soil database indicates the actual/potential productivity under different land use systems. The information on loss of soil nutrients due to erosion helps policy makers and planners to identify policies that minimize soil degradation.

The data on misapplication of soil nutrients emphasize the need to shift the emphasis on soil fertility *per se* to imbalance between nutrient input and output. This calls for refinement of fertilizer recommendations. The environmental effect of such misapplication and nutrient mining calls for integrated nutrient management strategies for soil health restoration.

The extent and cost of land degradation are high and alarming. Adequate land use policies and land management programs must combine development and environmental goals and implement through integrated and participatory approach. Generation of off-farm employ-ment opportunities can reduce the pressure on marginal land.

The environmental and economic impact assessment of watershed development programme in the four watersheds indicates that the efforts of watershed development on soil and water conservation are economically viable.

There is no follow up and maintenance of soil and water conservation structures after implementation of the project. The watershed *sanghas* are defunct in these locations. The invest-ment in human and social capital in terms of improving skills and creation of awareness about soil use and management has been given less priority in the present pattern of watershed development programs. There is need to give importance to this that will directly contribute to planning and capacity building in farm households.

In areas with relatively low potential for agricultural development (Pettamanurahatti watershed) livestock holds a comparative advantage and complements farmhouse income. Currently there exists a strong tendency to achieve self-sufficiency by maintaining livestock among farm households.

Government policies with respect to fertilizer subsidies and support prices have impact on land resource use and management. Increase in support price/market prices of groundnut increased the pressure on marginal lands and depleting of soils. The differential pricing of fertilizer subsidies leads to imbalance in use of fertilizers (more of N and P and less of K).

Based on scientific assessment and farmers knowledge system, the problems of land use and management and production constraints were identified and ranked according to severity of problems and should be used for the research prioritization in natural resource management and development of location-specific policy strategies and measures for sus-tainable land management.

The legal aspects of land use and land ownership indicate that people who possess land records are better in managing the land than the other groups who do not possess land records. This justifies the need for giving priority attention to this area by government policy for providing land titles to the farmers.

Sustainable land management could only be a success once soil health care is ensured. In order to ensure soil health care, the introduction of soil health card in land development programmes is essential. The objective of soil health card is to generate awareness among farmers about the vital natural resource for its optimum use and to adopt land use as per land capability. It provides vital information for policy makers, soil conservationists for implementing development programmes and research prioritization.

People-centric approach should be well adopted in implementation of optimum land use plans as per the soil capability/suitability that can improve the productivity and net income of farm households on sustainable basis.

This project made an attempt at economic land evaluation by comparing cost and benefits for each land use on each (soil phases) land unit. In all situations it is realistic to use economic measures of cost and benefits for quantifying the land use potential and suitability.

The suitability and productivity of crop depends on *in situ* land qualities. There is positive relationship of land productivity with soil depth and water holding capacity and negative relationship with soil erosion, gravel, salinity and slope of land.

The accessibility of ready market and transport facilities influences on the type and in-tensity of land use. Garakahalli watershed farmers having good accessibility to Bangalore market are growing more of commercial crops like mulberry, banana and coconut when compared to Nalatwad where they are growing only sorghum due to lack of accessibility and market.

The spatial attributes of size of land holding influence the intensity of input use and the land slope, shape and size of the plot, influence on adoption of soil conservation and the land management practices.

The economic value of a land use system implemented on a given land area (land evaluation) is not equal to the market value (land valuation) although the predicted returns to a land unit of various land uses obviously influences its price. It was found that there is positive relationship between (R^2 =0.91) the economic value estimated by land evaluation and farmers perception on market value of land in all the four locations.

Sustainable land management is only possible through precision farming. Precision farming is the term used to describe the goal of increased efficiency in the management of agriculture. This study assessed the spatial variability of soil nutrients and gives an insight into need for practicing precision farming by following different levels of soil nutrients depending upon the soil fertility and yield potential of the crop in the watershed.

This study calls for use of both biophysical and socio-economic consideration in planning and implementation of government development programs in management of natural resources. The optimum land use plans provide site-specific conservation programmes and crop management, bringing out economic and environmental considerations in land management.

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