This study developed a dynamic and non-linear bioeconomic model, incorporating both economic and biophysical factors to assess the impact of technological and policy interventions on social well-being of the rural poor and condition of natural resource base in a micro-watershed of the semi-arid region of India. The results clearly indicate that care should be taken while framing policies for watershed development to avoid implementation of conflicting polices. Preferably, those technologies and policies that have multiple impacts in terms of meeting both welfare of the farmers and sustaining natural resource objectives must be prioritized. This study could be useful to policy makers and other development professionals seeking to improve the welfare of farmers and natural resource base in SAT rainfed region in India and other developing countries.

S. Nedumaran

Swamikannu Nedumaran holds a PhD in Agricultural Economics from TamilNadu Agricultural University, India. He is currently an Economist in International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad, India. His research includes natural resource management and application of mathematical programming for policy analysis.

978-3-659-26439-9

Impacts of Micro-Watershed Management

Nedumaran

S. Nedumaran

Assessing Impacts of Micro-Watershed Management in Semi-Arid India

A Bioeconomic Modeling Approach

LAP LAMBERT Academic Publishing

S. Nedumaran

Assessing Impacts of Micro-Watershed Management in Semi-Arid India

S. Nedumaran

Assessing Impacts of Micro-Watershed Management in Semi-Arid India

A Bioeconomic Modeling Approach

LAP LAMBERT Academic Publishing

Impressum / Imprint
Bibliografische Information der Deutschen Nationalbibliothek: Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

Bibliographic information published by the Deutsche Nationalbibliothek: The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Coverbild / Cover image: www.ingimage.com

Verlag / Publisher:
LAP LAMBERT Academic Publishing
ist ein Imprint der / is a trademark of
AV Akademikerverlag GmbH & Co. KG
Heinrich-Böcking-Str. 6-8, 66121 Saarbrücken, Deutschland / Germany
Email: info@lap-publishing.com

Herstellung: siehe letzte Seite /
Printed at: see last page
ISBN: 978-3-659-26439-9

Zugl. / Approved by: Coimbatore, TamilNadu Agricultural University, Diss., 2007

Assessing Impacts of Micro-Watershed Management in Semi-Arid India: A Bioeconomic Modeling Approach

S. Nedumaran

Assessing Impacts of Micro-Watershed Management in Semi-Arid India: A Bioeconomic Modeling Approach

Thesis submitted in part fulfillment of the requirements for the award of the degree of
DOCTOR OF PHILOSOPHY IN AGRICULTURAL ECONOMICS
to the Tamil Nadu Agricultural University, Coimbatore.

S. NEDUMARAN

CENTRE FOR AGRICULTURAL AND RURAL DEVELOPMENT STUDIES
DEPARTMENT OF AGRICULTURAL ECONOMICS
TAMIL NADU AGRICULTURAL UNIVERSITY
COIMBATORE – 641 003
India

2007

Contents

ABSTRACT

A watershed level, dynamic and non-linear bioeconomic model, incorporating both economic and biophysical aspects is developed to assess the impact of technological and policy interventions on social well-being of rural poor and condition of natural resource base in a micro-watershed of SAT region of India. Both socioeconomic and biophysical data required for developing the model is collected from a watershed (namely Adarsha watershed in Kothapally village, Ranga Reddy district, AP) developed by ICRISAT and its consortium partners to evaluate new integrated watershed development approach. The model maximizes the income of the whole watershed, which include three types of households based on land endowment (small, medium and large), who are spatially disaggregated into six different segment in the watershed landscape namely shallow, medium and deep based on soil depth under two types of land (dryland and irrigated land). The model maximizes the aggregate net present value of incomes of three household groups in the watershed over a 10 year planning horizon.

The model used simplified production function to represent farmers' response to different factors of production. The crop production in the model is affected by change in soil depth, which is reduced by soil erosion. The erosion level in the watershed is estimated for predicted land use pattern using USLE model. The yield-soil depth response for different crops grown in the watershed is estimated by using econometric method and the parameters are used in the bioeconomic model. The baseline model serve as starting point to assess the likely impact of alternative technology and policy interventions in the watershed. The watershed level bioeconomic model is used to assess the impact of alternative scenarios like change in the yield of dryland crops, irrigated area in the watershed, output price policies, output based water charges and improving non-farm employment opportunities and high population pressure.

The model predicts that the increase in the yield of dryland crops lead to increase area under sorghum/pigeonpea and maize/pigeonpea intercropping systems and reduced the area under cotton resulting in higher income for all the household groups. The

increase in yield of dryland crops has positive effect on incentives to conserve land resulting in less soil erosion and the nutrient mining in the watershed.
Increase in the irrigated area in the watershed has improved the income of the household by cultivating more area under irrigated cotton, sunflower and vegetables. However, increase in irrigated area has negative impact on natural resource by increasing soil erosion and nutrient mining in the watershed. The decrease in irrigated area has increased the incentive for conservation measures resulting in reduced soil loss. Due to change in cropping pattern towards dryland less nutrient erosive crops, the decrease in irrigated area reduces the nutrient mining in the watershed.

The better price of dryland crops improved the income of the all the household groups. The supply response of the farmers in the watershed for changes price of dryland crops has increased the area under sorghum/pigeonpea and maize/pigeonpea intercropping systems resulting in reduced erosion level in the watershed even with the lower investment of labour for conservation measures. The fodder availability in the watershed also increased due to increase in area of sorghum and maize resulting in higher livestock population in the watershed. The decline in area under nutrient erosive crops like cotton and sunflower and increased application of farmyard manure has resulted in decline of soil nutrient mining in the watershed.

Water usage charges appear to have negative impact on income of the farmers by reducing the area under the irrigated crops. The results also show that the changes in the cropping pattern affected the fodder supply in the watershed and hence reduced the livestock production. Water pricing also reduced the total soil erosion and nutrient mining in the watershed.

The increased access to non-farm employment opportunities leads to significant increase in the income of the three household groups. The soil erosion in the watershed increased over the years because of increased access to non-farm employment opportunities reducing the incentive to use labour for conservation measures. This may be due to the opportunity cost of labour for non-farm employment is higher than the labour used of conservation measures.

The increase in population pressure results in reduction of income for all three household groups compared to baseline level with constrained access to non-farm employment and no scope for increasing the area under cultivation in the watershed. The increased population allows the farmers to invest their surplus labour in the soil conservation measures resulting in less soil erosion in the watershed.

The results clearly indicate that care should be taken while framing policies for watershed development to avoid promotion of conflicting polices. Preferably, those technologies and policies that have multiple impacts in terms of meeting both welfare of the farmers and sustaining natural resources objectives must be prioritized. Hence appropriate policy instruments enacted to facilitate the same.

This study could be useful to policy makers and other development professionals seeking to improve the welfare of farmers and natural resource base in SAT rainfed region in India and other countries. For example, in this study support price policy to dryland crops give incentive to the farmers to cultivate more dryland crops. This resulting in overall improvement in income of all the households, increase income from livestock due to higher supply of fodder and higher investment in soil conservation measures showing balanced impact on livelihoods of the households and sustaining the natural resources in the watershed. Thus increasing the area under water saving dryland crops may help to sustain the groundwater resource over a long period of time. Beyond this, the watershed level dynamic bioeconomic modeling approach use in this study can be usefully adapted and applied in many other settings.

Acknowledgement

I wish to take this valuable opportunity to express my deep sense of gratitude and sincere thanks to **Dr. K. Palanisami,** Director, Centre for Agricultural and Rural Development Studies, Tamil Nadu Agricultural University (TNAU), Coimbatore and chairman of the Advisory Committee for his inspiring guidance, constructive criticism, constant encouragement and for the keen interest he has taken to give me the right perspective of research.

I extol fervently and modestly the genuine cooperation and inspiration offered to me by the co-chairman of my Advisory Committee, **Dr. Bekele Shiferaw,** Senior Scientist, GT-Markets, Policy and Impacts, ICRISAT, Nairobi, Kenya for providing research facilities, suggestions for research problem, immensely valuable and meticulous guidance, kind encouragement and constructive criticism throughout the period of the study and preparation of this dissertation. It was indeed an exciting and pleasant experience to have had worked with him.

I am highly thankful to the members of the Advisory Committee in ICRISAT, **Dr. Suhas P. Wani,** Principal Scientist, Regional Theme Coordinator (Asia), GT-Agroecosystems, ICRISAT, Patancheru and **Dr. Cynthia Bantilan,** Global Theme Leader, GT-Markets, Policy and Impacts, ICRISAT, Patancheru, for their continuous care and constant encouragement and well timed suggestions.

I extend my sincere thanks to the members of the Advisory committee in Tamil Nadu Agricultural University, **Dr. C. Ramasamy,** Vice Chancellor, Tamil Nadu Agricultural University, **Dr. C.R. Ranaganathan,** Professor and Head, Department of Physical Science and Information Technology and **Dr. D. Augustine Selvaseelan,** Professor, Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore for their candid support and encouragement during my period of study.

I wish to express my special thanks to **Dr. S. Marimuthu,** Scientist (Agronomy), GT-Agroecosystems, ICRISAT, Patancheru for his valuable comments on the draft of this thesis and also for his personal interest and encouragement given to me.

I am also thankful to **Dr. G. Alexender,** Visiting Scientist, and **Dr. D. Thirunavukarasu,** Communication Officer, International Livestock Research Institute, Patancheru for providing data related to livestock and their valuable discussion.

I appreciate and thank for the assistance and cooperation extended to me in providing data for my study and other supports by GT-Markets, Policy and Impacts staffs **(Mr. G.D. Nageshwara Rao, Mr. E. Jagadesh, Mr. Kenneth Muir, Mr. Krishnan, Mrs. Padmini)** and GT-Agroecosystems staffs **(Mr. L.S. Jangawad, Mr. K. Srinivas, Mr. Sudi Raghavendra Rao, Mr. V. Nageshwara Rao)** and all the other staff of ICRISAT.

I remember with pride the friendship of **Mr. S.M. Karuppanchetty,** Manager, Agri-Business Incubator, ICRISAT and his family and also I extend my special thanks for their great hospitality and kind help during a number of demanding occasions.

I am also very thankful to all my friends for their valuable moral support and their kind help during the period of study.

Special thanks are due to my wife **Smt. K.N. Tamilselvi** and my daughter **N. Rithu Varshini** for their inspiration, love, patience and understanding in the face of my long hours of work. Thanks are due to my parents and sister for their love, support and thoughtfulness. I shall remain grateful to them!

I acknowledge ICRISAT for providing financial support and research facilities.

Coimbatore

February, 2013 **(S. Nedumaran)**

CHAPTER I

INTRODUCTION

The last four decades have registered impressive gains in food production, food security and rural poverty reduction in India. In the era of 'Green Revolution', intensive use of irrigation, fertilizers, and pesticides along with High Yielding Varieties (HYVs) in favoured high potential zones was the major driving force for the success in past decades. However, many regions in less favoured rainfed areas of semi-arid tropics (SAT)[1] have not benefited from this process of agricultural transformation. Low productivity of rainfed agriculture with widespread poverty, the changing globalized environment, scarcity of water and degradation of productive resources (land, water, biodiversity) are threatening to further marginalize the agriculture and livelihoods in the Indian SAT (Rao *et al*., 2005). As opportunities for further expansion in more favoured regions are exhausted, food security and productivity growth in agriculture in India are increasingly dependent on the growth in rainfed regions. The emerging evidence of higher impacts on the poor and higher marginal productivity gains from public investments in the less favoured regions suggests the need to prioritize these hitherto overlooked areas in terms of technology development and policy (Fan and Hazell, 1999). It is important to recognize the potential of the less favoured lands, and design suitable strategies and policies for stimulating sustainable growth in this region.

The expected increase in the population in the coming decades and increasing urbanization in the developing countries such as India are not likely to be matched by the crop and livestock production with the current management practices (Rosegrant *et al*., 2001). This has serious implication for sustainable development and achievement of the millennium development goals in terms of human nutrition, health and welfare in the less favoured areas of the developing countries. Sustainable development is the process of increasing productivity and incomes for the current generation using available current resources as it is about preserving the stock and

[1] The Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) and FAO defines SAT as those area which has (a) crop growing period of 75-180 days; (b) mean monthly temperature higher than 18 degree Celsius for all the twelve months of the year; and (c) daily mean temperature during the growing period higher than 20 degree Celsius (Ryan and Spenser 2001).

quality of these resources for the benefit of future generations (Okumu *et al*., 2000). In order to maintain the long-term productivity of natural resources and to meet the needs of the increasing population in the SAT, new technologies, policies and improved access to market and better institutions are required. The new technologies include soil and water conservation measures, introducing high yielding and drought tolerant varieties, integrated pest management (IPM) and farming support policies enabling prudent long-term management of the natural resource base on which agriculture fundamentally depends. Technology and policy choices need to be made on the basis of not only their current impact but future economic and environmental outcomes as well.

1.1 Watershed development

Watershed development is one of the important development programmes aimed at improving land use and sustainability as well as improving the livelihood security of households in the rainfed areas. A watershed (or catchments) is a geographical area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize the utilization of surface and subsurface water for better crop production (Kerr *et al*., 2000). A watershed is a geographically defined boundary with high biophysical variation and lands that often fall under different property regimes. In watershed management projects, mechanical or vegetative structures are installed across gullies and rills and along contour lines, and land is often earmarked for particular land use based on its capability classification. This approach aims to optimize moisture retention and reduce soil erosion, thus maximizing productivity and minimizing land degradation. Watershed management is a holistic approach dealing across resources (water, soil, biodiversity, etc) with the aim of improving livelihood of the people through integrated (multiple) interventions, including utilization of improved crop genetic material and livestock production.

In India approximately 170 million hectares are classified as degraded land, roughly half of which falls in undulating semi-arid areas where rainfed farming is practiced (Farrington *et al*., 1999). To increase the natural resource productivity of the rainfed areas, a number of government projects, schemes and programmes were formulated and which support the micro watershed development. In India micro watersheds are generally defined as falling in the range of 500 – 1000 ha. The micro watershed concept aims to establish an enabling environment for the integrated use, regulation and treatment of water and land resources of a watershed – based ecosystem to accomplish resource conservation and biomass production objectives (Jensen *et al*., 1996). In realizing the potential of the micro watershed projects in enhancing the livelihood security of the poor in the rainfed areas, investment in India in the mid-1990's by the Indian government and international organizations in collaboration with the NGOs and other development agencies, amounted to about USD 500 million per year (Kerr *et al*., 2000).

Even though there are several exceptional case studies of successful watershed development in India (e.g., Wani *et al*., 2002; and Kerr *et al*., 2000), the impact of the approach on improving the welfare of the poor and the natural resource condition in the SAT areas is not fully known. So it is important to apply a holistic and integrated approach like bio-economic modeling to simultaneously assess and evaluate impact of watershed development on the welfare of the poor and the natural resource conditions at a micro level and also to identify effective policy instruments and institutional needs for enhancing the effectiveness of the watershed approach.

1.2 Problem focus

The SAT is spread over 55 less developed countries covering approximately 11 million square kilometers of land and approximately one tenth of the SAT area (170 million ha) is located in India. Much of the regions are densely populated and home for about 1.4 billion people, of which 560 million are rural poor (Ryan and Spencer, 2001). In 1997-98, the SAT areas in India accounted for 46.2 per cent of India's total net cultivated area and 31.9 per cent of gross irrigated area, 58.7 per cent of the area under coarse cereals, 59.7 per cent of the area under oilseeds, 52.6 per cent of the area under pulses and 60 per cent of the area under commercial crops such as cotton and sugarcane (Gulathi and Kelley, 1999). SAT areas in India are characterized by rainfed agriculture, low productivity, low yielding traditional crop varieties, uncertain and scattered rainfall and highly prone to human induced land degradation (like soil erosion and nutrient depletion). Seghal and Abrol (1994) compiled the available information on soil degradation and concluded that about 148 million hectares of land is subjected to water erosion, which is the most widespread form of land degradation in India. Soil erosion decreases soil depth of cultivable land, which could directly affect yield of crops grown by reducing the soil moisture content and rooting depth (Seghal and Abrol (1994); Littleboy *et al*., 1996; Alagarsamy *et al*., 2000). In India nutrient depletion caused moderate to severe land degradation of about 12 million hectares (Van Lynden and Oldeman, 1997). Sustainability of land use is not only affected by the soil and agro climatic factors like soil type, infiltration rate, rainfall intensity (Wani *et al*., 2003), it is also affected by other factors like quality of land resources, available technology, poverty, security of land use rights, ignorance of soil mining process, population growth and land use and environment policy. The economic policy reforms in developing countries may strongly modify the socio-economic environment of farm households, and can have a major impact on the sustainability of land use and soil conservation decisions (Heerink *et al*., 2001). Land degradation leads to decline in the quality of land, initiates a process that ultimately leads to poverty, hunger and malnutrition and further environmental degradation (Pinstrup-Anderson and Pandya-Lorch, 1994).

In an effort to improve the livelihood of poor households, to arrest land degradation (nutrient mining and soil erosion) and revitalize the mixed crop-livestock production system, the Government of India, with the help of development agencies and NGOs, started promoting watershed development approach. The International Crops Research Institute for Semi-Arid Tropics (ICRISAT) has also played a proactive role in research on soil and water management technologies for the SAT agriculture. Before the mid 1990’s, much of the work focused on developing technologies for improved soil, water and crop management on-station at ICRISAT center (e.g., Ryan and Pereira, 1979; Pathak and Laryea, 1990). In the late 1990s, ICRISAT initiated a consortium of research and development institutions and developed a package of production and conservation technologies. The package of technologies includes high yielding drought tolerant crop varieties, *in situ* and community based soil and water conservation technologies (Broad-bed and furrow (BBF) and field bunding, check dams and percolation ponds), animal drawn equipment (tropiculator) for BBF formation and integrated pest and nutrient management. The consortium members selected three benchmark watersheds in India for evaluating the impact of the technologies developed in actual farmers’ field conditions. The adoption of new high yielding crop varieties would require more chemical and organic fertilizers, hence the farmers require more cash and or access to credit. Through adoption of the tropiculator for BBF formation leads to higher demand for animal draught power for cultivation. All these putting pressure on the existing constrained resources of the farmers. The impacts of such interventions are not however evaluated in terms of their socio-economic and financial aspects. For evaluating the potential impact of technology and policy interventions, modeling of relations between economic policy and biophysical and technology conditions in watershed management is needed. The bioeconomic modeling approach may offers a good starting point for assessing and understanding the impact of technology and policy interventions of watershed development programme in the SAT agriculture.

1.3 Objectives

The overall objective of the study is to develop a methodology to analyze the possible impacts of technology change and policy incentives on household welfare and the quality of natural resources like soil, water, biodiversity etc.

The specific objectives of the study are

1. To study the inter-temporal impact of key integrated watershed management technologies (e.g., high yielding varieties and soil and water conservation structures) on household production, income, food security and land and water conditions in the selected micro-watershed.
2. To identify and evaluate effective technologies, economic policy instruments and the institutional needs for enhancing the effectiveness of the watershed programme.
3. To assess the impact of water pricing on land use, income of the households and sustainability of natural resource base.
4. To assess the impact of improved non-farm income on economic welfare of the household and land degradation.
5. To assess the impact of population growth on household production, income and welfare.

Based on the conceptual framework developed (presented in the methodology chapter) for the study, the following hypotheses are postulated. The bio-economic model will help to test these hypotheses.

1.4 Hypotheses

1. Technological interventions (including high yielding varieties, cropping system, cereal-legume rotations and increase in irrigated land) have a significant positive effect on per capita income and natural resource condition at the micro watershed level.
2. Growing population pressure leads to greater total income with lower per capita income.
3. The price and marketing policy bias against dry land crops has the potential to change the cropping pattern from water saving dry land crops to water intensive irrigated crops and cause negative effect on the natural resources (like ground water table, soil loss, soil nutrients, etc.).

1.5 Scope of the study

The present study has used a dynamic bioeconomic model, which integrates both economic behaviour of the farmers and biophysical factors with feedback mechanisms. This model is used to evaluate simultaneously both the economic and environmental (sustainability) impacts of the technologies and policies affecting natural resource use and management (*ex-ante* impact assessment). The outcome of the study will be useful for knowing the effectiveness of the new natural resource management (NRM) technologies and associated policies over a period of time on the welfare of the poor farm communities and in turn, the sustainability of the natural resource base in the watershed. Further, the study will highlight the appropriate land use strategy that may increase the income of the farmers with available new technologies without degrading natural resources. The simulation results of the study will predict the impacts of factors like population growth, high nutritional requirement, off-farm and non-farm employment on the welfare of the households and the sustainability of natural resources like soil, water and biodiversity in a watershed. The results of the study will be of immense use for planners, policy makers, researchers and governments in developing appropriate need based NRM technologies and framing relevant polices for improving economic welfare of the poor farming communities with sustainability use of natural resource in SAT.

1.6 Limitation of the study

The present study was undertaken as part of the requirements for a doctoral programme of the student researcher. There are constraints of time and resources and therefore some issues may not be explored in greater depth and in a more comprehensive manner. The lack of plot level biophysical data like soil depth, soil erosion, nutrient status and physical and chemical properties of the study area limits construction of biophysical plant growth models to generate crop productivity data and the marginal effects on yield due to changes in biophysical factors.

1.7 Organization of the thesis

The presentation of the study is organized under the following chapters.

Chapter I	:	Introduction: Problem focus, Objectives, Hypothesis, Scope and Limitation of the study are presented
Chapter II	:	Review of literature: A brief review of History of watershed programme in India, Review of Impact studies of watershed programme in India, Limitation and alternative methods for NRM impact assessment, Brief description of bioeconomic modeling, its classification, approaches and review of earlier bioeconomic model studies are given.
Chapter III	:	Methodology: Data collection, the structures of the bioeconomic model are presented.
Chapter IV	:	Description of study area: Demography and economic and biophysical features of the study area are described.
Chapter V	:	Results and Discussion: Results of the study are presented and discussed.
Chapter VI	:	Summary and Conclusions: Salient findings and conclusions are drawn with policy implications.

References

Appendices

CHAPTER II

REVIEW OF LITERATURE

In the present study a bioeconomic model will be developed by integrating simultaneously both biophysical and economic factors to study the impact of technology and policy interventions in a watershed on economic welfare of the farming communities and the sustainability of the natural resource base. For better understanding of the research problems, concepts related to the study and construction of bioeconomic modeling for the study objectives required a comprehensive review of the related literature. For better clarity and convenience, the chapter is organized under the following headings.

2.1 Evolution of watershed development approaches in India
2.1 Review of impact studies of watershed development programme in India
2.2 Limitations of the previous impact evaluation studies
2.3 Challenges in impact assessment of watershed development programme
2.4 Alternative methodological approaches for NRM impact assessment
2.5 Bioeconomic modeling
2.6 Approaches in bioeconomic modeling
2.7 Advantages of bioeconomic modeling in impact assessment studies
2.8 Review of past studies of bioeconomic modeling

2.1 Evolution of watershed development approaches in India

The concept and history of watershed development in India started way back in 1880 with the Famine Commission and then in the Royal Commission of Agriculture in 1928. Both Commissions laid the foundation for the organized research in a watershed framework. Small-scale watershed development programs to conserve soil and prevent land degradation like Lingajat Peetadhipathi, near Bijapur in Karnataka began during the early twentieth century. The activities included bunding activities in the then Bombay Provinces for rural employment during drought relief operations. In this sequence, Bombay Land Development Act, 1943, provided a model for other states enlightening watershed development. Realizing the importance of the watershed programs for land reclamation, a multidisciplinary Soil Conservation Department was set up at Hazaribagh under the Damodar Valley Corporation. Then, the government of India supported program started in the mid-1950s and the focus on watershed programs was sharpened with the establishment of the Soil Conservation Research, Demonstration and Training Center at eight locations, namely Dehradun, Chandigarh, Agra, Valsad, Kota, Hyderabad, Bellary and Ootacamund, which in turn established as Central Soil and Water Conservation Research and Training Institute (CSWCR&TI) by linking all the eight centers in 1956. The center started watershed activities in 42 locations mainly at a small scale to understand the technical processes of soil degradation and options for soil conservation (Joshi *et al*., 2004).

The first large-scale government supported watershed program was launched in 1962-63 to check siltation in the multi-purpose reservoirs as "Soil Conservation Works in the Catchments of River Valley Projects (RVP)". This was followed by another mega-project on 'Drought Prone Area Development Programme (DPAP) in 1972-73, which aimed at mitigating the impact of drought in vulnerable areas. On similar lines, the 'Desert Development Programme' (DDP) was added for development of desert areas and for drought management in the fragile, marginal and rainfed areas. These schemes were implemented in 45 catchments spread over 20 states in about 96.1 million ha area (Government of India, 2001a).

Meanwhile, CSWCR&TI started demonstration of its technologies in actual village conditions at four locations from 1974 onwards (Samra, 1997). The success of these programs was the precursor for launching a scheme of propagation of water harvesting and conservation technologies in rainfed areas in 19 locations in the country by the Department of Agriculture and Cooperation, Ministry of Agriculture. Subsequently, the CSWCR&TI and the Central Research Institute for the Dryland Agriculture (CRIDA) jointly with the state departments initiated additional 47 Operational Research Projects (OPRs) to validate soil and water conservation technologies under different agro-ecoregions and demonstrated the benefits of watershed activities to the farming community in the rainfed and hilly areas. Recognizing the importance of the watershed programs, the Ministry of Rural Development also adopted a similar approach in 22 locations in the rainfed areas during 1984. The watersheds established by the Department of Agriculture (19 Nos.) and Ministry of Rural Development (22 Nos.) were commonly known as the 'model watersheds', where ICAR institutes and State Agricultural Universities (SAUs) were also involved to provide research and technology support. During 1980s, several projects on watershed development assisted by bilateral donors and international funding agencies, like World Bank, were also launched in several states of the Country. Besides, a number of Non-government Organizations (NGOs) started working for the Integrated Watershed Development Programme in different parts of the country (Kerr, 2002).

The programs launched under the ORP of CSWCR&TI and CRIDA and 41 model watersheds focused in the framework for the Integrated Watershed Development Programme (IWDP), which includes a system combining erosion and runoff, and improved land management (i.e., through vegetative cover, bunds, check-dams and small percolation tanks) with irrigation wells for lifting groundwater on a sustainable basis so that the amount of water withdrawn is less than or equal to the annual recharge of groundwater. The system was an extension of the idea of water harvesting by which runoff water is collected in small ponds directly through gravity irrigation (Rajagopalan, 1991). The programme was organizationally multi-disciplinary and multi-agency and functionally participatory with the active involvement of farmers of the watershed. The key for the success of the IWDP was participatory planning and implementation by government agencies and NGOs. The impact was documented in terms of increased crop productivity, increased employment, better crops and cropping systems, which ensure higher and regular cash flow, additional area under sustained irrigation and cropping and reduced production risks (Joshi *et al*., 2004).

The severe drought during 1987 forced the government of India to give more thrust to agriculture in the rainfed areas. Even in the watershed developed rainfed areas in the country was not able to ease the effect of drought and the poor farmers in the areas were severely affected. The occurrence of severe drought put into question the relevance and effectiveness of the earlier implemented watershed programs. Hence, a committee was constituted to examine the effectiveness of watershed-based programs in the rainfed areas. The committee recommended watershed development programmes in the rainfed areas should optimize the production of rainfed crops (like pulses, oilseeds, coarse cereals, cotton, etc.), which improve the livelihood of the poor farmers along with soil and water conservation. The recommendations of the committee led to the formation of National Watershed Development Project for Rainfed Areas (NWDPRA). Then, the Ministry of Agriculture terminated all the earlier watershed programs during VII Five year plan and started new programs to cover both arable and non-arable areas and give more thrust for area-based approach for watershed development under NWDPRA. During the VIII Five year plan, an area of 4.23 million ha covering 2554 watersheds in 350 districts located over 25 states and two union territories were treated and developed with an expenditure of Rs. 9679 million. In the IX Five year plan, an outlay was raised to Rs.10200 million to treat 2.25 million ha, which was slightly more than half of the area treated in the VIII Five year plan (Joshi *et al*., 2004).

All the government-sanctioned programs in the 1980s paid more focus on soil and water conservation and attention to poverty alleviation in the sense that they operated in relatively poor and degraded areas. Economic improvement in these agricultural-dependent areas required making the land more productive, so poverty alleviation benefits were taken as implicit. The programs also employed very poor people to carry out watershed work. They all adopted the technological approaches used in model watersheds and none of them incorporated lessons related to institutional arrangements (Government of India, 1994a; World Bank, 1990). In earlier programs the benefits and costs of watershed were unevenly distributed among all the stakeholders and programs made little or no effort to organize communities in the watershed to solve the problems collectively. Where the village-level participation was attempted in the earlier watershed programmes, it typically involved one or two key people, such as the village sarpanch (leader) in the ICAR watersheds or a trained technician in the NWDPRA (Government of India, 1990).

The impact of these watershed programmes showed disappointing results associated with top-down implementation and management, inflexible or lack of site specific technology and lack of attention to institutional arrangements (Shah, 2000). Some of these programs showed good technical and economic performance in the early years, especially while project staffs were still in place and the work was heavily subsidized (IJAE, 1991). The benefits were not sustained for long beyond the project period in many cases (Reddy, 2000; Farrington *et al*., 1999; Government of India, 1994a; World Bank, 1990).

In the late 1980s, many NGOs introduced watershed development activities along with their other activities, were better able to target the poorest people's needs. MYRADA in Karnataka, the Aga Khan Rural Support Programme (AKRSP) in Gujarat, and Social Centre in Maharashtra, all provided excellent examples of such approaches (Farrington and Lobo, 1997; Hinchcliffe *et al*., 1999). These organizations devoted much attention to organizing politically and economically weaker groups to initiate self-help activities such as thrift and credits associations and build their organizational skills, which give confidence to demand better services from the government agencies. This approach was used in the NGOs implemented watersheds to encourage people participation and sharing net benefits from watershed development (Fernandez, 1994).

In the 1990s several European bilateral agencies established major watershed initiatives. Generally these projects aimed to promote collaboration between government and NGO projects to draw on the strengths of each and to make government agencies more sensitive to institutional issues. Some of the projects, including Indo-German in Maharashtra and Indo-British in Karnataka, drew on some NGOs approaches to promote benefit sharing, and they tried to implement on large scale the associated institutional approaches (Farrington and Lobo., 1997; Ninan, 1998). Ninan 1998 however found that despite a common focus on poverty alleviation in projects sponsored by the European Union, Danida, and the German Development Bank, benefits tended to favour landowners, whereas the landless benefited only marginally.

All these programs had their own guidelines, norms, funding patterns and technical components based on their respective and specific aims (Government of India, 1994b). In 1994 the Ministry of Rural Development introduced new comprehensive guidelines for all its projects that bypassed the state-level bureaucracy, giving unprecedented autonomy to village-level organizations to choose their own watershed technology and obtain assistance from NGOs rather than government line departments (Government of India, 1994a, b). These guidelines were used by the centrally sponsored schemes for watershed development under the Ministry of Rural Development and the Ministry of Agriculture.

The 1994 guidelines were in operation for five years. The guidelines were revolutionary in the extent to which they devolved power, promoted indigenous technology, and created a role for NGOs. This period has seen many successes as well as some failure in the watershed development. Shah (2001) reviewed the performance of projects under the new guidelines in Gujarat state and found that benefits were heavily skewed towards wealthier households. Hence greater flexibility of the guidelines was essential to enhance the robustness of the response to the regionally differentiated demands that characterize rural India. Since different ministries were involved in the watershed development, it was decided to develop common guidelines. The Ministries of Agriculture and Rural Development jointly developed the 'Common Approach/Principles of Watershed Development' in 2000 (Government of India, 2000). The Ministry of Agriculture brought out the new guidelines based on the 'Common Approach' in 2000 for NWDPRA as Watershed Areas for Rainfed Agriculture System Approach (WARASA) or Jan Sahbhagita. The approach allow for decentralization of procedures, flexibility in choice of technology and provisions for active involvement of the watershed community in planning, execution and evaluation of the programme.

In 2001 Ministry of Rural Development prepared a document of revised guidelines (Guidelines for Watershed Development) based on the common principles (Government of India, 2001b). The new guidelines give more flexibility that was needed at village/watershed level. These guidelines, inter alia, envisage the convergence of different programs of the Ministry of Rural Development, Ministry of Agriculture and other Ministries and Departments. Following the 73rd and 74th Amendments to the Constitutions of India in the early 1990s, the Panchayati Raj Institutions (PRIs) have been mandated with enlarged role in the implementation of developmental programs at the grassroots level, and accordingly their role has been more clearly brought out. The 1994 guidelines were made more flexible, and workable with more participation of the community. The new guidelines provide more emphasis on local capacity building through various training activities and empowering community organization.

To further simplify procedures and involve the Panchayat Raj Institutions (PRIs) more meaningfully in planning, implementation and management of economic development activities in rural areas, the new Guidelines called Guidelines for Hariyali were documented in 2003 by Ministry of Rural Development (Government of India, 2003). All the new projects under the area development programmes have been implemented in accordance with the Guidelines for Hariyali with effect from 1.4.2003. The additional points in these guidelines over the Common Approach were

I. Ensuring overall development of rural areas through the Gram Panchayats and creating regular sources of income for the Panchayats from rainwater harvesting and management.
II. Employment generation, poverty alleviation, community empowerment and development of human and other economic resources of the rural areas.
III. Mitigating the adverse effects of extreme climatic conditions such as drought and desertification on crops, human and livestock population for the overall improvement of rural areas.
IV. Restoring ecological balance by harnessing, conserving and developing natural resources i.e. land, water, vegetative cover especially plantations.
V. Encouraging village community towards sustained community action for the operation and maintenance of assets created and further development of the potential of the natural resources in the watershed.
VI. Promoting use of simple, easy and affordable technological solutions and institutional arrangements that make use of, and build upon, local technical knowledge and available materials.

In order to ensure drinking water availability with special emphasize on mitigating drinking water scarcity in rural dry areas in drought years Ministry of Rural Development on 29th November 2004 included in the Guidelines for Hariyali a sub-para to Para 23 as "gram panchayat should constitute a drinking water committee with the help of Watershed Development Team (WDT) that would consist of women representatives in majority from various community groups. This committee should oversee implementation of watershed activities concerning drinking water security".

A watershed development fund (WDF) was established by the National Bank for Agriculture and Rural Development (NABARD) during 1990-91, to integrate all the watershed programs in 100 priority districts in different states of the country. A total of Rs. 2000 million, which includes Rs. 1000 million by NABARD and a matching fund by the Ministry of Agriculture, was made available under the fund. The WDF was set up on the lines of the Rural Infrastructure Development Fund (RIDF) to help the state governments augment their watershed development programs (Sharma 2001). The main purpose of the fund was to create the framework conditions to replicate and consolidate the isolated successful initiatives under the different watershed development programs. The watershed programs in India were categorized into six different programs based on techniques, administration, planning and system composition (Joshi *et al*, 2004). They are:

1. Operational Research Project (ORP) taken up by ICAR at different locations in the country.
2. World Bank financed projects – The Bank financed four watershed research for development projects in Manoli (Maharashtra), Kabbalnala (Karnataka), Maheswaram (Andhra Pradesh) and Parua Nala (Madhya Pradesh). These were taken up with active participation of State Agricultural Universities (SAUs). These projects were managed by scientists and demonstrated encouraging results.
3. State government projects – The state governments of Andhra Pradesh, Karnataka, Madhya Pradesh and Maharashtra took up watershed development programs in a large scale.
4. National Watershed Development Programme activated by the Central government and implemented by state governments with some need-based modifications.
5. NGOs Projects – Projects undertaken by NGOs (humanitarian or philanthropic) like MYRADA in Karnataka, the Aga Khan Rural Support Programme (AKRSP) in Gujarat and Social Centre in Maharashtra, which have relatively less scientific inputs and manpower but more participation from the local communities in the region concerned.
6. NGO-Government projects – These are collaborative programs taken up by the NGOs and the government. Some examples include the Indo-German Watershed Development Programme (IGWDP) in Maharashtra funded by the German government and the Indo-British watershed programme in Karnataka funded by the British government.

Different Ministries and agencies are involved in watershed research and development programs, which mainly include the Ministry of Agriculture, the Ministry of Rural

Development, the Ministry of Environment and Forests, Indian Council for Agricultural Research (ICAR), NGOs and international agencies (e.g. ICRISAT). The watershed programs of the Ministry of Rural Development include:

Drought Prone Area Programme (DPAP)

Desert Development Programme (DDP)

Integrated Watershed Development Project

Watershed Projects under Externally Aided Schemes

Support to NGOs and

Wasteland Development Task Force

The watershed programs undertaken by the Ministry of Agriculture include:

1. Soil and water conservation in the catchments of River Valley Projects
2. Integrated Watershed Management in the Catchments of Flood Prone Rivers
3. Watershed Development Projects in Shifting Cultivation Areas and
4. National Watershed Development Programme in Rainfed Areas.

Similarly, ICRISAT has been developing and evaluating various livelihood focused integrated natural resource management technologies (like soil and water conservation, high yielding varieties, cropping systems, cereal-legume rotations, integrated nutrient and pest management) using landscape-based multi-disciplinary approach that brings together a consortium of partners with complementary roles in implementing the program in the semi-arid and rainfed parts of the country. This is often implemented in collaboration with various NARS and a number of NGOs, which are actively involving in watershed development activities at the local level.

2.1.1 ICRISAT's New Approach: The Integrated Watershed Management Model

Based on lessons learned from long term watershed-based research ICRISAT and its national partners developed a new farmer participatory integrated watershed management consortium model for efficient management of natural resources. The main objective of Integrated Watershed Management (IWM) is to improve rainfed agricultural production through watershed development and to reduce poverty of farmers through increased systems' productivity through sustainable use of natural resources. The unique feature of this watershed is that it followed the consortium approach. The purpose of developing a consortium is to provide technical backstopping of the on-farm watersheds and draw expertise from different international, national, government organization and NGOs. The consortium members are: ICRISAT, Central Research Institute for Dryland Areas (CRIDA), National Remote Sensing Agency (NRSA), M Venkatarangaiah Foundation (MVF), an NGO, DPAP of the state Government, and community in the watershed. Based on the criteria like existence of a large proportion of dryland farming, few water harvesting structures, and minimum interventions to conserve soil and water ICRISAT, DPAP and MVF in consultation with other stakeholders selected Adarsha watershed to implement the new integrated watershed development model. Among the consortium partners ICRISAT and CRIDA provide technical support, DPAP provide financial support, and NGO mobilize the community for collective action. The farmers are involved in all the stages of the watershed activities from initiation to implementation. Several forms of interventions are designed for the watershed recognizing the needs of the individual farmers, which related to (i) soil and water conservation, (ii) integrated nutrient management, (iii) integrated pest management, (iv) improved cropping system, and (v) wasteland development. Technologies for soil and water conservation include earthen and masonry checkdams, gully control structures, gabion structure, broad-bed and furrow, use of tropiculator for planting, fertilizer application and intercultural operations, field bunding and plantation of Gliricidia on the field bunds. Integrated nutrient management includes vermicomposting, soil incorporation of Gliricidia and nutrient budgeting. Pheromone traps, nucleus polyhedrosis virus (NPV) and indigenous measures are used for IPM to reduce the consumption of chemicals. New cropping systems like sorghum and maize intercropping with pigeon pea and chickpea are introduced. Afforestation is done for development of the wastelands.

To plan, implement and execute various activities of watershed development few committees are formed as per the new guidelines of the Ministry of Agriculture. The committees are democratically elected, which include

1. Watershed Association: The working committee consists of a chairman, a secretary, 8 committee members, and all farmers in the village as members.
2. Watershed Committee: This committee consists of a president, a secretary, and all the farmers in the village as members.

3. Women Self-Help Groups for Vermicomposting: Ten groups are formed with 15 members each for taking up vermicomposting as enterprise in the village.
4. User Groups: User groups are formed for looking after and maintenance water harvesting structures and
5. Self-Help Groups: Self-Help Groups are formed to undertake watershed development activities.

The important features of the integrated watershed management model adopted in Adarsha watershed, Kothapally are as follows (Wani *et al*., 2002)

1. The model involves participation of beneficiaries through cooperative model and not through contractual mode.
2. It uses new science tools for management and monitoring of watershed.
3. It focuses mainly to improve the livelihoods of the people through a holistic system's approach rather than merely addressing soil and water conservation.
4. This model is formed for facilitating technical backstopping, motivating beneficiaries and arranging inputs and output markets.
5. It recommends low-cost soil and water conservation structures and amalgamates traditional indigenous knowledge with the new knowledge for efficient management of natural resources.
6. It takes care of maximizing private benefits by emphasizing more use of individual farmers-based conservation measures for raising productivity in individual farms along with community-based soil and water conservation measures.
7. It evolves a dynamic framework of continuous monitoring and evaluation by the stakeholders.
8. It empowers individuals in the watershed and strengthens village institutions for managing the watershed program.

2.2 Review of impact studies of watershed development programme in India

The watershed programs in the country are undertaken with multiple objectives ranging from rehabilitation of degraded areas to conservation of the natural resource base and improvement of the productivity of agriculture. Mitigating adverse impacts of droughts and resource degradation will contribute to reducing production risk and protecting livelihoods. Conservation of the resource base will contribute to sustainable productivity growth in agriculture, while the later will improve the incomes of the poor and contribute to poverty reduction.

There is lack of systematic and large-scale impact assessment studies on the performance of watershed programs in India. Individual scholars, NGOs and international agencies undertook some impact studies largely on a project basis. There is lack of proper indicators and evaluation methods to assess the impacts of the programs on livelihoods and sustainability (Joshi *et al*., 2004). The review of the past impact studies of watershed programs are discussed under two broad indicators namely (i) impact of watershed development on livelihoods and (ii) impact of watershed development on sustainability.

2.2.1 Impact of watershed development on livelihoods

Watershed communities are dependent on the watershed agro-ecosystem for their livelihoods. All interventions in the biophysical processes occurring within watershed ecosystems are bound to have an impact on the livelihoods of watershed communities. The different approaches used for impact assessment of watershed development and the livelihood elements evaluated are reviewed and the findings are discussed separately.

i. Drinking water

Drinking water is the most basic component of livelihood needs. Drinking water referred to water used for drinking by human beings and livestock as well as water used for other domestic purposes. The watershed development guidelines recommended drinking water shortage as one of the criteria for selection of the watersheds. In fact, an assured source of potable drinking water should be the minimum benchmark to judge the success of the watershed programme (Joy *et al*., 2004).

A more comprehensive study by Kerr *et al*. (2000) covered a wide spectrum of intervention modes, several agencies and 70 project villages and control villages in the states of Andhra pradesh and Maharashtra. He reported that all the projects had promoted water harvesting through small tanks and dams directly or indirectly to increase the level of water in wells for drinking water. He found that the AGY / IGWDP projects had the largest increase in the percentage of villages with adequate drinking water.

The study by Reddy *et al*. (2001) conducted a study in four watershed villages in three districts (Anantapur, Kurnool and Mahbubnagar) of Andhra pradesh. They concluded that the use of drinking water had increased in all the villages after the advent of watershed development. He found that in three out of four villages, the time spent on fetching water was much less than earlier. In one of the village, the time saved was about 82 per cent when compared to pre-project situation.

Kakade *et al*. (2001) studied BAIF Institute of Watershed Development- Karnataka (BIRD-K) watershed interventions in seven watersheds, which covered the total geographical area of watersheds about 7000 ha and about 2500 households, to understand the impact of watershed development programs on drinking water and access to rural poor. He found that the problem was more complicated in many places, because people draw water for both drinking and agriculture from the same aquifer, making it difficult to estimate the domestic household benefits. Since the water was used for the first two crops (*kharif* and *rabi*), generally there was no water left in the summer months for drinking or domestic purposes. In the study he recommended controlled utilization of water for irrigation to be incorporated in the projects to avoid conflicts between drinking water and irrigation needs.

ii. Fodders and fuel

To assess the performance of the watershed projects the availability of fodder from common lands is used as an indicator. The increase in availability of fodder helps some landless people in watershed villages to rear some livestock, which may help them to improve their livelihoods.

The study by Kerr *et al*. (2000) also assessed the performance of the watershed projects based on the availability of fodder, especially from common lands. They found that in the villages where ban on grazing land was enforced, the number of small ruminants like goats had decreased. In some watersheds he observed that grazing land restriction had led to both change in herd composition and a shift from open grazing (goats) to stall-feeding (buffaloes and improved cows).

Karanth and Abbi (2001) observed that the main reason for the farmers in Kalmandargi village in Gulbarga district of Karnataka not rearing goats was because common lands had been encroached or brought under cultivation and under such circumstances farmers moved to employment-oriented urban-ward migration.

The study by Reddy *et al*. (2001) showed that the share of fodder from commons had increased in all four sample watershed villages in three districts (Anantapur, Kurnool and Mahbubnagar) of Andhra pradesh. The availability of fodder after the project had increased to about three to 12 per cent for beneficiary households. He also reported that the time spent on fetching fuel-wood had increased in the three villages out of four villages studied that indicated that the advent of watershed development had not improved the access to fuel-wood in those villages. The study showed that CPRs played an important role in meeting the fuel-wood needs and their shares varied from 34 per cent to 72 per cent in the four villages.

Hazra (1999) reported that before the watershed interventions, 87 per cent of the total energy needs of the about 60 sample households in Khariya Nala watershed in Jhansi, Maharashtra were met from cow-dung cakes while firewood and crop residue had contributed only about seven per cent and six per cent respectively. But in the post-project period, the fuel consumption had changed and consumption of firewood and crop residues had gone up to 55 per cent and 20 per cent respectively. The cow-dung thus saved was later used as farmyard manure for growing crops.

iii. Food and cash crops

Improved productivity of crops, especially rainfed crops, and its contribution to the livelihoods of the people was an important operational indicator of the performance of the watershed development projects. It was also an important indirect indictor of the contribution of watershed projects to the enhancement of ecosystem productivity. The review showed that soil and water conservation treatments, coupled with specific productivity enhancement measures had definitely increased productivity or at least helped to stabilize the *kharif* crops especially under normal rainfall conditions.

Erappa (1998) found that there has been an increase in the productivity of crops cultivated as a result of watershed development programmes across all land holding sizes of NWDPRA watershed in Manjenahalli village in Hassan district of Karnataka. He also observed in the same watershed that there had been an increase in the productivity of crops like pigeon pea (from 1.5 bags to 3 bags per acre), hybrid sorghum (from 4 bags to 6 bags per acre) and pearl millet (from 6 bags to 7 bags per acre). Similarly, the study by MANAGE in the Manchal watershed (Rangareddy district, Andhra Pradesh) with a small sample size of 80 farmers showed that the productivity of crops like castor, sorghum, tomato and pearl millet increased by 50, 44, 65 and 50 per cent respectively as a result of watershed development (MANAGE, n.d).

Wani *et al*. (2002) observed that in ICRISAT's benchmark watershed in Andhra Pradesh (Adarsha watershed) crop productivity increased significantly with adoption of improved cropping systems and improved management practices. The yield of maize had recorded two to three-fold increase (3.3 to 3.8 t/ha) when compared to the baseline yields of about 1.5 t/ha.

iv. Incomes and benefit

In most of the impact studies, increase in income was taken as important success indicator for watershed development. The review showed that there had been an increase in the income levels of the people through various means and options like increased productivity, shift towards high value and more profitable crops, increased availability of employment, development of allied sectors like dairy and non-land based activities.

However, an increase in the yield does not always translate into an increase in net income for producers. Many studies had shown that the increase in productivity had been achieved with higher cost, which may offset the effect of yield gain. It was also reported that as a results of watershed development, the composition of the inputs changes, and there was more dependence on modern inputs like improved or hybrid seeds, chemical fertilizers and pesticides etc. This had resulted in higher cost of cultivation in watershed projects as compared to non-watershed projects. Hence net returns would be a better indicator to assess whether the incomes have increased or not (Erappa, 1998).

The study by Reddy *et al*. (2001) in Andhra Pradesh indicated that in the four watershed villages in three districts (Anantapur, Kurnool and Mahbubnagar) of Andhra pradesh, only three watersheds reported increased net returns in the case of paddy and only two in the case of groundnut. The increased net returns varied from Rs. 534 per acre to Rs. 1,105 per acre. However, in none of the four villages do food constitute the largest item and the share of food in total household expenditure had gone down over the last five years.

Chopra (1999) had studied 13 watershed projects cutting across different states and agro-climatic zones to do an economic evaluation of the watershed projects using multivariate analysis. The study showed that there was a wide range of benefit-cost ratios ranging from 1.25 to 3.8, and the internal rate of return varied from 12.33 per cent to 41 per cent.

Wani *et al*. (2002) reported that farmers' incomes as well as cropping system productivities had increased in the Adarsha benchmark watershed in Andhra Pradesh. The benefit-cost ratio under maize/pigeon pea cropping system was 3.5, which was higher than the traditional cotton system B-C ratio of 1.5.

Joshi *et al*. (2005) employed meta-analysis to study the performance of the watershed programs in India. Meta-analysis is a statistical procedure that integrates about 311 case studies of watershed programs across India in different agro-ecological locations with varied size, type, source of funding, rainfall, regional prosperity or backwardness etc. The study reported that the mean benefit-cost ratio of a watershed program in the country was about 2.14 and internal rate of return was 22 per cent. They also found that the performance of the watershed was at its best in the areas that targeted low and medium income groups and also where there was effective people's participation and rainfall ranging between 700 to 1000 mm. They finally concluded that watershed programs failed to generate sufficient livelihood benefits where there was a lack of appropriate institutional arrangement, suitable technological backstopping and capacity building for all the stakeholders.

v. Employment and migration

It is often assumed that watershed development will decrease the extent of migration. In the Kerr *et al*. study (Kerr *et al*., 2000) changes in the pattern of migration were taken as indicators of changes in employment opportunities, agricultural productivity and overall quality of life. The review of literatures, own field visits and interactions with officials showed that watershed development had the potential to bring down migration at least temporarily, especially in the initial phase of the programme when the emphasis was on physical works which can generate local employment.

Reddy *et al*. (2001) reported in his study in four watershed villages in three districts (Anantapur, Kurnool and Mahbubnagar) of Andhra pradesh that employment opportunities had increased during *rabi* and summer season because of availability of water for irrigation and people shifting more towards horticulture and vegetable cultivation.

Deshpande and Reddy (1991) analyzed the state level Comprehensive Watershed Development Progrmme (COWDEP) of Maharashtra and found significant changes in the household economy. They also reported that employment generation in each of the watersheds ranged between two to 30000 man-days depending upon the agro climatic zones, indicating the positive contribution of watershed interventions on curbing rural-to-urban migration.

The study by Kerr *et al*. (2000) showed that with the exception of AGY and IGWDP villages, seasonal migration rose in every project category. The AGY and IGWDP villages had a net reduction in overall migration and the possible reasons for this may be improvements in infrastructure and access to services, which created opportunities for local employment.

2.2.2 Impact of watershed development on sustainability

The central concern of watershed development activity had traditionally been soil and water conservation (SWC). SWC programs aim to arrest ecosystem degradation and facilitate ecosystem regeneration. Only few studies were available which had looked at the sustainability impacts of watershed development programmes in India. However, most of them were performance studies and evaluation, and the indicators used to study were increase in cropped area, irrigated area, crop intensity, cost of cultivation, rise in groundwater levels, number of wells, change in cropping pattern and net returns (Deshpande and Reddy, 1994; Erappa, 1998; Chopra, 1999; Karanth and Abbi 2001). An increase in all these variables and parameters was taken as a measure of success.

Only a few impact assessment studies went beyond these conventional indicators and to some extent tried to incorporate the impact of watershed development interventions on the ecosystem in their performance criteria. One such study was by Kerr and Chung (2001) who worked out a detailed list of ideal and operational indicators (Table 2.1).

The indicators listed by Kerr and Chung indicated the status or condition of the ecosystem and deserved more attention than they had received. The operational indicators mentioned above were evolved because the ideal indicators require long term empirical measurement or could not be easily used in the field for various reasons and they may not entirely cover the phenomenon they aim to measure. For example 'visual assessment of rill and gully erosion' may not capture other types of erosions like sheet erosion where the thin layer of topsoil was gradually but uniformly removed from less sloping lands. So the degree of turbidity in the water flowing out of the patch of land could be a better or at least an additional, supplementary indicator of the status of soil erosion (Joy *et al*., 2004).

However, it should be noted that hardly any of the studies base themselves on a list like the one Kerr and Chung provided. So there was very little quantifiable or hard data available in aspects of ecosystem status and environmental sustainability. So, one was forced to rely, in spite of their limitations, on qualitative narratives and judgements. This section looked at biophysical impacts on the ecosystem in only two critical areas, namely, (i) impact on runoff and soil erosion, and (ii) impact on groundwater level and availability.

Table 2.1 Ideal and operational indicators of performance

S. No	**Performance criteria**	**Ideal Indicator**	**Operational indicators used in Kerr and Chung study**
1	Soil erosion	Measurement of erosion and associated loss	▪ Visual assessment of rill and gully erosion (current only)
2	Measure taken to arrest erosion	Inventory, adoption and effectiveness of soil and water conservation (SWC) practices	▪ Visual assessment of SWC investment and apparent effectiveness (current only) ▪ Adoption of conservation-oriented agronomic practices ▪ Expenditure on SWC investments
3	Ground water recharge	Measurement of ground water levels (controlling for aquifer characteristics, climate variation and pumping volume)	▪ Approximate change in number of wells ▪ Approximate change in number of well recharged or defunct ▪ Change in irrigated area ▪ Change in number of season irrigated for a sample plots ▪ Change in village level drinking water adequacy
4	Soil moisture retention	Time series, intra –year and inter-year variations in soil moisture, controlling for climate variation.	▪ Change in cropping pattern ▪ Change in cropping intensity on rainfed plots ▪ Relative change in yields (higher, same or lower)
5	Agriculture profits	Net return at plot level	▪ Net return at plot level, current year only
6	Productivity of non- arable crop	Change in production from common property resources (CPRs) and forest land	▪ Relative change in production from CPRs and forest land (higher, same or lower)

Source: Based on (Kerr and Chung, 2001)

i. Impact on runoff and soil erosion

The evaluation studies reported that watershed development interventions had a positive impact on controlling soil erosion. The general review by Kerr *et al*. (2000)

pointed out very interesting findings about the erosion of crop and non-crop land. It suggested that irrigated plots were generally well maintained and showed the least erosion. Dry croplands, on the other hand, were prone to erosion because they were not as well maintained as irrigated lands.

The study of Kakade (1997) in the Adihalli and Myllanhalli watersheds of BIRD-K in Arsikere taluk, Hassan district, Karnataka calculated run-off on observed values of soil parameters before and after the watershed treatment. It showed that prior to watershed development programme, at a peak rainfall intensity of 60 mm/hr, the volume of water flowing from a 100 ha area in one hour was about 18000 m^3 whereas it was as low as 1600 m^3 in the post intervention period. This indicated a staggering 90 per cent reduction in run-off at the peak intensity of rainfall at a recurrence interval of 10 years.

Karanth and Abbi (2001) compared certain landscape processes like erosion, sediment accumulation in the downstream, gully formation and formation of ravines to indicate the ecological conditions of the watershed. Based on the indicators, they found that watershed project villages were better compared to non-project villages in Gulbarga district of Karnataka. The study also found that due to watershed development the surface run-off had reduced by 30 per cent over a decade for similar rainfall conditions (quantity and intensity).

Wani *et al*. (2002) observed in the benchmark watershed in Andhra Pradesh that runoff was 12 per cent in the undeveloped micro watershed while it was only 6 per cent in the treated watershed where the soil and water conservation measures were undertaken. They also reported that soil loss in the watershed was considerably reduced to less than 1 t/ha after the watershed intervention programme was implemented in the village.

ii. Impact on groundwater level and availability

Water is the most critical resource in the context of sustainability, equity and livelihood assurance. Because of certain inherent characteristics of water like uni-directionality of flow on slopping lands, there is also the possibility of externalities often leading to conflicts. Hence it is very important to understand how watershed interventions affect the sustainability of water resources. Although water table may increase, especially in areas close to various water conservation structures like check dams and percolation tanks, such gains can be more than offset by the unregulated increase in the number of open wells and tube wells (Shiferaw *et al*., 2003b).

According to Kakade (1997) in the Adihalli and Myllanhalli watersheds of BIRD-K in Hassan district, Karnataka, the water table had risen by 3.7 m after the watershed intervention in three years. However, the number of bore wells had increased from 50 to about 110 and 20 more new open wells had been dug for irrigation. They also reported that the area irrigated had increased from 44 ha to 173 ha after the intervention of the watershed project.

Hanumantha Roa (2000) reported that according to an evaluation study by the Andhra Pradesh Water Conservation Mission conducted in 2000 watersheds across the state found that in as many as 90 per cent of the watersheds water levels are increased to varying levels despite a decline in rainfall by 28 per cent and nearly 0.17 million hectare of additional area has been brought under irrigation.

Kakade *et al*. (2001) found that in one of the study villages, Rajkot, groundwater resource have been over exploited through the use of a large number of bore and dug wells meant for irrigation purposes. They also reported that the exploitation rate was more than the potential recharge rate for the region.

Batchelor *et al*. (2002) in the case study of Gundlur Tank in Chinnahagari watershed, Karnataka found that the flow of water into the tank had declined by about 40 per cent, mainly because of increased water harvesting in the upstream and increased groundwater extraction in most places. The reduction of inflows into the tank downstream was much greater during low rainfall years, causing severe water shortages in the region.

Wani *et al*. (2002) observed in the benchmark watershed in Kothapally, Andhra Pradesh that after construction of check dams and percolation ponds in the village, the groundwater table had increased tremendously. This was evident by the increase in the water level in the open wells near to the check dams. They also found that due to increased supplemental irrigation in the post-rainy season the cropping intensity in the village was increased. This shows that while watershed interventions could improve groundwater level, increased extraction and shifts in cropping intensity and pattern towards water intensive crops could lead to depletion. New policies and institutional arrangements are required to encourage sustainable use.

2.3 Limitations of the previous impact evaluation studies

Many previous studies on impact evaluation of watershed interventions in India were done by comparing the scenario of before/after (or) with/without approaches (e.g., Deshpande and Reddy, 1990; Kerr *et al*., 2000; Reddy *et al*., 2001; Sreedevi *et al*., 2004). These approaches have their own strengths and weaknesses. In before/after study, the evaluator measures the level of outcome indicators in a watershed area before and after intervention. In this the before scenario is used as a control against which the effect of the intervention can be compared. This is a weak approach that may give biased results as it assumes that without the project, the pre-intervention values of the outcome indicator would have remained the same over time (Campbell and Russo, 1999). It poses a serious threat to the validity of the findings.

The second approach with/without design is useful when no baseline data are available (Kerr and Chung, 2005). Randomization is impossible and sample selection bias is likely in this situation. To control this bias, the evaluator must find a control site that is similar to the treatment sites in as many factors as are hypothesized to affect the outcome. But in practice sites vary in many ways and cause serious threat to validity of the results.
The parameters used by these approaches for the impact evaluation are: (1) Economic factors (like change in yield, expansion of arable land (ha), irrigation potential created etc), (2) Social factors (change in seasonal migration, distribution of benefits, organizational capabilities, etc.) and (3) Environmental factors (like change in groundwater table, vegetative cover, improvement/change in soil quality etc). These indicators are used to make decisions on whether to expand, adjust, or drop project, programme, or policy interventions. But we are in need of a comprehensive impact assessment, which can include both productivity and environmental and sustainability objectives and help assess the complementarities and the tradeoffs within the framework farm household economic behaviour. Such information is useful for planning, setting priorities, and allocating resources to alternative interventions.

To study the broad range of impacts from watershed interventions requires examining a range of multi-dimensional impacts that include effects on the quality of the resource base as well as the flow of ecosystem services that provide basic support functions in agro-ecosystems. These non-market benefits imply that conventional economic impact studies that measure marketable benefits alone are fundamentally incompatible with measuring the wider range of environmental benefits that watershed projects seek to generate. The methods for assessing the multi-faceted impacts from watershed interventions are far less developed than methods for assessing impacts for crop improvement research (Izac, 1998; Shiferaw and Freeman, 2003). For example, Alston *et al*. (2000) found that over 50 per cent of research investments were for crop research, while NRM research accounted for less than five per cent. The limited number of studies on NRM impact assessment, despite the increased interest on sustainability issues, suggests that tracing the practical linkages between NRM interventions with changes in the resource base, the environment, and human welfare is filled with complexities (Nelson and Maredia, 1999).

2.4 Challenges in impact assessment of watershed development programme

Watershed impact assessment needs to address important conceptual and methodological challenges that arise from several unique features of natural resource management (NRM). These challenges include through attribution, measurement, spatial and temporal scales, multidimensional outcomes (like economic, environmental, and social), and valuation (Shiferaw *et al*., 2004). The cross-commodity and integrated nature of NRM interventions makes it very challenging to attribute impact to any particular one among them. In crop genetic improvement where the research outputs are embodied in an improved seed, it is less difficult to attribute yield improvements to the investment in research (Freeman *et al*., 2005). For example, in the evaluation of watershed programmes in India, it was difficult to attribute improvements in resource conditions and farm incomes to specific interventions, since increased participation and collaboration among range of R&D partners was identified as significant determinants of success (Kerr, 2001). The fact that most agricultural NRM interventions are information-based but not embodied in an easily measured indicator that complicates the attribution of observed impacts (Freeman *et al*., 2005).

Identifying appropriate spatial boundaries for assessing NRM impact is often fraught with difficulty (Campbell *et al*., 2001; Sayer and Campbell, 2001). A watershed development programme typically involves different spatial scales, from farmers' fields to entire watershed catchments, implying that many levels of interaction need to be considered in assessing the impacts of research interventions. Multiple scales of interaction create upstream and downstream effects that complicate impact assessment. For example, assessing the impact of land use interventions in a watershed may need to take into account multiple interactions on different scales because erosion and runoff in the upper watershed may not have the same impact on water quality downstream. It is also likely that interventions could have different effects, which in some cases can generate negative impacts on different spatial scales. For example, soil and water conservation intervention can have a positive impact on crop yields upstream but negative impacts by reducing water availability downstream where water is a limiting factor for production, or positive impacts by reducing sedimentation, runoff and flooding when water is not a limiting factor (Freeman *et al*., 2005).

The temporal dimension of NRM impact also presents methodological difficulties for impact assessment through slow-changing variables and substantial lags in the distribution of costs and the benefits. For example, soil loss, exhaustion of soil fertility, and depletion of groundwater resources take place gradually and over a long period of time. In some cases it is difficult to perceive the costs or the benefits of interventions to reverse these problems. In other cases, assessing the full range of the impacts of investments related to these slow-changing variables in a holistic manner may involve intensive monitoring of multiple biophysical indicators on different spatial scales over long period of time. These factors make impact monitoring and assessment of NRM interventions a relatively slow and expensive process. Differences in time scale for the flow of costs and benefits are translated into lags in the distribution of costs and benefits that complicate impact assessment. Typically, costs are incurred upfront while delayed benefits fall in incremental quantities over a long period of time (Pagiola, 1996; Shiferaw and Holden, 2001).

NRM interventions generate multidimensional biophysical outcomes across resource, environmental and ecosystem services. These might include changes in quality and movement of soil, quantity and quality of water, sustainability of natural resources, and conservation of biodiversity. So appropriate indicators are needed to evaluate the impacts of NRM interventions on the biophysical conditions of

- soil (Sahrawat *et al*., 2005) indicators like soil depth, bulk density, infiltration, pH, organic matter,
- water resources (Pathak *et al*., 2005) indicators like run off volume, total water in soil profile, plant available water, groundwater depth in open wells and
- The flow of ecosystem services that support agro-ecosystems (Wani *et al*., 2005) indicators like vegetation index, carbon sequestration, reduced land degradation, crop agro-biodiversity factor (CAB), reduced emission of greenhouse gases.

The multidimensionality of outcomes from NRM interventions means that impact assessment often faces measurement challenges, including very different measurement units and potentially the integration of very different natural resource outputs into some kind of uniform aggregate yardstick (Byerlee and Murgai, 2001).

2.5 Alternative methodological approaches for NRM impact assessment

The limitations and complexities associated with measuring, monitoring and valuing social costs and benefits associated with NRM interventions require more innovative assessment methods. An important factor that needs to be considered in the selection of appropriate methods is the capacity for simultaneous integration of both economic and biophysical factors and ability to account for non-monetary impacts that NRM interventions generate in terms of changes in the flow of resource and environmental services that affect economic welfare, sustainability and ecosystem health. Hence a mix of qualitative and quantitative methods is the optimal approach for capturing on-site and off-site economic welfare and sustainability impacts (Freeman *et al*., 2005). The approaches that are developed recently for evaluating the impacts of agricultural and NRM interventions are presented.

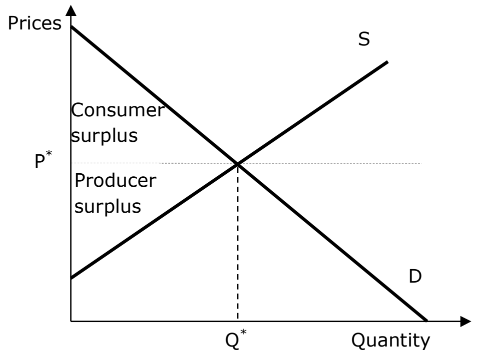
2.5.1 Economic surplus approach

The economic surplus approach to impact assessment is rooted in the microeconomics of supply and demand (Bantilan *et al*., 2005). The basic idea is simple and is illustrated in Fig. 2.1. Consumer demand can be described by downward sloping demand curve illustrating that some consumers are willing to pay more than others for given commodity. At a market-clearing equilibrium price, P*, those consumers who were willing to pay more than p* realize benefits by getting the product for less money than they were willing to pay. Across all consumers, the area beneath the demand curve, D, and above the equilibrium price, P*, measures the total value of consumer surplus.

Producer supply can be described by an upward sloping curve that illustrates that some producers can supply a product for a lower price than others. At a market-clearing equilibrium price, P*, those producers who could supply the products at a lower price obtain extra benefits. The aggregate benefits described by the area above the supply curve, S, and below the equilibrium price, P*, measure the total producer surplus. Together, consumer surplus and producer surplus sum to the economic surplus.

This is the most commonly used method for assessing the impact of agricultural research investment, particularly those related crop improvements. This approach estimates the benefits of research in terms of change in consumer surplus and producer surplus, resulting from a shift in the supply curve by introduction of new technology. Thus the economic surplus (sum of producer and consumer surplus) is taken as a measure of the gross benefit from research investment in a given year. The major challenge is to make a plausible link between changes in NRM practices and the supply of economic goods and services. The presence of non-marketed externalities further complicates the approach, although in theory, the social marginal cost of production could be used to internalize the externalities (Swinton, 2005). New methods (e.g., benefit transfer function) are developed to extend the economic surplus approach for assessment of non-marketed social gains from improved NRM technologies. Bantilan *et al*. (2005) used the economic surplus approach to estimate empirically the economic and environmental impact of groundnut production technology in central India (Maharashtra).

Fig. 2.1. Economic surplus divided between consumer and producer surplus.



P*, equilibrium price; Q*, equilibrium quantity; S, supply curve; D, demand curve

2.5.2 Econometric approach

Econometric approach is also used to link measures of output, costs and profits directly to past watershed development investments. The econometric approach uses regression models (like probit, logit, tobit, and two stage least squares (2SLS) regressions) to explain variations in agro-ecosystem services through changes in NRM pattern. This approach uses the changes in biophysical, economic and environmental indicators as proximate indicators of impact of the NRM technologies. The indicators include changes in land productivity; total factor productivity; reduction in costs (e.g., reduced use of fertilizers, pesticides); reduced risk and vulnerability to drought and flooding; improved net farm income and change in poverty levels (e.g., head count ratio). However, there are some limitations in this approach related to data availability and measurement errors, and problem in internalizing externalities and inter-temporal effects. For example, the time-varying nature of impacts of NRM practices require time-series data, ideally panel data with repeated observations from the same households and plots over a period of many years so that the dynamics of these impacts and their feedback effected on household endowments and subsequent NRM decisions are adequately assessed (Pender, 2005).

Unfortunately, household and plot-level panel data sets with information on both NRM practices and causal factors and outcomes are quite rare. In the absence of such data, inferences about NRM impacts will remain limited to those possible based on available short-term experimental data and cross-sectional econometric studies. These can provide information on near-term impacts, for example, on current production, income and current rates of resource degradation or improvement, but do not reveal feedback effects such as how changes in income or resource conditions may lead to changes in future adoption, adaptation or non-adoption of NRM practices (Pender, 2005; Barrett *et al*., 2002).

Assessing the multiple and complex mechanisms by which NRM (and other factors) may affect outcomes is an important issue, and one that is more difficult to address when limited dependent variable models (such as the probit, ordered probit, and tobit models) or other non-linear models are estimated. In linear system of structural equations, the total impacts of any variable on the outcomes can be determined by total differentiation of the system and by adding up the partial effects (Fan *et al*., 1999). But with limited dependent variable models or other non-linear models, this approach does not work. There will be no simple general relationship between the estimated coefficients of the structural model and the total impact, these relationships all depend on the level of each variable in non-linear models.

Pender (2005) applied an alternative approach to estimate total effects in non-linear models by using predictions from the estimated model to simulate both indirect and direct impacts of changes in the explanatory variables. Even though econometric models are useful in assessing the NRM impacts, they are not without problems and limitations. The most important problems are problems of endogeneity of NRM practices and omitted variable bias, which can be addressed through careful data collection and use of instrumental variables estimators.

Kerr and Chung (2005) also applied the econometric approach to assess the impact of the watershed programme in the semi-arid tropics of India. In this study they used instrumental variables approach for evaluation because of inadequate data on baseline conditions and lack of hydrological data (such as groundwater level, runoff, soil erosion, etc.). The study found that the more-participatory projects were more successful in protecting upper catchments to promote water harvesting. On the other hand, too often protection of upper catchments came at the expense of landless people whose livelihood relied heavily on them.

2.5.3 Bioeconomic modeling approach

The individual impacts of various technologies are known but there is little information on their combined impact or on the role of policy and institutional arrangements in conditioning their outcomes (Okumu *et al*., 2000). In addition past studies seldom included the biophysical factors (like soil erosion, nutrient depletion, water conservation etc.) in their studies, which have a direct effect in the productivity of the numerous enterprises (like crop production, livestock production, forestry, pasture development). In the recent past, the methodologies that are capable of simultaneously addressing the various dimensions of agriculture and NRM technology changes and the resulting tradeoffs among economic, sustainability and environmental objectives have been developed (e.g., Barbier, 1998; Barbier and Bergerson, 2001; Holden and Shiferaw, 2004; Holden *et al*., 2004). The main innovation in the development of such methodologies is the integration of biophysical and economic information, into a single integrated bio-economic model. Bioeconomic models link economic behavioural models with biophysical data to evaluate potential effects of new technologies, policies, and market incentives on human welfare and the sustainability of the environment or natural resources (Shiferaw and Freeman, 2003). So it helps the researchers in the selection of technologies that may improve the farmers' economic efficiency and welfare as well as the condition of the natural resource base over time.

The models can also be used to account for externalities if the generation of externalities can be linked with NRM and economic factors (Shiferaw *et al*., 2004). Bioeconomic models have been applied at the level of the household (e.g., Holden and

Shiferaw, 2004; Holden *et al*., 2004; Holden *et al*., 2005), at village and watershed levels (e.g., Barbier, 1998; Barbier and Bergerson, 2001; Sankhayan and Hofstad, 2001; Okumu *et al*., 2002) and for agricultural sector (e.g., Schipper, 1996). Bioeconomic models are difficult to develop and require estimation of several parameters. Since this study uses the bioeconomic modeling approach for evaluating the impact of new integrated watershed management technologies and policies, the following sections are devoted towards discussing the conceptual issues and typologies of the bioeconomic modeling approach.

2.6 Bioeconomic modeling

When dealing with rainfed agriculture and livelihood improvement in semi-arid fragile areas two major components need to be considered seriously. The first component deals with socio-economic aspects related to household behaviour, market structure, institutional arrangements, technology improvement and policy incentives. The second component views degradation of the natural resource base in terms of its biological processes related to water and nutrient cycling, plant and animal growth and erosion. Analysis of rainfed agriculture the in semi-arid tropics therefore requires contributions from both biophysical and economic sciences.

Combining information from biophysical and economic spheres does not necessarily lead to an integrated approached since the results from one analysis do not always fit into the other (Hengsdijk and Kruseman, 1993). To overcome these difficulties, quantitative approaches have been developed which allow enhanced interdisciplinary communication and interaction between biophysical and economic factors. These are commonly referred to as 'bioeconomic models' (Kruseman, 2000).

2.6.1 What is bioeconomic modeling?

In order to simultaneously evaluate the economic and environmental (sustainability) impacts of natural resource management (NRM) technologies and policies affecting natural resource use and management in the rural areas, a mix of information from biophysical and social sciences is needed. An important role of bioeconomic modeling is to stimulate this complex interaction between biophysical and socio-economic phenomena and make it transparent for policy debates. Several related definition on bioeconomic modeling exist in the literature (Kuyvenhoven *et al*., 1998a; Barbier, 1998; Barbier and Bergerson, 2001; Holden and Shiferaw, 2004 and Lee and Barrett, 2000).

According to Kruseman (2000) bioeconomic modeling is a "quantitative methodology that adequately accounts for biophysical and socioeconomic processes and combines knowledge in such a way that results are relevant to both social and biophysical science". The key issue refers to the synergy between biophysical and socio-economic sciences. Synergy implies that there are feedback mechanisms from the interdisciplinary analysis.
King *et al* (1993) defined "bioeconomic model is a mathematical representation of a managed biological system. Bioeconomic models describe biological processes and predict the effects of management decisions on those processes. They evaluate the consequences of management strategies in terms of some economic performance measure". This definition emphasized more on the biophysical sciences and management decisions than on the interaction between socio-economic and biophysical sciences.

Holden (2005) stated, "Bioeconomic models link human behaviour to biophysical resource use and stock changes. Applied bioeconomic models are numerical programming models that may be based on theoretical dynamic models. These models are a useful tool for interdisciplinary analysis like NRM impact assessment because they allow integration of biophysical and socio-economic dimensions of the problem in a consistent manner. Bioeconomic models can also be useful to predict adoption and impact of new NRM technologies; predict impacts of projects and policies targeting NRM; and make sensitivity analyses to assess the robustness of uncertain assumptions".

2.6.2 Classification principles for bioeconomic modeling

To review different bioeconomic models, a separation is made between different types of studies. The important criteria for distinguishing between different studies of bioeconomic models are (i) time scale and (ii) level of aggregation or spatial scale (Kruseman, 2000; Holden, 2005). This section first discusses the time scale, followed by level of aggregation. The two criteria are then combined into a matrix of possible approaches.

2.6.2.1 Time scale

Time scale is very important because the realization of impacts of new NRM technologies on sustainability of natural resources are often a process that continues for a long time. For example soil and water conservation (SWC) measures have their effect in incremental quantities over a long period of time. Hence accounting for and considering temporal scales can create difficulties not only mathematically but also conceptually. Processes that are important in the short run may be insignificant in the long run and vice versa (Fresco and Kroonenberg, 1992). Temporal periods, to which models refer, define the notion of time scales used in this framework of model classification. A distinction is made between past, present, near future and far future. Temporal scale incorporated into the model varies between models, which are static, some are comparative static and others are dynamic, depending on the degree to which changes over time are traced in the analysis.

2.6.2.2 Aggregation level

The distinguishing criteria for level of aggregation are (i) plot/field/enterprise level, (ii) the farm household level, (iii) village/watershed level and (iv) regional and higher level.

At the lowest level (plot/field/enterprise) behavioural aspects are exogenous, since many of the components necessary for determining allocative efficiency are not included. At this level many of the biophysical processes are studied like plant soil interaction, macronutrients and carbon balances and in general plant and animal growth, which are crucial element of the biophysical component in the bioeconomic models.

The farm household level is the focal point of micro-economic analysis. Interactions between different components of the farming system are analyzed and linked to the behaviourial aspects of resource allocation, production, technology choices, investment and consumption.

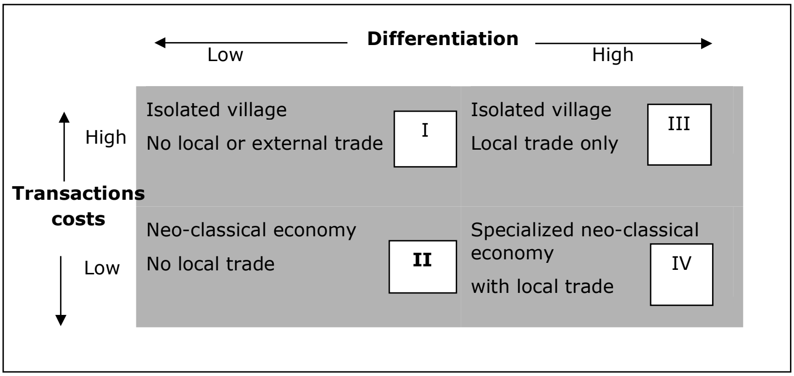
The next level of aggregation is interaction of number of farms/households in agro-ecological or socio-economic terms. In a watershed/village decisions taken by upstream farmers/resource users may affect the production possibilities for downstream farmers through runoff and soil erosion. Within village factor markets for land, labour and capital are balanced through exchange relations.

At higher levels of aggregation the influence of individual households is of little importance. Macroeconomic relationships predominate in agro-ecological zones/regional analysis. The choice of aggregation level is guided by different principles. From the viewpoint of economics the place where decisions are made or a point where other agent influence such decision (through externalities) is the relevant level. Generally that is the household level. In cases where differentiation between households is high and interactions between households are significant, a combination of household and village/watershed analysis is necessary (Holden *et al*., 1998).

Analyzing the effects of certain policies on the agricultural sector or a region always relies implicitly or explicitly on decision making at the farm household level. The degree of heterogeneity of households and the degree of integration of households in exchange mechanisms for inputs, commodities and production factors will determine the appropriate modeling approach (Holden, 2005).

Following Holden *et al.* (1998), a typology of village or regional models can be made (Figs 2.2 a and b). With high transaction costs and market imperfections and low farm differentiation, the assumption of non-separable household models without trade is used (Holden and Shiferaw, 2004; Holden *et al*., 2004). With low transaction costs and well function markets, separable farm household models can be used (Singh *et al.*, 1986). With a high level of differentiation that leads to trade within the village, local market clearance has to be taken into account. Depending on the level of transaction costs, computable general equilibrium (CGE) models with separable (Taylor and Adelman, 1996) or non-separable (Holden and Lofgren, 2005) household models are used. If CGE models cannot be fully specified, partial equilibrium models for tradable commodities can be used (Bade *et al.*, 1997; Deybe, 1998).

a.



b.

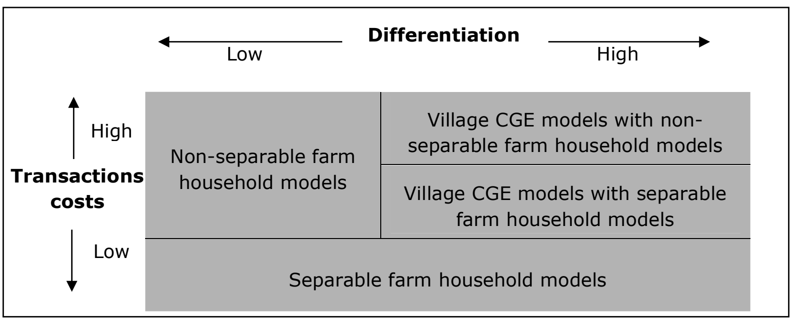


Fig. 2.2. a. Village economy typology and b. Typology of village computable general equilibrium (CGE) economy models (Source: Holden *et al*., 1998)

2.6.3 Matrix of bioeconomic modeling approaches:

The main distinguishing criteria of bioeconomic modeling approach are time scale (past and present, near future, far future) and aggregation level (sub-farm, farm, village/watershed, region). Based on the two criteria, Kruseman (2000) developed a three by four matrix to fit various bioeconomic modeling approaches (Table 2.2).

Table 2.2 Matrix of bioeconomic modeling approach

	Past and present	Near future	Far Future
Plot/field	Production function analysis, activity budgeting	Precision farming	Technical coefficient generator
Farm Household	Farming system analysis	Farm household modeling	Quantified farming system approach (QFSA)
Village/water shed	Village level SAM	Village level CGEs, dynamics system simulation	Land evaluation
Region/Sector	Aggregate models	CGEs, multi-market models	Multiple Goal Linear Programming (MGLP)

Source: Kruseman (2000)

Descriptive models of the past and present are models that describe reality using empirical evidence. Ideally, they are based on sound theoretical foundations and specified relations using experimental data, surveys and statistics. Explorative models of the far future build on descriptive models, but take them to the outer boundaries of conceivable reality. Predictive models of the near future also build on descriptive models, but different from explorative studies in the sense that predictive models explicitly start from the present and move towards the future, whereas explorative models take an unqualified step into the future and start the analysis from there.

It is clear from this discussion that the distinction between approaches is not clear, where elements from one approach are also found in others. The same holds for the level of aggregation. Information from the plot level is used at the farm household level. Information from farm household level models is again incorporated into village and watershed models. This importance in distinguishing between approaches is to address the right questions with appropriate tools.

2.7 Approaches in bioeconomic modeling

This section deals with the historical origins, analytical foundations and methods of bioeconomic modeling in more detail. According to Kruseman (2000) studies explaining the past and present are discussed under the section called descriptive explanatory bioeconomic models. Studies aimed at far future are categorized under the heading of exploratory bioeconomic models, while studies concerning the near future are covered in the section called predictive bioeconomic models.

2.7.1 Descriptive explanatory bioeconomic models

Traditional agricultural production economics is being used for some bioeconomic analysis. Production function analysis has been widely used for a systematic comparison of differences in cropping and production systems between farmers, based on econometric techniques. Traditionally, agro-ecological data are not directly used in these production functions, but now it's becoming increasingly popular (Mausolff and Farber, 1995; Pattanayak and Mercer, 1998).

In the early 1980's Farming System Research (FSR) contributed detailed descriptions of the current land use and farming practices which helped substantially for a better understanding of the conditions under which farmers in the post Green Revolution era operate, since the benefits of technological change were not always accruing to them (Tripp *et al*., 1990). FSR explains the existing gaps between experimental and field research where the results of FSR are too location specific and difficult to quantify. Moreover FSR lacks a methodology to effectively address policy issues that constraints farming system (Jones *et al*., 1997). Recently, operational research methods have been used for a quantified farming system analysis (QFSA) with a strong economic orientation and a more systematic treatment of biophysical components (Van Rheenen, 1995).

At village level, social accounting matrices (SAM) describe interactions between households in markets for inputs, commodities and production factors (Holden *et al*., 1998). At present there are very few village level SAMs that include biophysical information relating to soil degradation (Holden and Lofgren, 2005). At higher level of aggregation, the link between soil degradation and economic development is also made through econometric analysis (Qu *et al*., 1997).

2.7.2 Explorative bioeconomic models

Explorative models have the clear aim to review future options for improved resource use under different agro-ecological and socio-economic conditions. The main goal of these models is to explore the outer boundaries of the feasible future under certain conditions and to identify tradeoffs between the interests of different stakeholders (farmers, consumers, government, etc.).

At plot or field level, production ecology offers a wide range of models to generate technical input-output coefficients for different land use activities. In the production ecology tradition, the so-called Technical coefficient Generators (TCGs) are oriented towards increasing land productivity through the use of technically efficient and sustainable options (Kruseman, 2000). It has the strong quantitative and exclusive biophysical orientation.

In explorative farm household models quantified farming system analysis is used such as Farm household Level Optimal Resource Allocation (FLORA) (Van Rheenen, 1995). A different type of explorative approach is farm management analysis concerning cost-benefit and multi-criteria analysis for the evaluation of investments in soil conservation measures (De Graaff, 1996) or for the selection of agricultural research priorities (Alston *et al*., 1995). Traditional cost-benefits analysis has been extended to account for environmental effects (Arrow *et al*., 1996). This method offer information about economically feasible technologies and thus provides a building block for bioeconomic models.

At higher level of aggregation, procedures for land evaluation have been developed as a framework for linking information from soil sciences with other biophysical and sometimes socio-economic models to access soil degradation under different forms of land use (Van Lanen, 1991). In recent years the main emphasis of explorative studies at regional level is on techniques to explore long-term impact of agricultural development in terms of technology choice using Multiple Goal Linear Programming (MGLP) (Van Keulen, 1990).

It can be concluded that biophysical approaches clearly took the lead in most of the explorative research where sustainable land use was at stake. Interestingly some of the analytical procedures used at regional level are derived from economic farm management analysis.

2.7.3 Predictive Bioeconomic models

Short run predictive models are developed for the purpose of decision support at different levels. These approaches clearly take into account the behaviour of individual farmers, and their interactions and exchange relations that give rise to changing production conditions, and hence resource allocation. Often simulation techniques are used to assess system performance under new technologies and alternative policy interventions. The starting point of predictive models is always a base run which is validated against the current situation.

At field level, forecasting models provide useful information for the design and operation of precision farming systems. Detailed knowledge on soil conditions and production factors and input requirements for spatially defined units and temporally defined operations permit substantial improvements of input application efficiencies (Bouman *et al.*, 1995). The basis of precision farming is that farmer's objectives of input use efficiency and societal objectives of reduced degradation and pollution can be settled, since production systems become more sustainable and cost effective at the same time.

Bioeconomic models at the farm level can be divided into a number of separate methodologies like optimal control models and farm household modeling.

A different way of dealing with the inter-temporal soil resource use is optimal control models (Barrett, 1991; Pagiola, 1996; Shiferaw, 1998). Results from these analyses show that renewable resources will be exploited efficiently as long as current income is used for replacement investments to restore resource stocks. Most of these models assume separable household models, hence production decisions are independent of consumption requirements.

Bioeconomic models at the farm level can also make use of the procedures developed from farm household modeling (Singh *et al*., 1986; de Janvry *et al*., 1991; Sadoulet and de Janvry, 1995). These models explicitly accounts for natural resource endowments, input and production factor allocation decisions, and technology and enterprise choice and consumption preferences under varying conditions of market development. Biophysical information that will affect yields and resource conditions can be linked to the production side of the farm household model (Ramaswamy and Sanders, 1992; Kruseman *et al*., 1995; Holden *et al*. 2004; Shiferaw and Holden, 2005) using mathematical programming techniques.

At village/watershed level bioeconomic models have been developed for analyzing villages, watersheds and comparable micro-regions as a single profit maximizing unit (Barbier, 1996; Barbier and Bergeron, 2001; Sankhayan and Hofstad, 2001; Okumu *et al*., 2002; Sankhayan *et al*., 2003). These approaches are used to study the impact of new technologies and policy interventions on economic welfare and sustainability of natural resources like soil, water, forestry, etc. The next approach is the village level CGE model, which can be used for the purpose of evaluating the impacts of alternative NRM policy interventions on economic welfare and natural resource degradation by accounting for local market clearing conditions (Taylor and Adelman, 1996; Holden and Lofgren, 2005).

Most of the available approaches developed for forecasting purposes use explicit treatment of biophysical and socio-economic processes. At different levels of analysis these processes interact in different ways. At the field level biophysical processes dominate, while at the farm level there is a strong interaction between the biophysical and decision making processes. At higher level of aggregation, the interaction between the two realms becomes more difficult to incorporate in models, since the effects of aggregate behaviour and policy change on natural resources are indirectly interlinked and reciprocal.

2.8 Advantages of bioeconomic modeling in impact assessment studies

Bioeconomic models are used to incorporate changes in the biophysical conditions of natural resource use within the economic behavioral models with the purpose of exploring or understanding the two way interaction (i.e. how changes in biophysical conditions affect welfare and vice versa). Such models are useful to evaluate the potential effects of new agricultural and NRM technologies, policies and market incentives on human welfare as well as the quality of the resource base and the environment. Possibilities to address dynamic issues and linking changes in biophysical indicators with economic models are important advantages of this method (Shiferaw *et al*., 2004). The integrated framework allows a consistent analysis of technology impacts within a given socioeconomic and policy setting.

According to Holden (2005) the main advantages of using bioeconomic models for NRM technologies and policy impact assessment are:

1. They allow consistent treatment of complex biophysical and socio-economic variables, providing a suitable tool for interdisciplinary analysis
2. They allow sequential and simultaneous interactions between biophysical and socio-economic variables
3. They can be used to assess the potential impacts of new technologies and policies (*ex-ante* impact assessment)
4. They allow disturbing variation to be controlled (*ceteris paribus* conditions) for evaluation of impacts of certain interactions by isolating effects from other influences
5. They can capture both direct and indirect effects (i.e. the total effect of technology or policy change can be estimated)
6. They can be used to carry out sensitivity analyses in relation to various types of uncertainties.

2.9 Review of past studies of bioeconomic modeling

This section provides review of various studies in which different bioeconomic modeling approach have been used for assessing the impact of NRM technologies and policies interventions.

Barbier (1998) has developed a recursive and dynamic linear bioeconomic modeling method that stimulates a village's response to population and market pressure in a sub-humid region of Burkina Faso. The model has integrated a biophysical model of soil conditions and plant growth which predicts yields and land degradation for different type of land, land use and cropping patterns. The linear programming model simulate farmer's plan aggregated at the village level under constraints of food consumption, land area, soil fertility, soil depth, labour, risk aversion and cash availability. The soil erosion level for the village was calculated using the Modified Universal Soil Loss Equation (MUSLE) and Erosion Productivity Impact Calculator (EPIC) was used to generate crop productivity data and marginal effect of erosion on crop yields. The results of the study showed that population pressure led to intensification and investment in land conservation practices but not necessarily to better farm incomes. The simulation results also indicated that the best way to increase production per farmer was to let farmers migrate from the high population-density areas to the low population density area because intensification per hectare was still more expensive than the fallow system.

Kuyvenhoven *et al*. (1998b) had developed a farm household modeling approach that linked agro-technical and economic data to identify the effects of adopting alternative technologies and price reforms, transaction costs, access to credit and land taxes on sustainable land use and farm household welfare in southern Mali. The results indicated that intensification of cropping systems could be achieved through better access to animal traction and more and improved use of fertilizers. The study found that with full knowledge of sustainable technology and in the absence of transaction costs the nutrient and carbon balance could be improved. The study revealed that structural policies (e.g. rural infrastructural development, input delivery systems, development of rural financial markets and property rights) were more effective than price policies (e.g. higher cotton prices and lower fertilizer prices) to reduce soil degradation while maintaining positive income effects.

Shiferaw and Holden (1999) used a static bioeconomic non-separable farm household model to analyze the resource-use pattern, sustainability impacts and economic benefits to smallholder farmers from adoption of soil conservation technologies (soil bunds and stone bunds). The model was developed for an area with good agricultural potential and relatively good market access but with significant market imperfections in the Ethiopian highlands. The model included the onsite user costs of soil erosion. Soil loss was estimated based on Universal Soil Loss Equation (USLE) and experimental data were used to estimate a translog production function to assess effect soil erosion on crop productivity. The user cost was calculated as the net present value of the permanently lost land productivity for the dominant crop, teff (*Eragrostis tef*). The results of the study revealed that the erosion control investments were undermined by the presence of market imperfections, poverty and high rate of time preference among the smallholders. And also the lack of technologies that provide quick returns to subsistence constrained farmers appeared to discourage conservation investments. The study also emphasized the need for cross-compliance type of policies that link input and credit subsidies with conservation requirements.

Barbier and Bergeron (2001) had developed a time-recursive bioeconomic micro-watershed model with a five year planning horizon for singe year decision. The model maximized the additive discounted utility of two household groups (ranchers and small scale farmers) split into 18 farm sub-models based on spatial location of land types in the hillsides of Honduras. The model contained a local labour market with an endogenous wage rate that was linked to an external labour market. The model was run for as much as 100 years (1975-2075) and was updated every year. Resources carried over from one period to the next included population, livestock, tree volume of different aged trees, soil depth, soil conservation structures, and ploughs. In the model soil erosion was modeled as a function of crop choice by area and the presence or absence of conservation technologies. Erosion affected yields through both loss of nutrients and soil depth. The biophysical model Erosion Productivity Impact Calculator (EPIC) was used to generate the crop productivity data, based on land use practices and soil quality while the Modified Universal Soil loss Equation (MUSLE) was used to estimate erosion levels in the watershed.

The objective of this study was to simulate the effect of population growth, new technologies (improved varieties and sprinkler irrigation), market liberalization, road construction, and land reforms on NRM, soil erosion, input use, crop yields and income. The simulation results suggested that technology improvements helped to overcome diminishing returns to labour due to population pressure. The improvement in the access to market had increased the per capita incomes of the farmers. The results of the model indicated dairy production are a viable option for improving the economic welfare of the communities in the watershed. An increase in the price of inorganic fertilizers has lead to an increase in soil erosion because this has encouraged farmers use less fertilizer, and increase in cropped area to compensate for lower yields.

Sankhayan and Hofstad (2001) used a village-level dynamic, stochastic and non-linear programming model to study the complex woodland degradation process in Lambatara village in southern Senegal. The model had incorporated both economic and ecological aspects and simultaneously assessed the effects of three major causes of woodland degradation, namely land clearing, grazing, and extraction done for wood fuel, poles and charcoal. In the model woodland degradation was measured through loss of vegetative biomass per unit of land. They observed that population pressure could aggravate woodland degradation processes while introduction of improved technology in agriculture, higher cotton prices, increased rural wages, and reduced charcoal prices could retard the process of degradation.

Okumu *et al*. (2002) had developed a dynamic non-linear bioeconomic model to examine the economic outcomes and land use changes associated with the introduction of new technologies and policy interventions in Ginchi watershed in the central highlands of Ethiopia. The biophysical aspect of the watershed were linked to the economic decision framework through an exponential soil loss-crop yield decline model relating crop yields to cumulative soil loss, fertilizer use and dung manure applications. The Universal Soil Loss Equation (USLE) model was used to calculate the annual soil loss in the watershed. The model treated the Ginchi watershed as a single profit-maximizing unit and planned for a twelve-year time horizon. The results of the study revealed that even though the contemporary practices and policies had increased the cash incomes by more than 40 per cent over a twelve year planning period, the average per ha soil loss was as high as 31 tonnes per hectare. But with the adoption of the integrated package of new technologies, the results showed that there was a possibility of two and half times increase in cash incomes and decline of 28 per cent in aggregate erosion levels even with the population growth rate of 2.3 per cent. The simulation results of the model indicated that higher rates of growth in nutritional requirements and population led to significant strains on the watershed system. The study also stressed a need for more secure land tenure policy than currently prevailed in the area to facilitate uptake of the new technology packages for production and conservation of natural resource.

Sankhayan *et al*. (2003) had developed a watershed level dynamic, non-linear bioeconomic model to analyze the system behaviour in terms of land use changes and forest degradation process. The model was applied at a watershed level in Mardi, Nepal to investigate the impacts of alternative policy scenarios like introduction of agricultural technology represented through high yielding varieties of paddy and maize, reduction in population growth rate, and increase in price of major agricultural crops. A biological growth function was used for calculating the growth of vegetative biomass of trees in the forest. The results showed that technological improvement and increased crop prices could increase the cropped area while a decline in the population growth rate had the opposite effect. Reduced population growth and higher prices for major agricultural crops led to overall reduction in forest degradation. So the study concluded that family planning policies aimed at reduction of population growth rate and increase in prices of major agricultural crops could be effective policy instruments for slowing down the process of forest degradation.

Holden and Shiferaw (2004) had developed a non-linear non-stochastic dynamic non-separable bioeconomic farm household model with risk. This model was applied to a severely degraded crop-livestock farming system in the Ethiopian highlands with high population density, where droughts threaten food security. They included imperfections in markets such as missing markets, price bands, credit rationing, and share tenancy in the model. The bioeconomic model was used to analyze the combined effects of land degradation, population growth, market imperfections and increased risk of drought on household production, welfare and food security. They found that the indirect effects of drought on household welfare through the impacts on crop and livestock prices are higher than the direct production effects of drought. They also observed that provision and adoption of credit for fertilizer has led to increased grain production and improved household welfare and food security. Provision of credit also has a negative effect on conservation incentives but they found that linking a conservation requirement to the provision of credit for fertilizer might mitigate that effect.

Holden *et al*. (2004) assessed the impact of non-farm income on household welfare, agricultural production, conservation investment and land degradation in the form of soil erosion for a less-favoured area in Ethiopian highlands by using a dynamic bioeconomic model. The simulation results showed that access to non-farm employment has reduced the total agricultural production and farm input used. And also reduced the farm households' incentives to invest in conservation and that led to more overall soil erosion and more rapid land degradation.

Holden *et al*. (2005) had developed a dynamic non-separable bioeconomic model and used to analyze the combined effects of land degradation, population pressure, market imperfections, and increased risk of drought on household production, welfare, and food security in Andit Tit, Ethiopia. The model was also used for assessing the impact of increased access to credit for fertilizer, off-farm income, food-for-work (FFW) interventions and planting of eucalyptus trees as alternatives for local development. The results of the study predicted that increased use of fertilizer credit has helped to increase agricultural productivity, food security and income, but reduced farmers' incentives to invest in soil and water conservation, leading to greater land degradation. They also found that better access to off-farm income and FFW could improve household income and vulnerability to drought but reduced the incentives for food production and land conservation. The results revealed that a policy combining promotion of tree planting and FFW for conservation of cropland might increase the household income as well as more sustainable land use.

Shiferaw and Holden (2005) used a multiperiod farm household level bioeconomic model to access the economic and environmental impacts of conservation technologies for resource poor household in Andit Tit, central highlands of Ethiopia. The results showed that when land was relatively abundant, households are unlikely to carry out labour- intensive conservation investments, but increases in scarcity of land, associated with growth in family size increased the incentive for investing in conservation technologies. The results also predicted that the economic incentive to invest in conservation drastically decreased when the new technologies increase scarcity of land (take land out of production or structures occupy productive land) and decrease crop yield in short term. So they suggested the need to develop NRM technologies that provide attractive economic gains along with sustainability benefits to create sufficient incentives for investment in beneficial conservation.

Summing up

To summarise, the chapter briefly reviewed the history of the watershed development programme, the impact of these programs in India as well as the different modeling approaches for evaluating the impact of technologies and policies associated with watershed interventions. Earlier watershed development programmes started with the aim to conserve soil and reduce land degradation through various conservation investments but the approach has gradually move to improve the livelihoods of the marginal farmers through integrated genetic natural resource management. However, the earlier impact studies of watershed development programmes in India have only examined the performance of the watershed programme by using economic indicators like change in income of the farmers, productivity of crops, increase in livestock number, access to drinking water and environmental indicators like increase in ground water level, reduction in soil erosion and increased land cover. The impact studies lacked simultaneous integration of the economic and biophysical factors and the capacity to account for non-monetary impacts that watershed interventions generate in terms of flow of resources and environmental services that affect social well-being and natural resource sustainability.

A review of methodological advances in NRM impact assessment has also provided a good background for developing a bioeconomic model to examine the impact of watershed development program, integrating both economic and biophysical factors as well as multi-dimensionality of NRM outcomes. Hence, the present study attempts to develop a methodology for assessing the multi-dimensional impacts of the NRM technologies and related policy interventions made in the Kothapally watershed in Andhra Pradesh. The model is applied to the watershed village to examine the effect of alternative interventions on the welfare of farming communities and sustainability of the natural resources.

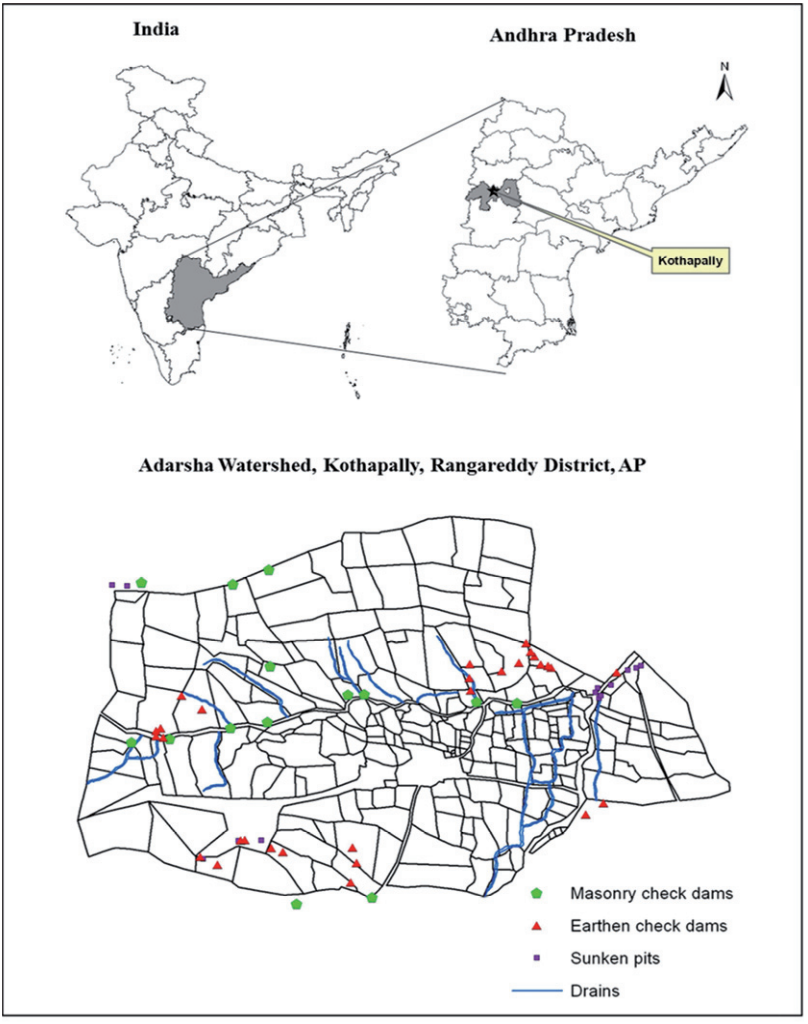
Chapter III

METHODOLOGY

It is evident from the literature review that the impact studies of watershed interventions in India so far focused on biophysical and socioeconomic aspects distinctly. But the fact that technology and policy interventions in a watershed can have simultaneous impact on both biophysical and socioeconomic features has been proven in the recent impact studies of watershed management (Barbier, 1998; Barbier and Bergerson, 2001; Okumu *et al*., 2002). These studies used the bioeconomic modeling approach that allows integration of both biophysical and socioeconomic dimensions. In this study, an integrated bioeconomic model has been developed for a micro watershed in the semi-arid tropics of India to assess the impact of technology and policy interventions on social well-being of rural households and natural resource conditions. The first part of this chapter explains the selection of the study area, sampling design, data collection and the method of analysis used to estimate model parameters, which are used in bioeconomic model of the study. The second part of the chapter focuses on the construction of the bioeconomic model for the study area.

3.1 Selection of the study area

Based on lessons learnt from the success of on-station soil, water and nutrient management (SWNM) research in watershed, ICRISAT developed a new Integrated Genetic Natural Resource Management (INRM) model which is being evaluated in five on-farm and three on-station watersheds covering various agro-ecological, socio-economic and technological situations in India, Thailand and Vietnam. In one of the on-farm watersheds (Map 3.1) in India (Adarsha watershed, Kothapally), a participatory community watershed management programme was initiated in collaboration with the Drought Prone Area Programme (DPAP) of Government of India. Along with ICRISAT, a consortium of NGOs and national research institutes is testing and developing technological, policy and institutional options for integrated watershed management in the village (Wani *et al*. 2002; Shiferaw *et al*. 2003a). A package of integrated genetic and natural resource management practices are being evaluated on farmer's fields (including SWC, new high yielding varieties, IPM and INM) through participatory approaches.



Map 3.1: Location of study area – Adarsha Watershed, Kothapally, Rangareddy District, AP

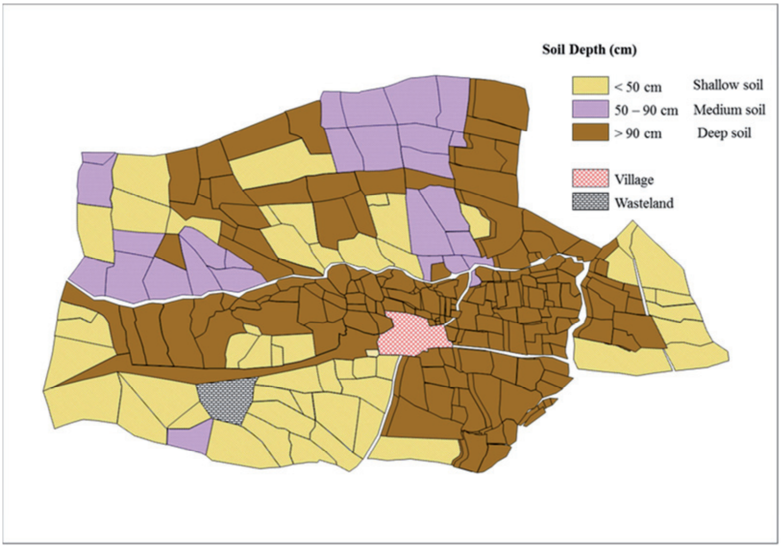
A number of impact studies were carried out to assess the impact of technological interventions in the village. However an impact study which simultaneously integrates the biophysical and socioeconomic information in a dynamic decision making framework is lacking. So in this study the Adarsha watershed in Kothapally village is selected as the study area for construction of the bioeconomic model to study the *ex-ante* impacts of the technology and policy interventions on the welfare of the farming communities and the condition of the natural resources. The site was selected because of availability of adequate biophysical and socioeconomic data covering a period of 6-7 years and baseline information, which was collected prior to various integrated interventions. The rich primary data was collected by an interdisciplinary team of ICRISAT scientists. This unique dataset was used in the study for construction and validation of the bioeconomic model.

3.2 Data

3.2.1 Biophysical data

ICRISAT has installed an automatic weather station in Kothapally village, which allows regular monitoring of diverse biophysical parameters (e.g., temperature, rainfall, runoff, soil and nutrient loss etc). The runoff, soil loss and nutrient loss from the treated and untreated segment of the watershed are measured using the automatic water level recorder and sediment samplers located at two different places in the watershed. ICRISAT has also conducted detailed physical and chemical analysis of the soils of watershed before implementing the project, which is being used as baseline data (Wani *et al*., 2002).

The plot level data (e.g., soil depth, soil type, plot size, etc) was collected through periodical visits and measuring some plots in the watershed and by interviewing the households owning or renting the plots. Based on information collected, the watershed area is divided into three soil depth classes based on top soil depth (Map 3.2), namely shallow (less than 50 cm), medium (50-90 cm) and deep soil (above 90 cm). The watershed is also further divided into two land types namely irrigated and rainfed or dryland based on the availability of irrigation facilities to the field (Wani *et al*., 2002). The summary of the data is presented in Table 3.1.



Map3.2: Soil depth map of Adarsha Watershed, Kothapally

3.2.2 Socioeconomic data

In 2001, ICRISAT has conducted a census of all households in Kothapally village and five adjoining villages/non-watershed/control villages (namely Husainpura, Masaniguda, Oorella, Yankepally and Yarveguda) lying outside the watershed with comparable biophysical (rainfall, soil and climate) and socioeconomic conditions. Access to market may differ slightly as some villages may be closer to the main road leading to the nearest town (Shankarpally). The major difference is in terms of access to new production and resource management technology. Households within the catchments benefit from new varieties and land and water management options and households outside the project area do not have such access yet. The important socioeconomic features of the six villages are presented in detail in Appendix 1.

Analysis of this data provided useful information about the general profile of the rural economy and institutions prevailing in the watershed and non-watershed villages. Based on the information from the census analysis a random sample of 60 households from watershed village (Kothapally) and another 60 households from non-watershed villages were selected for detailed survey. A well-structured pre-tested questionnaire was used for data collection. The data was collected annually for three years (2002-2004). Along with other standard socioeconomic data, detailed plot and crop-wise input and output data were collected immediately after harvest from the operational holdings of all the sample households. The associated biophysical data on major plots (like soil depth, soil type, level of erosion, slope of the plot, fertility status etc) were collected using locally accepted soil classification systems. Trained enumerators were employed who resided in the sample villages and collected the data during the course of the survey.

Table 3.1 Classification of land based on soil type and land type in Adarsha watershed, Kothapally

Farmers	**Soil type**	**Land type (ha)**	
		Dryland	**Irrigated land**
Small (< 2.0 ha) (n=202)	Shallow	47.99	13.07
	Medium	22.28	5.36
	Deep	54.68	15.08
	Total	**124.95**	**33.50**
Medium (2.01 - 4.0 ha) (n=57)	Shallow	44.33	16.05
	Medium	19.54	6.59
	Deep	47.02	18.52
	Total	**110.89**	**41.16**
Large (> 4.01 ha) (n=30)	Shallow	40.73	18.80
	Medium	19.29	7.71
	Deep	46.32	21.69
	Total	**106.34**	**48.20**
All* (n=289)	Shallow	133.05	47.92
	Medium	61.11	19.66
	Deep	148.02	55.29
	Total	**342.18**	**122.86**

* Land less labours not included
Source: Shiferaw, 2002

The price data for the crops, livestock and market characteristics for crop produce, inputs and livestock were collected during the household survey, in the local markets and also through focus group discussion in the sample villages.

3.3 Estimation of crop yield change in relation to soil depth

Soil degradation process generally results in the loss of topsoil causing a reduction in water holding capacity and loss of nutrients in the soil, which affects crop yields severely in rainfed agriculture. Water holding capacity takes different forms in short and long run. In the long run, water holding capacity is permanently reduced because shallower soil contains less space to store water. In the short run, erosion is correlated with high runoff, indicating that when erosion is taking place, the soil captures less moisture to supply crops. A minimum threshold soil depth must be available for the crops to grow, below which crop yield could be drastically reduced even in a good rainfall year. Alagarswamy *et al*. (2000) derived a non-linear yield-soil depth relationship by using a crop growth simulation model (CROPGRO-soybean model).

In this study due to lack of calibrated crop growth models for all crops cultivated in the watershed, an econometric technique is used to estimate the relationship between soil depth and crop yields (and hence the crop yield decline for soil depth change). Incorporation of biophysical information (like soil depth, soil types, soil organic matter (SOM), etc) into production function analysis, using econometric techniques is becoming popular and useful (Mausoff and Farber, 1995; Pattanayak and Mercer, 1998).

For econometric estimation of yield variation due to changes in topsoil depth, the household survey and plot and crop-wise input and output data collected by ICRISAT during 2002 and 2003 covering 12 villages in four districts of Andhra Pradesh is used. This includes data collected from Kothapally watershed village and five adjoining villages in Rangareddy district. The plot level and crop specific data consists of information on differences in soil quality (soil depth, soil types and soil fertility), risk of soil degradation, slope gradients and soil and water conservation investments. The crop-wise input and output data contained detailed information on crops grown, plot size, irrigated or rainfed, variety grown (local or HYV), family and hired labour used for different operations, bullock labour, fertilizers (organic and inorganic), pesticides sprayed and crop and residual yield. The plot level and crop-wise input and output data of different years were pooled into a single dataset to estimate crop-wise soil depth yield relationships using econometric approaches.

In order to capture the non-linear effects of soil depth, a quadratic production function was used for relating output with inputs and other factors reflecting farm characteristics such as soil depth and soil type. The general form of the quadratic production function is

$$Y_c = \beta_0 + \beta_i X_i + \beta_j Z_j + \beta_{ii} X_i^2 + \beta_k D_k + e_i$$

Where,

Y_c = yield of crop c in kg/ha (c = crop grown in the watershed)

X_i = inputs (i = labour (man days), N, P, K, FYM, (tons per ha) and number of irrigation)

Z_j = biophysical variables (j = soil depth in ordinal values)

D_k = dummy variables [k = year dummy, variety dummy (improved or local), irrigation dummy (irrigated or rainfed)]

βs = coefficients

e_i = the error term $e \approx N(0, \delta^2)$

The variable soil depth (d) of each plot of the farm is not the exact topsoil depth in meters but in ordinal categories. The plots are placed in any one of the four categories (1= shallow depth soil (d < 0.5 m); 2= medium depth soil (0.5< d <1m); 3= deep depth soil (1<d< 1.5 m); and 4= very deep depth soil (d >1.5 m)). The difference between any two categories of soil depth is 50 cm. So the marginal effect of 1cm of soil depth change on crop yield is estimated as follows.

$$\lambda = \frac{\beta \text{ of the soil depth}}{\text{Difference between the two soil depth categories (i.e. 50 cm)}}$$

Where,

λ = the marginal change in yield for 1 cm change in soil depth

β = the coefficient of soil depth in the quadratic production function

The statistical package STATA is used for estimating the production functions. The econometric results from the estimated quadratic production function for all crops grown in the watershed are presented in Appendix 2. The marginal effect of changes in soil depth on crop yield in the watershed is presented in Table 3.2.

The estimated relationship between soil depth and decline of crop yields for cereals and legumes in the Adarsha watershed is consistent with what has been observed by Seghal and Abrol (1994) under experimental data on soil depth-productivity relationship based on three year experiments on vertisols in Nagpur, Maharashtra.

The average yield of crops without inorganic fertilizers (like N and P) for different soil depth classes (shallow, medium and deep) is estimated econometrically by running a linear production function with yield per ha as dependent variable and fertilizer nutrients (N and P) and soil depth groups as explanatory variables. The general form of the linear production function is

$$Y_c = \beta_0 + \beta_1 X_i + \beta_2 SD1\_dummy + \beta_3 SD2\_dummy + e_i$$

Where,

Y_c = yield of crop c in kg/ha (c = crop grown in the watershed)

X_i = inputs in kg/ha (i = N and P)

SD1_dummy = soil depth dummy (1 for shallow soils and 0 otherwise)

SD2_dummy = soil depth dummy (1 for medium soils and 0 otherwise)

βs = coefficients

β_0 = intercept term (crop yield without fertilizer nutrients on deep soils)

e_i = the error term e ≈ N(0, δ^2)

Table 3.2 Marginal response of crop yields to change in soil depth and plant nutrients (N and P)

Crops	Number of observations (n)	Marginal effect of soil depth (kg/cm/ha)	Marginal effect of fertilizer nutrients (kg crop/kg of nutrients)			
			N	N^2	P	P^2
Sorghum	342	2.43	7.78	-0.06	3.22	-0.02
Maize	308	3.34	13.45	-0.05	-7.69	0.08
Chickpea	147	3.78	12.22	-0.06	0.26	0.04
Pigeon pea	625	0.37	0.95	-0.03	-4.88	0.13
Sunflower	67	3.44	5.77	0.21	2.69	0.10
Onion	43	57.2	17.60	0.04	60.34	-0.05
Vegetables	160	10.16	2.02		-5.20	
Paddy	253	0	19.09	-0.21	-4.98	-0.01
Cotton	236	0.34	2.78		0.02	

The average yield of different crops for different soil depth classes are estimated as follows

1. Shallow soil = $\beta_0 + \beta_2$
2. Medium soil = $\beta_0 + \beta_3$
3. Deep soil = β_0

The estimated linear production functions for the crops are presented in Appendix 3. The average yield of crops without the effect of nutrients (N and P) and soil depth is given in Table 3.3.

Table 3.3 The average yield of crops in different soil depth classes (kg/ha) without nutrient fertilizers

Crops	Soil depth classes		
	Shallow	Medium	Deep
Sorghum (local)	418.98	468.63	643.25
Sorghum (HYV)	550.43	827.75	902.5
Maize	1231.41	1284.43	1983.94
Chickpea (local)	287.48	421.49	1029.14
Chickpea (HYV)	290.53	480.86	1077.39
Pigeon pea (local)	93.65	120.9	145.75
Pigeon pea (HYV)	106.16	161.15	188.59
Sunflower	33.37	807.72	897.56
Onion	6066.48	9334.77	11514.23
Vegetables	4154.89	4796.9	6465.23
Cotton[1]	1337.9	1337.9	1337.9
Paddy[2]	3427.36	3427.36	3427.36

Note: 1 and 2 – The soil depth dummies are not statistically significant. The reason may be that paddy is grown in flooded field conditions that will reduce the effect of soil depth on yield and cotton is a deep rooted plant, which may reduce the effect of soil depth on crop yield. So the same basic yield is used for all soil depth classes.

3.4 Estimation of soil loss on cropland

The average soil loss per ha of cropped area in the watershed is calculated by using Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), which is being widely used for soil loss prediction. Average annual soil loss due to sheet and rill erosion from a crop area is predicted by the following equation.

$$A = R * K * L * S * C * P$$

Where,

A = Average annual soil loss (t/ha/yr)

R = Rainfall erosivity factor

K = Soil erodability factor (t/ha per unit of R)

L = Slope length factor

S = Slope gradient or steepness factor

C = Land cover factor

P = Conservation practice factor

Rainfall erosivity factor (R)

Narain *et al*. (1982) calculated the rainfall erosivity index (EI_{30}) for Kota in Rajasthan using the formula of Wischmeier and Smith (1978).

$$EI_{30} = \frac{KE \times I_{30}}{100}$$

Where,

EI_{30} = erosive index

KE = kinetic energy of storm (metre tons per ha cm)

I_{30} = maximum 30 minutes rainfall intensity

The estimated average erosive index for an average rainfall of 784 mm in Kota is 354. This value is used in the present study to calculate the erosive index for Adarsha watershed where the average rainfall in the area is around 800 mm. The extrapolated value of erosive index for the study area is 361.

Soil erodibility factor (K)

Narain et al. (1982) estimated soil erodibility factor for Kota region in Rajasthan by using the formula of Wischmeier and Smith (1978). The soil type and climatic condition of the study area is similar to the Kota in Rajasthan. So in this study, the soil erodibility factor for clay soil in Kota (106.3 kg/ha/unit of R at 1 % slope) is used to estimate the erodibility factor for Adarsha watershed.

The formula for estimating erodibility factor K is

$$K = A / R$$

$$A = A_0 / S$$

Where,

K = erodibility factor (kg/ha/unit of R)

A = expected soil loss from fallow plot (kg/ha)

A_0 = observed soil from fallow plot (kg/ha)

S = slope gradient factor

R = rainfall erosivity factor

Slope length factor (L)

The slope length factor is calculated by using the formula given by Wischmeier and Smith (1965).

$$L = [\lambda / 22]^{0.5}$$

Where,

λ = the field slope length in meters

Slope Gradient Factor (S)

The slope gradient factor is also calculated by using the formula given by Wischmeier and Smith (1965).

$$S = [0.43 + 0.30(s) + 0.43(s)^2]/6.613$$

Where,

s = the slope percentage of the field

Crop cover and management factor (C and P)

The C values for dominant crops cultivated during monsoon season and P values for major conservation practices were computed from the field experiments data by CSWCRTI, Dehradun and its regional stations (Singh *et al*., 1981; Narain *et al*., 1982; Verma *et al*., 1983 and Kurothe, 1991). The C and P factors for the Adarsha watershed are given in Appendix 4.

The average annual soil loss per ha for different crops grown in Adarsha watershed without any conservation practices are estimated using USLE and the estimated values is presented in Table 3.4.

Table 3.4 Estimated soil loss (t/ha) using USLE method

S.No	Crops	Soil loss (t/ha)*
1	Sorghum	3.41
2	Maize	2.99
3	Pigeon pea	5.45
4	Chickpea	3.07
5	Cotton	5.45
6	Sunflower	3.56
7	Onion	4.89
8	Vegetables	4.56

Note: * the soil loss per ha is with only contour bunding but not other *insitu* S&W conservation practices (e.g. BBF and bund strengthening by planting *Glyricidia*).

3.5 Conceptual framework of bioeconomic model

The conceptual framework of bioeconomic household model given in Figure 3.1 explains the mechanisms occurring in rural areas and draws mainly on the theory of induced innovation in agriculture (Boserup, 1965 and Binswanger and McIntire, 1997). This theory argues that people endogenously adapt to changes in the conditions they confront, and these adaptive responses are the main sources of technical and institutional change in agriculture. Boserup (1965) also argued that technological and institutional innovations are caused by population growth and resulting changes in land use.

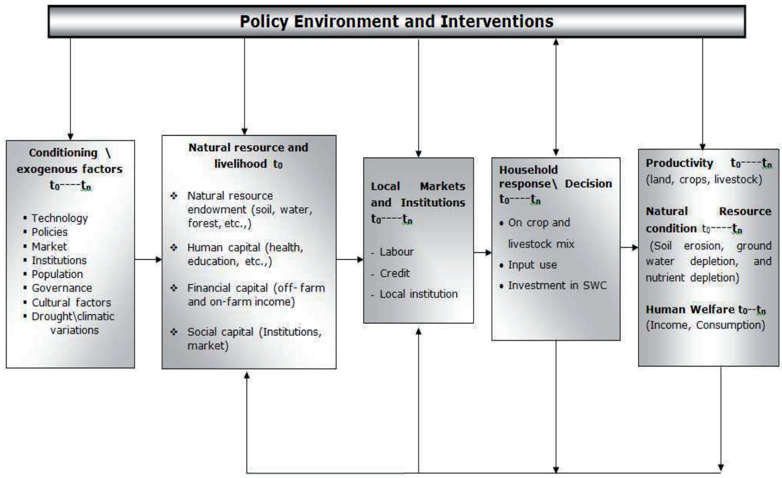
Other authors have expanded on Boserup's model by incorporating other exogenous factors that also stimulate endogenous agriculture change. Wani *et al*., (2002) argue that improved crop management practices (high yielding varieties, INM, IPM, soil and water conservation) significantly increased the yields of the dry land crops like sorghum, maize, pigeon pea when compared to the traditional crop management system followed by the farmers, also cause agriculture growth in the SAT region.

The soil and water management technologies in the watershed including field bunding, gully plugging and check dams across the main water course, along with improved soil, water, nutrient and crop management technologies significantly reduces runoff of rainwater and soil loss compared to the untreated land in the watershed. The SWC technologies also play an important role in increasing the groundwater level of most wells; particularly those located near the check dams and encourage supplemental irrigation for the crops grown in the post rainy season (Wani *et al*., 2002).

Lele and Stone (1989) argue that government policies play an important role in shaping the nature and impacts of agricultural change, particularly the impact on natural resources and the environment. According to Gulati and Kelley (1999) the low returns to some of the dry land crops like sorghum and pulses (chickpea and pigeon pea) are due to policy distortions (public distribution and pricing policies in India) that lower relative prices of these commodities compared to other competing crops like rice and wheat. The indirect subsidies (like free power for lift irrigation, fertilizer and seed subsidies, etc) to the irrigated crops make farmers to shift from the water saving dry land crops to other water intensive crops like paddy, cotton, vegetables and flowers (Shiferaw *et al*., 2003b).

Shiferaw and Holden (1998) and Shiferaw *et al*., (2003a) argue that availability of credit and households with more male workforce are positively influencing the SWC investment. The increase in average off-farm income per capita or per ha of cultivated land is negatively associated with net return to cropping and also lowers per ha labour input, fertilizer use and investment in SWC.

Figure: 3.1 Conceptual Framework



The conceptual framework incorporates these exogenous factors of agricultural change under the term conditioning / shift factors (Figure 3.1). External factors include the natural rate of population growth, changes in market access and development of market for input and output, exogenous technological change (like HYV, SWC technologies, cropping systems, cereal-legume rotations, etc.) and changes in government policies affecting the prices, access to resources, property rights and other factors of agricultural production. The impact of these factors will be affected by local natural resource endowment, human, financial and social capital in a particular watershed. These variables can be thought of as determining the constraints on decisions at the community and household levels.

The conceptual framework of a bio-economic household model (Figure 3.1) gives the interaction of exogenous factors with household decisions, production, consumption and the condition of the natural resource base. These changes in turn induce the endogenous household decision on land use, livestock mix, adoption of soil and water conservation technologies, new crop varieties and fertilizer use, which jointly determine the rate of land degradation, productivity and income. The outcome of these changes is reflected in economic performances, natural resource conditions and social well-being of the households. The conceptual framework described above will be used to simulate the resource use and investment behaviour of farm households in the case study watershed. Based on the conceptual framework the hypotheses of the study are postulated.

3.6 Bioeconomic model for Adarsha watershed, Kothapally

A farm household linear programming model has been widely used to predict the impact of technology and policy interventions on human needs and environment (Nakajima 1986; Shiferaw and Holden, 1998). More recently, a new type of model called bioeconomic model has been developed and used as a tool for assessing the impact of technologies and policies on the natural resources and human welfare. A bioeconomic model links mathematical programming models of farmer's resource management decisions to biophysical models that describe production process as well as the condition of natural resources (Barbier and Bergeron, 2001) addressing both agricultural production and environmental concerns.

3.6.1 Watershed level maximization

A watershed (or catchments) is a geographical area that drains to a common point, which makes it an attractive unit for technical efforts to conserve soil and maximize the utilization of surface and subsurface water for better crop production (Kerr, *et al*., 2000). A watershed is a geographically defined boundary with high biophysical variation and lands that fall under different property regimes. Assessment of production and conservation technologies at a household level is, however, too restrictive as it ignores the natural delineation of the landscape, and hence the biophysical scale of the problem. It also avoids consideration of resource multi-functionality and multi-dimensional trade-offs that emerge from household agricultural production (Rhoades, 1998). In the rural villages several farm level constraints such as human labour, bullock labour, and irrigation water are not strictly binding at the farm level and the households interact with each other through labour and water markets. Household decisions include communal considerations at a landscape level, especially where a community participatory watershed management approach is in place. Thus the analysis of the problem at an aggregate watershed level is viewed as more appropriate than individual household level.

A dynamic non-linear bioeconomic model is developed for Adarsha watershed, where community participatory watershed project was implemented[2]. The model designed at the micro watershed level, includes three household groups (small, medium, and large framers), who are spatially disaggregated by six different segments in the watershed landscape (defined by two land types and three soil depth classes). This gives 18 farm submodels within the watershed model.

The model maximizes the aggregate net present value of income of the watershed over a 10 year planning horizon. The income of the household groups is defined as the present value of future income earned from different livelihood sources (like crop, livestock, non-farm, wage, etc.) subject to constraints on level, quality and distribution of key production factors (e.g., land, labour, capital, bullock power, soil depth), animal feed requirement and minimum subsistence food requirements for the consumers in each household group.

3.6.2 The division of the micro watershed or landscape units

The micro watershed is delineated into three types of soil based on the top soil depth, namely (i) shallow depth soil (less than 50cm), (ii) medium depth soil (50-90 cm) and (iii) deep depth soil (greater than 90 cm). Each soil type is further divided into two types of land based on the availability of irrigation facilities as (i) irrigated land and (ii) rainfed or dryland. The entire micro watershed is grouped under three groups of farm types namely (i) small farmers (< 2 ha), (ii) medium farmers (2.01- 4.0 ha) and (iii) large farmers (> 4.01 ha). Hence three soil types, two land types and three groups of farmers lead to 18 land management units in the watershed.

The spatial disaggregation of the watershed helps to avoid major externality problems (Barbier and Bergeron, 2001) arising across the 18 land units. The major advantage of spatial divisions is to identify more homogenous units for tracking the effect of new crop and NRM technologies. This is also to account for yield differences on different soils and differences in the required management practices. The plots in the watershed are all sloping towards some common drainage channels, hence the movement of soil and nutrients does not get deposited in neighboring plots or fields in the watershed. Since the eroded soil is not assumed

[2] The model is developed in the General Algebraic Modeling System (GAMS) (Brooke, Kendrick and Meeraux, 1992)

to be deposited in the nearby farmers' fields, the externality does not affect the model solution while running on micro watershed level.

In Adarsha watershed, the rainwater collected in the checkdams constructed across the main streams is not used by the farmers for irrigation directly. The water harvested through checkdams will be used for natural recharging of groundwater in the watershed. Farmers are not allowed to use the water in the checkdams for irrigation or other purposes. This reduces the externality problem between upstream and downstream farmers as the upstream farmers do not capture all the benefits of water conservation.

3.6.3 Population and labour

The available farm family labour in the watershed is constrained by the active population residing there each year. Based on the exogenously given initial population in each household groups and annual growth rate of population in the region, the total workforce in each household group is projected. The total family labour days available for each household group in each season is calculated by deducting the regional festival holidays and important village functions in available labour days in a season for each work force in a household group. Allocation of available family labour into on-farm and off-farm activities in the village and non-farm activities outside the village is incorporated in the model seasonally. Farmers can hire or sell seasonal labour days within the watershed to meet seasonal scarcities in family labour. The hiring in and out of labour days within the watershed occurs at exogenously given wage rates, which assumed to be same for both hiring in and out of labour in the watershed.

The availability of non-farm employment is assumed to be limited in the model. The wage rate for non-farm employment is higher compared to farm labour wages due to skills needed in non-farm employment, which includes tailoring, construction works, driving, industrial works etc. The young workers in the watershed are regularly going to nearby towns to find non-farm employment. To find non-farm employment the labours has to spend some money for traveling and this is also included in the model by assuming some cost for travel to nearby town.

3.6.4 Crop production

The model includes nine crops like sorghum, maize, paddy, cotton, chickpea, pigeon pea, vegetables, sunflower and onion. Sorghum, maize, paddy, cotton, and vegetables are cultivated during rainy (*kharif*) season and chickpea, vegetables, sunflower and onion are grown during post-rainy (*rabi)* season. Cotton, vegetables and onions are cultivated in both rainfed and irrigated fields. Paddy is grown only under irrigated condition. Sorghum and maize crops are intercropped with pigeon pea in the ratio of 80:20 during *rainy* season. Crop choice in the watershed depends on the profitability (prices and yields), food, fodder, labour demand and distribution, suitability of different type of soil and land types and access to inputs (like seeds and fertilizers).

A simplified crop production function is used in the model to represent farmers' average expected response to different factors of production. The production functions are specified for each crop, soil type, land type and year of the planning horizon[3]. The yield of the crop depends on the type of land (irrigated or rainfed), the amount of input application (seeds and fertilizers) and soil depth. Parameters for production functions are obtained from the results of the econometric analysis of the primary data. The total production of crop by household group is obtained by the yield multiplied by the cropped area of each household group.

3.6.5 Produce allocation and consumption

In the model, produces of sorghum, paddy, chickpea, and pigeon pea can either be stored and consumed by the population or sold in the nearby markets. The maize and sunflower production are not consumed directly by the population, however they are stored and sold in the markets. The vegetables produced in the watershed, which are perishable and unable to store are taken to the local markets (like Rythu Bazaar and sandha) by the farmers themselves for selling or some traders directly purchase the vegetables harvested in the fields for marketing to nearby towns.

The population in the watershed is assumed to consume a fixed amount of grains and vegetables depending upon the nutritional requirement for each year. The minimum nutrient requirement for each consumer in the watershed for a year is

[3] A complete development of the equation is given in the structure of bioeconomic model

constrained in the model to a quantity ensuring a minimum daily calorie intake and protein requirement per adult equivalent (ICMR recommendation for an adult for moderate activity in rural India is 2400 calories and 60 g of proteins per day).
The model is also flexible for complementing consumption by buying grains in the village or nearby markets. All the prices are exogenously given in the model based on the market prices for selling and buying of grains in the village and nearby markets.

3.6.6 Livestock production

Cows, buffaloes, bullocks, sheep, goats, and backyard poultry (chicken) are the common livestock types in the watershed. The productivity of livestock, birth rates, mortality rates, feed requirement, labour required for maintenance, milk production and culling rates are included in the model. Livestock population in the watershed is determined by initial population, birth and mortality rates. Each livestock unit requires labour time, veterinary expenses and dry matter as feed throughout the year. Bullocks are used for land preparation and transportation and cows and buffaloes for producing milk, which is sold or consumed in the farm. Livestock is fed with crop residues produced in the watershed or purchased feed in case of scarcity. Stover yields are modeled as a function of crop type and crop grain yields. Total fodder production and purchased feeds must satisfy the livestock dry matter requirements in the model. The livestock dung is collected and converted into farmyard manure (FYM), which involves labour time. During sowing of crops the FYM is broadcasted in the fields along with inorganic fertilizers. The quantity of manure produced by each household in the watershed in a year must be less than or equal to manure applied in the fields.

To simplify the model solution the number of animals in each category is treated as a continuous number, not an integer[4]. This applies to rearing, purchase, slaughter, and sale of animals. The decision to buy or sell animals may depend on livestock productivity, mortality rates, buying and selling prices, fodder availability, and cash constraint. The model itself can stimulate the size of the livestock herds based on the constraints given in the model and if it's economically profitable the model allows the households groups for buying and selling of livestock.

---

[4] A separate integer programming is required to model livestock number in integers. If we introduce in the present model, it will further complicate the model solution.

3.6.7 Land degradation

The main form of land degradation in the model is soil erosion and nutrient depletion. The soil depth in each land units depends on the initial soil depth and the cumulative level of soil erosion in the land units. Soil erosion affects soil depth in the model through a transition equation (Holden *et al*. 2005). The equation for estimating change in soil depth due to soil erosion in the 18 land units in the watershed is as follows

$$Sd_t = Sd_{t-1} - \tau Se_t$$

Where,

Sd = soil depth in cm

Se = soil erosion in tons per ha

τ = conversion factor (100 tons of soil erosion per ha reduces 1cm of soil depth)

Soil erosion under cropped area in the watershed is estimated using USLE model and exogenously included in the model. The total soil erosion in a land unit in the watershed is a function of the area grown under each crop in the unit land and soil loss under respective crop.

Nutrient balance in production-system is used to ascertain the sustainability of the systems (Pathak *et al*., 2005). Soils have a nutrient reserve controlled by their inherent fertility and management. A negative balance of such nutrients as N, P and K indicates nutrient mining and non-sustainability of the production system. The soil nutrient depletion in the model focuses on the nutrients nitrogen and phosphorus, and potassium, which are considered to be the main nutrients limiting crop production in the watershed. The balance or depletion per unit of land in the watershed depends on crop choice, yield of grains and residues, application of fertilizers and manures, soil or land type and erosion level[5] in the watershed. The nutrient balances in the soil are measured using the input and output factors governing the nutrient flow in the soil in kg/ha/yr (Stroorvogel and Smaling, 1990; Okumu *et al*., 2002). The input and output factors considered in this study are listed in Table 3.5.

[5] Nutrients are also lost through eroded soil, and this soil is richer in nutrients than the soil remaining behind.

Table 3.5 Input and output factors in nutrient balance equation.

Input	output
1. Mineral fertilizers	1. Harvested grains
2. Manures applied	2. Crop residues
3. Deposition of nutrients	3. Erosion
4. Biological N fixation	4. Leaching

3.7 Mathematical statement of the micro watershed level bioeconomic model

The model maximizes the present value of future income for the whole watershed. The watershed is managed by three groups of farmers. Each group has access to two types of land and three soil depth classes. This leads to 18 homogenous land units in the watershed.

The constraints are land, labour, capital, bullock labour, food, fodder for livestock, and soil depth. The main activities are crops, livestock production and on-farm and off-farm activities.

Endogenous variables are capitalized, coefficients are in small letters, and indices are subscripts.

Sets

a	livestock production activities
a1	milking animals (cows and she buffaloes)
a2	bullocks
c	crop production activities
ct	conservation technology used to reduce soil erosion
cr	type of credit (formal and informal)
f	type of fertilizers (urea and DAP)
fl	fertilizer level used (fl = 1, 2,........,10)
h	three household groups (small, medium and large)
l	two land types depending upon irrigation (irrigated and rainfed)
n	dietary nutrients for human consumption (carbohydrates, protein and fat)
pn	plant nutrients in fertilizers (N and P)
r	discount rate
s	three soil depth classes (shallow, medium and deep)
sa	seasons (12 months of the year)

t	time in years
z	consumption of other purchased products (like meat, oil, egg, etc)

Variables

ASOILER	average soil erosion in each land unit in tons
BUYSED	amount of crop seed stocks purchased in tons
BUYCON	amount of crop product brought for household consumption in tons
BULHIRE	number of bullock days hired
CROP	crop production activities in ha
CROPYL	crop yield after erosion in tons per ha
CRESID	crop residual bought for animal feed in tons
CONS	on-farm consumption of crop product in tons
CONOWNA	on-farm consumption of young animals born or own animal slaughtering activities in heads
CONPURA	the amount of purchased animals consumed in heads
CONOP	the amount of other products consumed in tons (like meat, oil, egg, milk)
CREDIT	credit borrowed from different sources in Rupees
CUMSOILER	cumulative soil erosion in each land unit in each year in tons
CDEPTH	soil depth reduction from initial depth in cm
DEPTH	soil depth change due to erosion in cm
DMANURE	total manure (in tons) production per year
FERTBUY	fertilizers purchased in market in tons
FALLOW	fallow land in ha
FAMLAB	family labour in man-days
HINCOME	household group income in Rupees
HIRLAB	hired labour to work in the field in man-days
INCOME	income of the household group in Rupees
LABHIN	labour hired in from other households within the watershed in man-days
LABOFM	labour used in off-farm activities in man-days
LABNFM	labour work in non-farm activities in man-days
LIVPROD	livestock production activities in number
LIVBUY	livestock purchased in number during the year
LIVSAL	livestock sold in number during the year
LIVREAR	new born rearing activities in heads
MANUSE	amount of animal manure applied on the fields in tons
MPROD	milk production in litres
MILCONS	milk consumed in litres
MILSAL	milk sold in litres
MIG	permanent migration of population
NITRO	nitrogen applied to crops in tons
POP	population of the watershed village

PHOS	phosphorus applied to crops in tons
RENTIN	land rent in from other household group for cultivation in ha
RENTOUT	land rent out by household group to other group in ha
SEED	amount of own crop product used as seed stock in tons
SELCROP	amount of crop production sold in tons
STORED	crop product stored for next year in tons
STOREDC	crop product stored for consumption in next year in tons
STOREDS	crop product stored for sale in next year in tons
TINCW	total income of the watershed in Rupees
TPROD	total production of crops in tons
SOILER	amount of soil eroded in each land unit in tons
TSOILER	amount of soil eroded in whole watershed in tons
WFORCE	work force in the watershed

Coefficients

area (h,l,s)	available cultivable area of land (ha) for household group *h*, land type *l* and soil type *s*
amilkp (a1)	average milk production per milking animal *a1* per year
bprice (c)	the buying price of crop output *c* in Rupees per ton
bwage	wage rate for bullock hiring in Rupees
bullreq (l,s,fl,c,sa)	bullock days required for a ha of crop production *c*, in land type *l*, soil type *s*, fertilizer level *fl* and in season *sa*
bavail (a2, sa)	the number of bullock labour days available in season *sa*
brate	birth rate or calving rate of female animal
cprice (c)	the market price of crop output *c* in Rupees per ton
concost (a1)	average amount spent for buying concentrates for milking animals *a1* in a year
conslab (c,ct)	labour used for conservation of field for crop *c* grown with conservation technology *ct*
cost(c)	the cost of pesticides used for each crop *c* in Rupees per ha
cnut(n,c)	the composition of nutrient *n* (carbohydrate, protein and fat) in crop products *c* consumed
culrate	the culling rate for livestock
drymreq (a)	dry matter requirement for each livestock type *a* in tons per year
dm	dry matter content of the crop residual
erosion (c,ct)	soil loss in tons per ha of each crop *c* cultivated with conservation technology *ct*
erfact	erosion soil depth conversion factor (100 tons soil erosion per ha reduces 1cm of soil depth)
fprice (f)	the price of chemical fertilizers type *f* in Rupees per ton
fertlev (pn,fl)	level *fl* of plant nutrients *pn* applied in tons per ha

fnut (pn,f)	the composition of plant nutrients *pn* per ton of fertilizers *f* (urea and DAP)
fmig	fraction of population migrating
irate (cr)	interest rate in per cent for different credit type *cr* in per cent
labsup (h,sa)	labour supply per workforce in each household group *h* in season *sa*
labuse (h,l,s,fl,c,sa)	labour required (man-days) for ha of crop *c* cultivation by household group *h*, in land type *l*, soil class *s* using fertilizer level *fl* in season *sa*
livlab(h,sa)	labour required for livestock herd maintenance (man-days) for household group *h* in season *sa*
lprice (a)	the market price of livestock *a* in Rupees per head
livnut (n,a)	the composition of nutrients *n* (carbohydrate, protein and fat) in livestock *a* consumed
mprice	the price of milk in village market in Rupees per litre
mrate	the mortality rate for livestock
manpypa (a)	collectable dry manure produced by livestock *a* (in tons) per year per animal
manut (pn)	the composition of plant nutrients *pn* (N and P) per ton of manure (FYM) applied
nfwage	the non-farm wage rate in Rupees
nres (c,pn)	marginal effect of crop *c* yield for change in plant nutrients N in tons
nsqres (c)	marginal effect of crop *c* yield for change in plant nutrients N square (N^2)in tons
nutreq (h,n)	the total annual nutritional requirement of the household group *h* for nutrient *n*
opnut (n,z)	the composition of nutrients *n* (carbohydrate, protein and fat) in other products *z* consumed
oprice (z)	the price of other products *z* consumed in Rupees per ton
popg	growth rate of population
pres(c,pn)	marginal effect of crop *c* yield for change in plant nutrients P in tons
psqres(c)	marginal effect of crop *c* yield for change in plant nutrients P square(P^2) in tons
pliv	proportion of productive milking animals
rprice	the price of crop residual in Rupees per ton
rent (l,s)	price of rent in and out land by land type *l* and soil class *s* in Rupees per ha
sprice (c)	the price of crop *c* seed stock purchased in Rupees per ton
seedrate (c)	seed rate of crop *c* per hectare in tons
sdepth (h,l,s)	initial soil depth (cm) in each land units of household group *h*, land type *l* and soil class *s*
stoyld (c)	the stover yield for a ton of crop *c* grain yield in tons

vetcost (a)	average veterinary cost for each livestock *a* in a year
wage	the village market wage rate in Rupees
yield (l,s,c)	average yield of crop *c* in different land type *l* and soil class *s* in tons per ha
yred (s,c)	marginal effect of crop *c* yield for 1cm change in soil depth in tons in soil class *s*

Equations

Income functions

The model maximizes total income of the watershed defined as the present value of the sum of household groups' income over *T* periods.

$$TINCW = \sum_{h=1}^{H}\sum_{t=1}^{T}(1/1+r)^{t}\cdot\left(INCOME_{h,t}\right) \qquad (1)$$

The household group *h* net income in time *t* is sum of crop, livestock, non-farm and wage income less the costs incurred for farm production (like seed cost, fertilizers cost, labour cost), livestock rearing cost, feed cost and interest paid for the credit received from different sources. The income equation is as follows.

$$\begin{aligned} INCOME_{h,t} &= \sum_{c=1}^{C} TPROD_{h,c,t}\cdot cprice_{c} - \sum_{c=1}^{C} BUYSED_{h,c,t}\cdot sprice_{c} \\ &- \sum_{f=1}^{F} FERTBUY_{h,f,t}\cdot fprice_{f} - \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{c=1}^{C} CROP_{h,l,s,fl,c,t}\cdot \cos t_{c} \\ &+ \sum_{a=1}^{A} LIVSAL_{h,a,t}\cdot lprice_{a} - \sum_{a=1}^{A} LIVBUY_{h,a,t}\cdot lprice_{a} \\ &+ \sum_{sa=1}^{SA} LABOFM_{h,sa,t}\cdot wage + \sum_{sa=1}^{SA} LABNFM_{h,sa,t}\cdot nfwage - \sum_{sa=1}^{SA} HIRLAB_{h,sa,t}\cdot wage \\ &- \sum_{sa=1}^{SA} HIRBUL_{h,sa,t}\cdot bwage - CRESID_{h,t}\cdot rprice + MILKSAL_{h,t}\cdot mprice \\ &- \sum_{cr=1}^{CR} CREDIT_{h,ct,t}\cdot irate_{cr} - \sum_{a=1}^{A} LIVPROD_{h,a,t}\cdot vet\cos t_{a} - \sum_{a2=1}^{A2} LIVPROD_{h,a2,t}\cdot con\cos t_{a2} \end{aligned} \qquad (2)$$

Crop production

Crop production is a function of yield of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t* and cultivated area of crop *c*, by household group *h*, in land type *l* and soil class *s*. The basic yield of a crop *c* in household group *h*, land type *l*, soil class *s* at time period *t* can be increased by the application of inorganic fertilizers (N and P) and conversely yield would be decreased by change in soil depth of the cropland due to erosion. The quadratic yield function in the model is given as

$$CROPYL_{h,l,s,fl,ct,c,t} = yield_{l,s,c} - yred_{s,c} \cdot CDEPTH_{h,l,s,t} + nres_c \cdot NITRO_{fl} + nsqres_c \cdot NITRO_{fl}^2 + pres_c \cdot PHOS_{fl} + psqres_c \cdot PHOS_{fl}^2 \quad (3)$$

Total crop production of crop *c* by household group *h* at time period *t* is a function of endogenous crop yield (CROPYL) of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t* and area (CROP) of crop *c*, in land type *l*, soil class *s*, at fertilizer level *fl*, conservation technology *ct*, at time period *t*.

$$TPROD_{h,c,t} = \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\left(CROPYL_{h,l,s,fl,ct,c,t} \cdot CROP_{h,l,s,fl,ct,c,t}\right) \quad (4)$$

The total crop production of crop *c* by household group *h* in year *t* is sold, stored, consumed by population and used as seeds. The household group *h* in year *t* is allowed to store the crop product for consumption and sell in the following year *t+1*. The crop production balance equation for crop *c* by household group *h* in year *t* is as follows

$$TPROD_{h,c,t} = CONS_{h,c,t} + SELCROP_{h,c,t} + SEED_{h,c,t} + STORED_{h,c,t} \quad (5)$$

$$STORED_{h,c,t} = STOREDC_{h,c,t+1} + STOREDS_{h,c,t+1} \quad (6)$$

Land use constraint

All the cultivable land in the watershed is divided into 18 homogenous land units. Each land unit is used for different combination of crops and the remaining land is left as fallow. The farmers in the watershed are allowed to rent in land for cultivation from other farmers. The land constrained equation in the model is

$$\sum_{c=1}^{C}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT} CROP_{h,l,s,fl,c,ct,t} + FALLOW_{h,l,s,t} + RENTOUT_{h,l,s,t} \leq area_{h,l,s} + RENTIN_{h,l,s,t} \quad (7)$$

The rented in (demand) land by land type *l,* and soil class *s* in year *t* must be less than or equal to rented out (supply) land by land type *l,* and soil class *s* in year *t*.

$$\sum_{h=1}^{H} RENTIN_{h,l,s,t} \leq \sum_{h=1}^{H} RENTOUT_{h,l,s,t} \quad (8)$$

Seed stock use

The seed rate per hectare of crop *c* is given exogenously. The total seed used by household group *h* in year *t* must be equal to sum of own seed stock (SEED) used by household group *h*, of crop *c* in year *t* and purchase seeds (BUYSED) by household group *h*, of crop *c* in year *t*.

$$seedrate_c \cdot \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT} CROP_{h,l,s.fl,ct,c,t} = SEED_{h,c,t} + BUYSED_{h,c,t} \quad (9)$$

Fertilizer use

The macronutrients *pn* (N and P) required for crop *c* are applied through inorganic fertilizers (like urea and DAP) and farmyard manure (FYM). The nutrients applied to the fields by household group *h* in year *t* in the watershed must be equal to sum of inorganic fertilizers bought and FYM applied to the field by the household group *h* in year *t*. The equation is given by

$$\begin{aligned}\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{c=1}^{C}\sum_{ct=1}^{CT} CROP_{h,l,s,fl,ct,c,t} \cdot ferlev_{pn,fl} &= \sum_{f=1}^{F}\left(fnut_{pn,f} \cdot FERTBUY_{h,f,t}\right) \\ + MANUSE_{h,t} \cdot 0.6 \cdot manut_{pn} + MANUSE_{h,t-1} \cdot 0.4 \cdot manut_{pn} & \end{aligned} \quad (10)$$

Capital or credit constraint

The capital is constrained in the model, the expenses incurred by household group *h* in year *t* for crop *c* and livestock *a* production is met through cash income earned by the household group h at time period t through sale of crop c, livestock a, off income and non-farm income earned. The model is assumed to have access for formal and informal credit in the village. The capital and credit constraint equation of household group h in year t in the model is as follows.

$$\begin{aligned}
&\sum_{c=1}^{C} BUYSED_{h,c,t} \cdot sprice_c + \sum_{c=1}^{C} BUYCON_{h,c,t} \cdot bprice_c + \sum_{a=1}^{A} CONPURA_{h,a,t} \cdot lprice_a \\
&\sum_{z=1}^{Z} CONOP_{h,z,t} \cdot oprice_z + CRESID_{h,t} \cdot rprice + \sum_{a=1}^{A} LIVBUY_{h,a,t} \cdot lprice_a \\
&+ \sum_{cr=1}^{CR} \left(CREDIT_{h,cr,t-1} \cdot (1 + irate_{ct}) \right) + \sum_{sa=1}^{SA} HIRLAB_{h,ss,t} \cdot wage + \sum_{sa=1}^{SA} HIRBUL_{h,sa,t} \cdot bwage \\
&+ \sum_{f=1}^{F} FERTBUY_{h,f,t} \cdot fprice_f + \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C} CROP_{h,l,s,fl,ct,c,t} \cdot \cos t_c + \sum_{l=1}^{L}\sum_{s=1}^{S} RENTIN_{h,l,s,t} \cdot rent_{l,s} \\
&+ \sum_{a=1}^{A} LIVPROD_{h,a,t} \cdot vet\cos t_a + \sum_{a2=1}^{A2} LIVPROD_{h,a2,t} \cdot con\cos t_{a2} \\
&\leq \sum_{cr=1}^{CR} CREDIT_{h,cr,t} + \sum_{c=1}^{C} SELCROP_{h,c,t} \cdot cprice_c + \sum_{a=1}^{A} LIVSAL_{h,a,t} \cdot lprice_a + \\
&+ \sum_{sa=1}^{SA} LABOFM_{h,sa,t} \cdot wage + \sum_{sa=1}^{SA} LABNFM_{h,sa,t} \cdot nfwage + + MILKSAL_{h,t} \cdot mprice \\
&+ \sum_{l=1}^{L}\sum_{s=1}^{S} RENTOUT_{h,l,s,t} \cdot rent_{l,s} \qquad (11)
\end{aligned}$$

Food consumption

The subsistence food consumption needs of the population are defined in terms of minimum nutrient requirement (carbohydrates, protein and fat). The daily calorie requirement for a consumer is converted into nutrients and multiplied with total consumers in household group h in year t to arrive the total minimum nutrients required in tons. It is important to note in each year the population growth will affect the number of consumers in each household group and therefore the minimum food requirement also grows proportionally with population growth. The minimum nutrient requirement of the population is met by on-farm consumption of crop c output, purchased consumption crop c products, consumption of own animals a, consumption of purchased animals a and consumption of purchased product z (like meat, egg, oil, etc). The food consumption constraint equation for household group h in year t is given as

$$\sum_{c=1}^{C} CONS_{h,c,t} \cdot cnut_{n,c} + \sum_{c=1}^{C} BUYCON_{c} \cdot cnut_{n,c} + \sum_{a=1}^{A} CONOWNA_{h,a,t} \cdot livnut_{n,a} + \sum_{a=1}^{A} CONPURA_{h,a,t} \cdot livnut_{n,a} + \sum_{z=1}^{Z} CONOP_{h,z,t} \cdot opnut_{n,z} \geq nutreq_{h,n,t} \quad (12)$$

Population and labour

The population in household group *h* at the end of year *t* is the beginning population (POP_{t-1}) adjusted for population growth rate (popg) minus permanent migrants (MIG). The permanent migration is limited to a fraction of the population. The population in household group *h* at time period *t* is converted into workforce (WFORCE) based on age and adjusted for growth rate of population.

$$(1+popg) \cdot POP_{h,t-1} - MIG_{h,t} = POP_{h,t} \quad (13)$$

$$MIG_{h,t} \leq fmig \cdot POP_{h,t} \quad (14)$$

$$(1+popg) \cdot WFORCE_{h,t-1} - WMIG_{h,t} = WFORCE_{h,t}$$

(15)

$$WMIG_{h,t} \leq fmig \cdot WFORCE_{h,t} \quad (16)$$

The labour days used by household group *h* for different farm activities (crop and livestock) in season *sa* at time period *t*, labour days used for conservation of land by household group *h* at time period *t,* labour days work on other household group farms (LABOFM) by household group *h* at time period *t*, and labour days work non-farm (LABNFM) by household group *h* at time period *t* have to be less than or equal to family labour (FAMLAB) in household group *h* in season *sa* at time period *t* plus the labour days hired in from other household group within the watershed (LABHIN) by household group *h* in season *sa* at time period *t*.

$$\sum_{l=1}^{L} \sum_{s=1}^{S} \sum_{fl=1}^{FL} \sum_{ct=1}^{CT} \sum_{c=1}^{C} \left(CROP_{h,l,s,fl,ct,c,t} \cdot labuse_{l,s,fl,c,sa} \right) + \sum_{l=1}^{L} \sum_{s=1}^{S} \sum_{fl=1}^{FL} \sum_{ct=1}^{CT} \sum_{c=1}^{C} \left(CROP_{h,l,s,fl,ct,c,t} \cdot conslab_{c,ct} \right) + livlab_{h,sa,t} + LABOFM_{h,sa,t} + LABNFM_{h,sa,t} \leq FAMLAB_{h,sa,t} + LABHIN_{h,sa,t} \quad (17)$$

The family labour plus off-farm and non-farm labour in household group *h* in season *sa* at time period *t* is less than the total work days available per household group *h* at time period *t*.

$$FAMLAB_{h,sa,t} + LABOFM_{h,sa,t} + LABNFM_{h,sa,t} \leq lab\sup_{h,sa} \cdot WFORCE_{h,t} \quad (18)$$

The following equation ensures the equilibrium of the supply of and demand for wage labour within the watershed in season *sa* at time period *t*.

$$\sum_{h=1}^{H} LABHIN_{h,sa,t} = \sum_{h=1}^{H} LABOFM_{h,sa,t} \quad (19)$$

Soil erosion and soil depth

The total annual soil loss in each land unit at time period *t* in the watershed is the result of cropping activities (CROP) for crop *c* by household group *h,* in land type *l,* soil class *s* at time period *t*. The following equation determines the soil loss in each land unit at time period *t*.

$$\sum_{fl=1}^{FL} \sum_{ct=1}^{CT} \sum_{c=1}^{C} \left(CROP_{h,l,s,fl,ct,c,t} \cdot erosion_{c,ct} \right) = SOILER_{h,l,s,t} \quad (20)$$

The total soil erosion in the watershed in year *t* is given by

$$\sum_{h=1}^{H} \sum_{l=1}^{L} \sum_{s=1}^{S} SOILER_{h,l,s,t} = TSOILER_{t} \quad (21)$$

The average soil erosion in each land unit at time period *t* is given by

$$ASOILER_{h,l,s,t} = \frac{SOILER_{h,l,s,t}}{area_{h,l,s}} \quad (22)$$

The cumulative soil erosion in each land unit in each year *t* is given by

$$CUMSOILER_{h,l,s,t} = ASOILER_{h,l,s,t-1} + ASOILER_{h,l,s,t} \quad (23)$$

The soil depth decrease as a result of soil erosion in each land unit in year *t* is given by

$$DEPTH_{h,l,s,t} = sdepth_{h,l,s} - erfact \cdot CUMSOILER_{h,l,s,t} \quad (24)$$

The change in soil depth from the initial soil depth of the land in year *t* is given by

$$CDEPTH_{h,l,s,t} = sdepth_{h,l,s} - DEPTH_{h,l,s,t} \quad (25)$$

Livestock modeling

The adult animal production by household group *h* in year *t+1* depends on initial animal in the start of the year *t*, animal bought, sold, young animal reared in the year, culling rate and mortality rate of the animal. The livestock type *a* production by household group *h* in a year *t* is estimated as follows.

$$\begin{aligned} LIVPROD_{h,a,t+1} &= (1 - culrate - mrate) \cdot LIVPROD_{h,a,t} + LIVBUY_{h,a,t+1} \\ &+ LIVREAR_{h,a,t} - LIVSAL_{h,a,t+1} \end{aligned} \quad (26)$$

Production of young animal type *a* by household group *h* in year *t* is computed based on the birth rate or calving rate of animal, consumption of young animal on-farm and selling of young animal in year *t*. The equation for young animal balance is given as

$$brate \cdot LIVPROD_{h,a,t} = LIVREAR_{h,a,t} + CONOWNA_{h,a,t} + LIVSAL_{h,a,t} \quad (27)$$

These equations are adjusted for different animal type *a* depending on the time required in different age classes and their reproduction characteristics[6].

Livestock feed requirement

The feed requirements for livestock type *a* in year *t* in the watershed have to be fulfilled by locally produced forage by crop *c* by household group *h,* in land type *l,* soil class *s,* at time period *t* or purchased crop residual by household group *h,* at

[6] The details are given below the equation for each animal in GAMS model in appendix

time period *t*. The equation for livestock feed by household group *h,* at time period *t* is follows.

$$\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,c,t}\cdot CROPYL_{h,l,s,fl,c,t}\right)\cdot stoyld_{c} + dm\cdot CRESID_{h,t} \geq \sum_{a=1}^{A} LIVPROD_{h,a,t}\cdot drymreq_{a} \quad (28)$$

Milk production

The milk production in the watershed by household group *h,* at time period *t* is estimated by multiplying number of cow or she buffalo in household group *h,* at time period *t*, milk production per cow or she buffalo per year and the proportion of productive cows or she buffaloes. The milk produced by household group *h,* at time period *t* is either sold or consumed by the household groups.

$$amilkp_{a1}\cdot pliv\cdot LIVPROD_{h,a1,t} = MPROD_{h,a1,t} \quad (29)$$

$$MILCONS_{h,t} + MILSAL_{h,t} = \sum_{a1=1}^{A1} MPROD_{h,a1,t} \quad (30)$$

Bullock labour constraint

In the watershed farmers use bullock labour for land preparation, preparation of soil beds, transportation of produce from field to home and transportation of FYM to the fileds. In the model the demand for bullock labour days for household group *h,* at time period *t* must be satisfied by available bullock labour and through hiring of bullock by household group *h,* at time period *t* in the watershed.

$$\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\sum_{c=1}^{C}\left(CROP_{h,l,s,fl,c,t}\cdot bullreq_{l,s,fl,c,sa}\right) \leq bavail_{a2,sa}\cdot LIVPROD_{h,a2,t} + BULHIRE_{h,a2,sa,t} \quad (31)$$

Manure production

Organic manure (FYM) is used in the crop production to supply micronutrients along with inorganic fertilizers (urea and DAP). The manure production by household group *h,* at time period *t* is limited by number of livestock produced and reared and collectable manure production by each animal type *a* of household group *h,* at time period *t* in the watershed. The manure production by each household group in year *t* in the watershed is given as

$$DMANURE_{h,t} = \sum_{a=1}^{A}\left(LIVPROD_{h,a,t} \cdot manpypa_a\right) + \sum_{a=1}^{A}\left(LIVREAR_{h,a,t} \cdot manpypa_a\right) + \sum_{a=1}^{A}\left(LIVBUY_{h,a,t} \cdot manpypa_a\right) \quad (32)$$

The farmyard manure applied (MANUSE) in the fields by household group *h*, at time period *t* must be less than the manure production (DMANURE) by household group *h*, at time period *t*.

$$MANUSE_{h,t} \leq DMANURE_{h,t} \quad (33)$$

Soil nutrient balance

Nutrient depletion in the soils is one of the main causes for soil degradation. A soil nutrient balance in the watershed at time period *t* is the net removal (inflow minus depletion) of nutrients from the rootable soil layer. Nutrient balances are computed using the following equation (Okumu *et al*., 2002).

$$NUTBAL_{pn,t} = \left[\sum_{c=1}^{C}\left(TCAREA_{c,t} \cdot nutpha_{c,pn,t}\right) + \sum_{c=1}^{C}\left(TCAREA_{c,t} \cdot nitrofix_{c,pn}\right) + \sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{h=1}^{H} area_{l,s,h} \cdot nutdep_{pn}\right]$$

$$- \left[\begin{array}{l}\sum_{h=1}^{H}\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{c=1}^{C}\sum_{fl=1}^{FL}\sum_{ct=1}^{CT}\left(CROPYL_{h,l,s,fl,ct,c,t} \cdot npkconh_{c,pn}\right) + \sum_{h=1}^{H}\sum_{l=1}^{L}\sum_{s=1}^{S}\sum_{c=1}^{C}\left(CROPRESY_{h,l,s,c,t} \cdot npkconr_{c,pn}\right) \\ + TSOILER_t \cdot nleros_{pn}\end{array}\right]$$

Where,

NUTBAL	nutrient balance of N and P in time *t*
TCAREA	total area of each crop *c* cultivated in the watershed in ha in time *t*
CROPYL	grain yield of each crop *c* in land type *l*, soil type *s*, fertilizer level *fl* and household group *h* in time *t*

CROPRESY	crop residual yield of each crop *c* in land type *l*, soil type *s*, and household group *h* in time *t*
TSOILER	total soil erosion in watershed in time *t*
nutpha (c,pn,t)	amount of nutrients *pn* applied on a unit (ha) of crop activity *c* through chemical fertilizers and FYM in time *t*
nitofix (c,pn)	amount of nutrient *pn* added to the soil by crop activity *c* e.g. nitrogen fixation.
nutdep (pn)	per ha addition of nutrient *pn* through atmospheric deposition
npkconh (c,pn)	amount of nutrient *pn* contained in a unit grain of crop *c* harvested
npkconr (c,pn)	amount of nutrient *pn* contained in a unit residual of crop *c*
nleros (pn)	amount of nutrient *pn* in a unit of soil lost through erosion

CHAPTER IV

DESCRIPTION OF THE STUDY AREA

The utility of research can be valued only when the results are analyzed with the background information of the study region such as economic, biophysical, social, and natural resources conditions. This will provide the background for analysis, interpretation and discussion of the results and helps in drawing meaningful inferences. The information regarding the geographical location, demography, land use pattern, temperature, rainfall, soil types, irrigation, distribution of fertilizers, and other infrastructural features of the Andhra Pradesh state, Ranga Reddy district and Adarsha watershed in Kothapally village are highlighted in this chapter.

4.1 Location

Andhra Pradesh is the fifth largest State in India covering 274 400 sq kms. It lies between 12º 14' and 19º 45' N latitudes and 76º 50' and 84º 50' E longitudes and occupies about eight per cent of the total geographical area of the country. It is bounded by Maharastra in the North, Orissa and Chattisgarh in the Northeast, Tamil Nadu in the South and Bay of Bengal in the East and Karnataka in the West. The state is divided into three administrative regions viz., Coastal Andhra, Rayalaseema and Telangana, which occupy 34 per cent, 24 per cent and 42 per cent respectively of total geographical area of the state. These regions are incidentally the traditional agro-climatic zones of the state. Andhra Pradesh has 23 districts spread over three regions with nine in Costal Andhra, four in Rayalaseema and ten in Telangana.

Ranga Reddy District is located in Northern Telangana plateau between 16º 30' and 18º 20' N latitudes and 77º 30' and 79º 30' E longitudes which is characterized by hot and moist semi-arid conditions. It is bounded by Medak district in the North, Mahbubnagar in the South and Nalgonda district in the East and Karnataka state in the West. The district covers an area of 753 000 ha and divided into 37 revenue mandals.

4.2 Population

The population characteristics and distribution of population of the state and district are furnished in Table 4.1.

As per the census of 2001, the total population of Andhra Pradesh is about 76.11 million, in that 50.57 per cent is male population, 49.43 per cent is female population and 72.65 per cent of the population is found in rural areas. Its decennial growth rate is 14.44 per cent. This translates into a population density (per sq.km) of 277 persons and about 5.25 person per ha of net sown cultivable land in the rural areas of the state. In terms of literacy, the state of Andhra Pradesh ranks 29th among the 32 States and nine Union Territories of India (Census of India, 2001). The level of literacy in Andhra Pradesh in the year 2003 is about 61.60 per cent. The total population of Andhra Pradesh constitutes 15.93 and 6.31 per cent of schedule caste and schedule tribe population respectively. The population of the State is further divided into main workers, marginal workers and non-workers that constitute 38.10, 7.70 and 54.20 per cent respectively to the total population.

The total population of the Ranga Reddy district is about 3.59 million out of which, 51.57 per cent is male population, 48.58 per cent is female population and only about 48.58 per cent of the population lives in the rural areas. Its decennial growth rate is 37.41 per cent, which is double when compare to the State growth rate. The population density is 479 persons per sq.km and 5.86 persons per ha of net sown cultivable land in the rural areas of the district. The literacy level in the district is 67.91 per cent, which is slightly above the state literacy level. In the total population of the district schedule caste and schedule tribe population constitutes 17.22 and 4.29 per cent respectively. The distribution of the total population in the district into main workers, marginal worker and non-workers are about 35.20, 4.70 and 60.10 per cent respectively.

Table 4.1 Population characteristic of Andhra Pradesh and Ranga Reddy district (based on 2001 census)

Particulars	Andhra Pradesh	Ranga Reddy district
Total population (in millions)	76.11	3.59
Male population (in millions)	38.49 (50.57)	1.85 (51.57)
Female population (in millions)	37.62 (49.43)	1.74 (48.43)
Rural population (in millions)	55.29 (72.65)	1.64 (48.58)
Population growth rate (%) (1991-2001)	14.44	37.41
Density of population (per sq.km)	277	479
Rural population density (person per ha of net sown area)	5.25	5.86
Literacy rate (%)	61.60	67.91
Schedule caste population to total population (%)	15.93	17.22
Schedule tribe population to total population (%)	6.31	4.29
Distribution of Total population		
Main workers (in millions)	29.00 (38.10)	1.26 (35.20)
Marginal workers (in millions)	5.86 (7.70)	0.17 (4.70)
Non – workers (in millions)	41.25 (54.20)	2.16 (60.10)

Figures in parentheses indicate percentage to total population.
Source: Census of India, 2001, Directorate of Census Operation, Hyderabad.

4.3 Agro-climatic features

4.3.1 Soils

In coastal Andhra region, red loams, sandy clay loams and black cotton soils are the predominant soil types. In Rayalaseema region, red loams, red sandy loams and black clay soils are important while sandy loams, black soils and loamy sands are the important soil types in Telangana[7]. The Ranga Reddy district is in Telangana region of Andhra Pradesh, where black soils are predominant soil type.

[7] Perspective Plan for Coastal Andhra and Telangana, 1972

4.3.2 Climate

Based on the climate conditions, Andhra Pradesh comes under the tropical and sub-tropical regions of the country. The climate is largely semi-arid to arid for the state as a whole while the Coastal belt presents humid to sub-humid climate. The Ranga Reddy district is in Telangana region comes under semi-arid tropics.

4.3.3 Seasons

There are three distinct seasons in Andhra Pradesh, namely rainy (*kharif*), post-rainy (*rabi*) and summer. Rainy is the main agricultural season, which commences in June and ends in October. Post-rainy commences from November and ends on February, while summer extend from March to May.

4.3.4 Temperature

The maximum and minimum temperatures range from 24ºC to 45ºC and 12ºC to 25ºC respectively. Season-wise, the mean maximum and minimum temperatures range from 29ºC to 32ºC and 20ºC to 25ºC in *rainy*. They are 24ºC to 29ºC and 12ºC to 20ºC in *post-rainy*. The maximum temperature touches 45ºC.

4.3.5 Rainfall

Andhra Pradesh receives rainfall in four distinct periods viz., South-west monsoon period (June to September), North-east monsoon period (October to December), winter period (January to February), and hot weather period (March to May). The rainfall distribution in Andhra pradesh and Ranga Reddy district from 2000-01 to 2002-2003 is presented in the Table 4.2. The figures revealed that most of the total rainfall in Andhra Pradesh is received in South-west (70.90 per cent) and North-east (21.19 per cent) monsoon periods. Ranga Reddy district received 77.6 per cent of the total rainfall during South-west monsoon period and only 15.48 per cent during North-east monsoon period. Both Andhra Pradesh and Ranga Reddy district received deficit rainfall in all the four seasons during the period from 2000-01 to 2002-03 because of drought in two consecutive years (2001 and 2002).

Table 4.2 Rainfall distributions in Andhra Pradesh and Ranga Reddy district (average of 2000/01 to 2002/03)

(in mm)

Season	Andhra Pradesh	Ranga Reddy district
South West monsoon[1]		
Rainfall	570 (70.90)	582 (77.46)
Normal	624 (66.38)	588 (75.20)
% of deviation over normal	-8.65	-0.91
North-east monsoon[2]		
Rainfall	170.33 (21.19)	116.33 (15.48)
Normal	224 (23.83)	132 (16.99)
% of deviation over normal	-23.96	-12.31
Winter period[3]		
Rainfall	12 (1.49)	7.33 (0.98)
Normal	14 (1.49)	8 (1.02)
% of deviation over normal	-14.29	-8.33
Hot weather[4]		
Rainfall	51.67 (6.42)	45.67 (6.08)
Normal	78 (8.30)	53 (6.79)
% of deviation over normal	-33.76	-13.84
Total Annual rainfall		
Rainfall	804 (100.00)	751.33 (100.00)
Normal	940 (100.00)	781 (100.00)
% of deviation over normal	-14.47	-3.79

Note: Figure in the parentheses indicate percentage to annual rainfall
Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.
1. June to September; 2. October to December; 3. January to February; 4. March to May

4.4 Land utilization pattern

The land utilization pattern in Andhra Pradesh state and Ranga Reddy district are presented in the Table 4.3. The share of area under cultivation to the total geographical area in Andhra Pradesh is about 46.40 per cent, of which 38.24 per cent is net sown area, while 8.16 per cent is the area sown more than once. About 22.60 per cent of the total geographical area is occupied by forest followed by 7.61 per cent by barren and uncultivable land, 2.55 per cent by cultivable wasteland, 9.43 per cent by land put to non-agricultural uses, 2.46 per cent by permanent pastures and other grazing lands and 1.01 per cent by land under miscellaneous, trees, groves not included in the net area sown. Fallow lands occupy about 18.90 per cent in which current fallow land is 12.78 per cent and other fallow land is 6.12 per cent.

Table 4.3 Land utilization pattern (average of 2000/01 to 2002/03)

(Area in '000 hectares)

S. No.	Particulars	Andhra Pradesh	Ranga Reddy district
1.	Total geographical area	27440.05 (100.00)	753.25 (100.00)
2.	Forest	6199.23 (22.60)	73.08 (9.65)
3.	Barren and uncultivable land	2089.66 (7.61)	38.51 (5.05)
4.	Cultivable waste	700.65 (2.58)	23.60 (2.92)
5.	Land put to non-agricultural uses	2552.38 (9.30)	88.67 (11.69)
6.	Permanent pastures and other grazing lands	676.06 (2.46)	42.36 (5.58)
7.	Land under miscellaneous, trees, groves not included in the net area sown	277.032 (1.00)	6.70 (0.80)
8.	Current fallows	2942.43 (10.72)	149.75 (19.79)
9.	Other fallows	15.06 (5.49)	6.10 (8.10)
10.	Net area sown	10492.43 (38.24)	274.35 (36.42)
11.	Area cultivated more than once	2240.69 (8.16)	26.21 (3.48)
12.	Gross cultivated area	12733.12 (46.40)	300.53 (39.90)
13.	Cropping Intensity	1.21	1.09

Note: Figures in the parentheses indicate percentage.
Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.

The Ranga Reddy district covers an area of 753 247 ha. The land use pattern in the district shows that 36.39 per cent is the net sown area and the area cultivated more than once is only 3.45 per cent, which indicates mostly rainfed agriculture in the district. The forest occupies about 9.69 per cent, permanent pastures and other grazing lands is 5.58 per cent and the non-agricultural land (barren, non-agricultural uses and settlement) occupies about 25.24 per cent. About 19.79 per cent is under current fallow land due to poor monsoon in the district.

4.5 Area under food and non-food crops

In Andhra Pradesh about 68.57 per cent and 31.43 per cent of total cropped area is under food and non-food crops respectively (Table 4.4). In Ranga Reddy district about 85.68 per cent of the total cropped area is under food crops and only 14.32 per cent under non-food crops (Table 4.4), this is because the district is in semi-arid tropics with low annual rainfall and subsistence farming practiced by farmers. The area sown more than once is also low (8 per cent) in Ranga Reddy district, this is due to rainfed agriculture and less irrigation source. It is observed from the Table 4.5 that in Andhra Pradesh, among food grain crops paddy occupies 30.57 per cent, total pulses occupies 13.21 per cent and sugarcane occupies only 1.28 per cent of the total cropped area. Among non-food crops the major area is cultivated by groundnut 14.11 per cent and cotton occupies 8.2.4 per cent of the total cropped area in Andhra Pradesh. In Ranga Reddy district the important crop among food crops is sorghum, which occupies 24.52 per cent of the total cropped area and followed by 16.56 per cent of paddy and 10.86 per cent of pigeonpea. Among non-food crops in Ranga Reddy district cotton occupies 6.40 per cent of the total cropped area followed by groundnut only 2.13 per cent. It is clear from the Table 4.5 that Ranga Reddy district has comparative advantage for dryland crops like sorghum and other millets due to low rainfall and less irrigation facilities.

Table 4.4 Area under food and non-food crops (average of 2000/01 to 2002/03)

(Area in '000 ha)

S.No	Particulars	Andhra Pradesh	Ranga Reddy district
1.	Total food crops	8730.52 (68.57)	257.49 (85.68)
2.	Total non-food crops	4002.60 (31.43)	43.04 (14.32)
3.	Total cropped area	12733.12 (100.00)	300.53 (100.00)
5.	Area sown more than once	2240.69	26.21
6.	Net sown area	10492.43	274.32

Note: Figures in the parentheses indicate percentage to total cropped area.

Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.

Table 4.5 Area under different crops and its share to total cropped area (average of 2000/01 to 2002/03)

(Area in '000 hectares)

S. No.	Particulars	Andhra Pradesh	Ranga Reddy district
I	**Food crops**		
	a. Cereals and millets		
	Paddy	3979.71 (30.57)	51.55 (16.56)
	Sorghum	718.71 (5.52)	76.68 (24.52)
	Pearl millet	114.95 (0.88)	1.09 (0.38)
	Finger millet	95.69 (0.74)	7.03 (2.23)
	Maize	440.50 (3.39)	8.41 (2.68)
	Total minor millets	65.55 (0.50)	0.49 (0.15)
	Total cereals and millets	**54.28 (41.70)**	**1.470 (46.82)**
	b. Pulses		
	Pigeonpea	415.63 (3.20)	34.10 (10.86)
	Chickpea	188.34 (1.44)	5.185 (1.62)
	Black gram	515.11 (3.96)	8.62 (2.74)
	Green gram	475.99 (3.66)	18.50 (5.87)
	Horse gram	96.29 (0.74)	1.94 (0.62)
	Total pulses	**1724.38 (13.24)**	**68.74 (21.88)**
	Total food grain crops	**71.52 (54.49)**	**2.160 (68.79)**
	c. Spices and condiments		
	Chillies	225.18 (1.73)	3.10 (0.98)
	Turmeric	61.54 (0.47)	5.82 (1.84)
	Coriander	82.31 (0.63)	0.28 (0.089)
	Ginger	2.25 (0.017)	0.060 (0.019)
	Total spices and condiments	379.56 (2.91)	9.31 (2.96)
	d. Vegetables		
	Onion	29.87 (0.23)	2.33 (0.74)
	Bendi	21.23 (0.16)	1.11 (0.35)
	Tomatoes	75.66 (0.58)	10.82 (3.43)
	Brinjal	21.10 (0.16)	1.94 (0.62)

	Total vegetables	224.54 (1.73)	22.64 (7.18)
	Sugarcane	**165.69 (1.28)**	**2.05 (0.67)**
	Total food crops	**8730.52 (68.57)**	**257.49 (85.68)**
II	**Non-food crops**		
			a. Edible oils
	Groundnut	1837.2 (14.11)	6.74 (2.13)
	Sunflower	291.34 (2.24)	1.32 (0.42)
	Safflower	18.87 (0.14)	3.99 (1.26)
	Sesamum	157.70 (1.21)	1.62 (0.51)
	Coconut	100.36 (0.77)	0.025 (0.007)
	Total edible oils	**2438.50 (18.73)**	**13.78 (4.37)**
	b. Non-edible oils		
	Castor	264.09 (2.03)	12.43 (3.95)
	Linseed	6.27 (0.048)	0.28 (0.08)
	Niger seed	18.40 (0.14)	0.59 (0.18)
	Total non-edible oils	**290.61 (2.23)**	**13.32 (4.23)**
	c. Fiber crops		
	Cotton	1072.50 (8.24)	20.12 (6.40)
	Mesta	77.70 (0.59)	0.0
	Total non-food crops	**4002.60 (31.43)**	**43.04 (14.32)**
	Total cropped area	**12733.12 (100.00)**	**300.53 (100.00)**

Figures in the parentheses indicate percentage to total cropped area.
Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.

4.6 Irrigation

Andhra Pradesh is popular as “River State”. It commands irrigation facilities through Godavari, Krishna, Pennar, Vamsadhara and Nagavalli rivers. The coastal Andhra receives the benefits from the canal system of Godavari, Krishna and Pennar and also from river valley projects like Nagarjuna Sagar and Polavaram, K.C. Canal system and river valley projects. Nagarjuna Sagar and Tungabhadra are irrigation potentials for Rayalaseema. The projects of Musi, Nagarjuna Sagar, Sree ram Sagar, Kadam and Nizam Sagar provides irrigation for Telangana region. The Table 4.6 revealed that the percentage of gross area irrigated to the total cropped area is 35.63 per cent for Andhra Pradesh, while it is only 23.15 per cent in Ranga Reddy district. This shows that most of the crops are grown in rainfed condition and also the low potential of irrigation system in the district.

Table 4.6 Area irrigated in Andhra Pradesh and Ranga Reddy District (average of 2000/01 to 2002/03)

(Area in '000 ha)

S.No	Particulars	Andhra Pradesh	Ranga Reddy district
1.	Net area irrigated	3613.66	52.93
2.	Area irrigated more than once	922.53	16.64
3.	Gross area irrigated (GAI)	4536.19	69.57
4.	Total cropped area	12733.12	300.53
5.	% of GAI to total cropped area	35.63	23.15

Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.

4.7 Productivity

The average productivity of the crops like paddy, pearl millet, maize, black gram, cotton, chillies and sugarcane are low in Ranga Reddy district when compared to State average yield (Table 4.7). But for dry land crops like sorghum, pigeon pea, chickpea and sunflower the yields are more than the State average yield. This show the comparative advantage of the dry land crops to Ranga Reddy district.

4.8 Consumption of fertilizer nutrients

Andhra Pradesh is the second largest consumer of fertilizer nutrients[8] (N, P_2O_5 and K_2O) in India, next to Uttar Pradesh (Fertilizer statistics, 2005). From the Table 4.8, it is observed that the consumption of inorganic fertilizers nutrients like nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) are 1193.40, 528.40, and 212.96 thousand tonnes respectively for the State as a whole. In the state, about 5 per cent of the fertilizer nutrients are distributed to Ranga Reddy district. The Table 4.8 shows that the availability of total NPK per ha of gross cropped area in Ranga Reddy district is 318.81 kg per ha, which is higher than the State availability (148.63 kg/ha). This clearly indicates that the farmers in the district apply more fertilizers to the crops grown per unit area.

[8] This indicates only fertilizer nutrients (N, P_2O5 and K_2O) from different sources and not the total fertilizers sold in marker with carrier materials.

Table 4.7 Productivity of important crops in Andhra Pradesh and Ranga Reddy district area (average of 2000/01 to 2002/03)

(Kg per ha)

S. No.	Particulars	Andhra Pradesh	Ranga Reddy district
1.	Paddy	2781	2381
2.	Sorghum	796	822
3.	Pearl millet	856	500
4.	Finger millet	1143	1169
5.	Maize	3172	2269
6.	Pigeon pea	348	585
7.	Chick pea	979	1237
8.	Black gram	541	442
9.	Groundnut	841	1106
10.	Sunflower	665	607
11.	Cotton	254	201
12.	Chillies	1831	1841
13.	Sugarcane	66190	63643

Source: Season and Crop Report of Andhra Pradesh, 2000-01 to 2002-03.

Table 4.8 Consumption of fertilizer nutrients in Andhra Pradesh and Ranga Reddy District (average of 2000/01 to 2002/03)

(‘000 tonnes)

S. No	**Particulars**	**Andhra Pradesh**	**Ranga Reddy district**
1	Nitrogen (N)	1193.40	49.38
2	Availability (kg/ha)	91.68	156.76
3	Phosphorus (P_2O_5)	528.40	33.11
4	Availability (kg/ha)	40.59	105.12
5	Potassium (K_2O)	212.96	17.93
6	Availability (kg/ha)	16.36	56.91
7	Total NPK	1934.7	100.42
8	Availability (kg/ha)	148.63	318.81

Source: Fertilizer Statistics, Fertilizer Association of India, 2005.

4.9 Infrastructural facilities

Infrastructural facilities are sine-qua-non for the development of people in any region. They consist of educational institutions, road and transport facilities, and banks and co-operatives.

4.9.1 Educational institutions

The state of Andhra Pradesh as on 2001 has 58249 primary schools, 11464 high schools, 2718 junior colleges and 1080 degree colleges in six universities. In Ranga Reddy district there are about 1760 primary schools, 808 high schools, 152 junior colleges.

4.9.2 Road and transport facilities

The road and transport facilities are very important for the farmers to gain access to markets. Access to markets facilitates the farmers to diversify agriculture and to obtain better price for the produce. The state of Andhra Pradesh has good network of motorable roads. It has 4104 kms of national highways, and 61039 kms of public works department road (state government). The state has 109430 kms of panchayati Raj and municipalities' road. The road density for Andhra Pradesh is 2.79 km/1000 population and 0.64 km/sq.km of state geographical area. The state is well connected by rail and the number of stations and length of railway track, as 2002 are 619 and 5147.24 kms respectively.

The total length of roads in Ranga Reddy district is 5464 kms. The national highway connecting the Hyderabad and Pune with a total distance of 110 kms passes through the district and about 1931 km of state government roads are connection important town in the other districts like Nalagonda, Karimnagar and warangal. The road density for the district is 0.79 km/1000 population and 0.73 km/sq.km of geographical area which indicates the poor road and transport facilities in the district.

4.9.3 Banks and co-operatives

The main source of formal credit to farmers is nationalized banks and co-operative societies. The farmers get short and long term credit from the banks and cooperatives for the purchase of inputs for crop production, land reclamation, purchase of tractors and agricultural equipments (like sprayers, motors pumps, etc). Andhra Pradesh has 5322 commercial banks, which include 2432 banks in rural areas, 1228 banks in semi-urban areas, 1073 banks in urban areas and 589 in metropolitan cities like Hyderabad and Vishakapattinam. Based on 2001 census data, the average population per bank in the State is 14 thousand. In the State there are about 22 Central co-operative banks and 4678 Primary Agricultural Credit Societies to serve the agricultural and non-agricultural communities.

Ranga Reddy district has 199 commercial banks in that 92 are in rural areas, 52 each in semi urban and urban areas. The average population per bank in this district is 18 thousand people. About 142 Primary Agricultural Credit Societies with a total membership of 171 thousand members are also operating in the district, which gives short and long term loans to small and medium farmers.

The annual credit plan for Andhra Pradesh and Ranga Reddy district is given in the Table 4.9. In Andhra pradesh crop loan occupies about 40.28 per cent of the total plan outlay followed by non-priority sector 17.55 per cent and non-farm sector 11.60 per cent. The values show that banking sectors in Andhra Pradesh has concentrated more on crop loan distribution to the farmers. On the contrary, in Ranga Reddy district only 19.44 per cent of total plan outlay of credit is occupied by crop loans and higher loans are given to other priority sector and non-farm sector about 25.61 and 23.12 respectively. This indicates that crop loan in the district is not well reached to farmers and this might be due to more rainfed agriculture in the district.

The farmers receive crop loans based on crops and area cultivated from commercial and cooperative banks. The loan amounts vary for different crops and different for crops grown in irrigated and rainfed conditions. The scale of finance is calculated by District Level Technical Committees (DLTCs) for each year based on the cost of cultivation of each crop. The farmers can use this credit for purchase of inputs like seeds, fertilizer and to meet the contingency expenses. The farmers have to repay the loan amount at the end of the cropping period at interest rate of 9-11 per cent.

Table 4.9 Annual credit plan under different sectors for Andhra Pradesh and Ranga Reddy district (2004-05)

(Rs. in millions)

S.No	Particulars	Andhra Pradesh	Ranga Reddy district
1	Crop loan	9488.66 (40.28)	168.74 (19.44)
2	Agricultural term loan	1715.17 (7.28)	123.03 (14.18)
3	Allied activities	1166.55 (4.95)	36.21 (4.17)
4	Non-farm sector	2732.38 (11.60)	199.73 (23.12)
5	Other priority sector	4320.88 (18.34)	222.27 (25.61)
6	Total priority sector	19423.66 (82.45)	750.00 (86.45)
7	Non-priority sector	4135.50 (17.55)	117.89 (13.55)
8	Total plan outlay	23559.16 (100.00)	867.89 (100.00)

Source: Andhra Pradesh state credit plan, 2004-05.

4.9.4 Kisan credit card

The kisan credit card (KCC) was started by the Government of India (GOI) in consultation with the Reserve Bank of India (RBI) and NABARD in 1998-99. This card is issued for all the eligible farmers with good track record for two years with the banks. The credit limits for the card is fixed based on operational land holding, cropping pattern and scale of finance. The farmers can withdraw cash credit using this KCC to meet production credit need and cultivation expenses and repay within 12 months. The card is valid for three years and the interest rate for amount up to Rs.25 000 is 11 per cent and above 25 000 to 2 lakhs is 13 per cent. In Andhra Pradesh banking sectors has issued 5663 thousand KCC to farmers covering 90 per cent of the crops loan borrowers in 2004-05 and also stand first among all other states in the country in issuing KCC (State Credit Plan, 2005).

4.9.5 Crop insurance

To mitigate the crop loss risk due to drought, flood and other natural calamities, Agricultural Insurance Company of India (AICI) introduced crop insurance scheme as a risk management tool, which gives some financial security to the farmers. In Andhra Pradesh about 1633.85 thousand farmers in *rainy* and 158.23 thousand farmers in *post-rainy* season are benefited by crop insurance scheme in five years (AICI, 2005). To encourage the farmers to avail this facility the banking sectors are linking crop insurance with crop loans. But the farmers are not willing to take the credit linked insurance because of high premium rate for some cash crops (State Credit Plan, 2005).

4.10 Watershed development programme in Andhra Pradesh

Andhra Pradesh in 1997 launched a 10-year Perspective Plan for development of all the degraded lands in the state over 10 years. The action plan for development includes wetlands, degraded lands (i.e. drylands which being cultivated under rainfed conditions) and degraded reserve forest. Under this 10-year Perspective Plan of watershed development aiming at developing 10 million ha from 1997-2007, 3.16 million ha land is under treatment by taking up 7135 watershed projects (Joshi *et al*., 2004).

About 5472 watershed projects have been developed in Andhra Pradesh covering an area of 2.763 million ha with an investment of Rs. 5800 million using participatory approaches (Table 4.9). Over 0.2 million ha are being treated under the Integrated Wastelands Development Programme.

Table 4.10 Watershed development in Andhra Pradesh

Year	**No. Of watersheds**	**Area (million ha)**
1995-96	687	0.344
1996-97	94	0.047
1997-98	628	0.314
1998-99	2759	1.379
1999-2000	1092	0.546
2000-01	212	0.106
Total	5472	2.736

Source: Joshi *et al*., 2004

4.11 Brief description of the study area – Adarsha watershed, Kothapally

The bioeconomic modeling framework is applied to study the impact of integrated watershed interventions on economic well-being of the communities and environmental sustainability of Adarsha watershed located in Kothapally village of

Ranga Reddy district, Andhra Pradesh. This section provides a brief description of the case study area highlighting location, demography characteristics, biophysical aspects, market and institutional arrangements and social infrastructure conditions in Adarsha watershed.

4.11.1 General overview

The Adarsha watershed is located in Kothapally village (lies between longitude 78 º 5′ to 78 º 8′ E and latitude 17 º 20′ to 17 º 24′ N) in Ranga Reddy district. It is situated in Telangana region of Andhra Pradesh, nearly 50 km from Hyderabad, the capital city of the state. The watershed covers an area of 502.20 ha of which 465.75 ha land is cultivable and remaining land account for permanent fallow, wasteland, settlement and common property land (Shiferaw, 2001). The area under irrigation in the watershed is only 20 per cent of the total cultivable land and the remaining land is under rainfed cultivation. The watershed is inhabited by 308 households where in 289 are farm households and 19 are landless labourers. The local population number 1624 inhabitants. The annual average rainfall in the area is about 800mm of which 85 per cent of it occurs between June to October (South west monsoon). Droughts are common in this part of region, where recently southwest monsoon failed in two consecutive years (2001 and 2002). The farmers grow crops in two seasons namely rainy season (*kharif*) from June to October and post rainy season (*rabi*) from November to February. The crops grown under rainfed condition in *rainy* season include sorghum, pigeon pea, maize, cotton, paddy, sunflower, and vegetable bean. The farmers cultivate paddy, vegetables, sunflower, chickpea and onion in post rainy season using residual moisture and supplement irrigation. Production of crops and livestock are well integrated in the watershed. Shiferaw *et al*. (2002) estimated more than two-third (72 per cent) of the sample households owned some livestock in addition to indulging in crop-production activities.

4.11.2 Household characteristics

In Kothapally, large farmers (greater than 4 ha land holding) constitute about 10 per cent of the total households possess 38 per cent of the farmland with average landholdings of 6.84 ha. Medium farmers (2 to 4 ha) are about 18 per cent of the total households hold 29 per cent of the farmland with an average landholding of 2.81 ha. On the contrary, small farmers (less than 2ha) who constitute 58 per cent of the households hold only 33 per cent of the farmland with an average landholding of 0.89 ha (Table 4.11).

Households in Kothapally are highly heterogeneous in caste. About 54 per cent of the households belong to backward communities (BC), 15 per cent to minority community (Muslims), 20 per cent to scheduled caste (SC) and 9 per cent to other castes (Wani and Shiferaw, 2005). The average family size in Kothapally is 5.27 persons. The family size is more in large and medium farmers compared to small farmers (Table 4.12). The average weighted work force per household is 3.73 and average consumer unit per household is 4.57 persons, indicating the average consumer/worker ratio is 0.70.

Table 4.11 Land holdings of different household groups in Kothapally (in 2001)

Households	**No. of households**	**Total land area (ha)**	**Average land holding (ha)**
Small (<2ha)	202 (65.58)	159.67 (34.38)	0.72
Medium (2.01-4ha)	57 (18.51)	150.29 (32.16)	2.38
Large (>4.01)	30 (9.74)	155.79 (33.46)	4.71
Landless	19 (6.17)	0	0
Total	**308 (100.00)**	**465.75 (100.00)**	**1.37**

Note: Values in parentheses indicate the percentage to the total
Source: Shiferaw, 2001.

Cattle and sheep are dominant types of livestock, but goat and backyard poultry are also common (Table 4.12). The small farmers are rearing more livestock when compared to the medium and large farmers, because of additional income they get through sale of livestock and milk. Bullock is the main source of traction power for ploughing and transportation. The farmers also rent bullock to other farmers for ploughing in peak season. Animal manure is used for fuel or as manure on crops. Crop residues are used as animal fodder. Sometimes, farmers buy fodder from other farmers to meet the shortage. The farmers usually keep their female calves and sell the males or rear locally as bullock. There is no cooperative milk society in the village, so some young boys in the village collect the milk from the farmers and sell it in the nearby towns. The milk production in the village is low where the local breed produces only 2.5 litres per animal per day during the lactation period.

4.11.3 Biophysical characteristics

The watershed is characterized by undulating topography (the slope of the land is about three per cent) and predominately black soils which range from shallow to medium deep black with a depth range from 30 to 90 cm. The watershed is classified into three types of soil depth namely shallow depth soil (less than 50cm), medium depth soil (50-90cm) and deep depth soil (greater than 90 cm). About 39 per cent of the total area in the watershed is shallow depth soil, 16 per cent is medium depth soil and 45 per cent of the area is deep depth soil. The detailed characterization of the soils shows that they are low in available N (11mg per kg of soil), available P (1.4 to 2.2 mg per kg of soil), Zinc (Zn), boron (B), and sulphur (S) in addition to low in organic carbon and mineral N content (Wani *et al*., 2003).

The main source of irrigation in the watershed is open wells and tube wells. There are about 64 open wells and 34 tube wells in the watershed, most of which are located along the main water course. After construction of check dams and other soil and water conservation structures in the village, the yield of the wells significantly improved particularly those located near the check dams. Due to additional recharge of groundwater, a total of 200 ha are irrigated in post-kharif season and 100 ha in post-rabi season. Mostly vegetables were grown, during 2002-2003 cropping season (Wani *et al*., 2003).

4.11.4 Agriculture in Kothapally

The major sole crops grown in the village during *rainy* season are cotton, maize, sorghum and paddy, and intercrops grown are sorghum/pigeonpea and maize/pigeonpea. Based on the availability of residual moisture and irrigation facility, in *post rainy* season the farmers grow chickpea and vegetables. Cotton is an important cash crop, grows well in the black soil of the region and occupied about 200 ha in 1998. But after four years of watershed activities the area under cotton cultivation decreased from 200 ha to 80 ha (60per cent decline), with simultaneous increase in maize and pigeon pea areas, which give more profit compared to cotton (Wani *et al*., 2003).

The productivity of the crops grown in Kothapally using traditional varieties is low but after implementing improved soil and water management practices like broad-bed and furrow (BBF), use of tropiculator for planting, fertilizer application and improved crop varieties has increased the productivity of the crops even in the drought years. The farmers use farmyard manure (FYM), DAP and urea fertilizers for crops like paddy, cotton and vegetables.

Table 4.12 Basic household and farm characteristics of different household groups in Kothapally (in 2001)

Particulars		Landless	Small	Medium	Large	Total
Number of households		19.00	202.00	57.00	30.00	308.00
Total population		89.00	993.00	356.00	186.00	1624.00
Average family size		4.68	4.92	6.25	6.20	5.27
Total work force		68.75	699.00	247.00	132.75	1147.50
Average work force		3.62	3.46	4.33	4.43	3.73
Total consumer units		77.75	860.05	308.85	159.70	1406.35
Average consumer units		4.09	4.26	5.42	5.32	4.57
Land holding information (in ha)						
Shallow land (< 50cm)	Irrigated	0	13.07	16.05	18.80	47.92
	Rainfed	0	47.99	44.33	40.73	133.05
Medium land (50-90cm)	Irrigated	0	5.36	6.59	7.71	19.66
	Rainfed	0	22.28	19.54	19.29	61.11
Deep land (> 90cm)	Irrigated	0	15.08	18.52	21.69	55.29
	Rainfed	0	54.68	47.02	46.32	148.02
Livestock information						
Bullocks		0	72	73	54	199
Cows		1	3	3	7	14
She Buffaloes		4	111	59	37	211
Sheep			147	125	20	292
Goat		2	69	16	9	96
Poultry		3	180	46	14	243

Source: Shiferaw, 2001.

4.11.5 Market conditions and institutional arrangement

Kothapally village is well connected to major markets in towns like Chevella and Shankarpally, about 20 km away. The major cash crops in the area are cotton and vegetable beans, grown almost entirely for sale. The farmers directly take the products to the nearby markets or middlemen purchase them in the farmers' fields and sell them in the markets. Due to lack of well-connected roads the transportation costs are high, but more importantly there are high information costs related to selling of surplus cereals. The high transaction costs are evident in varying differential prices between different markets in the region, which causes the missing and incomplete markets for important commodities and services.

The farmers gain access to capital credit from formal and informal sources. The formal source of credit in Adarsha watershed is mainly the cooperative bank. The informal sources are moneylenders, friends, and relatives. Shiferaw *et al*. (2002) found that about 60 per cent of the sample farmers obtain credit from either formal or informal source. Of this some 70 per cent obtain credit from cooperative banks and the remaining 30 per cent from informal sources. The rate of interest is substantially lower in formal sector (9.4 per cent) than in the informal sector per year (14.8 per cent).

The labour market is active in Kothapally village around 70 per cent of the all farms employ hired labour during peak seasons. Wage labour is the primary source of income for 20 per cent of the households and is a secondary activity for 15 per cent of the households (Shiferaw, 2001). Seasonal migration is only 5 per cent, probably because of demand for labour is high in the micro watershed. The mean number of family labour per hectare for large farmers in Kothapally village is only one labour (Wani and Shiferaw, 2005), so this account for low productivity in large farmer field compare to small farmers.

Land is the main productive asset in the area. The farmers are the owners of the land (private property) and in the watershed only 8 acres of land is under common property resources. The farmers rent the land for one or two seasons, where rent for the land varies between Rs. 2000 to Rs.10000 per ha depending on land quality (irrigated or rainfed).

4.11.6 Social infrastructure

Kothapally village has one government school and one private school (up to 9th standard). About 75 per cent of the children in the village are sent to school. All households in the village have gained access to electricity. About 18 telephone connections are in the village and also the quality of the roads in the village is good.

CHAPTER V

RESULTS AND DISCUSSION

This chapter is dedicated to the presentation of the results and discussion with a view to draw specific inferences and policy implications. The results in this chapter are discussed under the following sections:

5.1 Validation of the watershed level bioeconomic model
5.2 The baseline model simulation results
5.3 The analyses of alternative scenarios

5.1 Validation of the watershed level bioeconomic model

The bioeconomic model was implemented as an aggregate level dynamic non-linear programme partly similar to the models used by Okumu et al. (2000) and Barbier and Bergerson (2001). The model treats the study area as a single profit maximizing unit, planning for a 10 year time horizon. The model attempts to simulate different households' decision-making processes in the watershed by choosing a land use mix constrained by seasonal resource availability (e.g. labour, land, bullock, capital etc). Risk[9] of drought, pest and diseases and constraint of water availability is not incorporated in the model due to limited time series data and the large size of the model.

Model validation is performed to represent the ground realities during the initial years of simulation by comparing base run results with actual survey data for different household groups in terms of income per household, area under crops and erosion level. The result of the comparison establishes the validity of the model and its ability to replicate correctly the decisions taken by farmers in the watershed. The actual cropping pattern of different household groups in the watershed in 2003 and the predicted cropping pattern (range of areas over 5 years) are given in Table 5.1. The results show that the ranges of predicted baseline results are similar to the actual data across the three household groups. The model results predict that maize and cotton occupy the major area during

[9] One of the limitations of this model formulation is its assumption of perfect knowledge of market prices and yields (i.e. certainty), with limited explanation of how income from each activity varies across time or how the individual activities interact to produce variable aggregate incomes. The model also assumes that farmers in the watershed explicitly represent optimization behaviour.

rainy season which is consistent with the situation prevailing in Kothapally watershed. The remaining area is occupied by vegetables, paddy and sorghum during *rainy* season and chickpea and sunflower during *post rainy* season.

The income per household for three household groups projected by the model and the average income per household in the year 2003 are given in Table 5.2. The predicted incomes from baseline model results are similar to the observed income for the different households in the watershed.

The average soil loss per ha of crop land predicted by the model is compared with the soil loss measurement done in the watershed using sediment sampler. The measured soil loss in Kothapally watershed (treated and untreated watershed) is in the range of 1-3 tons per ha (Wani et al., 2002). The soil loss predicted by the baseline model is in the range of 3.5 - 4.5 tons per ha over 10 years. The two quantities differ slightly because the soil loss calculated by soil sediment sampler at the stream is not reflecting the exact soil loss at the plot/field level because the stream may deposit part of its sediments eroded from the field over the course before it takes off as stream from the micro watershed. The study conducted by Singh et al. (2003) for six years from 1995/96 to 2000/01 in the model watershed (BW7) at ICRISAT station, measures the soil loss at field level and reported that the soil loss per ha is in the range of 2.5 and 4.5 tons in two land management types (BBF and flat respectively) for an average annual rainfall of 800mm in Vertic Inceptisol soils. This value on soil loss per ha is consistent with results predicted by the model for the study area. Hence, the predicted soil loss in the watershed (Adarsha watershed) by the bioeconomic model is valid because of prevailing similar soil type and climatic conditions for both ICRISAT on-station watershed and the study area.

Table 5.1 Cropped areas in 2003 and predicted ranges of cropped area over 5 years (ha)

Crops/ Households	Observed 2003 area in ha				Baseline model results: Predicted areas in ha (range over 5 years)		
	Small	**Medium**	**Large**	**Total**	**Small**	**Medium**	**Large**
Sorghum/pigeonpea[a]	15.57	11.13	11.73	38.43	47.50-26.00	0.00-8.50	0.00-1.57
Maize/pigeonpea[b]	59.83	42.51	53.85	156.19	59.14-42.71	59.60-48.12	67.38-47.17
Paddy	12.08	12.90	12.72	37.70	0.00-10.00	0.00-10.00	0.00-10.00
Cotton	28.59	38.13	37.24	103.96	43.26-16.57	0.00-24.44	21.47-41.24
Sunflower	8.36	5.25	11.08	24.69	22.50-29.50	20.04-31.43	28.12-48.45
Chickpea	6.21	21.73	13.07	41.01	5.79-16.57	11.01-31.85	1.57-22.70
Vegetables[c]	12.65	18.41	21.08	52.14	18.29-36.07	9.04-34.25	10.97-40.51

[a, b] sorghum and maize intercropped with pigeon pea cropping system. The sole sorghum and
maize area in the watershed is very less and also not a profitable cropping system.
[c] Vegetables area is the aggregated area of all vegetable crops grown in the watershed (like tomato, cluster bean, ladies finger, brinjal, carrot, and cow pea)

Table 5.2 Income per household in 2003 and predicted ranges of income for different household over 10 years ('000 Rs.)

Households	Observed 2003 Income	Predicted model Income (range over 10 years)
Small (n=30)	25.22	18 - 24
Medium (n=17)	32.73	44 – 54
Large (n=10)	84.79	75 – 99

n = sample size or number of observations

5.2 The baseline model simulation results

The primary purpose of constructing the bioeconomic model is to explore the impact of technologies and policy interventions on the well-being of the farmers and condition of the biophysical factors in the watershed. This section discusses about the simulated results having socio-economic and biophysical data surveyed during 2003 in the watershed as the input in the model.

5.2.1 The Baseline scenario

A baseline version of the bioeconomic model has been run with the population and consumption set as observed in 2003 level with existing technology and inorganic fertilizer use to simulate agricultural activities in the watershed over 10 year time horizon. Population growth in the watershed is assumed to occur at the current district average annual rate of 2.5 per cent over this period. It is also assumed that the inputs and output prices are exogenous and constant over simulation period. The model is also allowed to increase or decrease the number of livestock based on the availability of feed balance in the watershed.

5.2.2 Land use pattern in Adarsha watershed, Kothapally

The simulated land use over 10 years in the watershed is shown in Figure 5.1. The area under cotton and maize predicted by baseline model is more or less same in the initial year of simulation compared to land use observed in 2003. (In this chapter, initial year refers to the first year of the simulation). The model results show that the area under maize may decline by about 23.84 per cent and area under cotton is increased by about 40.38 per cent in the 10 year period simulated. The reason for increasing area under cotton in the simulation results might be due to the non-incorporation of risk of drought and pest incidence in the model. Cotton is considered as more profitable crop when there is no pest infestation and also it is deep rooted crop, which is less susceptible to drought in the shallow depth soils. Maize is a shallow rooted crop and its yield decreases with decline in soil depth. The results predicted that soil depth will decline due to soil erosion over 10 year. The maximum area under paddy in the watershed is constrained in the model not to exceed the 2003 level because paddy is high water consuming and water scarcity is gradually increasing in the semi-arid districts and irrigated area is unlikely to expand (Shiferaw et al., 2003b). If the paddy area is not constrained, then the simulated cropping pattern is not analogous with observed cropping pattern in the watershed. The model allocates entire irrigated land to paddy in the *rainy* season because paddy is more profitable than other irrigated crops cultivated in the watershed. In reality farmers do not cultivate entire irrigated land with paddy because of water scarcity and uneven distribution of rainfall in the area. The cultivable area under vegetable is constant over the years in the model results because it is constrained by the seasonal market demand[10].

The simulated land use pattern based on soil types in the watershed is given in the Table 5.3 and Figure 5.2. The baseline simulated results show that the shallow soils with depth less than 50 cm are predominantly cultivated for cotton and less of maize. However, the model results indicate that maize is replaced by cotton over the years in shallow soils because of decline in the yield of maize due to decreasing soil depth. Medium soils with soil depth of 50-90 cm are cultivated with sorghum and paddy of about 85 per cent of the cultivable land and the remaining land with maize and cotton during *rainy* season, whereas 28 per cent of land is covered by sunflower in *post rainy* season. In deep soils with soil depth above 90cm the model results show intensive cultivation of vegetables, sunflower, maize, chickpea, and paddy. Sunflower and chickpea are cultivated in deep soils in *post rainy* season due to high residual soil moisture content and water holding capacity of the deep soils. This is consistent with the production situation observed in Kothapally village where the deep soils are under chickpea and sunflower during *post rainy* season. Vegetables are shallow rooted which produces high yield only in the deep soils, a land use pattern also observed in the watershed.

The simulated land use by different land types in the watershed is given in Figures 5.3 and 5.4. The rainfed land is dominated by dryland crops like maize, sorghum, cotton and chickpea. During *rainy* season farmers grow about 15 per cent of rainfed land with

---

[10] The vegetable market for all the villages in the mandal is Shankarpally or Patancheru town. If production is more than the market demand then the vegetable prices in the markets drastically decrease which sometimes do not even cover the variable cost of production during *rainy* season. The price of vegetables in the model is constant over years and it's not varying by season according to supply and demand in the market. So the production of vegetables is constrained in the model based on market demand to mitigate the problem of price fluctuation of vegetables during higher production.

vegetables and sunflower in baseline results. The model results show that the cotton area in rainfed land is slowly increasing by replacing area under maize cultivation (Figure 5.3). The maize area in rainfed land is declined by 23.85 per cent over 10 years. In *rainy* season paddy, cotton and vegetables are cultivated in the irrigated land (Figure 5.4). The results also predicted that during *post rainy* season sunflower is cultivated under irrigated land because of its short duration (3months) nature and requires only two to three supplemental irrigation to yield better.

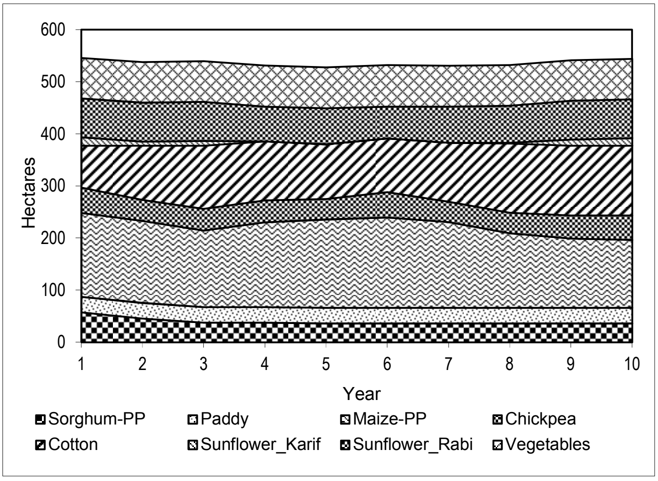


Figure 5.1: Simulated land use pattern in the watershed (ha)

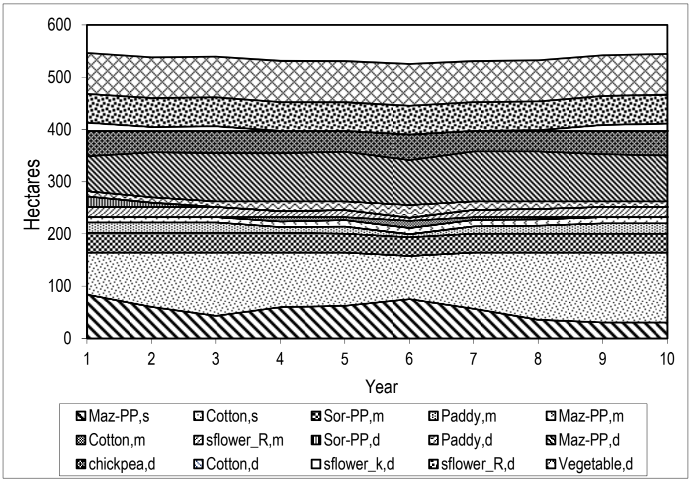


Figure 5.2: Simulated land use pattern by soil type (s = shallow, m = medium, d = deep) in the watershed (ha)

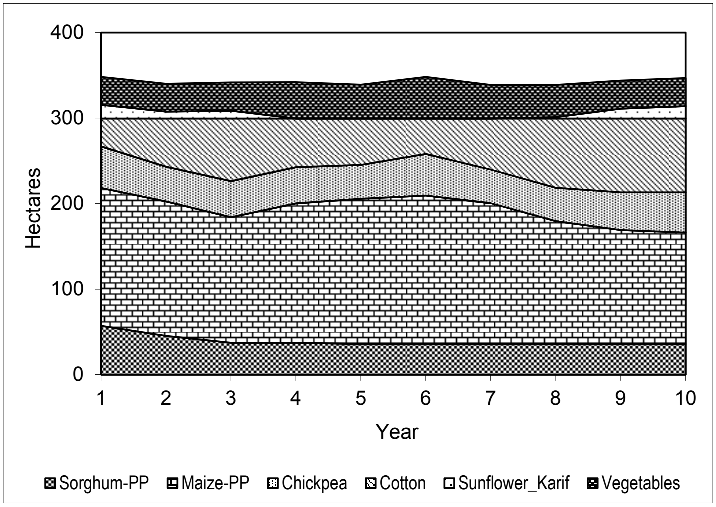


Figure 5.3: Simulated land use in Rainfed land in the watershed (ha)

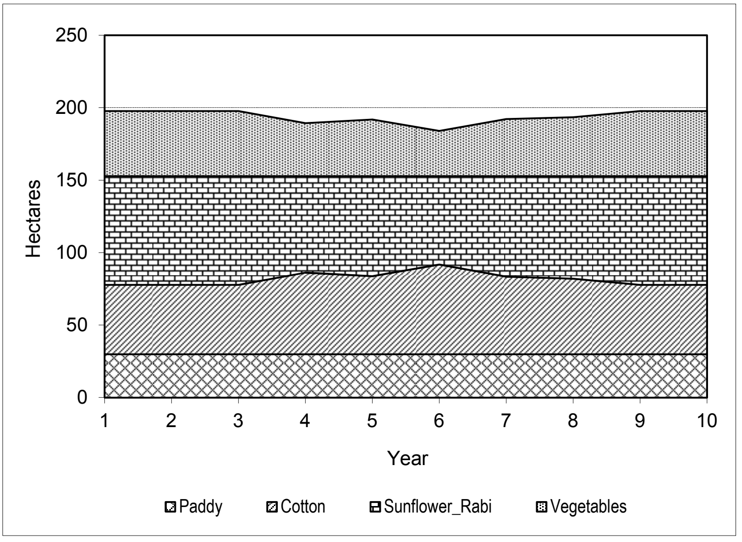


Figure 5.4: Simulated land use in Irrigated land in the watershed (ha)

Table 5.3: Crop activity by soil type in the watershed: Results from the baseline scenario (In hectares)

Activity by soil type	Model Result (year)									
	1	2	3	4	5	6	7	8	9	10
Shallow soil										
Sorghum-PP*	0	0	0	0	0	0	0	0	0	0
Paddy	0	0	0	0	0	0	0	0	0	0
Maize-PP**	84.18	60.54	43.55	59.95	62.43	75.38	57.11	35.82	30.78	30.60
chickpea	0	0	0	0	0	0	0	0	0	0
Cotton	80.64	104.28	121.27	104.87	102.30	82.44	107.71	129.00	134.04	134.22
sunflower *rainy*	0	0	0	0	0	0	0	0	0	0
sunflower *post rainy*	0	0	0	0	0	0	0	0	0	0
Vegetables	0	0	0	0	0	0	0	0	0	0
Medium soil										
Sorghum-PP	37.63	37.64	37.63	37.63	36.06	36.06	36.06	36.06	36.06	36.07
Paddy	19.66	19.66	19.66	11.27	13.80	5.82	14.11	15.47	19.66	19.66
Maize-PP	10.33	10.33	10.33	10.33	11.90	11.90	11.90	11.90	11.90	11.90
chickpea	0	0	0	0	0	0	0	0	0	0
Cotton	0	0	0	8.39	5.86	13.84	5.56	4.19	0	0
sunflower *rainy*	0	0	0	0	0	0	0	0	0	0
sunflower *post rainy*	19.66	19.66	19.66	11.27	13.80	5.82	14.11	15.47	19.66	19.66
Vegetables	0	0	0	0	0	0	0	0	0	0
Deep soil										
Sorghum-PP	19.63	7.86	0	0	0	0	0	0	0	0
Paddy	10.34	10.34	10.34	18.73	16.20	24.18	15.90	14.53	10.34	10.34
Maize-PP	66.65	86.38	92.85	92.49	95.37	86.26	95.70	95.69	90.53	87.81
chickpea	48.60	40.64	42.03	42.39	39.52	48.62	39.18	39.19	44.35	47.07
Cotton	0	0	0	0	0	0	0	0	0	0
sunflower *rainy*	15.79	7.83	9.21	0	0	0	0	1.55	11.48	14.19
sunflower *post rainy*	55.29	55.29	55.29	55.29	55.29	55.29	55.29	55.29	55.29	55.29
Vegetables	77.75	77.77	77.77	78.95	78.60	79.73	78.58	78.40	77.82	77.83

Note: * sorghum/pigeonpea intercropping system
** Maize/pigeonpea intercropping system

5.2.3 Income

The simulated baseline household incomes for the three household groups are given in Figure 5.5. There are sizable differences in the income level for different group of households. The simulated baseline results of the per household income show that there is 32 per cent decline in household income for large farmers compared to 15 per cent for the small farmers over 10 years period. The magnitude of decline in income is low in the small farmers group because they earn more income from the off-farm source by hiring out excess labour while large farmers need to hire more labour to cultivate their land and do not have much surplus labor left to hire out for earning additional income. However, for the medium farmers the income level seems to be more stable over the 10 year period. The stability of income may be due to the situation that 32.16 per cent of total cultivable land in the watershed has been occupied by medium farmers who constitute 18 per cent of the total households in the watershed, whereas 66 per cent of small farmers in the watershed occupy only 34.38 per cent of cultivable land.

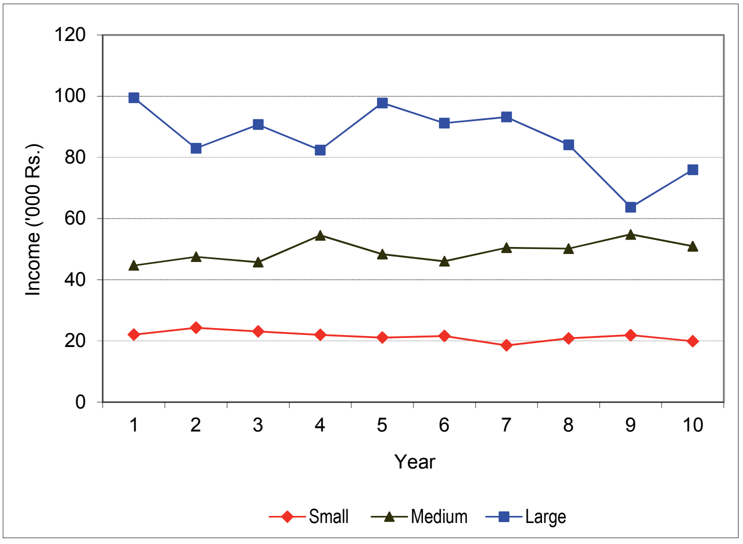


Figure 5.5: Simulated income per household by household group (‘000 Rs.)

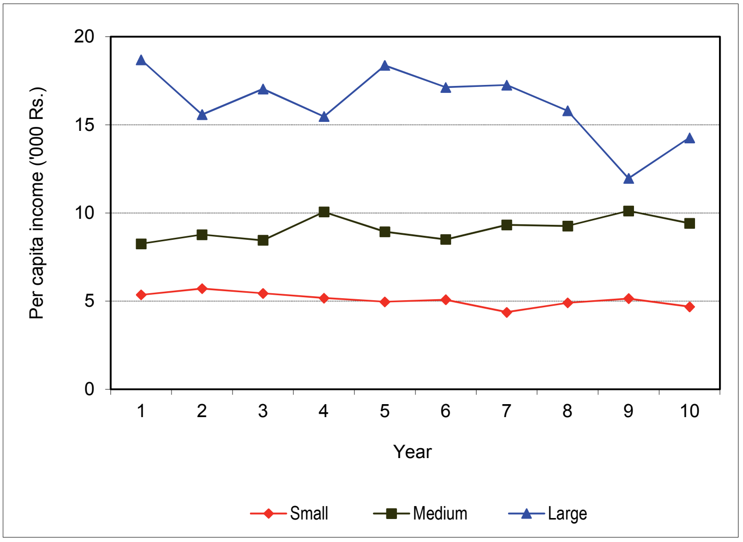


Figure 5.6: Simulated per capita income by household group ('000 Rs.)

The per capita income for the different household groups is given in figure 5.6. The per capita income of the small farmer group is declining over the years in baseline results, this may be because of increase in population growth and constrained access to non-farm employment opportunities and reduced off farm wage employment in the watershed. The per capita income of the large farmer group is decreasing because of increase productivity loss caused by land degradation over the years. The per capita income for large farmer is three and two times higher than small and medium farmers respectively. The model results indicate that the per capita income levels for the small and medium farmers are below poverty line income of Rs.12000 per person per year. Under the conditions of increasing population pressure, limited access to non-farm activity in the watershed and scarcity of cultivable lands only large farmers are able to earn income above the poverty line income.

The breakdown of household income in the watershed by its component sources and for different household groups is given in Figures 5.7 to 5.10. The baseline model results show that there are some changes in the income sources over 10 years of time. Generally, the model results predict that the in the watershed level income from livestock and off-farm wages increases gradually, while crop income remains more or less constant over the years (Figure 5.7). The increase in off-farm income may be due to increased hiring out of labour by small farmers to compensate for declining farm income. The livestock income is increasing because the number of small ruminants (sheep and goats) sale in the watershed has increased gradually over the simulation period. It shows the watershed has some potential for rearing small ruminants which earn households regular income with more profit compared to income from cows and buffaloes.

The results predict that the small household group crop income is declining over the years and off-farm wage and livestock income is gradually increasing (Figure 5.8). The reason for decrease in crop income of the small farmer group is due to decline in crop sale over the years. The increase in the consumer units over the years leads to more on-farm consumption of cereals and pulses, which reduces the crop sale of small household group. Among the three household groups, the wage income is more in small farmer group because they hire out more labour to work in large and medium households farms. The crop income in medium and large household group is gradually increasing over the years because of increased use of labour and fertilizers (Figures 5.9 and 5.10). The wage income for large and medium household group is very less compare to small farmers.

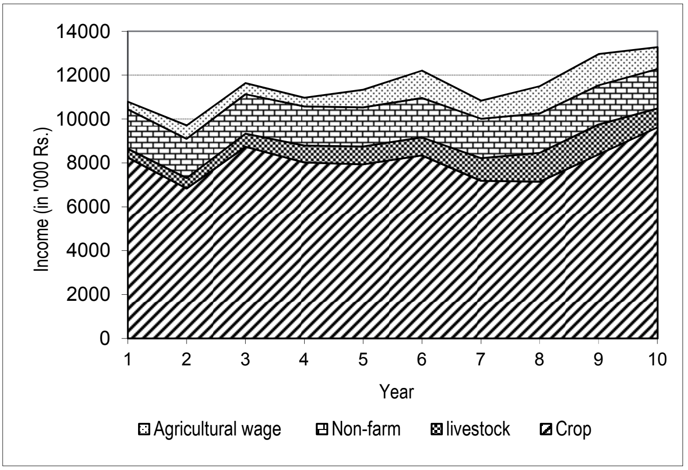


Figure 5.7: Simulated source of income (GDP) in the whole watershed ('000 Rs.)

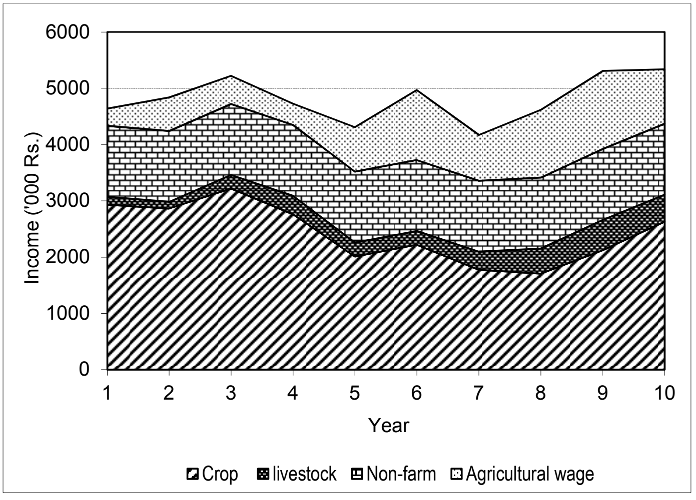


Figure 5.8: Simulated source of income for small household group ('000 Rs.)

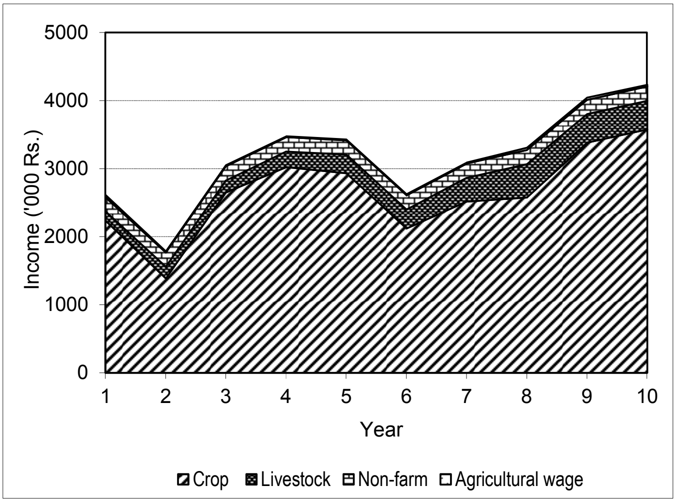


Figure 5.9: Simulated source of income for medium household group ('000 Rs.)

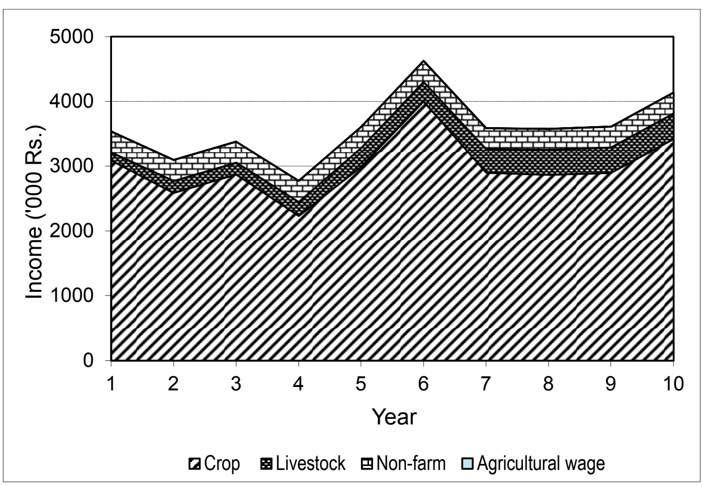


Figure 5.10: Simulated source of income for large household group ('000 Rs.)

5.2.4 Erosion and soil depth

In the bioeconomic model, soil erosion estimated using the USLE model with two levels of conservation is crop specific. The erosion in the watershed is calculated based on the cropping pattern and level of labour used in conservation measures. The baseline model results predicted that the amount of soil loss for the whole micro watershed is 1859.37 tons (i.e. 4.4 tons per ha) for the initial year. However, the soil loss gradually decreases over the simulation period due to the increasing investment of labour by the farmers for *in situ* soil and water conservation activities at the field/plot level. If conservation is not an option (i.e. no labour used for conservation), then the simulated erosion increases to 6 tons per ha. However, farmers do use labour for conservation activities like strengthening of the bunds, formation of BBF and planting of *Gliricidia* to keep the bunds intact.

The total soil erosion per year, average soil loss per ha and cumulative soil loss over the years in the watershed are given in the Table 5.4 and Figures 5.11 and 5.12. In the initial year, the average annual soil loss per ha is 4.40 tons per ha. However soil loss declines to 3.69 tons per ha at the terminal period by adoption of conservation practices in 10 years of time, which is 22 per cent less than the soil loss at the initial year of simulation. The model results predict that the cumulative soil loss in the watershed at the terminal period reaches, about 17058.41 tons.

Table 5.4 The total annual, cumulative and average soil loss in the watershed: Results from baseline scenario (tons)

Year	Annual soil loss	Cumulative soil loss	Average annual soil loss per ha
1	1859.38	1859.38	4.40
2	1791.07	3650.45	4.24
3	1770.08	5420.52	4.19
4	1712.83	7133.36	4.05
5	1747.25	8880.61	4.14
6	1737.44	10618.05	4.11
7	1685.28	12303.32	3.99
8	1614.58	13917.90	3.82
9	1581.63	15499.53	3.74
10	1558.88	17058.41	3.69

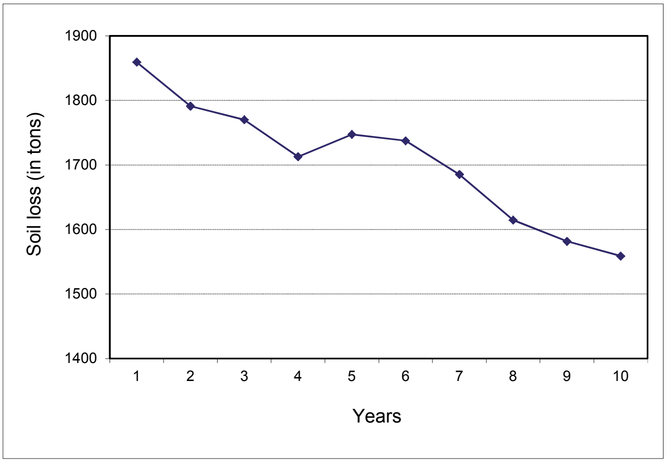


Figure 5.11: Simulated annual soil loss in the watershed (tons)

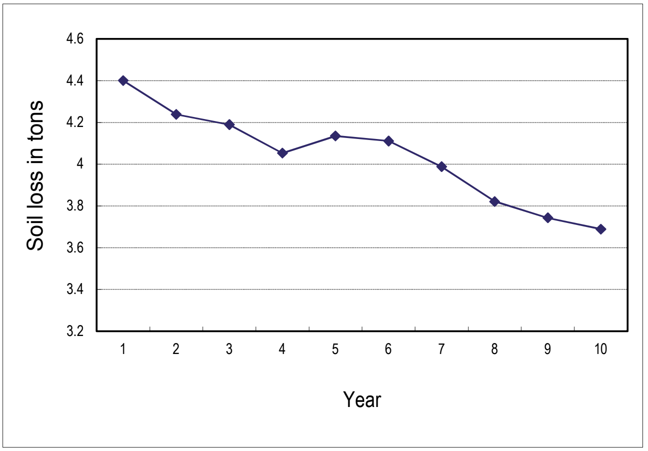


Figure 5.12: Simulated average soil loss in the watershed (t/ha)

5.2.5 Labour use for conservation in the watershed

It is hypothesized that intensification of land use and investments to enhance land productivity will be limited when land is more abundant than labour (Boserup, 1965). Shiferaw and Holden (2005) found that large farmers with scarce labour will have lower incentives to increase the intensity of labour use for conservation to enhance land productivity.

The labour (man-days/ha) used for conservation in the watershed is given in Figure 5.13. The model results predict that the labour per ha of cultivable land used for conservation measures is increasing over the years. The simulation results indicate that the small farmers are using more labour for conservation compared to medium and large farmers, which shows that small farmers have more incentive to invest labour for soil and water conservation practices than the medium and large farmers. The results indicate that the amount of labour used for conservation and fertility management is much higher for land-scarce small farmers than land-abundant large farmers. The result is consistent with what Boserup (1965) and Shiferaw and Holden, (2005) found in their study.

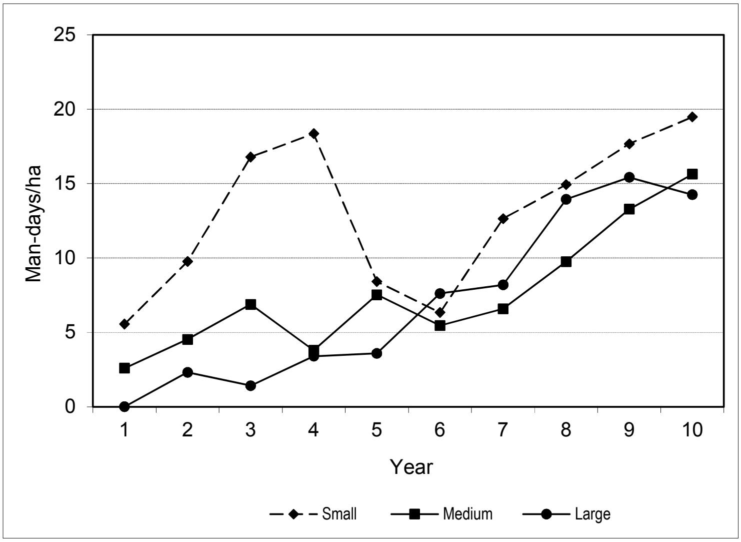


Figure 5.13: Simulated labour used for conservation by household groups (man-days/ha)

In the baseline simulation results, the reduction in soil depth over 10 years is comparatively higher on shallow soils when compared to medium and deep soils because farmers grow cotton in shallow soils, which is deep rooted and highly erosive crop[11]. The model allocates more shallow land to cotton because cotton yields are not very sensitive to change in soil depths[12]. The results indicate that with existing cropping pattern on shallow soils may reduce soil depth to the lowest threshold level more quickly where cultivation of crops is not possible. Figure 5.14 indicates that the magnitude of decline in soil depth is more in irrigated land due to more cropping intensity and the cultivation of high erosive vegetables.

[11] Cotton is cultivated in rows with wide spacing which expose soil surface to rainfall and cause more erosion in the rainy season.

[12] Cotton is deep root crop unlike maize, sorghum, vegetables and sunflower, which can penetrate roots deep in to the soil and absorb water from soil subsurface. So the soil depth does not affect the yield of crops. But irrigation will increase the yield of cotton.

Figure 5.14 also reveals that the rate of soil depth decline is relatively more in large and medium farmer fields compared to small farmers, reflecting the high erosion in the medium and large farmers' land holdings. The amount of labour used for conservation measures by large and medium farmers is less compared to small farmers may lead to higher soil erosion and faster reduction of soil depth in large and medium farmers' cultivatable lands

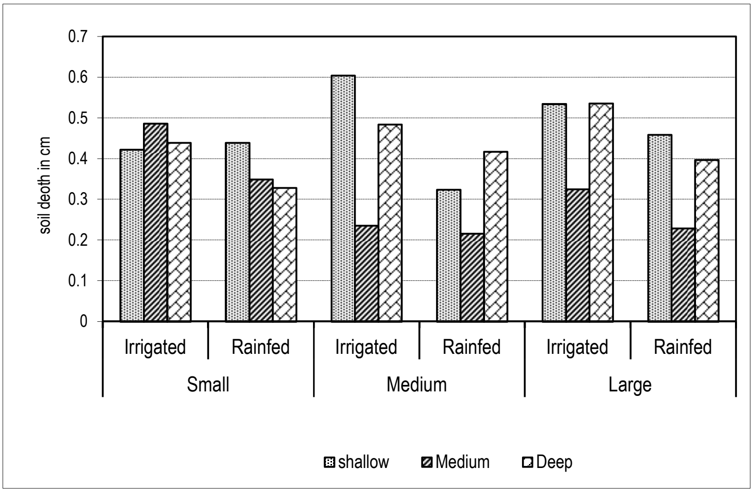


Figure 5.14: Change in soil depth in the watershed over 10 years (in cm)

5.2.6 Inorganic fertilizers and farmyard manure application

The farmers apply nutrients through inorganic fertilizers (urea and DAP) and farmyard manure. Figures 5.15 and 5.16 show that the simulated inorganic and farmyard manure applied (kg/ha) for crop production in the watershed by different household groups. The baseline simulation results show that the inorganic fertilizer application declines over time and then increases slightly towards the end of the planning period. The results indicate that the reduction in inorganic fertilizer application in the watershed is substituted by increased application of the farmyard manure. The production of farmyard manure increased in the watershed due to increase in the number of livestock over the years. However at the end of the simulation period the number of cows and buffaloes declined and thereby farmyard manure application in the watershed declines[13]. The application of inorganic fertilizer (kg/ha) by medium and large farmers is higher when compared to small farmers in the initial years (Figure 5.15). But the small farmers start increasing the application of inorganic fertilizer above the large farmers' level towards the end of the simulation. This indicates that the small farmers are start practicing intensive agriculture (because of less per capita land) to increase the production of crops per unit area to maximize the income whereas the large farmers has abundant land in the land scare economy following low input agriculture. The model predicts that the large farmers apply more farmyard manure (kg/ha) compared to that of medium and small farmers (Figure 5.14). The simulated baseline results shows the large farmer group have increased the cattle population over the years compared to small and medium farmer group (Table 5.5), which might be the reason for increasing the application of farmyard manure over the years.

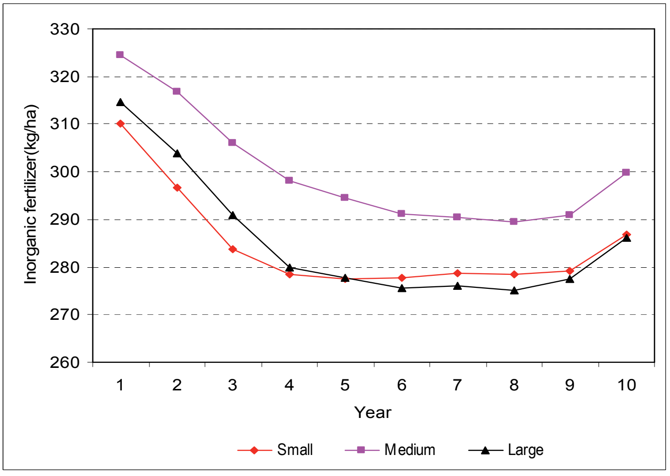


Figure 5.15: Simulated inorganic fertilizers applied (kg/ha) in the watershed

[13] Cattle and buffaloes are the major source of dung. On average about 250 kg/yr of collectable manure can be produced by a single cattle or buffaloes. The proportion of manure production per live weight of animal is 0.87.

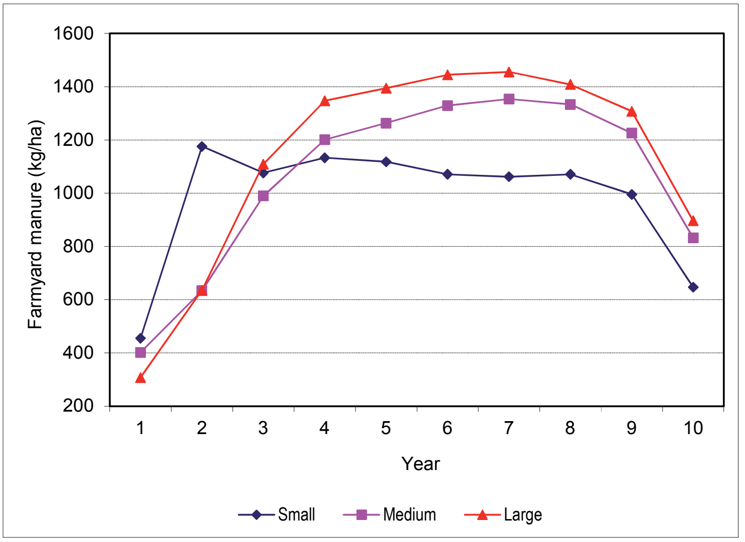


Figure 5.16: Simulated farmyard manure applied (kg/ha) in the watershed

5.2.7 Nutrient balance

The nutrient balance results for simulated baseline scenario assuming constrained credit for purchasing inorganic fertilizers[14] and application of farmyard manure produced in the watershed are depicted in Figure 5.17. The projected nutrient balance under this farming system in the watershed is -13.60 tons N, 11.15 tons P and -93.16 tons K in the initial year. This model results show that the nutrients N and K are over extracted from the soil for the simulated land use in the watershed causing nutrient mining in the watershed[15]. The K nutrient balance in the model result is very low because the only source of inflow for potassium is through FYM and natural deposition. In the model potassium fertilizer is not included to reflect the actual farmers practice

[14] The farmers in the watershed apply mostly urea and DAP for all the crops grown without potassium fertilizers. Even the amount of fertilizers applied to crops in the watershed is less than the recommended level.

[15] The long term experiment conducted in ICRISAT during 1980 found that the annual dryland crops (sorghum, millets and pigeonpea) showed no response to K nutrient. The K nutrient is mostly present in the non grain parts of the crops. If the crop residues are incorporated into the soil, K nutrient will stock up in the soils again (ICRISAT, 1981). Even though the depletion or mining rate is high for K, it will not affect the crop yield immediately. But continuous high rate of depletion over a long period without incorporating the crop residues back into the soil may affect the yield of the crops.

in the watershed. The farmers are applying P nutrient above the recommended level and hence P balance in the soil is positive. The optimizing behaviour results from the model show an increasing nutrient loss over the years. The magnitude of N and K nutrients loss increased by 4.6 and 5.5 per cent respectively from the level of initial year and P level is also reduced by 5.4 per cent over the initial year. The results indicate that the present level of nutrient management in the watershed will cause nutrient mining and lead to permanent land degradation in the future.

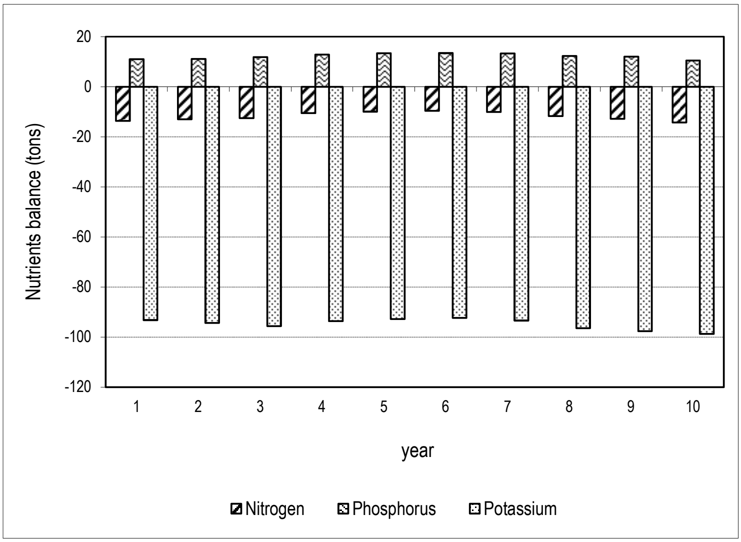


Figure 5.17: Simulated annual nutrient balances (in tons) in the watershed

5.2.8 Livestock rearing in the watershed

Figure 5.18 depicts the simulation results for the number of different livestock types by household group. The model results predict that cattle population is gradually decreasing whereas the small ruminants are increasing at a faster rate. The bullock number in the watershed declines in the initial years of simulation and then remains constant showing around 80 bullocks would be the optimum number to meet the draught power demand in the watershed. Similarly, the number of milking cows increases and then starts to decline over the years whereas the number of she buffaloes declines right from the initial year. The declining trend in rearing milking animals (local breeds and low milk yield) might be due to low productivity compared to small ruminants, whereas small ruminants show increasing trend over the years. The feed requirement for cattle is also higher than the small ruminants. The milk price received by the farmers from private buyers is low compared to milk cooperative prices. This may also contribute to the low profitability of milking animals in the watershed. The small farmers have reduced the number of milking animals by 70.58 per cent over years, whereas medium and large farmers had sized down the milking animals only to 14.70 and 20.51 per cent respectively compared to the population level at the initial year. The simulated livestock number for different household groups for 10 years is given in Table 5.5. The decline in maize area over the years reduces the feed availability in the land scare small farmers group which may leads to sizing down of cows and buffaloes and increasing the less feed requiring small ruminants and also driven by the profitability of sheep and goats relative to cows and buffaloes.

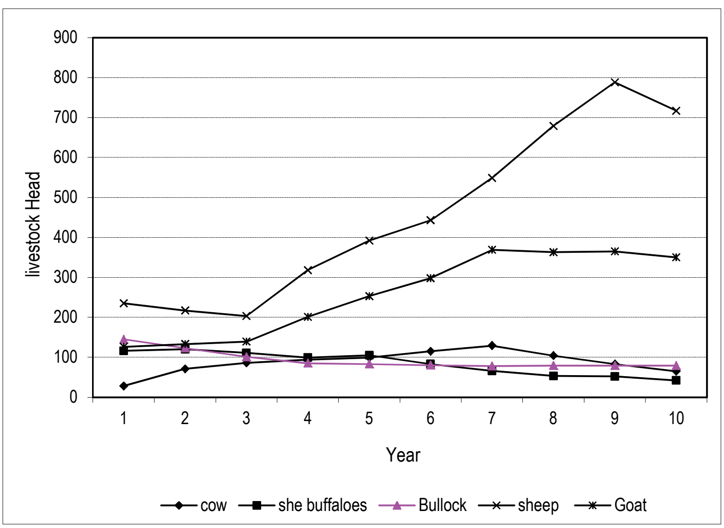


Figure 5.18: Simulated livestock number in the watershed

Table 5.5 The simulated livestock in the different household group in the watershed (number)

Year	Household Groups														
	Small household group					Medium household group					Large household group				
	cow	she buffaloes	Bullock	sheep	Goat	cow	she buffaloes	Bullock	sheep	Goat	cow	she buffaloes	Bullock	sheep	Goat
1	8	50	60	110	70	8	31	55	90	30	12	35	30	35	26
2	20	40	52	97	66	22	35	47	81	35	29	45	24	39	32
3	26	37	41	86	63	27	33	37	75	39	33	41	23	42	37
4	26	31	33	140	97	32	31	30	118	54	36	37	22	60	50
5	28	25	26	170	120	33	37	31	146	69	38	43	26	76	64
6	33	20	21	190	137	38	29	26	163	83	44	34	33	90	78
7	36	16	21	236	170	43	23	26	203	103	50	27	31	110	96
8	29	12	22	291	163	35	19	27	250	103	40	22	30	138	97
9	23	20	23	335	161	28	15	29	287	105	32	17	27	166	99
10	18	16	23	300	156	22	12	29	267	100	25	14	27	150	94

5.3 The analyses of alternative scenarios

In this section, the bioeconomic model is used to evaluate alternative scenarios related to the hypothesis formulated in chapter I. The alternative scenarios discussed include

5.3.1Impact of changes in yield of dryland crops (increase and decrease by10%)
5.3.2 Impact of changes in irrigated area of the watershed
5.3.3 Impact of changes in output price
5.3.4 Impact of output-based water charges (share of output 5 and 10%)
5.3.5 Impact of increased access to non-farm employment opportunities
5.3.6 Impact of increase in population pressure in the watershed

5.3.1 The impact of changes in yield of dryland crops

The main objective of integrated watershed management is to enhance the productivity of agriculture. The introduction of high yielding and drought tolerant crop varieties and improved cropping systems is an important component of watershed development intervention to increase the income of the farmers. Wani et al. (2003) reported that introduction of improved sorghum, maize, pigeonpea and chickpea varieties and intercropping systems has improved the income of the farmers in the Kothapally watershed. In this study, an attempt is made using bioeconomic model to test the hypothesis that introduction of technological innovations (like improved crop varieties and cropping systems) compensates for decreasing return to labour and improves the natural resource base over the years. The study simulates two scenarios to test this hypothesis, a) dryland crops (sorghum, maize, pigeonpea and chickpea) yield increased by 10 per cent and b) dryland crops yield decreased by 10 per cent. The analysis will highlight the degree of changes in the per capita income of the households, soil loss and households' decision on soil conservation measures.

The simulated results for a 10 per cent increase or decrease in the yield of dryland crops are presented in Figures 5.19 to 5.25. The results show that the area under sorghum/piegeonpea and maize/pigeonpea intercropping system increased by 5 and 12 per cent respectively in the initial year of simulation when yield of dryland crops increased by 10 per cent compared to the baseline level. On the contrary, the area under rainfed cotton in the watershed declined by 30 per cent compared to baseline level. This shows that an increase in yield of dryland crops increases the relative profitability of sorghum/pigeonpea and maize/pigeonpea intercropping systems compared to cotton. Hence, the farmers cultivate sorghum/piegeonpea and maize/pigeonpea cropping system by reducing the area under cotton. Decreasing the yield of dryland crops by 10% has reduced the area under maize/pigeonpea intercropping system by 6 per cent and increased the cotton area by 7 per cent in the watershed compared to baseline. Under this scenario the area under maize/pigeonpea is declining over the years and replaced by rainfed cotton and sunflower.

The changes in per-capita income of the three groups of households for simulated scenarios of changing yield of dryland crops are presented in Figures 5.19 to 5.21. The per capita income of all three groups households is above baseline level when the yields of the dryland crops are increased. The increase in yield of the dryland crops in the watershed increases fodder production, which in turn enhances the carrying capacity of livestock in the watershed. This increased livestock production increases the income from livestock gradually for all the household groups.

The results show that if the yield of dryland crop decreases, the per capita income for the three households is slightly higher than the baseline level (Figures 5.19 to 5.21) in the first year of simulation and then it starts declining over the years. When the yield for dryland crops decline, households attempt to diversify into livestock production. This leads to higher livestock income in the first year which temporarily raises the income of the households. However, the decline in the area under sorghum and maize affects the fodder production in the initial year forcing farmers to sell their livestock. As household income declines over time the per capita income decreases below the baseline level at the end of the simulation period. The reason is the effect of decreased livestock production because of less supply of fodder due to the reduced dryland crops area.

The total erosion and average soil loss per hectare for the changes in the yield of dryland crops is given in Figures 5.22 and 5.23. The soil erosion under the scenario of increased yield of dryland crops is higher than the baseline level at the initial years and starts declining from the fifth year of simulation. The increase in area of the dryland crops cultivation increases the demand for on farm labour in the initial year which reduces the incentive to use the labour for conservation measures and they cause higher soil erosion in the initial year of simulation. However, the population growth in the watershed over the years drives the farmers to use more labour for conservation measures in the field decline the soil erosion towards the end of the simulation period. The results show that the decline in soil erosion is 6 per cent compared to the baseline in the final year of simulation. Under the decreased dryland crop yield scenario, the soil erosion has not changed much compared to baseline scenario.

The labour used for soil conservation measures in response to change in crop yields is given in Figure 5.24. The results show that the farmers use less labour for conservation measures in the initial year under the scenario of increased dryland crop yield resulting in higher soil loss in the watershed. However the simulation shows that farmers try to counter this process by increasing labour for conservation measures towards the end of simulation. If the yield of dryland crops decreased, the labour used of conservation measures is similar to baseline level. The increase in area under sorghum and maize and decline in the area of high nutrient mining crop like cotton and sunflower under the scenario of increased yields of dryland crops has reduced soil nutrient mining by 4, 1, and 3 per cent N, P, and K respectively compared to baseline level. If the yield of dryland crops has decreased by 10 per cent, the results show that nutrient balances in the watershed are similar to baseline level (Figure 5.25).

It seems that adoption of new improved varieties of dryland crops like sorghum, maize and pigeonpea under intercropping systems has the potential to improve the income of the farmers. It also opens scope for increasing the income from livestock through efficient crop-livestock integration. The scenario also improves the natural resource condition by reducing soil erosion and nutrient mining by increasing the area under the cereal-legume cropping systems (sorghum/pigeonpea and maize/pigeonpea) and decline the area under high erosive and nutrient mining crops like cotton and sunflower.

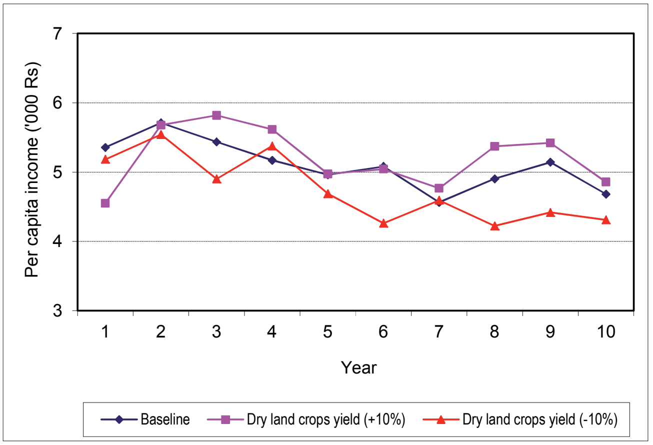


Figure 5.19: Simulated per capita income for small farmers: Alternative scenario for change in yield of dryland crops

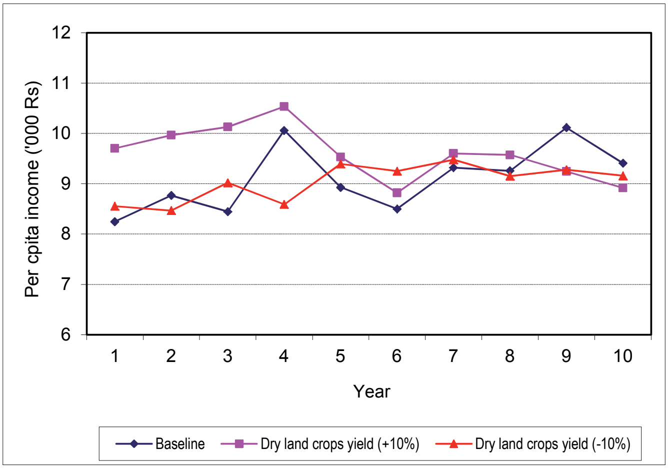


Figure 5.20: Simulated per capita income for medium farmers: Alternative scenario for change in yield of dryland crops

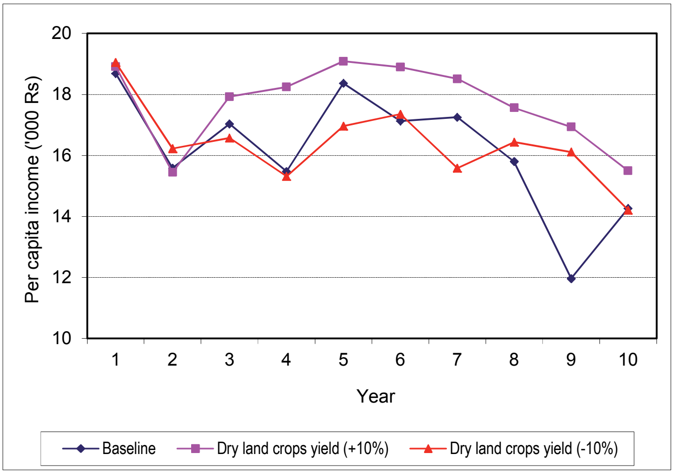


Figure 5.21: Simulated per capita income large farmers: Alternative scenario for change in yield of dryland crops

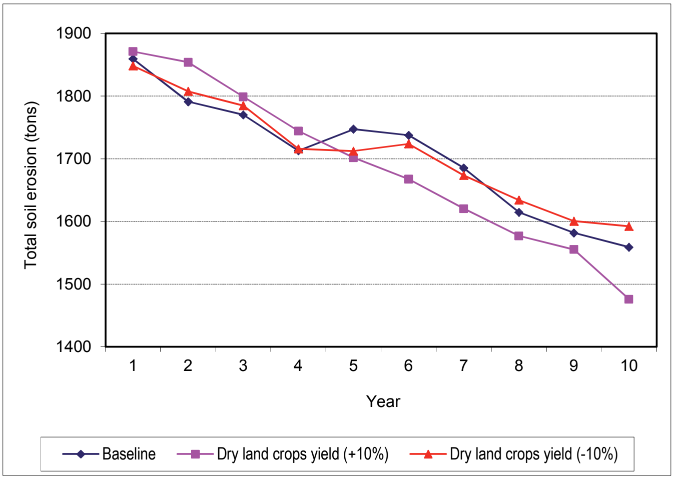


Figure 5.22: Simulated total soil erosion in the watershed: Alternative scenario for change in yield of dryland crops

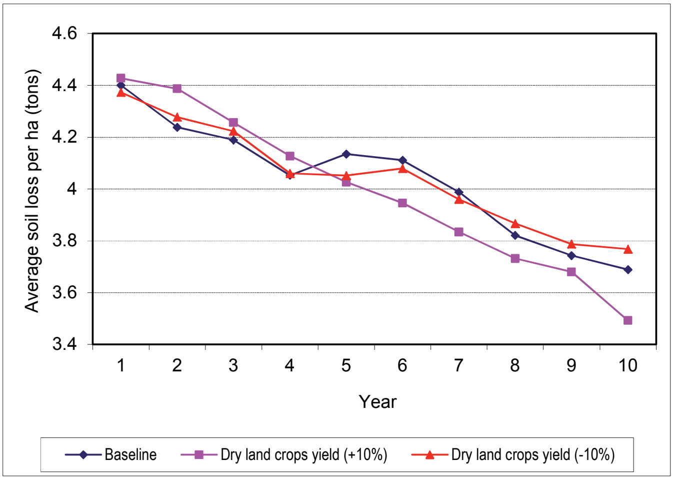


Figure 5.23: Simulated average soil loss per ha in the watershed: Alternative scenario for change in yield of dryland crops

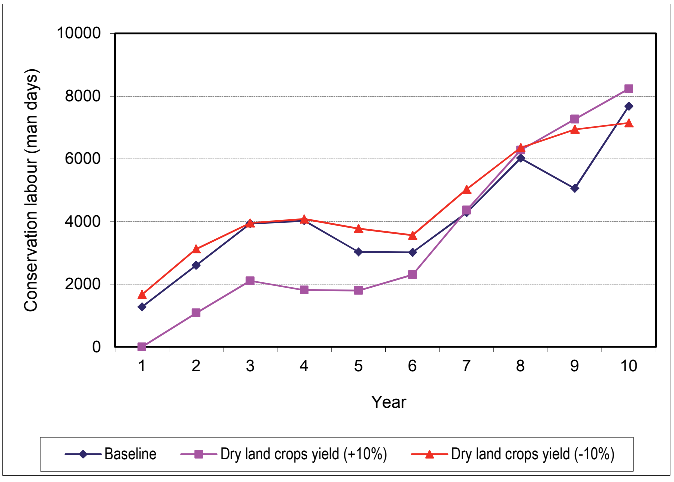


Figure 5.24: Simulated conservation labour used in the watershed: Alternative scenario for change in yield of dryland crops

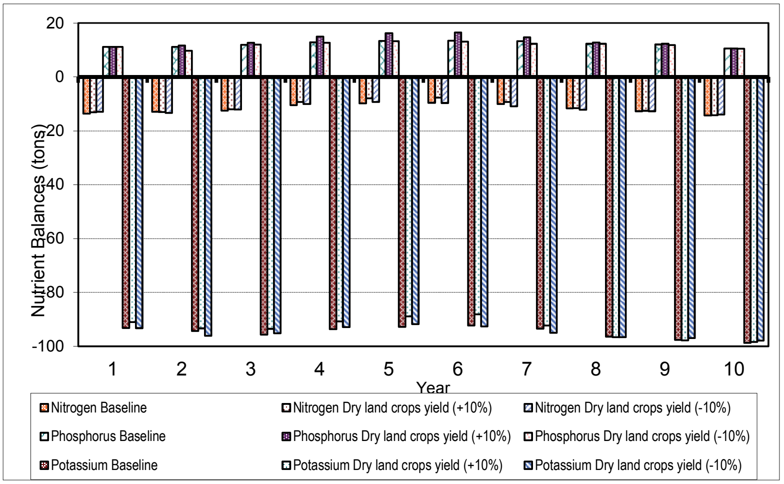


Figure 5.25: Simulated nutrient balances in the watershed: Alternative scenario for change in yield of dryland crop

5.3.2 Impact of change in irrigated area in the watershed

The important objective of watershed development programme is to conserve rainwater by reducing out flows from the watershed by constructing check dams and other *in situ* water conservation systems. The stored water will certainly improve the groundwater table, which inturn help to increase the area under irrigation in the watershed. In this context, simulation is carried out to assess the impact of changes in irrigated area resulting from adoption of soil and water conservation measures on household welfare, soil loss and nutrient balance in the watershed. Hence, the baseline scenario in the watershed is compared with two alternative scenarios a) increasing irrigated area by 25 per cent and b) reducing the area under irrigation by 25 per cent. These changes are simulated through comparative adjustments in dryland area so that the total cultivable area in the watershed remains unchanged. The scenario of decreasing the area under irrigation may be perceived as increased restriction by the community on use of ground water or decline in water availability for irrigation due to groundwater depletion.

Figures 5.26 to 5.32 show the impact of increasing or decreasing 25 per cent irrigated area on per capita income of the three household groups. The results show that if irrigated area increases by 25 per cent the per capita income of all the three household groups is more than the baseline level. This is due to higher productivity of crops like cotton, vegetables and sunflower under irrigation and increasing the area of these crops under irrigation results in increased production in the watershed. The increased marketable surplus of these crops increased the income of the household groups. The scenario of decreasing the irrigated area by 25 per cent leads to reduction in the per capita income for small farmers, whose rate of decline is faster over the years of simulation. Similarly, the per capita income of medium household is also lower than the baseline level if irrigated area is reduced by 25 per cent. Although a mixed trend seems to appear in large farmers, per capita income is generally higher than the base level income when area irrigated decreases (Figure 5.28). The results indicate that large farmers increase area under rainfed vegetables and cotton by reducing the area under maize, which results in higher per capita income towards the end of the simulation.

Figures 5.29 and 5.30 indicate the level of total soil erosion and average soil loss per hectare resulting from adjustments in irrigated area. The results show that soil erosion is higher when irrigated area increases in the watershed compared to the baseline level. The area under the irrigated cotton, sunflower and vegetables increases because of expanding irrigated land. The increase in the area of erosive crops (wide spaced crops) like cotton and vegetables results in higher erosion by 2 per cent compared to baseline level. On contrary, reduction in irrigated land in the watershed increased the area under less erosive dryland crops like maize and sorghum reducing the soil erosion by about 7 per cent.

The simulated labour used for conservation measures for two irrigation scenarios compared with the baseline level is given in Figure 5.31. When irrigated area increases by 25 per cent, the labour used for conservation measures is les than the baseline level in the initial years and increases above the baseline level towards the end of simulation. When the irrigated area decreased by 25 per cent total soil erosion is below the baseline level, even though the total labour used for conservation is lower than the baseline level. This is because of changes in cropping pattern, where area under less erosive dry land crops like maize and sorghum increases in the watershed.

The soil nutrient balance (Figure 5.32) indicates that nutrient mining is higher compared to the baseline level when irrigated area increases by 25 per cent. The aggregate nutrient mining in 10 years is about 22.50, -7.16 and 4.48 per cent over the baseline level for N, P and K respectively. This is due to increase in the area of high nutrient extraction irrigated crops like vegetables, cotton and sunflower compared to baseline level. When irrigated area is reduced by 25 per cent in the watershed the aggregate nutrient mining over 10 years is reduced by about -21.61, 18.11 and -6.12 per cent over the baseline level for N, P and K respectively. The reduced irrigated area increases the area under cereal-legume cropping systems like maize/pigeonpea and sorghum/pigeonpea which remove comparatively less nutrients from the soil and also improves the nutrient content by biological atmospheric fixation.

The increase in irrigated area in the watershed even it improves the welfare of the farmers, the change in the cropping pattern cause negative effect on the environment by increasing the erosion level and soil nutrient mining.

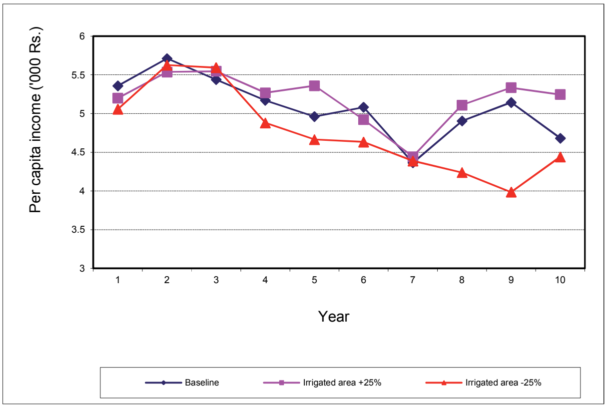


Figure 5.26: Simulated per capita income for small farmers: Alternative scenario for change in irrigated area

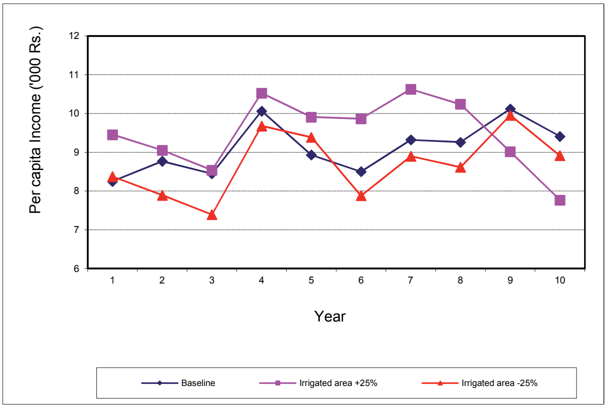


Figure 5.27: Simulated per capita income for medium farmers: Alternative scenario for change in irrigated area

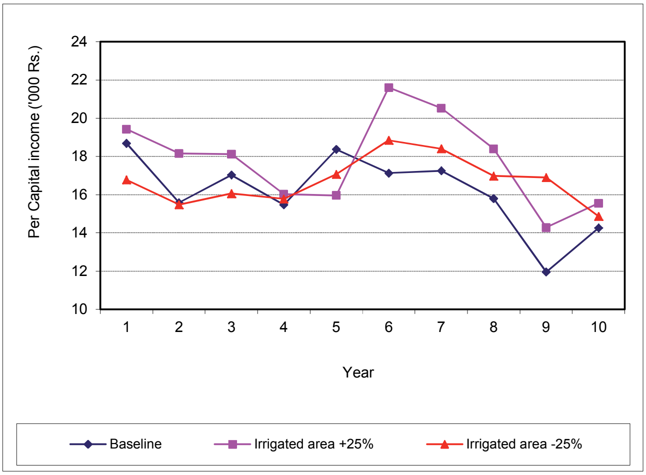


Figure 5.28: Simulated per capita income for large farmers: Alternative scenario for change in irrigated area

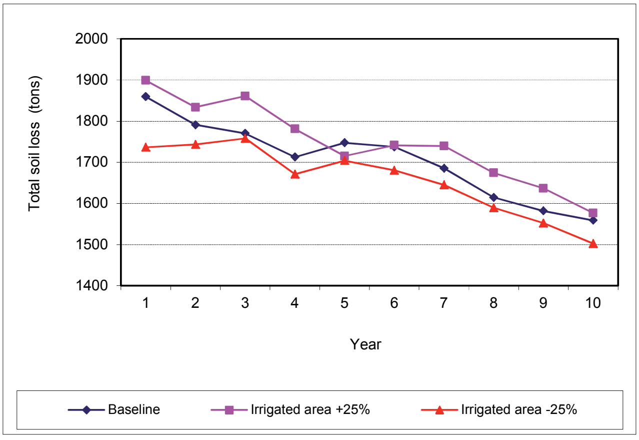


Figure 5.29: Simulated total soil loss: Alternative scenario for change in irrigated area

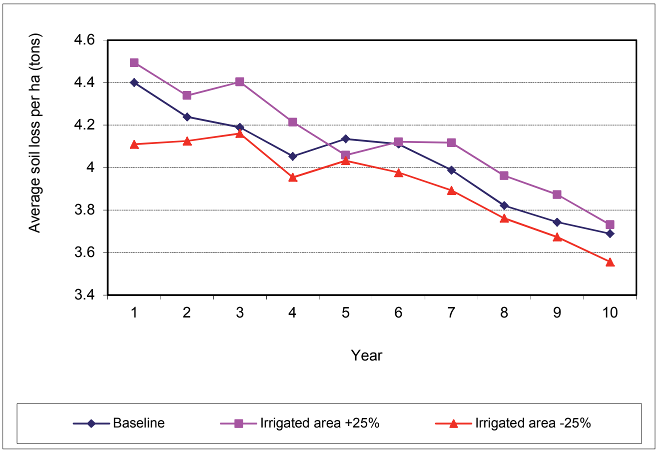


Figure 5.30: Simulated average soil loss per ha: Alternative scenario for change in irrigated area

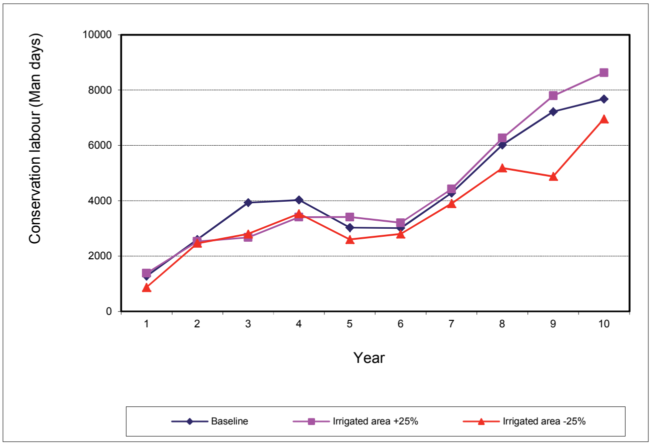


Figure 5.31: Simulated conservation labour used in the watershed: Alternative scenario for change in irrigated area

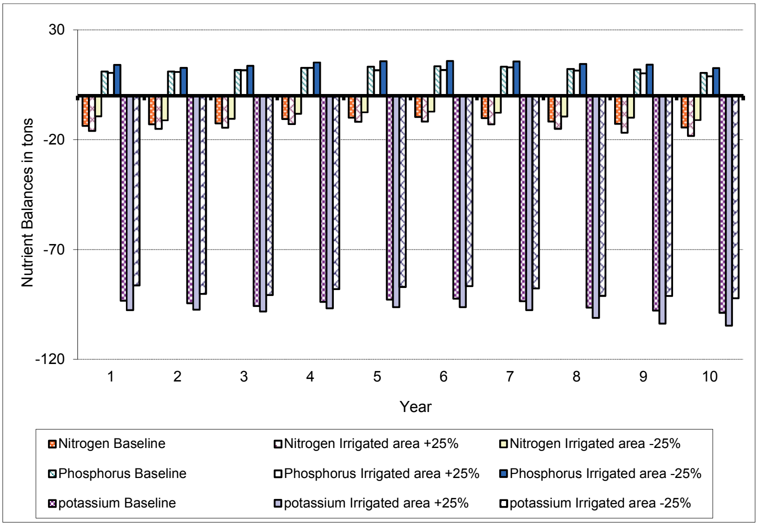


Figure 5.32: Simulated nutrient balances under alternative scenario for change in irrigated area

5.3.3 Impacts of change in output prices

5.3.3.1 Price support of dry land crops

The incentive effect of increasing the price of dryland crops (sorghum, maize, pigeonpea and chickpea) by 10% is shown in Figures 5.33 to 5.39. In response to the relative price changes in dryland crops, the farmers in the watershed modify their land use pattern and cropping systems. The results show that the area under maize/pigeonpea and sorghum/pigeonpea intercropping system increases by 18 and 4 per cent respectively due to the increase in the price of the crop produces. The result revealed that the maize/pigeonpea cropping system is price elastic[16] (1.8) whereas the sorghum/pigeonpea cropping system is price inelastic (0.4). This may be due to higher productivity of maize/pigeonpea compared to sorghum/pigeonpea cropping system. The area under cotton declines by 67 per cent in the initial year of simulation compared to that of baseline scenario.

Figures 5.33 to 5.35 show that better prices of dryland crops improve the per capita income of the households. The magnitude of increase in the per capita income is higher for the medium and large households, whereas it is less for small households compared to baseline per capita income of the respective households. The lower rate of increase in the per capita income of small households is due to their higher consumption requirement coupled with increased population, which inturn lower the marketable surplus of sorghum, pigeon pea and chickpea produced by the small households.

Figures 5.36 and 5.37 show that increasing the output price of dryland crops lead to decrease in the total soil erosion and average soil loss per hectare in the watershed compared to baseline scenario. Despite the lower investment of labours on conservation measures under the situation of increasing price of dryland crops (Figure 5.38) the reduction in soil erosion occurs due to change in cropping patterns in the watershed in response to price change.

---

[16] Elasticity is referred as percentage change in area by percentage change in price, if >1 elastic and <1 inelastic.

The supply response of the farmers in the watershed for change in dryland crops price has increased the area under sorghum and maize. This keeps down erosion level in the watershed even with the lower level of labours used for conservation measures. The average per ha soil loss is reduced in the watershed by 3 per cent compared to the baseline level. Due to increase in an area of sorghum and maize, the fodder availability in the watershed also increased up to 10%, so the livestock population especially the cattle are increased compared to the baseline population.

The decline in area under nutrient erosive crops like cotton and sunflower and increased application of farmyard manure[17] has resulted in decline soil nutrient mining in the watershed. The Figure 5.39 compares the baseline nutrient balances with the scenario of increasing price of dryland crops, which shows that the reduction in nutrient loss of 23, 13 and 6 per cent N, P and K respectively.

5.3.3.2 Decline with price of irrigated crops

Figures 5.33 to 5.39 present the effect of depressing the price of irrigated crops grown (cotton, vegetables, onion and sunflower) by 10 per cent on the per capita income, soil loss, labour used for conservation and nutrient balances. The simulation results reveal that the farmers respond to change in price of irrigated crops by decreasing the area under cotton, sunflower and vegetables crops grown during *rainy* season. The situation results in the increased area under maize and sorghum by 15 per cent compared to baseline level in the watershed. Even though, the farmers respond to the lower price of irrigated crops by increasing area under dryland crops, their per capita income is declined below the baseline level. The magnitude of decline in per capita income of large household is higher by about 37 per cent compared to baseline level at the initial year of simulation. The decline in per capita income in the scenario is due to the loss of additional income by decreasing the area under cotton, sunflower and vegetables. However, this loss of income is higher than the additional income obtained from production of dryland crops like maize and sorghum.

The change in cropping pattern by increased area under dryland less erosive crops (sorghum and maize) results in reduced total soil erosion (Figure 5.36) and average

[17] The increase in livestock population compared to baseline level due to increased fodder production has contributed to higher production of FYM in the watershed.

soil loss per hectare (Figure 5.37) in the watershed compared to the baseline level. The lower level of soil erosion is achieved with less investment of labour used for soil conservation (Figure 5.38). The results also suggest that the labour used for conservation measures is slightly higher under the situation where the prices of irrigated crops decreased by 10% compared to the scenario of increased (10%) price of dryland crops. It is found that there is not much difference in the nutrient loss from the watershed when either price of irrigated crops decreased or dry land crop increased. However the nutrient loss under scenario of decreased price of irrigated crops is less than the baseline level. From the results it is observed that the reduced soil erosion and nutrient mining is achieved when the price of irrigated crops reduced.

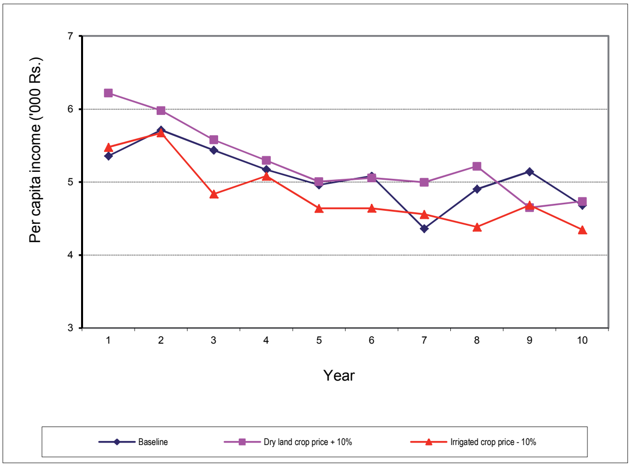


Figure 5.33: Simulated per capita income for small farmers: Alternative scenario for prices change

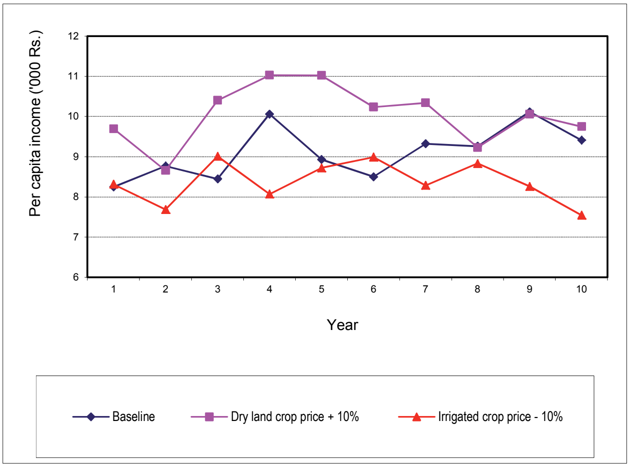


Figure 5.34: Simulated per capita income for medium farmers: Alternative scenario for prices change

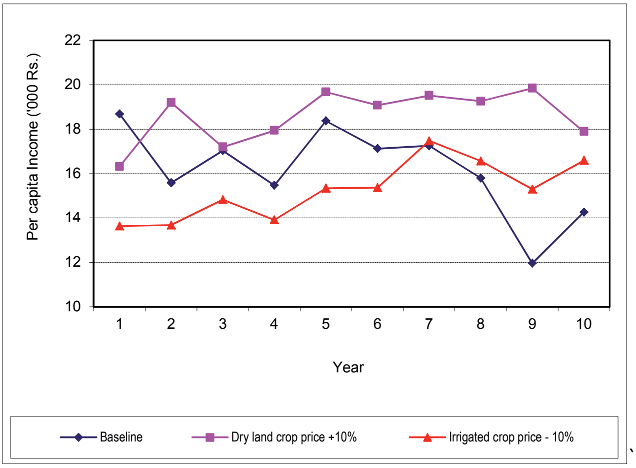


Figure 5.35: Simulated per capita income for large farmers: Alternative scenario for prices change

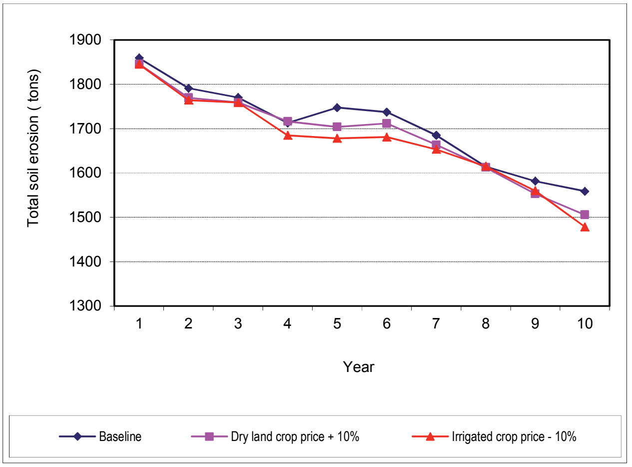


Figure 5.36: Simulated total soil loss in the watershed: Alternative scenario for prices change

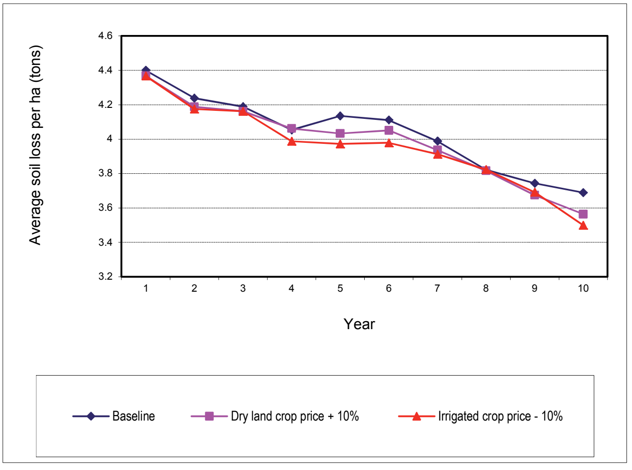


Figure 5.37: Simulated average soil loss per ha: Alternative scenario for prices change

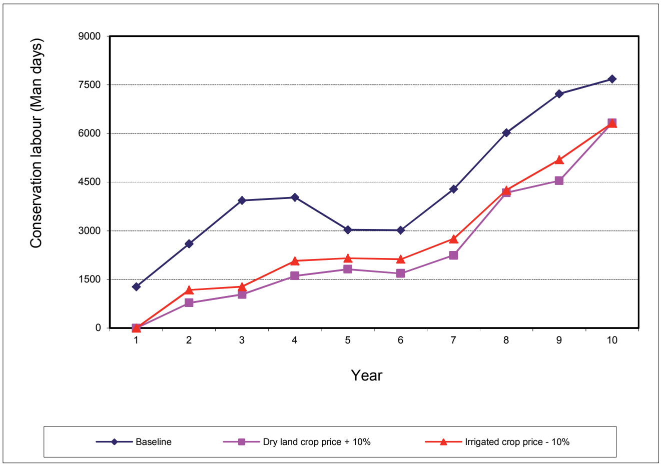


Figure 5.38: Simulated conservation labour used in the watershed: Alternative scenario for prices change

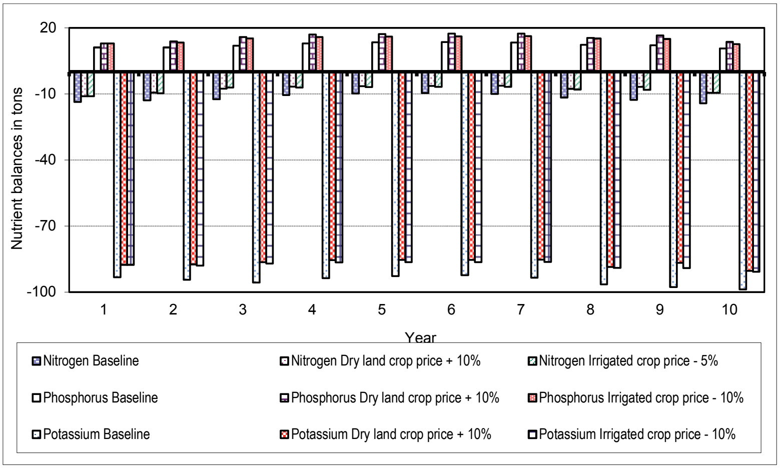


Figure 5.39: Simulated nutrient balances in the watershed: Alternative scenario for prices change

5.3.4 Impact of output-based water charges (share of output 5 and 10%)

In India, irrigation water and energy prices are highly subsidized by the government. Groundwater for small scale irrigation is also free to all farmers who can privately invest in tube and open wells. The electricity is free for lifting the groundwater in some states of India. These kinds of policies often lead to overuse and depletion of groundwater reserves (World Bank 1993). With increasing investment in small scale irrigation, depletion of groundwater in many dryland semi-arid villages is occurring at alarming rates. It is evident from the study conducted by Shiferaw *et al*., (2003) in 12 villages in Andhra Pradesh that about 65 per cent of open wells and 28-44 per cent of tube wells have dried up in each of non-watershed villages. This clearly shows that the groundwater in these villages is extracted over and above the natural recharge of aquifers in the villages.

The free availability of irrigation water induces a shift towards water-intensive crops (like paddy, sugarcane and turmeric), which give high net returns to free irrigation. But the water productivity (measured as rupees per hour of irrigation) is low for high water demand crops like paddy and sugarcane. It is high for high-value crops (like cotton, vegetables, sunflowers and onion) with low water demand (Shiferaw et al, 2003). Hence it is necessary to develop economic incentives and water charges to regulate groundwater extraction and also for shifting cropping pattern towards water-saving crops with high net water productivity. In the present study, an attempt was made to study the impact of output based water charges on cropping pattern changes, household per capita income, soil erosion, incentive to invest labour for conservation measures and nutrient mining. The bioeconomic model was used to stimulate two water pricing scenarios: a) 5 per cent of output share as water charge, and b) 10 per cent of output share as water usage charge. The complete simulation results of water pricing on the impact of household welfare and sustainability indicators are depicted in Figures 5.40 to 5. 46. The model results indicate that water pricing has changed the cropping pattern in the watershed. By charging 10 per cent share of output as water charges, the model recommends only onion crop in irrigated land in the watershed. The other irrigated crops like cotton, vegetables and sunflower, which grown in baseline results are replaced by onion crop. The higher yield and high response to fertilizers and low price of onion make the crop more profitable compared to other crops like vegetables, paddy, cotton and sunflower when water charges are included in the model. The model results indicate that the irrigated area is allocated to paddy and onion when charging 5 per cent share of output. The area under paddy is about 27 hectares in the first year of simulation and it gradually decreased over the year and the area is replaced by onion. The results show that when irrigation of crops is charged based on output share makes the farmer to cultivate crops which give more yield per unit of irrigation. Even if the price of the crop is low, the higher yield increases the profitable of the crop after the payment of water charges. The model results indicate crops with lower yield with higher prices become less profitable when the water is priced based on output share.

The effect of water pricing on the per capita income of the different households is given in Figures 5.40 to 5.42. The shift in the cropping pattern has the impact on income of the households. The results indicate that the per capita income of all the household groups is below the baseline level. The lower per capita income is mainly due to reduced area under high value crops like vegetables, cotton and sunflower under irrigated condition. The reduction in per capita incomes are about 50 and 37 per cent for small farmers, 12 and 18 per cent for medium farmers and 15 and 19 per cent for large farmers for 10 and 5 per cent of water pricing based on the output share respectively compare to baseline level. The results also show that changes in the cropping pattern affects the fodder production in the watershed, which lowered the livestock production and also the income from livestock.

The impact of water charges on the amount of soil erosion and average soil loss per hectare is given in Figures 5.43 and 5.44. The results show that water pricing reduce the total soil erosion and the soil loss per hectare by about 27 and 33 per cent for 10 and 5 per cent share of output as water charges respectively compared to the baseline level. This is due to less area under high erosive crops like cotton and vegetables in irrigated land. The results also show that the less demand for on-farm labour due to less area under cultivation of high labour demand crops like cotton and vegetables, which give the farmers incentive to employ more labour for conservation (Figure 5.45). This also contributes to the reduced soil erosion in the watershed. The increase in labour used for conservation measures in the watershed is about 71 per cent higher than the baseline level for both level of water pricing. The labour for conservation is increasing over the years but the rate of increase is less compared to the baseline level. The simulated nutrient balances given in the Figure 5.46 shows that nutrient mining has reduced by imposing water pricing. This is because of changes in cropping pattern in the watershed. The high nutrient mining crops like cotton and vegetables area are reduced in the watershed by about 220 and 63 per cent compared to baseline level.

It appears therefore, that charging irrigation water does not give win-win benefits as the per capita income of the farmers in the watershed is reduced. Because of less area under high nutrient uptake crops like vegetables, paddy and cotton the degradation of natural resources like soil and nutrients is reduced significantly. Hence, it reveals that the water pricing has the potential to reduce the natural resource degradation. It is necessary to test the alternative water pricing method like volume based water charges (Rupees per hour of water pumped) which may give increased per capita income to farmers as well as incentive for reducing natural degradation[18].

[18] The bioeconomic model used in this study does not include the water model. If water requirement for different crops and constraint of water availability in the watershed is given than we can charge for the water the crops consumed and stimulate and analyze how the cropping pattern is changing from high water consuming crops to water-saving high value crops and also the impact on welfare and sustainability indicators.

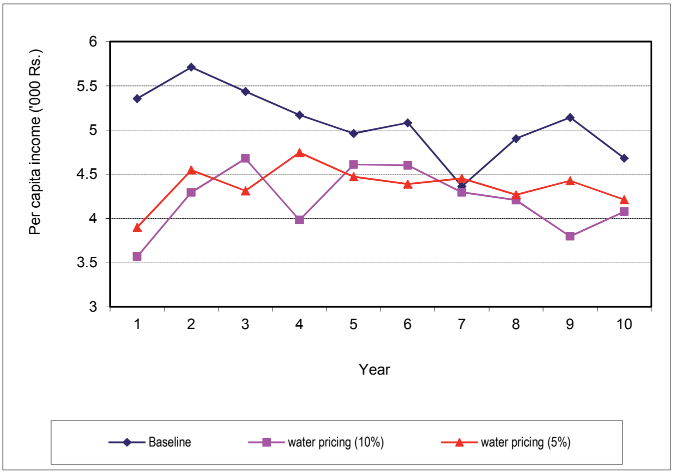


Figure 5.40: Simulated per capita income for small farmers: Alternative scenario for water pricing

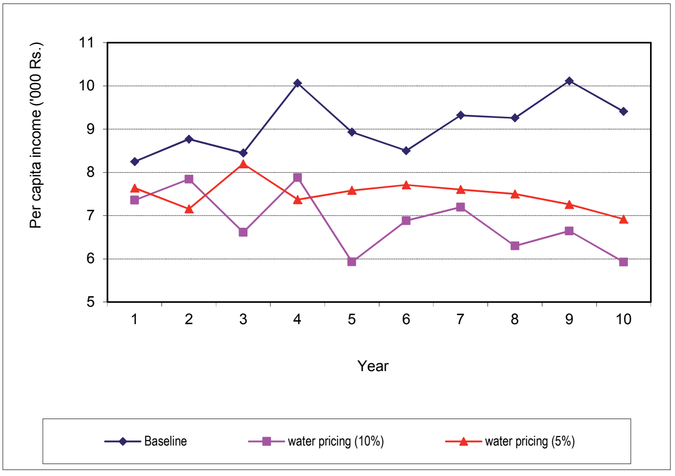


Figure 5.41: Simulated per capita income for medium farmers: Alternative scenario for water pricing

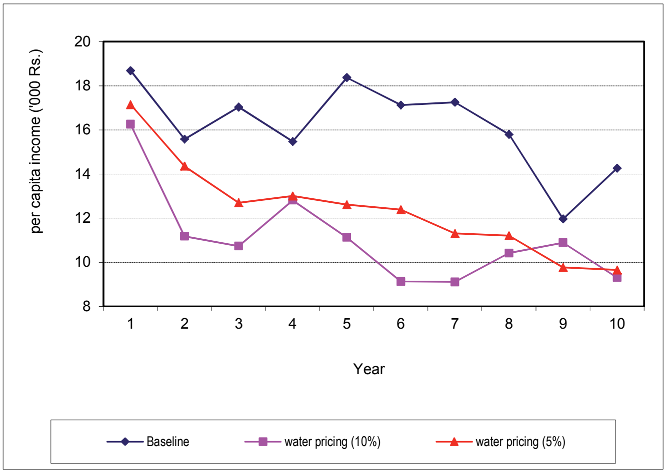


Figure 5.42: Simulated per capita income for large farmers: Alternative scenario for water pricing

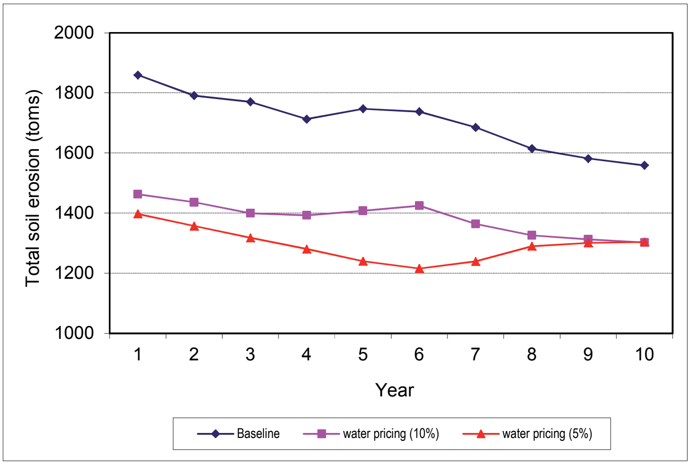


Figure 5.43: Simulated total soil erosion in the watershed: Alternative scenario for water pricing

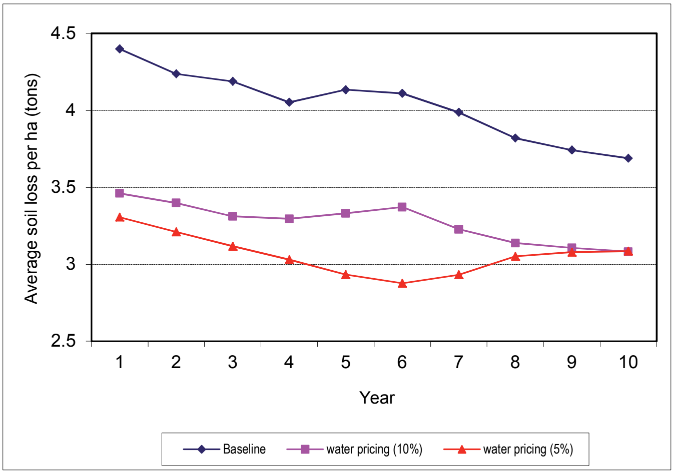


Figure 5.44: Simulated average soil loss per ha: Alternative scenario for water pricing

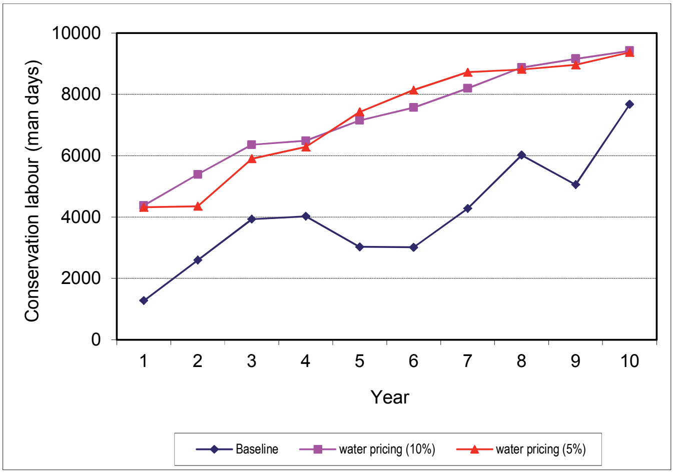


Figure 5.45: Simulated conservation labour used in the watershed: Alternative scenario for water pricing

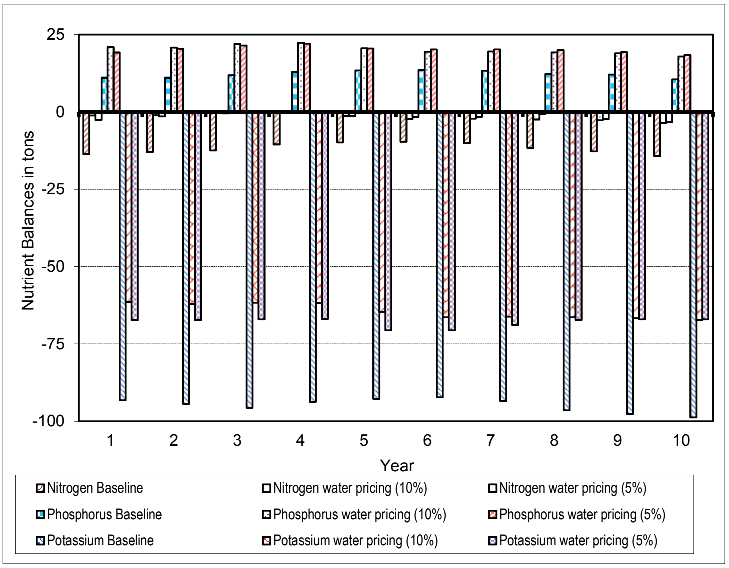


Figure 5.46: Simulated nutrient balances in the watershed: Alternative scenario for water pricing

5.3.5 Impact of increased access to non-farm employment opportunities

The watershed bioeconomic model is used to explore the impact of increased access to non-farm employment opportunities on household welfare, agricultural production, soil erosion, conservation incentives and nutrient mining in the watershed. Other than introducing soil and water conservation and productivity enhancement technology, watershed development programme is also providing non-farm employment training (like vermi-compost production, NPV biopesticide production, tailoring etc) and capacity building training to empowering rural women to improve the scope for enhancing their livelihoods of the households. In this context, it is assumed that the watershed programme is increasing the non-farm employment opportunities in the watershed.

In Figures 5.47 to 5.53, the baseline scenario (where the non-farm employment is constrained) is compared with the alternative scenario of improved access to non-farm employment opportunities in the watershed. The results show that increase in non-farm employment leads to significant increase in per-capita income of the three household groups. The per capita income for small and medium household groups is about 17 and 12 per cent above the baseline level. It is also found that the per capita income declines over the years for small and medium farmers as the income contribution from agriculture is lower because the farmers reduce the area under cultivation of crops to divert more labour to non-farm employment.

The average soil loss per ha in the watershed for increased non-farm employment opportunities and baseline scenario is given in Figure 5.51. The result shows that the soil loss per hectare is higher by six per cent compared to baseline level in the watershed. Figure 5.50 indicates that the decrease in rate of soil loss over the years is less when the non-farm employment is higher in the watershed. This shows the farmers lack incentives to use labour for conservation to reduce soil loss. This is because the opportunity cost of labour for non-farm employment is higher than the labour used of conservation measures. The Figure 5.52 reveals that when non-farm employment is more in the watershed the farmers use zero labour for conservation measures in the initial years of simulation because of diversion of the farm labours to

non-farm employment which gives higher returns. However, the results show that increase in workforce due to population growth over years in the watershed allows the small and medium farmers to use their excess labour for conservation measures.
When non-farm employment opportunity is increased in the watershed the increase in soil erosion and 2 per cent increase in the area under cotton has increased nutrient loss over the period (Figure 5. 53).

It is concluded that provision of better non-farm employment opportunities in the watershed does not give win-win benefits as the natural resource base will suffer more because of negligence in natural resource management. These results are also consistent with findings of Shiferaw et al. (2003a), where they found that the diversification into non-farm livelihood strategies could decline the level of fertilizer use, labour use and conservation investments per unit of land and hence land productivity (net returns per unit of land) is lowered for households who earn a significant portion of income from non-farm sources.

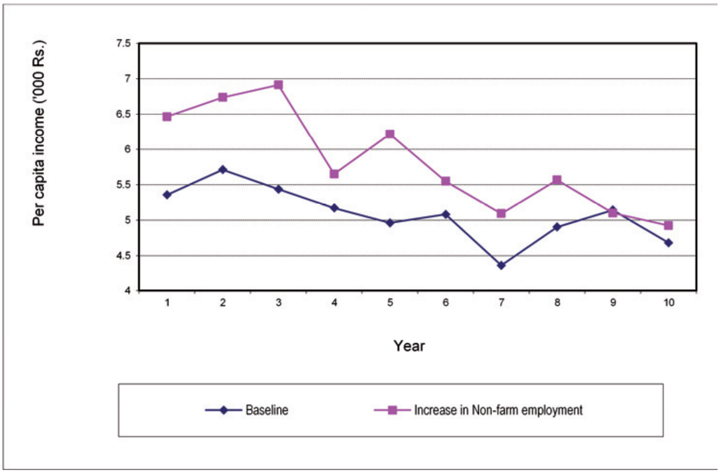


Figure 5.47: Simulated per capita income for small farmers: Alternative scenario for increase in non-farm activities

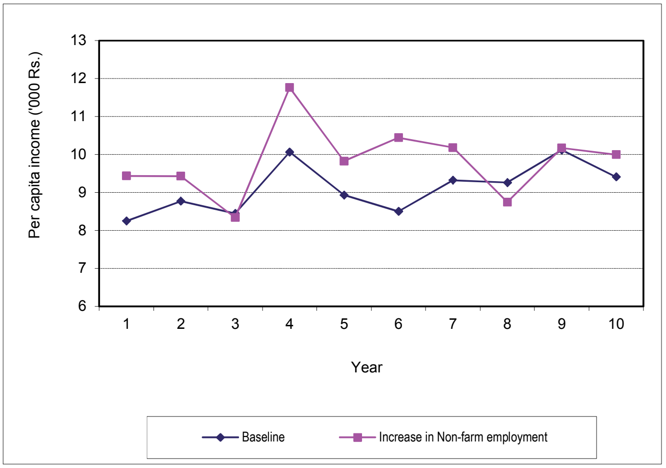


Figure 5.48: Simulated per capita income for medium farmers: Alternative scenario for increase in non-farm activities

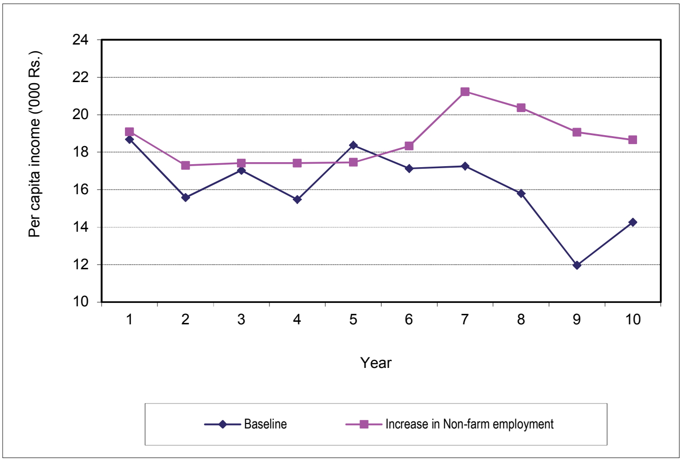


Figure 5.49: Simulated per capita income for large farmers: Alternative scenario for increase in non-farm activities

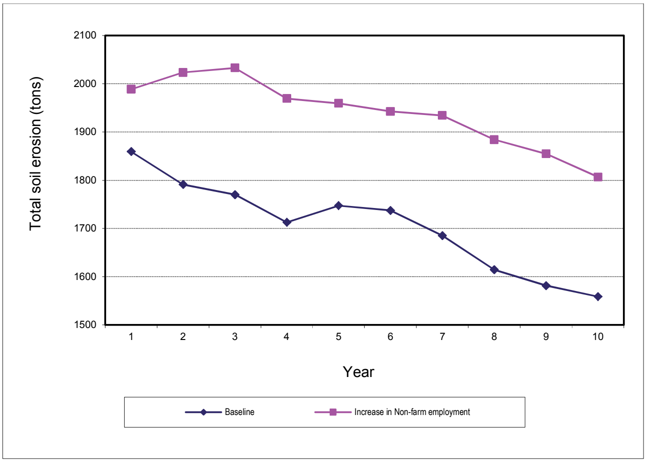


Figure 5.50: Simulated total soil loss in the watershed: Alternative scenario for increase in non-farm activities

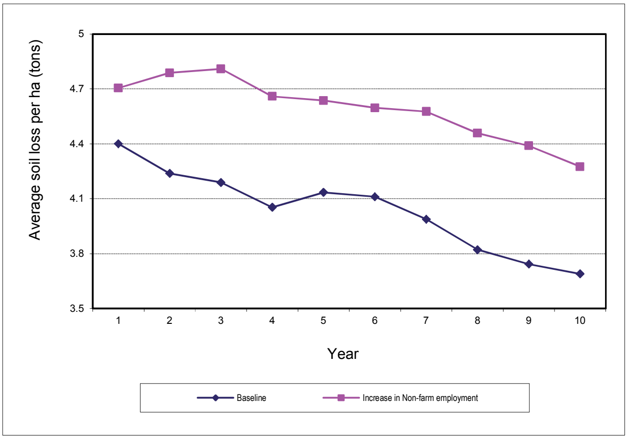


Figure 5.51: Simulated average soil loss per ha: Alternative scenario for increase in non-farm activities

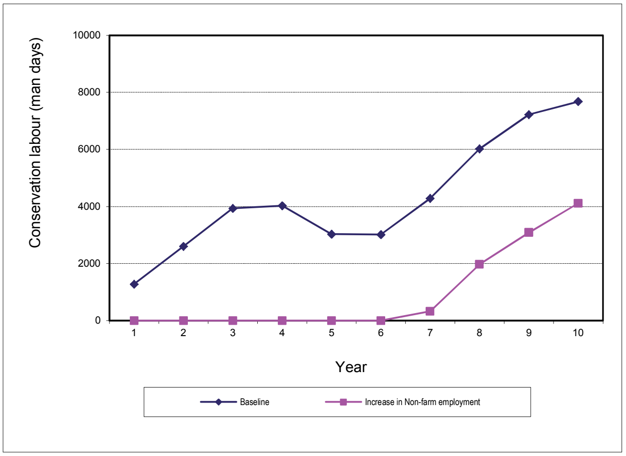


Figure 5.52: Simulated total conservation labour used in the watershed: Alternative scenario for increase in non-farm activities

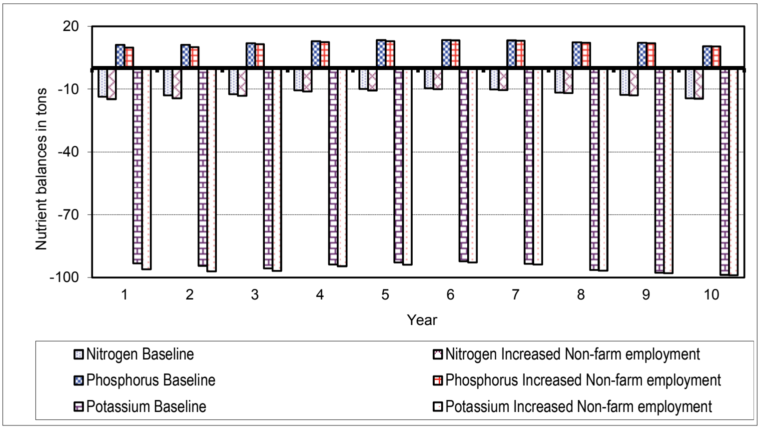


Figure 5.53: Simulated nutrient balances in the watershed: Alternative scenario for increase in non-farm activities

5.3.6 Impact of increase in population pressure in the watershed

The bioeconomic model developed for Adarsha watershed is used for assessing the impact of increasing population growth rate on household welfare and condition of natural resource base. In this simulation, it is assumed that the population growth rate is increasing from 2.5 to 3 per cent in the watershed keeping all other parameters unchanged from the baseline model. The model results of increased population pressure in the watershed are presented in Figures 5.54 to 5.60. The results predict that increased population pressure results in lower per capita income in all three households compared to baseline level with constrained access to non-farm employment and no scope for increasing the area under cultivation in the watershed. This is due to decline in crop sale caused by increase in on-farm consumption of cereals and pulses to meet the increased nutritional demand in the watershed. The results suggest that the per capita income does not change unless technological innovations or higher prices of outputs to compensate for decreased returns to labour in the watershed.

The simulated total soil erosion and average soil loss per hectare in the watershed under the scenario of increased population growth rate is given in Figures 5.57 and 5.58. The results show that the cumulative total soil erosion in the watershed decline marginally by about 2 per cent when compare to the baseline level. The population pressure in the watershed does not change the cropping pattern much compare to baseline results. The area under sorghum/pigeonpea is increased only by about 8 per cent by the small farmers to meet the increased nutritional requirement caused by increased population. The increase in workforce in the watershed due to population growth has increased the aggregate labour used for conservation measures over 10 years by about 18 per cent more than the baseline level (Figure 5.59). The results show that there is no marked change in demand for labour in the on-farm activities because there is no change in the cropping pattern, which allows the farmers to invest their excess labour in the soil conservation measures, which reduces the soil erosion in the watershed.

The results show that there is no major change in the nutrient balances compared to baseline level. It is evident that the population growth in the watershed improves the natural resource condition, when there are limited opportunities for non-farm employment in the watershed.

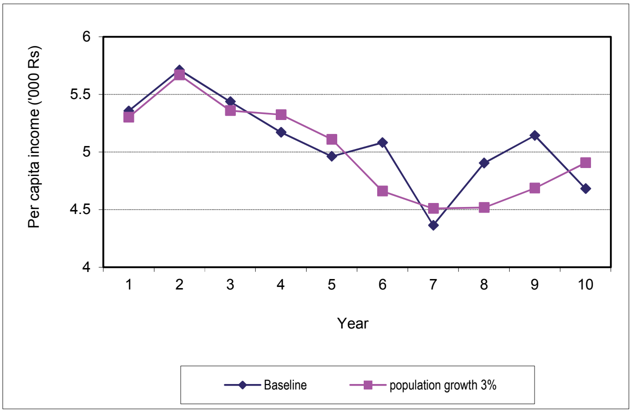


Figure 5.54: Simulated per capita income for small farmers: Alternative scenario for increased population growth

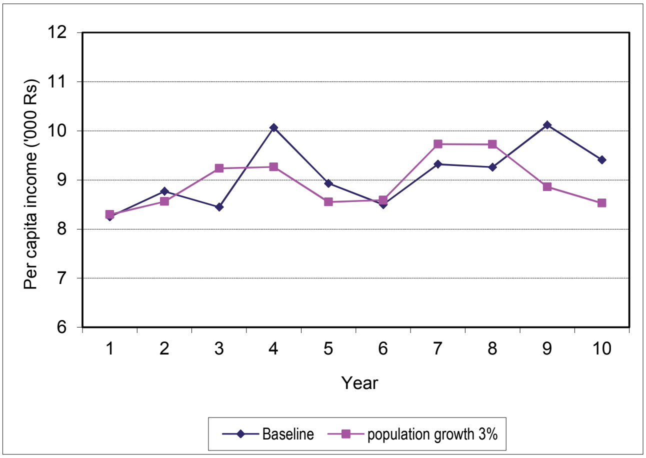


Figure 5.55: Simulated per capita income for medium farmers: Alternative scenario for increased population growth

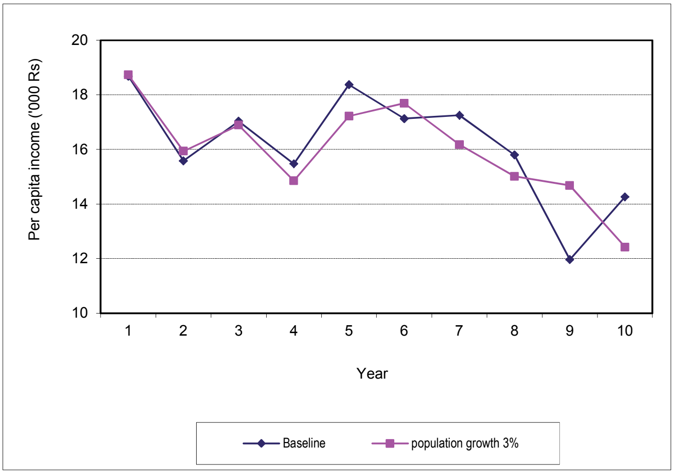


Figure 5.56: Simulated per capita income for large farmers: Alternative scenario for increased population growth rate

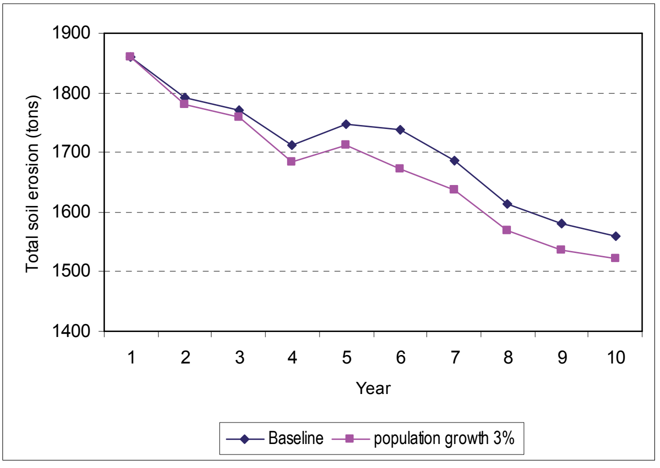


Figure 5.57: Simulated total soil erosion in the watershed: Alternative scenario for increased population growth rate

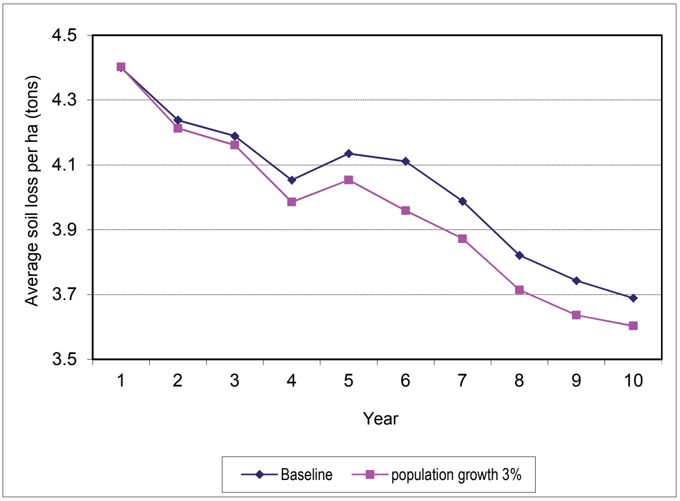


Figure 5.58: Simulated average soil loss per ha in the watershed: Alternative scenario for increased population growth rate

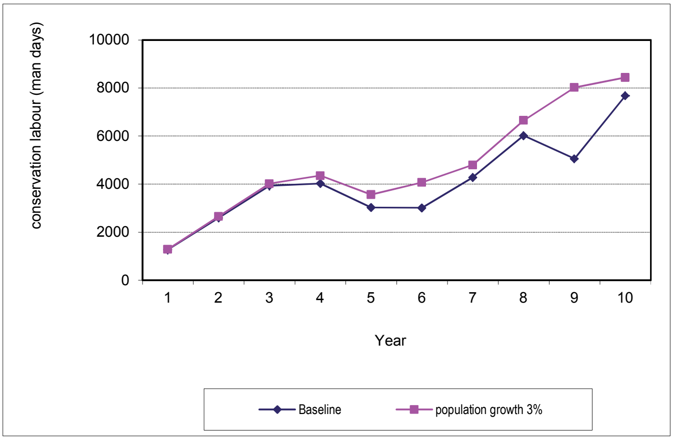


Figure 5.59: Simulated conservation labour used in the watershed: Alternative scenario for increased population growth rate

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

In an effort to improve the livelihood of poor households, to arrest land degradation (nutrient mining and soil erosion) and revitalize the mixed crop-livestock production system in rainfed SAT, the Government of India, started promoting watershed development approach with the help of development agencies and NGOs. The International Crops Research Institute for Semi-Arid Tropics (ICRISAT) has also played a proactive role in research on soil and water management technologies through the envelope of watershed development approach for the SAT agriculture. In the late 1990s, ICRISAT initiated a consortium of research and development institutions and developed a package of production and conservation technologies and evaluating the impact of the technologies under farmers' field condition.

Even though there are several exceptional case studies of successful watershed development in India, there is lack of empirical evidence on the impact of the approach on improving the welfare of the poor and the natural resource condition in the SAT. The previous impact studies of watershed development in India have hardly ever integrated the biophysical factors with economic factors to assess the complementarities and the tradeoffs within the framework of farm household economic behaviour. In this study a holistic and integrated approach is simulated using a bio-economic model, which is used to simultaneously assess and evaluate the multi-dimensional impacts of integrated watershed management on the welfare of the rural households and the natural resource conditions. The model is also used to identify effective policy instruments and institutional needs for enhancing the effectiveness of the watershed approach.

ICRISAT in the year 1998 developed a benchmark watershed in Kothapally village in Ranga Reddy district in Andhra pradesh by implementing new integrated watershed management approach with consortium partners. The productivity enhancing and soil and water conservation technologies developed by the consortium members have implemented and tested in the watershed to improve productivity, income and restore sustainability of land. The reason for selecting this case study area is because of the availability of both biophysical and socioeconomic data covering a period of 5-6 years required for developing the model. The biophysical data include soil erosion at watershed level, soil chemical and physical analyses and meteorological data. Household survey data was collected annually in three years period (2002-2004). The survey included detailed production data collected at the farm and plot level.

Bioeconomic models are useful tools in policy analysis because they can reflect the biophysical as well as socioeconomic conditions essential for decision making with in specific watershed/village. In this study, a watershed level dynamic non-linear bioeconomic model with crop-livestock integration is developed for the case study of Adarsha watershed. The model maximizes aggregate household income, which is modeled separately for three representative household groups. The three household types were identified based on land endowment (small, medium and large), which are spatially disaggregated into six different segment in the watershed landscape namely shallow, medium and deep based on soil depth under two types of land (dryland and irrigated land). The model maximizes the aggregate net present value of incomes of three household groups in the watershed over a 10 year planning horizon, which considered adequate for studies like this.

The model used simplified production function to represent farmers' response to different factors of production. Crop production in the model is affected by change in soil depth, which is reduced by soil erosion. The erosion level in the watershed is estimated for predicted land use pattern using USLE model. The yield-soil depth response for different crops grown in the watershed is estimated by using econometric method and the parameters are used in the bioeconomic model.

The nutrient balance in the watershed is estimated using nutrient balance equation by estimating the nutrient balance for simulation period based on inflow (fertilizer and manure application, biological fixation and atmospheric deposition) and outflow (crop grains and residual yield, erosion and leaching) of nutrients in the watershed.

The baseline model serves as a starting point for assessing the potential impact of alternative technological and policy interventions. The bioeconomic model used in this study analyses the combined effects of land degradation, population growth and market imperfections on household production, welfare and assesses their impact on natural resource base.

Based on the existing technology and use of inorganic fertilizer, the baseline version of the model was solved using population dynamics and nutritional consumption requirement observed during 2003. The important findings of the baseline results are as follows.

- The model results show that the area under maize may decline by about 23.84 per cent and cotton area increased by about 40.38 per cent in the 10 years period of simulation. The reason for increasing area under cotton in the simulation results might be due to the non- incorporation of risk of drought and pest incidence in the model.

- The baseline results indicate that shallow soils in the watershed are predominantly under cotton while the area share of maize on these soils is very limited. This indicates that over the years, production of cotton in shallow soils has replaced production of maize. The soils with medium depth are cultivated with sorghum and paddy (85 per cent of the cultivable land) and the remaining land was allotted to maize and cotton during rainy (*kharif*) season, whereas 28 per cent of the land is covered by sunflower in post rainy (*rabi*) season. In deep soils the model results show intensive cultivation of vegetables, sunflower, maize, chickpea and paddy. Sunflower and chickpea are cultivated in deep soils in post rainy season due to high residual soil moisture content and water holding capacity of the deep soils.

- The rainfed land in the watershed is dominated by dryland crops like maize, sorghum, cotton and chickpea. The results show that cotton area in rainfed land is slowly increasing by replacing area under maize. The area under maize in rainfed land has declined by 23.85 per cent over 10 years. In rainy season, paddy, cotton and vegetables are cultivated in the irrigated land.

- The result indicates that the household income for large and small farm households has declined by 32 and 15 percent respectively, however the income level for medium is stabilizing over the years. The per capita incomes for small and medium farmers in the watershed are decreasing over the years, which are less than the poverty income level.

- It is observed from the results that the overall GDP of watershed, income from livestock and off-farm wages increases gradually, while crop income remains more or less constant over the years. The baseline results also show that the crop income is declining over the years and off-farm wage and livestock income is gradually increasing for small household group. Among the three household groups, the wage income is relatively high for small farmer group compared to the remaining household groups because they hire out more labour to work in large and medium households farms.

- The baseline model results indicate that the amount of soil loss for the whole micro watershed is 1859.37 tons (i.e. 4.4 t/ha) for the initial year. However, the soil loss gradually decreases over the simulation period due to the increasing investment of labour by the farmers for *in situ* soil and water conservation activities at the field/plot level. The labour (per ha of cultivable land) used for conservation measures is increasing over the years. The simulation results show that the small farmers are using more labour for conservation measures compared to medium and large farmers.

- The reduction in soil depth over 10 years is comparatively high on shallow soils when compared to medium and deep soils and the magnitude of the decline in soil depth is more in irrigated land due to more cropping intensity and the cultivation of high erosive vegetables.

- The baseline results illustrate that the inorganic fertilizer application declines over time and then increases slightly towards the end of the planning period. The results indicate that the reduction in inorganic fertilizer application in the watershed is substituted by application of the farmyard manure.

- The application of inorganic fertilizer (kg/ha) by medium and large farmers is higher when compared to small farmers in the initial years. However, the results show that the small farmers start increasing the application of inorganic fertilizers towards the end of simulation period.

- The projected nutrient balance for the predicted farming system in the watershed is -13.60 tons N, 11.15 tons P and -93.16 tons K in the initial year. This shows that the nutrients N and K are over exploited from the soil for the predicted land use pattern causing nutrient mining in the watershed.

- The model results also show that cattle population is gradually decreasing whereas the small ruminants are increasing at a faster rate. The bullock number in the watershed declines and then remains constant showing around 80 bullocks would be the optimum number to meet the draught power demand in the watershed. The model also projected that the number of milking animals declined in the watershed. The small farmers have reduced the number of milking animals by 70.58 per cent over years, whereas medium and large farmers have sized down the milking animals only to 14.70 and 20.51 per cent respectively.

The watershed level bioeconomic model is used to evaluate alternative scenarios like a) change in yield of dryland crops, b) change in irrigated area in the watershed, c) change in output prices, d) output based water charges, e) increase in non-farm employment opportunities and f) increase in population pressure. The summary of the results is as follows:
When the yield of the dryland crops is increased by 10 per cent, the area under sorghum/pigeonpea and maize/pigeonpea intercropping system increases by 5 and 12 per cent compared to the baseline level and the area under cotton declined by 30 per cent. The per capita income of all three household groups is above baseline level when the yields of the dryland crops are increased. The increase in yield of the dryland crops in the watershed increases fodder production thereby enhances the carrying capacity of livestock in the watershed and increases the income from livestock gradually for all the household groups. The soil erosion in the watershed is less than the baseline level when the yield of dryland crops increases. The change in cropping

pattern (more area under less erosive cereal crops) and more labour used for conservation measures reduces the soil erosion in the watershed. The increase in area under sorghum and maize and decline in the area of high nutrient mining crops like cotton and sunflower under the scenario of increased yields of dryland crops has reduced soil nutrient mining of N, P and K by 4, 1, and 3 per cent respectively compared to baseline level. If the yield of dryland crops has decreased by 10 per cent, nutrient balances in the watershed would be similar to baseline level.

By increasing the irrigated area by 25 per cent, the per capita income of all the three household groups increases more than the baseline level. This is due to higher productivity of crops like cotton, vegetables and sunflower under irrigation and increasing the area of these crops under irrigation resulting in higher production in the watershed. It is observed that the soil erosion in higher than baseline level if irrigated area increases in the watershed. This is due to increase in the area of erosive crops like cotton and vegetables. Soil erosion is reduced by 7 per cent if the irrigated area is decreased by 25 per cent in the watershed. Labour used for conservation is slightly higher than the baseline if the irrigated area is increased. When the irrigated area decreased by 25 per cent total soil erosion is below the baseline level, even though the total labour used for conservation is lower than the baseline level. The soil nutrient balances indicate that nutrient mining is higher compared to baseline level when the irrigated area increased in the watershed. When the irrigated area decreases, the change in the cropping pattern has reduced the nutrient mining.

The better price of dryland crops improved the per capita income of all the household groups. The supply response of the farmers in the watershed for changes price of dryland crops has increased the area under sorghum/pigeonpea and maize/pigeonpea intercropping system. This reduces the erosion level in the watershed even with the lower level of labour used for conservation measures. The fodder availability in the watershed also increased up to 10 per cent due to increase in area of sorghum and maize resulting in higher livestock population especially the cattle compared to the baseline population. The decline in area under nutrient erosive crops like cotton and sunflower and increased application of farmyard manure[19] has decreased soil nutrient

[19] The increase in livestock population compared to baseline level due to increased fodder production has contributed to higher production of FYM in the watershed.

mining in the watershed. The decrease in the price of irrigated crops has shown similar trend like increase in price of dryland crops and however per capita income of the households is below the baseline level. This is because of loss in income due to low price of irrigated crops. The decline in the area of cotton and vegetables under irrigated land could lead to reduction in the soil erosion and nutrient loss.

Water charges based on output share lower the income of all the household groups. For 10 and 5 per cent as water charges based on the share output, the reduction in per capita incomes are about 50 and 37 per cent for small households, 12 and 18 per cent for medium households and 15 and 19 per cent for large households respectively compared to baseline results. The results also show that the changes in the cropping pattern affected the fodder supply in the watershed and hence reduced livestock production. Compared to the baseline level, the simulations for introducing water prices indicate that the soil loss per hectare would decline by about 27 and 33 percent for a 10 and 5 percent output share as water charges respectively. This is due to less area under highly erosive crops like cotton and vegetables as more land is irrigated and higher incomes allow use of more labour for investment in soil conservation measures. The nutrient balance indicates that the nutrient mining minimized because of less area under irrigated crops.

The increased access to non-farm employment opportunities leads to significant increase in the income of the three household groups. Per capita income for small and medium household groups is about 17 and 12 per cent, respectively, above the baseline level. The area under cultivation is slightly reduced in small and medium household groups. The soil erosion in the watershed increased over the years because increased access to non-farm employment opportunities reduces the incentive to use labour for conservation measures. This may be due to the opportunity cost of labour for non-farm employment, which is higher than the labour used for conservation measures.

The increase in population pressure results in reduction of income for all three household groups compared to baseline level with constrained access to non-farm employment and no scope for increasing the area under cultivation in the watershed. The decline in sale of crop produce is caused by increase in on-farm consumption of cereals and pulses to meet the increased nutritional demand in the watershed. The results show that there is no change in demand for labour in the on-farm activities because less change in the cropping pattern. This allows the farmers to invest their excess labour in the soil conservation measures resulting in less soil erosion in the watershed. The results indicate that there is no major change in the nutrient balances compared to baseline level. It is evident that the higher population growth in the watershed improves the natural resource condition, when there are limited opportunities for non-farm employment in the watershed.

6.2 Conclusions

The application of the bioeconomic model to Adarsha watershed, Kothapally in Ranga Reddy district of Andhra Pradesh helps to conclude the following:

1. The increase in the yield of dryland crops by introducing high yielding varieties and cereal-legume intercropping systems helps to improve the welfare of smallholder farmers by increasing the income while also enhancing the sustainability of the natural resource base. It stimulates sustainable intensification of production by controlling soil erosion and nutrient mining through investment in conservation and adoption of better land use patterns in the watershed. The increase in yield of dryland crops produced more fodder, which stimulates better integration of crop-livestock enterprises in the watershed. This provides opportunities for smallholder farmers to generate additional incomes which would otherwise decline over the years, and improve living conditions.

2. The increase in irrigated area under cotton, vegetables and sunflower due to the availability of water from community and *in situ* soil and water conservation in the watershed improves the income of the farmers. The erosion level and nutrient mining in the watershed however increases because of increase in the area under soil erosive and nutrient mining crops. It is important to promote irrigated cereal crops in the watershed so that erosion level will be minimized and improves the fodder production to create

complementarities with livestock production that would in turn increase manure availability and application in the field to sustain soil nutrients.

3. Supporting the price of dryland crops is a promising policy alternative that could generate multiple benefits for rural households. The price support for dryland crops improves the relative returns to these crops compared to other erosive crops. This increases the income of the farmers while reducing the land degradation levels in the watershed by reducing the amount of soil loss and nutrient mining. The income from livestock and production of manures in the watershed also increased because of higher production of fodder for livestock. This may also have effects on incentive to conserve cropland because the change in the cropping pattern reduced the demand for on-farm activities. It can be concluded that better prices for dryland crops could improve the welfare of farmers in the rainfed SAT regions while also minimizing land degradation and increasing the scope for diversifying income through livestock production.

4. The effect of water pricing policies has a negative impact on welfare of farmers by reducing the area under irrigated crops. However, it improves the sustainability of natural resources by reducing groundwater depletion, soil erosion and nutrient mining in the watershed. It indicates that in the short-term, the free extraction of water for irrigation improves the welfare of the farmers in the rainfed regions but it will potentially lead to depletion of groundwater resources because farmers lack incentives to adopt water-saving technologies and cropping practices. This is an important tradeoff that needs to be addressed by local communities, NGOs and governments involved in watershed programs. It indicates that under the current regime of free groundwater resources to smallholder farmers, there is a need to encourage (or even require) adoption of water-saving technologies and concerted community education to stimulate change in behavior. The long-term benefits from sustainable use of groundwater resources is likely to be much higher than unregulated open access utilization that will quickly deplete the resource, reduce incomes and increase vulnerabilities of farmers to frequent droughts.

5. An increase in non-farm employment opportunities in the watershed increases household welfare but reduces the households' incentive to use labour for conservation leading to higher levels of soil erosion and rapid land degradation in the watershed. This indicates that returns to labour are higher in non-farm than on-farm employment. This is another tradeoff between household welfare and sustainability indicators. There is therefore a need to complement a policy on the development of non-farm sector with a policy ensuring conservation of the natural resource base. Improving the productivity of agriculture to increase returns to labor on-farm is one important strategy to create incentives for investments in sustaining or improving productivity. Another strategy is to require compliance in terms of a minimum level of investment in natural resource management for households engaged in non-farm activities.

6. The results clearly indicate that care should be taken to avoid promotion of conflicting polices that produce tradeoffs among different social and community objectives. Preferably, those technologies and policies that have multiple impacts in terms of meeting both welfare of the farmers and sustaining natural resources objectives must be prioritized, and appropriate policy instruments enacted to facilitate the same.

6.3 Policy Implications

Based on the above results, the following are the policy implications.

1. An increase in yield of dryland crops and cereal-legume intercropping systems and reduced vulnerability to drought has a demonstrated potential to improve the welfare of the farmers as well as sustainability of the natural resource base. So it is important to concentrate more on crop-specific research to develop drought tolerant HYVs of dryland crops, which are also resistant to pests and diseases.

2. The integrated watershed development programme which links productivity enhancing interventions with integrated management of land, water and biodiversity resources has also created opportunities for farmers' drought-prone areas to improve livelihoods. In some cases, the economic and environmental benefits from watershed investments are realized over a long-

term and may not offer sufficient incentives for farmers to engage in community-based watershed activities. This may require continued technological and institutional support to communities to maintain collective investments and adopt approaches that enhance sustainable use of soils, biodiversity and groundwater resources.

3. The support price for dryland crops has demonstrated potential win-win outcomes that improve both household and community welfare and the quality of the natural resource base. Policy makers may therefore seriously consider supporting policies that enhance the competitiveness of dryland crops (like maize, sorghum and pigeonpea). A similar outcome can be expected of reducing the existing subsidies for irrigated crops (paddy and wheat) in order to create an environment that allows a fair level of competition between farmers growing rainfed and irrigated crops. This strategy would help in reduce annual price fluctuation of dryland crops and encourage farmers to cultivate more acreage of these crops, which are more suitable in semi-arid areas where water is limiting.

4. The model results indicate that farmer welfare could be improved by integrating crop-livestock sector. Hence, it is important for the watershed development programme to introduce high yielding milking animals and fast growing small ruminants. This would require concomitant improvements in availability of feeds and fodder for livestock and essential veterinary services for watershed communities, an area that has not received much attention in the past. Farmer cooperatives should be established or strengthened in watershed villages to ensure better prices for milk and to encourage farmers to diversify to livestock sector.

5. The study results show that soil erosion is not a major development problem or constraint to sustainability in the study area because erosion levels are low and can be controlled with modest investments. But even if erosion is controlled, farmers will still have to reduce soil nutrient depletion and the structural and biological life of the soil. Hence farmers should be encouraged to adopt

different technologies like composting, enriched farmyard manure, application of micronutrients and use of crops residues to restore the nutrients in the soil.

6.4 Recommendation for future research

- ❖ One important aspect that needs to be investigated further in SAT rainfed regions is the impact of drought on the welfare of farmers and how best such vulnerability can be reduced using technological and institutional innovations in the future. Simulation modeling along the lines developed in this study can be a fruitful approach to test and evaluate alternative policy options for drought mitigation and the associated impacts. It is possible to incorporate the risk of drought using rainfall and yield variability data into the bioeconomic modeling framework to investigate how alternative policy options and technological interventions may help farmers in coping with the effects of droughts with differing intensities.

- ❖ A water module should be included or linked to the watershed bio-economic model in order to evaluate the effect of alternative supply and demand side interventions on the sustainability of groundwater in the SAT rainfed regions. An important concern is to understand how free extraction of groundwater (a common practice across semi-arid regions) will continue to affect the sustainability of the resource over a long period of time and what policy options need to be put in place at different levels to reduce any undesirable outcomes.

- ❖ Another area that needs more attention is the distributional impacts of watershed interventions to different household groups as well as communities along the gradient (upstream and downstream interactions). Much less is now understood about the effect of watershed interventions at a higher geographical scale (e.g., sub-basin) and how this may affect livelihoods and environmental conditions beyond small watershed communities. Bio-economic models that take into account inflows and outflows (externalities) in the context of multiple watersheds would be appropriate for such analyses.

- ❖ It will also be useful to investigate how fast growing mechanization in rainfed agriculture would affect the welfare of the small and marginal farmers and how this would affect opportunities and incentives for out-migration especially for landless labourers in watershed villages.

- Last but not least, households in the rainfed SAT use mostly tree woods and cattle dung to meet their fuel energy requirements. It will be useful to study how increases in energy demand due to population growth contribute to devegetation and loss of important woodlands and compete with use of farmyard manure as fertilizer in watershed villages. An interesting extension of the bioeconomic model developed here would be to evaluate how new types of high-value tree crops and bio-fuel plantations (e.g., Jatropha and Pongamia) would enhance incentives for rehabilitating degrading lands and the associated economic and environmental benefits resulting from diversifying into or changing land use patterns in semi-arid regions.

Bibliography

A. BOOKS

Alston, J.M., G.W. Norton and P.G. Pardey (1995), *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*, Cornell University Press, Ithaca, New York, USA and London, UK, 558 pp.

Bantilan, M.C.S., K.V. Anupama and P.K. Joshi (2005), "Assessing Economic and Environmental Impacts of NRM Technologies: An Empirical Application Using the Economic Surplus Approach", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp.1245-268.

Barrett, C.B., J. Lynam, F. Place, T. Reardon and A.A. Aboud (2002), "Towards Improved Natural Resource Management in African Agriculture", In: Barrett, C.B., F. Place and A.A. Aboud (Eds.), *Natural Resource Management in African Agriculture: Understanding and Improving Current Practices*, CAB International, Wallingford, UK, pp. 287-296.

Boserup, E. (1965), *The Conditions of Agricultural Growth. The Economics of Agrarian Change under Population Pressure*, Earthscan Publications, London, UK, 124pp.

Bouman, J., J. Brouwer, A. Verhagen and H.W.G. Booltink (1995), "Site Specific Management on Field Level: High and Low Tech Approaches", In: Bouma, J., A. kuyvenhoven, B.A.M. Bouman, J. Luyten and H. Zandstra (Eds.), *Eco-Regional Approaches for Sustainable Land Use and Food Production*. Proceedings of a Symposium on Eco-Regional Approaches in Agricultural Research, 12-16 December 1994, ISNAR, Kluwer Academic Publishers, Dordrecht, The Hague, pp. 453-473.

Brooke, A., D. Kendrick and A. Meeraus (1992), *GAMS: A user's Guide*, Scientific Press, Redwood City, California, U.S.A.

Campbell, D.T. and M.J. Russo (1999), *Social Experimentation*, Sage Publication, Thousand Oaks, California, 407 pp.

Chopra, K. (1999) "Evaluation of Watershed Management Programmes in India: A Review", In: Farrington, J., C. Turton and A.J. James (Eds.), *Participatory* *watershed Development: Challenges for the Twenty-First Century*, Oxford University Press, New Delhi, pp. 34-49.

Farrington, J., C. Turton and A.J. James (1999), *Participatory watershed development: challenges for the 21st Century*, Oxford University Press, New Delhi, India, 400 pp.

Freeman, H.A., B. Shiferaw and S.M. Swinton (2005), "Assessing the Impact of Natural Resource Management Interventions in Agriculture: Concepts, Issues and Challenges", In: Shiferaw, B., H.A Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp. 4-16.

Gulathi, A. and T. Kelly (1999), *Trade Liberalization and Indian Agriculture*, Oxford Publication, New Delhi.

Hazra, C.R. (1999), "Biophysical Results of Watershed Rehabilitation in Kharaiya Nala". In: Farrington, J., T. Cathryn and A. J. James (Eds.), *Participatory Watershed Development: Challenges for the Twenty-First Century*, Oxford University Press, New Delhi, India, pp. 26-30.

Heerink, N., A. Kuyvenhoven and S.V.W. Maarten (2001), "Economic policy reforms and Sustainable Land Use in Developing Countries: Issues and Approach", In: Heerink, N., H.V. Keulen and M. Kuiper (Eds.), *Economic Policy Reforms and Sustainable Land Use: Recent Advances in Quantitative Analysis for Developing Countries,* Springer-Verlag, Heidelberg.

Hinchcliffe, F., J. Thompson, J. Pretty, I. Guijit and P. Shah (Eds.) (1999), *Fertile Ground: The Impacts of Participatory Watershed Management*, Intermediate Technology Publications, London.

Holden, S.T. and H. Lofgren (2005), "Assessing the Impact of natural Resource Management Policy Intervention with a Village General Equilibrium Model", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp. 295-318.

Holden, S.T. (2005), "Bioeconomic Modeling for Natural Resource Management Impact Assessment", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp. 295-318.

Jones, J.W., P.K. Thornton and J.W. Hansen (1997), "Opportunities for Systems Approach at the Farm Scale", In: Teng, P.S., M.J. Kropff, H.M.F. Ten Berge, J.B. Dent, F.P. Lansigan and H.H. Van Laar (Eds.), *Applications of Systems Approach at the Farm and Regional Level,* Vol.1., Kluwer Academic Publishers with IRRI, Dordrecht, pp. 1-18.

Kerr, J.M. and K.R. Chung (2005), "Evaluating the Impact of Watershed Management Projects: A Practical Econometric Approach". In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp. 223-243.

Lee, D.R. and Barrett, C.B. (eds.) (2000), *Critical Tradeoffs: Agricultural Intensification, Economic Development and the Environment*, Cornell University Press, Ithaca.

Nakajima, C. (1986), *Subjective Equilibrium Theory of the Farm Household*, Developments in Agricultural Economics, 3, Elsevier Publications, Amsterdam, 304 pp.

Okumu, B.N., M.A. Jabbar, D. Coleman and N. Russel (2002), "A Bioeconomic Model of Integrated Crop-Livestock Farming Systems: The Case of the Ginchi Watershed in Ethiopia", In: Barrett, C.B., F. Place and A.A. Aboud (Eds.), *Natural Resource Management in African Agriculture: Understanding and Improving Current Practices*, CAB International, Wallingford, UK.

Pathak, P., K.L. Sahrawat, T.J. Rego and S.P. Wani (2005), "Measurable Biophysical Indicators for Impact Assessment: Changes in Soil Quality", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp. 295-318.

Pender, J. (2005) "Econometric Methods for Measuring Natural Resource Management Impacts: Theoretical Issues and Illustration from Uganda", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp.127-154.

Qu, F., A. Kuyvenhoven, N. Heerink and T.V. Rheenen (1997), "Sustainable Agriculture and Rural Development in China: Past Experiences and Future Potential", In: Van den Bergh, J.C.J.M. and Van den Straaten (Eds.), *Economy* *and Ecosystem in Change: Analytical and Historical Approaches*. Edward Elgar, Cheltenham, pp. 185-200.

Sadoulet, E. and A. de Janvry (1995), *Quantitative Development Policy Analysis*, Johns Hopkins University Press, Baltimore and London.

Sahrawat, K.L., K.V. Padmaja, P. Pathak and S.P. Wani (2005), "Measurable Biophysical Indicators for Impact Assessment: Changes in Water Availability and Quality", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp.267-294.

Sehgal, J. and I.P. Abrol, (1994) Soil *Degradation in India: Status and Impact*. Oxford and IBH, New Delhi.

Shiferaw, B. and S. Holden (2005), "Assessing the Economic and Environmental Impacts of Conservation Technologies: A Farm-Level Bioeconomic Modeling Approach". In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp.267-294.

Singh, I., L. Squire and J. Strauss (1986), *Agricultural Household Models: Extensions, Applications, and Policy*, The World Bank, The Johns Hopkins University Press, Baltimore and London, 335pp.

Singh, P., S.P. Wani, P. Pathak, R. Sudi and M.S. Kumar (2003), Productivity and Resource Use Management of Soybean-based Systems in a Vertic Inceptisol Watershed, In: Wani, S.P., A.R. Maglinao, A. Ramakrishna and T.J. Rego (Eds.), *Integrated Watershed Management for Land and Water Conservation and Sustainable Agricultural Production in Asia*, Proceedings of ADB-ICRISAT-IWMI Project Review and Planning Meeting, 10-14 December 2001, Hanoi, Vietnam, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 259 pp.

Swinton, S.M. (2005), "Assessing Economic Impacts of Natural Resource Management using Economic Surplus", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, CAB International, Wallingford, UK, pp.155-174.

Taylor, J.E. and I. Adelman (1996), *Village Economics*, Cambridge University Press, Cambridge.

Tripp, R., P. Anandajayasekeram, D. Byerlee and L. Harrington (1990), "Farming Systems Research Revisited", In: Eicher, C.K. and J.M Staatz (Eds.), *Agricultural Development in the Third World*, The John Hopkins University Press, Baltimore and London, pp.384-399.

Wani, S.P., P. Singh, R.S. Dwivedi, R.R. Navalgund and A. Ramakrishna (2005), "Biophysical Indicators of Agro-ecosystem Services and methods for Monitoring the Impacts of NRM Technologies at Different Scales", In: Shiferaw, B., H.A. Freeman and S.M. Swinton (Eds.), *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impact,* CAB International, Wallingford, UK, pp.267-294.

Wischmeier, W.H. and D.D. Smith (1965), *Predicting Rainfall Erosion Losses from Crop Land East of the Rock Mountains*, Agricultural Handbook. No. 282, USDA. Washington. D.C., U.S.A.

Wischmeier, W.H. and D.D. Smith (1978), *Predicting rainfall erosion losses- A Guide for Conservation Planning*, Agricultural Handbook. No.527, USDA, Washington D.C., U.S.A.

B. PERIODICALS

Alagarsamy, G., P. Singh, G. Hoogenboom, S.P. Wani, P. Pathak and S.M. Virmani (2000), "Evaluation and Application of the CROPGRO-soybean Simulation Model in a Vertic Inceptisol", *Agricultural System,* 63, pp.19-32.

Arrow, K.J., M.L. Cropper, G.C. Eads, R.W. Hahn, L.B. Lave, R.G. Noll, P.R. Portney, M. Russel, R. Schmallensee, V.K. Smith and R.N. Stavins (1996), "Is there a Role for Benefit-Cost Analysis in Environmental, Health and Safety Regulation?", *Science,* 272, pp.221-222.

Barbier, B. (1998), "Induced Innovation and Land Degradation: Results from a Bioeconomic Model of a Village in West Africa", *Agricultural Economics,* 19, pp.15-25.

Barrett, S. (1991), "Optimal Soil Conservation and the Reform of Agricultural Pricing Policies", *Journal of Development Economics,* 36, pp.167-187.

Binswanger, H.P. and J. McIntire (1997), "Behaviour and Material Determinants of Production Relations in Land Abundant Tropical Agriculture", *Economic Development and Cultural Change,* 36 (1), pp.73-99.

Byerlee, D. and R. Murgai (2001), "Sense and Sustainability Revisited: The Limits of Total Factor Productivity Measures of Sustainable Agricultural System", *Agricultural Economics,* 26(3), pp. 227-236.

Campbell, B., J.A. Sayer, P. Frost, S. Vermeulen, M. Ruiz-Perez, A. Cunningham and P. Ravi (2001), "Assessing the Performance of Natural Resource Systems", *Conservation Ecology,* 5(2), 22.
[Online] http://www.ecologyandsociety.org/vol5/iss2/art22/index.html

de Janvry, A., M. Fafchamps and E. Sadoulet (1991), "Peasant Household Behaviour with Missing Markets: Some Paradoxes Explained", *The Economic Journal,* 101, pp.1400-1417.

Deshpande, R S. and V. Ratna Reddy (1990), "Social Dynamics and Farmer‵s Society: A Case study of Pani-Panchayat", *Indian Journal of Agricultural Economics*, 45(3), July –September.

Deshpande, R S. and V. Ratna Reddy (1991), "Differential Impact of Watershed based Technology: An analytical Study of Maharashtra", *Indian Journal of Agricultural Economics*, 46(3), pp. 261-269.

Deshpande, R S. and V. Ratna Reddy (1994), "Watershed Development Approach in Fragile Resource Region: An Analytical Study of Maharashtra", *Artha Vijnana*, 36(3), pp.296-305.

Deybe, D. (1998), "Can Agricultural Sector Models be a Toll for Policy Analysis? An Application for the Case of Burkino Faso", *Agricultural System*, 26, pp 211-230.

Fresco, L.O. and R.A. Kroonenberg (1992), "Time and spatial scales in ecological sustainability", *Land use policy*, July, pp.155-168.

Hanumanth Rao, C.H. (2000), "Watershed Development in India: Recent Experience and Emerging Issues", *Economic and Political Weekly*, 35(45), November 4, pp.3943-3947.

Holden, S. and B. Shiferaw (2004), "Land Degradation, Drought and Food Security in a Less-Favoured Area in the Ethiopian Highlands: A Bioeconomic Model with Market Imperfections", *Agricultural Economic,* 30, pp.31-49.

Holden, S., B. Shiferaw and J. Pender (2004), "Non-Farm Income, Household Welfare, and Sustainable Land Management in a Less-Favoured Area in the Ethiopian Highlands", *Food policy,* 29, pp.369-392.

Holden, S.T., J.E. Taylor and S. Hampton (1998), "Structural Adjustment and Market Imperfections: A Stylized Village-wide Model with Nonseparable Farm Households", *Environment and Development Economics,* 4 (1). pp 69-87.

IJAE (1991), "Subject 1. Watershed Development", *Indian Journal of Agricultural Economics,* 46(3), pp. 241 – 327.

Kerr, J. and K.R. Chung (2001), "Evaluation of Watershed Management Projects", *Water Policy*, 3(6), pp.537-554.

Kerr, J. (2002), "Watershed Development, Environment Services and Poverty Alleviation in India", *World Development,* 30(8), pp.1387-1400.

Kerr, J. (2001), "Watershed Project Performance in India: Conservation, Productivity and Equity", *American Journal of Agricultural Economics,* 83, pp.1223-1230.

King, R.P., D.W. Lybecker, A. Regmi and S.M. Swinton (1993), "Bioeconomic Models of Crop Production Systems: Design, Development and Use", *Review of Agricultural Economics,* 15(2), pp.389-401.

Kruseman, G., R. Ruben, H. Hengsdijk and M.K, Van Ittersum (1995), "Farm Household Modeling for Estimating the Effectiveness of Price Instruments in Land Use Policy", *Netherlands Journal of Agricultural Science* 43, pp.111-123.

Kuyvenhoven, A., J. Bouma, and H.V. Keulen (Eds.) (1998a), "Special Issue: Policy analysis for sustainable land use and food security", *Agricultural Systems* 58 (3).

Kuyvenhoven, A., R. Ruben and G. Kruseman (1998b), "Technology, Market Policies and Institutional Reforms for Sustainable Land Use in Southern Mali", *Agricultural Economics*, 19, pp. 53-62.

Littleboy, M., A.L. Cogle, G.D. Smith, K.P.C. Rao and D.F. Yule (1996), "Soil Management and Production of Alfisols in the Semi-Arid Tropics. Part IV: Simulating Decline in Productivity caused by Soil Erosion". *Australian Journal of Soil Research,* 34, pp.103-111.

Mausolff, C. and S. Farber (1995), "An Economic Analysis of Ecological Agricultural Technologies amongst Peasant Farmers in Honduras", *Ecological Economics,* 12, pp. 237-248.

Narain, P., B. Verma, and D.H. Rao (1982), "Prediction of Rainfall Erosion Potential and Some Parameters of Universal Soil Loss Equation at Kota (Rajasthan)", *Indian Journal of Soil Conservation,* 10(2-3), pp.60-68.

Pagiola, S. (1996), “Price Policy and Returns to Soil Conservation in Semi-Arid Kenya”, *Environmental and Resource economics*, 8(3), pp 255-271.

Pattanayak, S. and D.E. Mercer (1998), “Valuing Soil Conservation Benefits of Agro-Forestry: Contour Hedgerows in Eastern Visayas, Philippines”, *Agricultural Economics,* 18, pp.31-46.

Rajagopalan, V. (1991), “Integrated Watershed Development in India: Some Problems and Perspective”, *Indian Journal of Agricultural Economics,* 46(3), pp.242-260.

Ramaswamy, S. and J.H. Sanders (1992), “Population Pressure, Land Degradation and Sustainable Agricultural Technologies in Sahel”, *Agricultural System,* 40, pp. 361-378.

Reddy, R.V. (2000), “Sustainable Watershed Management: Institutional Approach”, *Economic and Political Weekly*, 35(40), pp. 3943-3947.

Sankhayan, P.L. and O. Hofstad (2001), “A Village-Level Economic Model of Land Clearing, Grazing, and Wood Harvesting for Sub-Saharan Africa: With a Case Study of Southern Senegal”, *Ecological Economics,* 38, pp. 423-440.

Sankhayan, P.L., N. Gurung, B.K. Sitaula and O. Hofstad (2003), “Bioeconomic Modeling of Land Use and Forest Degradation at Watershed Level in Nepal”, *Agriculture, Ecosystems and Environment,* 94, pp. 105-116.

Sayers, J.A. and B. Campbell (2001), “Research to Integrate Productivity Enhancement, Environmental Protection and Human Development”, *Conservation Ecology,* 5 (2), 32. [Online] http://www.ecologyandsociety.org/vol5/iss2/art32/index.html

Shah, A. (2000), “Watershed Programmes: A Long Way to Go”, *Economic and Political Weekly*, 35(35&36), August 26, pp.3155-3164.

Shiferaw, B. and S. Holden (1998), “Resource Degradation and Adoption of Land Conservation Technologies in the Ethiopian Highlands: A Case Study in Andit Tid, North Shewa”, *Agricultural Economics,* 18(3), pp.233-248.

Shiferaw, B. and S. Holden (1999), “Soil Erosion and Smallholders’ Conservation Decisions in the Highlands of Ethiopia”, *World Development,* 22(4), pp.739-752.

Shiferaw, B. and S. Holden (2001), "Farm-level benefits to investment for mitigating land degradation: empirical evidence from Ethiopia", *Environmental and Development Economics,* 6, pp.335-358.

Wani, S.P., P. Pathak, L.S. Jangawad, H. Eswaran, and P. Singh, (2003), "Improved management of vertisols in the semiarid tropics for increased productivity and soil carbon sequestration", *Soil Use and Management*, 19, pp. 217-222.

C.THESES

De Graaff, J. (1996), *The Price of Soil Erosion: An Economic Evaluation of Soil Conservation and Watershed Management*, Unpublished Ph.D Thesis, Wageningen Agricultural University, Wageningen, Netherlands.

Kruseman, G. (2000), *Bio-economic Household modeling for Agricultural Intensification*, Unpublished Ph.D Thesis, Wageningen Agricultural University, Wageningen, Netherlands.

Shiferaw, B. (1998), *Peasant Agriculture and Sustainable land use in Ethiopia: Economic analysis of constraints and Incentives for Soil Conservation*, Unpublished Ph.D Thesis, Department of Economics and Social Science, Agricultural University of Norway, Norway.

Schipper, R.A. (1996), *Farming in a Fragile Future: Economics of Land Use with Applications in the Atlantic of Costa Rica*, Unpublished Ph.D Thesis. Wageningen Agricultural University, Wageningen, Netherlands.

Van Lanen, H.A.J. (1991), *Qualitative and Quantitative Physical Land Evaluation: An Operational Approach*, Unpublished Ph.D Thesis, Wageningen Agricultural University, Wageningen, Netherlands.

Van Rheenen, T. (1995), *Farm Household Level Optimal Resource Allocation: An Explorative Study in the Limestone Area of East Java*, Unpublished Ph.D Thesis, Wageningen Agricultural University, Wageningen, Netherlands.

D. REPORTS/WORKING PAPERS

AICI. (2005), Annual *Report*, Agricultural Insurance Company of India, New Delhi.

Alston, M.J., C. Chang-Kang, M.C. Marra, P.G. Pardey and T.G. Wyatt (2000), *A Meta-analysis of rates of return to agricultural R&D: ex pede Herculem?,* Research Report no. 113, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A. 159 pp.

Bade, J., G. Kruseman, R. Ruben, P. Roebeling and H. Hengsdijk (1997), *Farm Household Modeling in a Regional Setting: The case of Koutiala Cercle in Mali*, DVL Report No.6, Wageningen: AB-DLO/WAU.

Barbier, B. (1996), Impact of market and population pressure on production, incomes and natural resources in the dryland savannas of West Africa: Bioeconomic modelling at the village level, EPTD Discussion Paper No. 21, IFPRI.

Barbier, B. (1998), "Induced Innovation and Land Degradation: Results from a Bioeconomic Model of a Village in West Africa", *Agricultural Economics,* 19, pp.15-25.

Barbier, B. and G. Bergeron (2001), *Natural Resource Management in the Hillsides of Honduras: Bioeconomic Modeling at the Micro watershed Level*, Research Report no. 123, International Food Policy Research Institute (IFPRI), Washington D.C, U.S.A., 59 pp.

Batchelor, C., Ashok Singh, M.S. Rama Mohan Rao and J. Butterworth (2002), *Mitigating the Potential Unintended Impacts of Water Harvesting*, paper presented in IWRA International Regional Symposium on "Water for Human Survival". Organized by International Water Resource Association, 26-29th November, 2002, New Delhi

Census of India. (2001), Directorate of Census Operation, Hyderabad.

Errapa, S. (1998), *Sustainability of watershed Development Programmes (WDPs) to dryland Agriculture in Karnataka: A study of two Sub-watersheds*, Project Report, Institute for Social and Economic Change, Bangalore.

Fan, S., and P. Hazell (1999), *Are Returns to Public Investment Lower in Less Favoured Rural Areas? An Empirical Analysis of India*, EPTD Discussion Paper No.43, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A., 39 pp.

Fan, S., P. Hazell, and D. Thorat (1999), *Linkages between Government Spending, Growth, and Poverty in Rural India*, Research Report no. 110, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A., 81pp.

Farrington, J., and C. Lobo (1997), *Scaling Up Participatory Watershed Development in India: Lessons from the Indo-German Watershed Development Programme*, Natural Resource Perspective 17, Overseas Development Institute, London.

Fernandez, A. (1994), *The MYRADA Experience: The Interventions of a Voluntary Agency in the Emergence and Growth of Peoples' Institutions of Sustained and Equitable Management of Micro Watershed*. Research Report, MYRADA, Bangalore. http:/www.myrada.org/publications.htm

Fertilizer Statistics. (2005), *Fertilizer Statistics*, The Fertilizer Association of India, New Delhi

Government of India. (1990), *WARASA: National Watershed Development Project for Rainfed Areas (NWDPRA) Guidelines* (1st ed.), Ministry of Agriculture, New Delhi.

Government of India. (1994a), *Reports of the Technical Committee on Drought Prone Areas Programme and Desert Development Programme*, Ministry of Rural Development, New Delhi.

Government of India. (1994b), *Guidelines for Watershed Development*, Ministry of Rural Development, New Delhi.

Government of India. (2000), *Common Approach for Watershed Development*, Ministry of Agriculture and Cooperation, New Delhi. http:/ www.nic.in/agricoop/guide.htm.

Government of India. (2001a), *Agricultural Statistics at a Glance*, Ministry of Agriculture, New Delhi.

Government of India. (2001b), *Guidelines for Watershed Development (Revised 2001),* Department of Land Resources, Ministry of Rural Development, New Delhi.

Government of India. (2003), *Guidelines for Hariyali*, Department of Land Resources, Ministry of Rural Development, New Delhi.

Hazell, P. (1998), *IFPRI Draft Proposal for Development of Bio-economic Models to Evaluate Technology, Policy and Institutional options for Ecoregional Development*, Submitted to International service for National Agricultural Research (ISNAR).

Hengsdijk, H. and G. Kruseman, (1993), *Operationalzing the DLV programme: An Integrated Agro-Economic and Agro-Ecological Approach to a Methodology for Analysis of Sustainable Land Use and Regional Agricultural Policy*, DLV Report No.1, WAU/AB-DLO, Wageningen.

Holden, S., B. Shiferaw and J. Pender (2005), *Policy Analysis for Sustainable Land Management and Food Security in Ethiopia: A Bioeconomic Model with Market Imperfections*, Research Report no. 140, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A., 76pp.

ICRISAT (1981), *ICRISAT Annual Report 1981*, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 364pp.

ICRISAT (2002), *Improving Management of Natural Resource for Sustainable Rainfed Agriculture,* TA RETA 5812 Completion Report Submitted to Asian Development Bank, The Philippines, September 2002, 94 pp.

Izac, A.N. (1998) *Assessing the Impact of Research in Natural Resources Management*, The World Agro forestry Centre (ICRAF), Nairobi, Kenya, 38 pp.

Jensen, J., S. Seth, T. Sawney and P. Kumar (1996), *Watershed Development: Proceedings of Danida's Internal Workshop on Watershed Development*, Watershed Development Coordination Unit, Danida, New Delhi.

Joshi, P.K., V. Pangare, B. Shiferaw, S.P. Wani, J. Bouma and C. Scott (2004), *Socioeconomic and Policy Research on Watershed Management in India: Synthesis of Past Experience and Needs for Future Research*, Global Theme on Agro Ecosystem Report no.7, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 88 pp.

Joshi, P.K., A.K. Jha, S.P. Wani, Joshi Laxmi and R.L. Shiyani (2005), *Meta-Analysis to Assess Impact of Watershed Program and People's Participation*, Comprehensive Assessment Research Report 8, Comprehensive Assessment Secretariat, Colombo, Sri Lanka, 17pp.

Joy, K.J. and S. Paranjape (2004), *Watershed Development Review: Issues and Prospects*, Technical Report, Centre for Interdisciplinary studies in Environment and Development, Institute for Social and Economic Change, Bangalore, 145 pp.

Kakade, B.k. (1997), *Soil and Water Conservation Structures in Watershed Development Programme*, Unpublished Report, BAIF Development Foundation, Pune.

Kakade, B.K., H.C. Kulkarni, K.J. Petare, G.S. Neelam, A. Marathe and P.R. Nagargoje (2001), *Integrated Drinking Water Resource Management*, Unpublished Report, BAIF Development Foundation, Pune.

Karanth, G.K. and Anil Abbi (2001), *Participative Integrated Development of Watershed (PIDOW), Report on Participatory Impact Assessment*, Swiss Agency for Development and Cooperation, New Delhi.

Kerr, J., G. Pangare, V.L. Pangare and P.J. George (2000), *An Evaluation of Dryland Watershed Development Projects in India*, Discussion paper no. 68, Environment and Production Technology Division, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A., 137 pp.

Kurothe, R.S. (1991), *Determination of C and P Factors for USLE for Important Crops and Management Practices in Vasad Region*, Annual Report, CSWCRTI, Dehradun, India, 98 pp

Lele, U. and W.S. Stone (1989), *Population Pressure, Environment and Agriculture Intensification: Variation on the Boserup Hypothesis*, MADIA Discussion Paper 4, World Bank, Washington D.C.

MANAGE, n.d., Economic Evaluation of Machal Watershed Development Project: A Study, Economic Evaluation Report, MANAGE, Hyderabad. http://www.nird.org.in/clic/machal.html

Nelson, M. and M. Maredia (1999), *Environmental Impacts of the CGIAR: An Initial Assessment*, Paper presented at the International Centers Week, October 25-29, 1999, Washington D.C., Standing Panel for Impact Assessment, Food and Agriculture Organization of the United Nations, Rome, Italy, 71pp.

Ninan, K.N. (1998), *An Assessment of European-Aided Watershed Development Projects in India from the Perspective of Poverty Reduction and the Poor*, CDR Working paper 98.3, Centre for Development Research, Copenhagen. http:/www.cdr.dk/working_papers/

Okumu, B., M. Jabbar, D. Colman, N. Russell, M. Saleem and J. Pender (2000), *Technology and Policy Impacts on the Nutrient Flows, Soil Erosion and Economic Performance at Watershed Level: The Case of Ginchi in Ethiopia*, Paper presented in conference on "Beyond Economics – Multidisciplinary Approaches to Development", December 11-14, 2000, Tokyo, Japan.

Pathak, P. and K.B. Laryea (1990), *Prospects of Water Harvesting and Utilization for Agriculture in Semiarid Tropics,* Proceeding of the symposium of "SADDC Land and Water management Research Program Scientific Conference", October 8-10, 1990, Gaborone, Botswana.

Pinstrup-Anderson, P. and R. pandya-Lorch (1994), *Alleviating Poverty, Intensifying Agriculture, and Effectively Managing Natural Resources, Food, Agriculture, and* *the Environment,* Discussion Paper 1, International Food Policy Research Institute (IFPRI), Washington D.C., U.S.A., 21pp.

Rao, K.P.C., M.C.S. Bantilan, K. Singh, S. Subramanyam, P. Deshingkar, P. Parthasarathy and B. Shiferaw (2005), *Overcoming Poverty in Rural India: Focus on Rainfed Semi-Arid Tropics*, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, 96pp

Reddy, R.V., M. Gopinath Reddy, S. Galab and Oliver Springate-Baginski (2001), *Watershed Development and Livelihood Security: An Assessment of Linkages and Impact in Andhra Pradesh, India*, Draft Report, Centre for Economic and Social Studies, Hyderabad and School of Geography, University of Leeds, Leeds.

Ryan, J.G. and M. Pereira (1979), *Assessment of Prospective Soil, Water and Crop Management Technologies for Semiarid Tropics of Peninsular India,* In: Socioeconomic Constraints to Development of Semiarid Tropical Agriculture, International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Patancheru, India.

Ryan, J.G. and D.C. Spencer (2001), *Challenges and Opportunities: Shaping the Future of Semiarid Tropics and their Implication*, International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Patancheru, India, 83 pp.

Rhoades, E. (1998), *Participatory Watershed Research and Management: Where the Shadow Fall*, Gatekeeper Series No. 81, International Institute for Environment and Development, London.

Rosegrant, M.W., M.S. Paisner, S. Meijer and J. Witcover (2001), *Global Food Projections to 2020: Emerging Trends and Alternative Futures*, International Food Policy Research Institute (IFPRI) 2020 vision book, Washington D.C., U.S.A., 206 pp.

Samra, R. (1997), *Status of Research on Watershed Management*, Central Soil and Water Conservation Research and Training Institute, Dehradun.

Sharma, R. (2001), Foreword, In: Joshi. M.M., S.K. Dalal and C.K Haridas (Eds.), *Watershed at Work*, Ministry of Agriculture, Department of Agriculture and Cooperation, Government of India, New Delhi, India.

Shah, A. (2001), *Who Benefits from Participatory Watershed Development? Lesson from Gujarat, India,* SARLP Gatekeeper series No. 97, International Institute for Environment and Development, London.

Shiferaw, B. and H.A. Freeman (Eds.) (2003), *Methods for Assessing the Impact of Natural Resource Management Research,* Summary of the Proceedings of an International Workshop, 6-7 December 2002, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, 136pp.

Shiferaw, B. (2001), *Census Data Collected by ICRISAT in Adarsha Watershed, Kothapally*, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

Shiferaw, B., G.V. Anupama, G.D. Nageswara Rao and S.P. Wani (2002), *Socioeconomic Characterization and Analysis of Resource-use Patterns in Community Watersheds in Semi-Arid India*, Working paper no. 12, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 44 pp.

Shiferaw, B., R.V. Reddy, S.P. Wani and G.D. Nageswara Rao (2003a), *Watershed Management and Farmers Conservation Investments in the Semi-Arid Tropics of India: Analysis of Determinants of Resource Use Decisions and Land Productivity Benefits*, Working paper no. 16, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 28 pp.

Shiferaw, B., S.P. Wani and G.D. Nageswara Rao (2003b), *Irrigation Investments and Groundwater Depletion in Indian Semi-Arid Villages: The Effect of Alternative Water Pricing Regimes*, Working paper no. 17, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 24 pp.

Shiferaw, B., H.A. Freeman and H. Woldemarian (2004), *Assessing the Impact of NRM Research: Methodological Paucity, Recent Progress and Future Directions*. Policy Brief No. 5, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

Singh, G., Rambabu and S. Chandra (1981), *Soil Loss Prediction Research in India*, Bulletin. No. T-12/D-9, Central Soil and Water Conservation Research and Training Institute, Dehradun, India.

Sreedevi, T.K., B. Shiferaw and S.P. Wani (2004), *Adarsha Watershed in Kothapally: Understating the Drivers of Higher Impact,* Global Theme on Agroecosystems Report no. 10, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 24 pp.

Stroorvogel, J.J. and M.A. Smalling (1990), *Assessment of Soil and Nutrient Depletion in Sub-Saharan Africa: 1983-2000*, Volume I: Main Report, The Winand Staring Centre, Wageningen, Netherlands.

State Credit Plan (2005), *State Credit Plan*, State Level Bankers Committee, Hyderabad, Andhra Pradesh, India.

Van Keulen, H. (1990), *A Multiple Goal Programming Base for Analysis of Agricultural Research and Development,* In: Rabbinge, R., J. Goudriaan, H. Van keulen, H.H. Van Laar and F.W.T Penning de Vries (Eds.), Theoretical production ecology: Reflection and prospects, Simulation monographs, Wageningen: PUDOC.

Van Lynden, G.W.J. and L.R. Oldeman (1997), *Assessment of the Status of Human-Induced Soil Degradation in South and South East Asia*, International Soil Reference and Information Centre, Wageningen, 35 pp.

Verma, B., S.N. Bhola, C. Prakash and S.N. Prasad (1983), *Soil and Water Loss Studies under Different Vegetative Covers Under 1% Slope in Kota Clay Soils*, Annual Report, Central Soil and Water Conservation Research and Training Institute, Dehradun, India, pp. 96-97.

Wani, S.P., T.K. Sreedevi, H.P. Singh, P. Pathak and T.J. Rego (2002), *Innovative Farmers Participatory Integrated Watershed Management Model: Adarsha Watershed, Kothapally, India (A Success Story),* International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 24 pp.

Wani, S.P., T.K. Sreedevi, H.P. Singh, P. Pathak, T.J. Rego, B. Shiferaw and S.R Iyer (2003), *Farmer-Participatory Integrated Watershed Management: Adarsha Watershed, Kothapally India – An Innovative and Upscale Approach*, Case 7, In: Karwood, R.R. and A.H. Kassam (Eds.), Research Towards Integrated Natural Resource management: Examples of Research Problems, Approaches and Partnerships in Action in the CGIAR, Interim Science Council and Centre Directors Committee on Integrated Natural Resource Management, CGIAR, Washington D.C., U.S.A.

Wani, S.P. and B. Shiferaw (Eds.) (2005), *Baseline Characterization of Benchmark Watershed in India, Thailand and Vietnam*, Global Theme on Agroecosystems Report no. 13, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India, 104 pp.

World Bank (1993), *Water Resource Management*, Policy paper, The World Bank, Washington, D.C., U.S.A.

World Bank (1990), *Staff Appraisal Report*, India: Integrated Watershed Development (Plains) Projects, The World Bank, Washington, D.C., U.S.A.

Appendix

Appendix 1: Important socio-economic features of the sample villages (2001).[a]

Issues	Kothapally	Husainpura	Masaniguda	Oorella	Yankepally	Yarveguda
No. of households	308	40	160	460	175	206
Land Resources						
Common property resources (acres)	8	10	8	3	10	0
Permanent fallow (ha)	10.53	22.28	1018.58	263.25	89.10	25.11
Cultivated land (ha)	465.75	142.97	810.00	799.88	377.87	144.59
- % area irrigated	34.8[b]	9.90	10.00	14.10	10.70	4.20
- % dry land	65.20	90.10	90.00	54.90	89.30	95.80
Degraded previously cultivated land (ha)	8.10	4.05	12.15	0.00	4.05	4.05
Other land (ha)	14.58	2.03	24.30	18.23	12.15	4.86
Total area (ha)	502.20	175.37	1868.27	1082.57	487.22	178.61
% cultivated area degraded	1.74	2.83	1.50	0.00	1.07	2.80
Water harvesting						
No. of check dams	10	0	0	0	0	1
No. of open wells	64	13	80	150	50	5
No. of tube wells	34	3	14	9	27	18
No. of community wells	13	1	2	2	11	10
Social infrastructure						
No. of private schools	1	1	0	0	0	0
No. of government schools	1	0	1	1	1	1
Highest school standard	9	5	7	10	6	7
Sending children to school (%)	74.7	75.0	75.0	82.6	80.0	72.8
Number of clinics	1	0	0	0	0	0
Number of phones	18	1	11	11	7	9
HHs having electricity (%)	100.0	100.0	100.0	100.0	91.4	87.4
Quality of roads	V. good	Bad	V. good	Good	Good	Good
Asset ownership and poverty						
Landless households (%)	3.2	0.0	1.9	0.7	2.9	2.4
Food secure households (%)	100.0	100.0	100.0	100.0	100.0	96.1
Poor (as per local norms) (%)	1.6	12.5	12.5	2.6	1.7	2.4
No. of seasonal migrants (%)	4.9	0.0	9.4	43.5	5.7	4.9
No. of permanent migrants (%)	1.6	15.0	31.3	0.9	2.3	2.9
Soil and water conservation						
Trees planted in 2001	5000	100	200	185	800	500
HHs planting trees (%)	51.9	37.5	25.0	15.4	45.7	15.5
HHs investing in SWC (%)	7.1	25.0	18.8	10.9	11.4	4.9
HHs using FYM (%)	60.0	100.0	93.8	34.8	80.0	87.4
HHs using mineral fertilizers (%)	100.0	100.0	93.8	93.5	100.0	97.1
Amount of fertilizer used (kg/ha)	123.45	123.45	123.45	123.45	123.45	246.90
HHs using pesticides (%)	90.0	100.0	93.8	70.0	90.0	82.5
Livestock (average ownership)						
Cattle	1.0	0.8	0.4	0.4	1.1	0.6
Buffaloes	0.7	0.1	0.9	0.0	1.4	0.6
Sheep	0.9	0.0	0.0	0.9	0.0	1.2
Goats	0.7	0.8	1.3	0.2	0.9	1.5

a Data collected through focus group discussions during the village-level surveys. Open and tube wells include those that may have dried up.
b Prior to the watershed interventions, the estimated area under irrigation was about 20%.
Source: Shiferaw *et al*. (2003a)

Appendix 2: The OLS results of the production function of crops for estimating the marginal response of yields for change in soil depth and nutrients (N and P)

Variables Dep: Yield in kg per ha	**Sorghum**		**Maize**		**Chickpea**		**Pigeon pea**		**Sunflower**	
	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics
Intercept	-110.311	-1.00	1056.014	2.29**	204.955	0.55	69.881	2.33**	71.707	0.30
Labour (days/ha)	4.059	2.47**	10.904	2.23**	0.318	0.15	4.377	4.71***	-1.224	-0.22
Nitrogen (kg/ha)	7.771	2.39**	13.446	2.82***	12.216	1.72	0.953	0.57	5.773	0.74
Phosphorus (kg/ha)	3.216	1.19	-7.686	-1.47	0.257	0.05	-4.882	-2.4**	2.698	0.33
FYM (qt/ha)	-0.832	-0.26	20.444	3.04***	17.648	2.41**	-1.699	-0.65	-6.706	-0.41
Labour x Labour	0.005	0.67	0.004	0.18	-0.003	-0.53	-0.016	-2.11**	0.027	0.91
Nitrogen x Nitrogen	-0.059	-1.88	-0.051	-1.04	-0.064	-0.94	-0.027	-1.02	0.213	1.91**
Phosphorus x Phosphorus	-0.020	-0.76	0.080	1.55	0.035	0.79	0.127	2.63***	0.098	0.69
FYM x FYM	0.033	0.81	-0.101	-1.31	-0.311	-2.11**	-0.001	-0.02	0.191	0.45
soil depth (Ordinal variable)	121.637	4.54***	167.219	2.32**	188.919	4.91***	18.342	2.33**	172.356	3.32***
variety dummy (1= improved)	269.654	5.71***	25.591	0.07	15.133	0.18	47.961	3.63***	175.207	1.47
Irrigation dummy (1= irrigated)			405.591	1.28	316.001	2.46**			335.536	2.36**
Pesticides (Rs. per ha)										
year1_dummy	437.338	5.4***	-438.542	-2.12**	-91.949	-0.6	36.551	1.53	-127.875	-0.9
Year2_dummy	43.609	0.59	-1067.83	-7.86***	42.669	0.32	-38.011	-2.05**	-65.677	-0.59
Adjusted R^2		0.438		0.332		0.291		0.457		0.512
N		342		308		147		625		67

Note: *, ** and *** indicate levels of significance at less than 10%, 5% and 1% level respectively

N- Number of observations

Appendix 2: Continued.

Variables Dep: Yield in kg per ha	Onion		Vegetables		Paddy		Cotton	
	coefficient	t-Statistics	Coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics
Intercept	4490.000	0.85	-1314.180	-0.98	4555.000	7.08***	1337.897	11.44***
Labour (days/ha)	27.768	0.78	10.730	3.77***	-4.864	-1.5*	1.657	2.31**
Nitrogen (kg/ha)	17.603	0.42	2.021	0.35	19.087	2.97***	2.781	2.96***
Phosphorus (kg/ha)	60.337	1.18	-5.206	-0.58	-4.9772	-0.75	0.018	0.02
FYM (qt/ha)	-188.939	-0.88		0.87	2.863	0.82	0.996	0.54
Labour x labour	0.008	0.13			0.005	0.95		
Nitrogen x nitrogen	0.039	0.27			-0.045	-1.64*		
Phosphorus x Phosphorus	-0.056	-0.2			-0.013	-0.28		
FYM x FYM	2.609	0.92			-0.002	-0.19		
soil depth (Ordinal variable)	2860.062	2.05**	507.936	1.47*	-134.681	-1.13		
variety dummy (1= improved)	4086.749	1.51*	1615.845	1.65*			85.869	0.94
Irrigation dummy (1= irrigated)			302.523	0.52				
Pesticides (Rs. per ha)							8.556	1.39*
year1_dummy	-5120.607	-1.96**	513.965	0.62	-997.242	-2.38**	-752.273	-6.9***
Year2_dummy	-3743.827	-0.85	1918.753	2.41**	-793.674	-2.49**	-790.109	-10.3***
Adjusted R^2	0.305		0.168		0.117		0.486	
N	43		160		253		236	

Note: *, ** and *** indicate levels of significance at less than 10%, 5% and 1% level respectively

N- Number of observations

Appendix 3: The OLS results of the linear production function of crops for estimating average yield in different soil depth types

Variables Dep: Yield in kg per ha	**Sorghum (local variety)**		**Sorghum (HYV)**		**Maize**		**Chickpea**		**Pigeon pea**	
	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics
Intercept	643.247	8.18***	902.501	7.15***	1983.944	11.24***	1077.393	10.76***	188.594	7.06***
Nitrogen (kg/ha)	4.149	2.56**	5.536	2.09**	6.979	2.99***	4.564	1.46*	-0.0367	-0.03
Phosphorus (kg/ha)	4.033	2.85***	4.584	2.04**	4.689	1.62*	0.933	0.45	10.271	9.43***
SD1_Dummy	-224.265	-2.57**	-352.072	-2.61***	-752.525	-3.79***	-786.856	-4.78***	-82.428	-2.66***
SD2_Dummy	-174.623	-2.09**	-74.746	-0.62	-699.507	-3.69***	-596.535	-5.95***	-27.441	-0.95
Adjusted R^2	0.16		0.179		0.107		0.402		0.343	
N	212		130		308		147		343	

Variables Dep: Yield in kg per ha	**sunflower**		**Onion**		**Vegetables**		**Paddy**[1]		**Cotton**[2]	
	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics	coefficient	t-Statistics
Intercept	897.560	6.92***	11514.23	5.51***	6465.227	10.19***	3427.362	12.14***	877.485	11.00***
Nitrogen (kg/ha)	4.525	2.13**	11.381	1.13	-0.953	-0.16	8.872	4.28***	5.471	5.24***
Phosphorus (kg/ha)	-2.232	-0.88	12.471	0.67	7.698	0.87	-2.068	-0.83	-0.609	-0.46
SD1_Dummy	-564.189	-4.64***	-5447.748	-1.8*	-2310.3	-2.95***	183.02	0.7	57.322	0.46
SD2_Dummy	-89.841	-0.78	-2179.459	-0.94	-1668.333	-2.58**	-154.334	-0.68	-55.359	-0.64
Adjusted R^2	0.326		0.068		0.038		0.082		0.173	
N	67		43		158		253		236	

Note: *, ** and *** indicate levels of significance at less than 10%, 5% and 1% level respectively

N- Number of observations

1, and 2 – The soil depth dummies are not statistically significant. Paddy is grown in flooded field condition so soil depth is not affecting the yield and cotton is very deep rooted plant so soil depth is not serious limiting factor for yield. So the same average yield is used for all soil types without any variation.

Appendix 4: C and P factors used in USLE

Crops	C Value	Conservation Practices	P value
Sorghum*	0.375	Intercrop	0.8
Maize*	0.333	Ploughing on contour	0.9
Chickpea	0.338	Applying mulch	0.6
Pigeon pea	0.600	Field bunding	0.6
Vegetables	0.502		
Cotton	0.600		
onion	0.538		
Sunflower	0.392		

Source: C and P values: Narain *et al*. (1982), Singh *et al*. (1981); Verma *et al*. (1983) and Kurothe, (1991)
Note: * sorghum and maize are intercropped with pigeon pea

Appendix 5: Estimated soil loss per ha of each crop grown in the watershed

The universal Soil Loss Equation (USLE) adapted for Adarsha watershed

$$A = R * K * L * S * C * P$$

Where,

A = Average annual soil loss (tons / ha / year)

R = Rainfall erosivity factor

K = Soil erodability factor (tons / ha per unit of R)

L = Slope length factor

S = Slope gradient or steepness factor

C = Land cover factor

P = Conservation practice factor

Factors	Crops							
	Sorghum	**Maize**	**Pigeon Pea**	**Chickpea**	**Cotton**	**Sunflower**	**Onion**	**Vegetables**
R	361	361	361	361	361	361	361	361
K	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106
L	0.953	0.953	0.953	0.953	0.953	0.953	0.953	0.953
S	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415
C	0.375	0.333	0.6	0.338	0.6	0.392	0.538	0.502
P	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Soil loss* (t/ha)	**3.41**	**2.99**	**5.45**	**3.07**	**5.45**	**3.56**	**4.89**	**4.56**

Source: Wischmeier and Smith (1978) in Narain *et al*. (1982)
R and K value: adapted from Narain *et al*. (1982)
L and S value: calculated using formula of Wischmeier and Smith (1965)
C values: Narain *et al*. (1982), Singh *et al*. (1981); Verma *et al*. (1983) and Kurothe, (1991)
Note: * the soil loss per ha is with only contour bunding but not other *insitu* S&W conservation practices (e.g. BBF and bund strengthening by planting *Glyricidia*).

Appendix 6: Simulation results of alternative scenarios over 10 years (only important variables which discussed in the results)

Dry land crops yield increased by 10%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.55	5.68	5.82	5.62	4.98	5.04	4.77	5.37	5.42	4.86
Medium Household	10.71	9.97	10.13	10.54	9.54	8.62	9.61	9.58	9.25	8.92
Large Household	18.91	15.45	17.93	18.25	19.09	18.90	18.51	17.56	16.94	15.50
Total soil erosion (tons)	1871.02	1853.93	1798.80	1744.14	1701.60	1667.58	1620.31	1577.10	1555.27	1475.96
Average soil loss (t/ha)	4.43	4.39	4.26	4.13	4.03	3.95	3.83	3.73	3.68	3.49
Conservation labour (man days)	0.00	1081.19	2107.94	1812.91	1798.44	2300.57	4361.10	6278.32	7265.31	8232.12

Dryland crops yield decreased by 10%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.19	5.54	4.90	5.38	4.69	4.26	4.59	4.22	4.42	4.31
Medium Household	7.96	8.47	9.02	8.59	9.40	9.25	9.48	9.15	9.28	9.16
Large Household	18.91	15.45	17.93	18.25	19.09	18.90	18.51	17.56	16.94	15.50
Total soil erosion (tons)	1847.97	1807.50	1784.64	1715.82	1712.20	1723.85	1673.45	1634.06	1600.49	1592.32
Average soil loss (t/ha)	4.37	4.28	4.22	4.06	4.05	4.08	3.96	3.87	3.79	3.77
Conservation labour (man days)	1674.03	3125.87	3951.12	4079.58	3775.95	3561.41	5022.59	6355.42	6936.34	7146.69

Irrigated area increased by 25%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.20	5.54	5.55	5.27	5.36	4.52	4.44	5.11	5.34	5.25
Medium household	9.45	9.05	8.54	10.53	9.91	9.87	10.63	10.24	9.02	7.77
Large household	19.42	18.16	18.12	16.03	15.96	21.60	20.53	18.40	14.28	15.55
Total soil erosion (tons)	1898.92	1833.74	1860.75	1780.91	1715.08	1741.45	1739.62	1674.31	1636.62	1576.58
Average soil loss (t/ha)	4.49	4.34	4.40	4.21	4.06	4.12	4.12	3.96	3.87	3.73
Conservation labour (man days)	1382.55	2534.02	2677.69	3411.53	3415.11	3203.11	4425.72	6265.80	7797.30	8628.94

Irrigated area decreased by 25%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.06	5.63	5.59	4.88	4.67	4.63	4.39	4.24	3.99	4.24
Medium household	8.38	7.90	7.39	9.68	9.39	7.88	8.90	8.61	9.95	8.91
Large household	16.78	15.48	16.06	15.78	17.08	18.85	18.41	16.98	16.90	14.87
Total soil erosion (tons)	1736.49	1743.26	1758.05	1670.99	1704.08	1680.37	1644.95	1589.46	1552.24	1502.48
Average soil loss (t/ha)	4.11	4.13	4.16	3.95	4.03	3.98	3.89	3.76	3.67	3.56
Conservation labour (man days)	868.86	2467.11	2802.88	3533.01	2601.24	2803.51	3899.72	5187.19	4882.00	6963.98

Dry land crop price increased by 5%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	6.22	5.98	5.58	5.30	5.01	5.06	5.00	5.22	4.65	4.73
Medium household	9.70	8.66	10.40	11.03	11.02	10.24	10.34	9.23	10.06	9.75
Large household	16.31	19.20	17.20	17.94	19.67	19.08	19.52	19.26	19.84	17.89
Total soil erosion (tons)	1845.75	1769.79	1758.84	1716.39	1704.03	1711.67	1663.61	1612.78	1553.01	1505.90
Average soil loss (t/ha)	4.37	4.19	4.16	4.06	4.03	4.05	3.94	3.82	3.67	3.56
Conservation labour (man days)	0.00	776.41	1033.92	1606.00	1811.78	1682.59	2242.55	4168.91	4541.25	6325.15

Irrigated crop price decreased by 5%

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.48	5.67	4.84	5.48	4.64	4.64	4.56	4.38	4.69	4.35
Medium household	8.31	7.69	9.01	8.07	9.72	8.99	8.29	8.83	8.26	7.55
Large household	13.64	13.68	14.82	13.92	15.34	15.36	17.47	16.57	15.30	16.59
Total soil erosion (tons)	1845.50	1764.25	1758.81	1684.96	1678.37	1681.12	1653.31	1615.33	1560.14	1478.58
Average soil loss (t/ha)	4.37	4.17	4.16	3.99	3.97	3.98	3.91	3.82	3.69	3.50
Conservation labour (man days)	0.00	1176.62	1273.88	2071.60	2153.30	2121.08	2748.15	4249.65	5189.67	6317.08

Water pricing (10%) share of output

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	3.57	4.30	4.68	3.98	4.61	4.60	4.30	4.21	3.80	4.08
Medium household	7.36	7.84	6.61	7.88	5.93	6.88	7.20	6.30	6.65	5.93
Large household	16.26	11.18	10.74	12.81	11.13	9.13	9.11	10.42	10.89	9.30
Total soil erosion (tons)	1462.66	1436.25	1399.57	1392.78	1407.89	1424.99	1364.12	1326.35	1313.06	1302.48
Average soil loss (t/ha)	3.46	3.40	3.31	3.30	3.33	3.37	3.23	3.14	3.11	3.08
Conservation labour (man days)	4376.98	5394.50	6359.45	6488.18	7155.25	7574.25	8197.35	8876.96	9164.42	9424.98

Water pricing (5%) share of output

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	3.90	4.55	4.31	4.75	4.47	4.39	4.46	4.27	4.43	4.21
Medium household	7.64	7.15	8.20	7.37	7.58	7.71	7.60	7.50	7.26	6.92
Large household	17.15	14.35	12.70	13.01	12.62	12.39	11.31	11.21	9.76	9.65
Total soil erosion (tons)	1397.39	1356.90	1317.63	1280.58	1239.93	1215.85	1239.24	1289.85	1301.09	1303.92
Average soil loss (t/ha)	3.31	3.21	3.12	3.03	2.93	2.88	2.93	3.05	3.08	3.09
Conservation labour (man days)	4320.31	4353.30	5907.34	6285.77	7428.60	8145.13	8724.73	8813.52	8962.35	9370.96

Increased Non-farm activates

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	6.47	6.74	6.91	5.65	6.22	5.55	5.09	5.57	5.10	4.92
Medium household	9.43	9.43	8.34	11.76	9.82	10.44	10.18	8.74	10.17	10.00
Large household	19.09	17.29	17.42	17.42	17.46	18.33	21.23	20.37	19.07	18.66
Total soil erosion (tons)	1988.46	2023.19	2032.66	1969.08	1959.46	1942.45	1934.08	1884.07	1854.72	1806.67
Average soil loss (t/ha)	4.71	4.79	4.81	4.66	4.64	4.60	4.58	4.46	4.39	4.28
Conservation labour (man days)	0.0	0.0	0.0	0.0	0.0	0.0	327.17	1974.40	3087.67	4113.49

Population growth rate increased from 2.5 to 3.0

Particulars	Years									
	1	2	3	4	5	6	7	8	9	10
Per capita Income ('000 Rs)										
Small household	5.30	5.67	5.36	5.32	5.11	4.66	4.51	4.52	4.69	4.91
Medium household	8.30	8.56	9.24	9.27	8.55	8.59	9.73	9.72	8.86	8.53
Large household	18.74	15.94	16.89	14.85	17.22	17.69	16.18	15.01	14.68	12.43
Total soil erosion (tons)	1860.19	1780.38	1758.43	1684.18	1712.87	1673.10	1636.45	1569.69	1536.90	1522.70
Average soil loss (t/ha)	4.40	4.21	4.16	3.99	4.05	3.96	3.87	3.71	3.64	3.60
Conservation labour (man days)	1292.03	2660.21	4022.02	4353.01	3564.68	4073.29	4800.40	6651.28	8019.01	8438.27

Appendix 7: A dynamic bioeconomic model for Adarsha watershed, Kothapally

In this appendix the full version of the non-linear watershed level bioeconomic model is presented in GAMS modeling language notation (Brooke et al., 1992). The detailed definition of indices (SETS), Parameters (PARAMETERS, SCALARS), variables (VARIABLES) and equations (EQUATIONS) are given.

***---------------------------SETS---------------------------------------**
SET

C	Crops production activities
CR(C)	Consumption of cereals
CC(C)	Consumption activities for crop products
CARFAT(NUT)	Carbohydrate and fat
CTYPE	Credit from government and informal sources
CL	Conservation level
FERTL	Fertilizer level
FERT	Inorganic fertilizer
IN(L)	Livestock initial stock
KAR(S)	Kharif season
KAR(C)	Kharif crops
L	Livestock raising activities in the watershed
LANDT	Land types
ML(L)	Milk producing animals
NUT	Nutrients for human consumption
NUTCP(NUT)	Nutrients carbohydrate and protein
NP	Soil nutrients
PAP	Purchased consumption commodities
PA(L)	Livestock purchase activities
PL(C)	Consumption of pulses
PRO(NUT)	Protein
RAB(S)	Rabi season
RAB(C)	Rabi Crops
RA(L)	Livestock rearing activities
RB(L)	Ram and buck
S	Seasons
SALE(L)	Livestock sale activities
SA(L)	Livestock slaughter activities
SG(L)	Sheep and goat
SOILT	Soil types depending on the depths
T	Time period
TFIRST(T)	First period
TLAST (T)	Last period

***------------------------TABLES----------------------------------**

TABLE ANPRICE(PAP,*)	Prices and nutrient composition of other products
TABLE ACROPYL(C,LANDT,SOILT)	Crop yield in different soil type (t/ha)
TABLE BULLREQ(C,LANDT,SOILT,FERTL,S)	Bullock labour used for crop production in days

```
TABLE CALNUT(NUT,*)        Calorie composition of nutrients (kcal/ton)
TABLE CROPSY (C,*)         Stover yield of crops (times of grain yield)
TABLE CROPNUT (C,NP)       Nutrient composition of grains (kg/tons harvested)
TABLE CREDINT(CTYPE,*)     Interest rate on credit
TABLE DRYMREQ(L,*)         Dry matter requirements (t/year)
TABLE EGGNCOM(NUT,*)       Nutrient composition of farm produced eggs
TABLE EROS(C,CL,*)         Labour used for conservation to reduce soil erosion (man-days)
TABLE FERTNUT(FERT,NP)     Fertilizer nutrients in proportion
TABLE FERTPR(FERT,*)       Fertilizer price (Rs/ton)
TABLE FERTZ(NP,FERTL)      Fertilizer use level (t/ha)
TABLE FERTRESP(C,*)        Marginal response to N and P of crops (t/ha)
TABLE HLABS(S,*)           Human labour available in each season (man-days)
TABLE LVLABREQ(H,S)        Labour requirement for livestock rearing (man-days)
TABLE LIVBIN (L,H)         Number of livestock in the household group
TABLE LIVNUT(L,NUT)        Livestock Nutrient composition (t/head)
TABLE LANDAV(LANDT,SOILT,H)                 Land available in hectares
TABLE LANDPRICE(LANDT,SOILT,*)              Rental value of the land (Rs/ha)
TABLE LANDREQ(C,LANDT,SOILT,FERTL,S)        Months of land occupation by crops
TABLE LABREQ(C,LANDT,SOILT,FERTL,S)         Crop labour requirements (man-days/ha)
TABLE MANNUT(NP,*)                          Manure nutrient in proportion
TABLE MILKNCOM(*,*)                         Nutrient composition of milk
TABLE NPKCONH (C,NP)                        N and P content of harvested product (kg/ton)
TABLE NPKCONR (C,NP)                        N and P content of crop residual (kg/ton)
TABLE NITROFIX (C,NP)                       Biological N fixation in the soil  (t/ha)
TABLE PERCONC(NUT,*)                        Calorie consumption from nutrients (%)
TABLE PRICES(C,*)                           Price for seeds, farm gate and market price of
                                        crops
TABLE SDEPTH(SOILT,LANDT)                   Initial soil depth in cm in the watershed
TABLE YIELDRED(C,LANDT,SOILT)               Crop yield reduction (t/cm of soil depth)
```

***----------------------PARAMETERS-----------------------------------**

```
PARAMETER
HHN(H)                  Number of Households in each household group
POP(H)                  Population of the different household group in the watershed
WFORCE(H)               Work force to the total population
CONSUNIT(H)             Consumer unit to the total population
PRICEL(L)               Price of livestock in Rupees
AMILKP(L)               Average milk production in litres per animal per year

PARAMETER
MANPYPA (L)             Collectable dry manure produced (tons) per animal per year;

MANPYPA(L)=(365*DRYMREQ(L,'WEIGHT')*DRYMREQ(L,'PDMANURE')
        *DRYMREQ(L,'RATECOL'))/1000;

DISPLAY MANPYPA;
```

***----------- Nutrient balance parameters----------------------**

```
PARAMETER
NUTDEP (NP)  Nutrient deposition per ha
NLEROS (NP)  Nutrient loss by soil erosion (tons/ton of soil loss)
LEACH (NP)    Nutrient loss by leaching (tons in the watershed)
NMANU (NP)   Nutrient loss by leaching (tons/ton manure)
```

***-----------------------Household and Population-----------------------**

```
PARAMETER
THHN(T,H)  Number of household in each household group in the watershed in period T;

THHN(T,H)=HHN(H)*(1+GRPOP)**(ORD(T)-1);
DISPLAY THHN;

PARAMETER
TPOP(T,H)  Total population of the different household group in the watershed in period T;
TPOP(T,H)=POP(H)*(1+GRPOP)**(ORD(T)-1);
DISPLAY TPOP;
```

***----------------------Total labour------------------------------------**

```
PARAMETER
TWFORCE(T,H)       Total work force of different household group in the watershed in period T
TLABORS(T,H,S)     Total labour available in each household group in each season (man-days)
TLABORY(T,H)       Total labour available in each household group  in period T (man-days);

TWFORCE(T,H)=WFORCE(H)*(1+GRPOP)**(ORD(T)-1);
TLABORS(T,H,S)=HLABS(S,'HUMANLAB')*TWFORCE(T,H);
TLABORY(T,H)=SUM(S,TLABORS(T,H,S));
DISPLAY TWFORCE,TLABORS,TLABORY;
```

***------------------Total consumers------------------------------------**

```
PARAMETER
TCONSUNIT(T,H)    Total consumer units of each household group in the watershed in period T;

TCONSUNIT(T,H)=CONSUNIT(H)*(1+GRPOP)**(ORD(T)-1);

DISPLAY TCONSUNIT;
```

***------------------Subsistence nutrient requirement-------------------**

```
PARAMETER
CARBRQY(T,H)     Annual carbohydrate requirements (tons)
PROTRQY(T,H)     Annual protein requirements (tons)
FATRQY(T,H)      Annual fat requirements (tons);

CARBRQY(T,H)=TCONSUNIT(T,H)*KCALRPY*PERCONC('CARBOHY','CALPGM')/
CALNUT('CARBOHY','KCALPT');
PROTRQY(T,H)=TCONSUNIT(T,H)*PROTRQ;
```

FATRQY(T,H)=TCONSUNIT(T,H)*KCALRPY*PERCONC('FAT','CALPGM')/
CALNUT('FAT','KCALPT');
DISPLAY CARBRQY,PROTRQY,FATRQY;

PARAMETER
NUTRQY(NUT,T,H) Annual nutrition requirement (tons);
NUTRQY(NUT,T,H)=(TCONSUNIT(T,H)*KCALRPY*PERCONC(NUT,'CALPGM')/
CALNUT(NUT,'KCALPT'))$CARFAT(NUT)+(TCONSUNIT(T,H)*PROTRQ)$PRO(NUT);
DISPLAY NUTRQY;
***---------------------Discount Factor----------------------------------**

PARAMETER
DF(T) Discount factor for each year;
DF(T)=1/(1+DRATE)**(ORD(T));
DISPLAY DF;

*---------------------------- **SCALARS---------------------------**
SCALARS

BULLWAGE	Wage rate for bullock (Rs/day)
CRESIDP	Crop residue price (Rs/t)
DRATE	Discount rate
DMRESID	Dry matter content of crop residue
GRPOP	Growth rate of population in the watershed
HINWAGE	Casual labour wage (Rs/day)
KCALRPY	Kilocalories per consumer per year
MILKPR	Selling price of milk (Rs/lt)
OFMWAGE	Non-farm wage rate (Rs/day)
PROTRQ	Protein requirement per consumer (t/yr)
PLIV	Productive livestock percentage
TRAVELCOST	Average travel cost per day per person to find nonfarm employment (Rs)

***---------------------------VARIABLES----------------------------------**
VARIABLES

***Income Variable**

CROPINC(T,H)	Value of crop sale in period *T* ('000 Rs)
CREDIT(T,CTYPE,H)	Credit borrowed from government and informal sources in period *T* ('000 Rs)
DISINC	Discounted watershed income in period *T* ('000 Rs)
INCOME(T,H)	Income of the household group in period *T* ('000 Rs)
INCOMEPH(T,H)	Income per household in period *T* ('000 Rs)
INCOMEPCAP(T,H)	Income per consumer unit in period *T* ('000 Rs)
LIVINC(T,H)	Value of livestock sale in period *T* ('000 Rs)
NFMINC(T,H)	Off farm income in period *T* ('000 Rs)
TINCW(T)	Total income of the watershed in period *T* ('000 Rs)
WAGEINC(T,H)	Wage income in period *T* ('000 Rs)

***Crop production and land management**

ACULT(T,LANDT)	Total area cultivated by land type (ha)
ACULTS(T,SOILT)	Total area cultivated by soil type (ha)
ACULTH(T,H)	Total area cultivated by household group (ha)
AVGCROPASM(T,C,LANDT,H)	Average crop area of different household group in different land type (ha)
CROPCUL(T,C,LANDT,SOILT,H)	Crop area in different soil and land type (ha)
CROPCULLAND(T,C,LANDT,H)	Crop area in different land type (ha)
CROPYL(T,C,LANDT,SOILT,FERTL,CL,H)	Change in crop yield after erosion(t/ha)
CROPRESY(T,C,LANDT,SOILT,H)	Crop residual yield (tons)
CROPY(T,C,LANDT,SOILT,H)	Crop grain yield (tons)
CROPAH(T,C,H)	Crop area cultivated by household group (ha)
FALLOW(T,LANDT,SOILT,H)	Land fallowed (ha)
KARAREACUL(T)	Total land area cultivated in Kharif season (ha)
OWNCULT(T,LANDT,SOILT,H)	Own land area cultivated (ha)
RENTOUT(T,LANDT,SOILT,H)	Land rented out (ha)
RENTIN(T,LANDT,SOILT,H)	Land rented in (ha)
RENTCULT(T,LANDT,SOILT,H)	Land rented in and cultivated (ha)
RABAREACUL(T)	Total land area cultivated in Rabi season (ha)
TACULT(T)	Total area cultivated in the watershed (ha)
TCROPS(T,C,SOILT)	Different crop area under each soil type (ha)
TCROPL(T,C,LANDT)	Different crop area under each land type (ha)
TCAREA(T,C)	Total area of different crops in the watershed (ha)
TPROD(T,C,H)	Total crop production by household group in period *T* (tons)
TPRODW(T,C)	Total crop production in the watershed in period *T* (tons)
XCROP(T,C,LANDT,SOILT,FERTL,CL,H)	Crop Production activities(ha)
XCONS(T,C,H)	On farm consumption of crop produce (tons)
XTCONS(T,C,H)	Total consumption of food crops (tons)
XSTOREDS(T,C,H)	Crop stored in period *T* for sale in the following year (tons)
XSTORED(T,C,H)	Crop stored for next year (tons)
XSTROEDC(T,C,H)	Crop stored in period *T* for consumption in the following year (tons)
XSELCROP(T,C,H)	Amount of crop production sold (tons)
XSEED(T,C,H)	Amount of own crop used as seed (tons)
XBUYSED(T,C,H)	Amount of crop purchased for seed stock (tons)
XBUYCON(T,C,H)	Amount of crop product purchased for consumption (tons)
XTSELL(T,C,H)	Total amount of crop production sold (tons)

***Family and bullock labour variables**

LABONF(T,H,S)	Labour used on farm in each season (man-days)
LABHIN(T,H,S)	Labour hired in from one group to another group of household within the watershed (man-days)
LABOUT(T,H,S)	Labour hired out from one group to another group of household within the watershed (man-days)
LABNFM(T,H,S)	Labour worked non-farm (man-days)
LABCONS(T,H)	Total labour used for conservation in period *T*(man-days)
TLABONF(T,H)	Total labour used on farm in period *T* (man-days)
TLABNFM(T,H)	Total labour used non-farm in period *T* (man-days)

TLABHIN(T,H)	Total labour hired in period *T* (man-days)
TLABOUT(T,H)	Total labour hired out in period *T* (man-days)

***Fertilizer**

DMANURE(T,H)	Total manure production in period *T*(tons)
FERTBUY(T,FERT,H)	Fertilizer bought by type (tons)
FERTNP(T,C,LANDT,SOILT,NP,H)	N and P applied through fertilizer (tons)
MANUSE(T,H)	Amount of manure applied in period *T* (tons)
NUTPHA(T,C,NP)	Fertilizer nutrients applied per ha (tons)
NUTAPP(T,C,NP)	Nutrients applied for each crops (tons)
NUTBAL(T,NP)	Nutrient balance (N, P and K) in the watershed (tons)
NUTINF(T,NP)	Nutrient inflow (N, P and K) in tons
NUTOUTF(T,NP)	Nutrient outflow (N, P and K) in tons

***Erosion and soil depth**

AVSERWAT(T)	Average soil erosion in the watershed in each period *T* (t/ha)
AVSEROS(T,LANDT,SOILT,H)	Average soil eroded in different land unit in each period *T* (t/ha)
CDEPTH(T,LANDT,SOILT,H)	Change in soil depth in different land type in each period *T* in cm
CSDEPTH(LANDT,SOILT,H)	Change in soil depth from initial depth in cm
CUMSEROS(T,LANDT,SOILT,H)	Cumulative soil erosion in each period *T* (tons)
DEPTH(T,LANDT,SOILT,H)	Soil depth of different soil type in each period *T* in cm
TSOILER(T,LANDT,SOILT,H)	Total soil eroded in different land unit in each period *T*(tons)
TEROSW(T)	Total soil erosion in the watershed (tons)

***Livestock activities**

BULLHIRE(T,H,S)	Bullock labour hired (days)
EGGSOWN(T,H)	Consumption of farm eggs
LABLIVREAR(T)	Value 1 for livestock production
LIVPROD(T,L,H)	Livestock production activities (heads)
LIVSALE(T,L,H)	Livestock selling activities (heads)
LIVBUY(T,L,H)	Livestock buying activities (heads)
LIVREAR(T,L,H)	Livestock born rearing activities (heads)
MILKPROD(T,L,H)	Milk production in the watershed in litres
MILKCONS(T,H)	Milk consumption by household group in litres
MILKSALE(T,H)	Milk sale by household group in litres
SUMLVK(T,L,H)	Total number of breeding stock in each period *T*
XCRESID(T,H)	Crop residue brought for livestock feed(tons)

***Consumption requirements**

BUYANIP(T,PAP,H)	Purchased food product (tons)

CONNUT(T,NUT,H) Actual consumption of nutrients by household groups (tons)
CONSOWNA(T,L,H) Own animal slaughtering activities
CONSPURA(T,L,H) Purchased animal slaughtering activities;

EQUATIONS

***------------------Objective Function: Discounted income----------**

```
OBJEQ.. DISINC=E=SUM (T,TINCW(T)*DF(T));
```

*optimizing the discounted total income of the watershed (summation of three HH income)

***--------------------- Income Function----------------------------**

```
INCOMEEQ(T,H).. INCOME(T,H)=E=(SUM(C,TPROD(T,C,H)*PRICES(C,'FARMPR'))
        -SUM(C,XBUYSED(T,C,H)*PRICES(C,'SPRICE'))
        -SUM(C,CROPAH(T,C,H)*PRICES(C,'OTHCOST'))
        +SUM((LANDT,SOILT),RENTOUT(T,LANDT,SOILT,H)
        *LANDPRICE(LANDT,SOILT,'LANDRV')
        +SUM((LANDT,SOILT),RENTIN(T,LANDT,SOILT,H)
        *LANDPRICE(LANDT,SOILT,'LANDRV'))
        +SUM(S,LABNFM(T,H,S)*OFMWAGE)
          -SUM(S,LABNFM(T,H,S)*TRAVELCOST)
          -SUM(S,LABHIN(T,H,S)*HINWAGE)
          +SUM(S,LABOUT(T,H,S)*HINWAGE)
          -SUM(S,BULLHIRE(T,H,S)*BULLWAGE)
          +SUM(L,LIVSALE(T,L,H)$SALE(L)*PRICEL(L)$SALE(L))
          -SUM(L,LIVBUY(T,L,H)*PRICEL(L))
          -SUM(L,LIVPROD(T,L,H)*DRYMREQ(L,'VETCOST'))
          -SUM(L,LIVPROD(T,L,H)$ML(L)*DRYMREQ(L,'CONCOST'))
          -SUM(CTYPE,CREDIT(T,CTYPE,H)*CREDINT(CTYPE,'IRATE'))
          -SUM(FERT,FERTBUY(T,FERT,H)*FERTPR(FERT,'FPRICE'))
          +MILKSALE(T,H)*MILKPR
          -XCRESID(T,H)*CRESIDP)  ;
```

* Income is revenue minus cost. Revenue is the sum of total value of the crop produce, livestock sales, value of milk produced, value of rent out land, and wages earned.

*Cost is the cash expenses for seed buy, rented in land, labour, fertilizer, livestock purchase, crop residue and interest on credit.

```
TINCWEQ(T).. TINCW(T)=E=SUM(H,INCOME(T,H));
```

***-----------------------Land constraint-----------------------------**

```
LANDBAL(T,LANDT,SOILT,H,S).. SUM((C,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERT,CL,H)
        *LANDREQ(C,LANDT,SOILT,FERTL,S))+FALLOW(T,LANDT,SOILT,H)
        +RENTOUT(T,LANDT,SOILT,H)=L=LANDAV(LANDT,SOILT,H)
```

```
        +RENTIN(T,LANDT,SOILT,H);

LANDBAL2(T,LANDT,SOILT,H).. OWNCULT(T,LANDT,SOILT,H)
        +RENTCULT(T,LANDT,SOILT,H)+RENTOUT(T,LANDT,SOILT,H)
        +FALLOW(T,LANDT,SOILT,H)=E=LANDAV(LANDT,SOILT,H)
        +RENTIN(T,LANDT,SOILT,H);

LANDBAL3(T,LANDT,SOILT,H).. OWNCULT(T,LANDT,SOILT,H)
        +RENTOUT(T,LANDT,SOILT,H)+FALLOW(T,LANDT,SOILT,H)
        =E=LANDAV(LANDT,SOILT,H);

LANDBAL4(T,LANDT,SOILT)..SUM(H,RENTIN(T,LANDT,SOILT,H))
        =L=SUM(H,RENTOUT(T,LANDT,SOILT,H));

LANDBAL5(T,LANDT,SOILT).. SUM(H,OWNCULT(T,LANDT,SOILT,H))
        +SUM(H,RENTOUT(T,LANDT,SOILT,H))+SUM(H,FALLOW(T,LANDT,SOILT,H))
        =E=SUM(H,LANDAV(LANDT,SOILT,H));

* Sum of hired in land in the watershed must be less than or equal to sum of hired out land in the watershed


*-----------------------Labour constraint------------------------------

SEALABREQ(T,H,S).. SUM((C,LANDT,SOILT,FERTL,CL),
        XCROP(T,C,LANDT,SOILT,FERT,CL,H)*LABREQ(C,LANDT,SOILT,FERTL,S))
        +SUM((C,LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
        *EROS(C,CL,'CONLAB')) +LABLIVREAR(T)*LVLABREQ(H,S)
        +LABNFM(T,H,S)+LABOUT(T,H,S=L=LABONF(T,H,S)+LABHIN(T,H,S);

SEALABAL(T,H,S)..           LABONF(T,H,S)+LABNFM(T,H,S)+LABOUT(T,H,S)
        =L=TLABORS(T,H,S);

*labour on farm + labour off farm + labour hired out to work in other farms within the watershed = Total labour days available in the watershed

SEALABAL2(T,S).. SUM(H,LABHIN(T,H,S))=E=SUM(H,LABOUT(T,H,S));

*sum of labour hired in the watershed = sum of labour hired out in the watershed

*------------------Bullock labour constraint----------------------

BULLREQEQ(T,H,S).. SUM((C,LANDT,SOILT,FERTL,CL),
        XCROP(T,C,LANDT,SOILT,FERTL,CL,H)*BULLREQ(C,LANDT,SOILT,FERTL,S))
        =L=HLABS(S,'BULLAB')*LIVPROD(T,'BULLOCK',H)+BULLHIRE(T,H,S);

*-------------------Seed use Constraint-------------------------------

SEEDREQ(T,C,H).. SUM((LANDT,SOILT,FERTL,CL),
```

```
        XCROP(T,C,LANDT,SOILT,FERTL,CL,H)*PRICES(C,'SEED'))
        =E=XSEED(T,C,H)+XBUYSED(T,C,H);
```

*total seed requirement for each crop for HH = amount of own seed stock used + amount of purchased seed stock

***--------------------Crop production balance--------------------------**

```
CPRODBAL(T,C,H).. SUM((LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FER,CL,H)
        *CROPYL(T,C,LANDT,SOILT,FERTL,CL,H))
        =E=XCONS(T,C,H)+XSELCROP(T,C,H)+XSEED(T,C,H)+XSTORED(T,C,H);
```

*Total production of each crop by each HH = on farm consumption crop produce + amount of crop produced sold + amount of crop produce used for own seed stock + amount of crop produce stored for next year

```
CPRODBALST(T,C,H).. XSTORED(T,C,H)=E=XSTOREDC(T+1,C,H)
        +XSTOREDS(T+1,C,H);
```

* Amount of crop produce stored for next year = amount of crop produce stored for consumption + amount of crop produce stored for sales

***-------------------Capital constraint equation------------------------**

```
CAPITALE(T,H).. SUM(C,CROPAH(T,C,H)*PRICES(C,'OTHCOST'))
          +SUM(C,XBUYCON(T,C,H)*PRICES(C,'PPRICE'))
          +SUM(L,CONSPURA(T,L,H)*PRICEL(L)$SA(L))
          +SUM(PAP,BUYANIP(T,PAP,H)*ANPRICE(PAP,'PRICE'))
          +XCRESID(T,H)*CRESIDP
          +SUM(S,LABNFM(T,H,S)*TRAVELCOST)
          +SUM(S,LABHIN(T,H,S)*HINWAGE)
          +SUM(S,BULLHIRE(T,H,S)*BULLWAGE)
        +SUM((LANDT,SOILT),RENTIN(T,LANDT,SOILT,H)
        *LANDPRICE(LANDT,SOILT,'LANDRV'))
          +SUM(L,LIVBUY(T,L,H)*PRICEL(L))
          +SUM(L,LIVPROD(T,L,H)*DRYMREQ(L,'VETCOST'))
          +SUM(L,LIVPROD(T,L,H)$ML(L)*DRYMREQ(L,'CONCOST'))
          + SUM(CTYPE,CREDIT(T-1,CTYPE,H)*(1+CREDINT(CTYPE,'IRATE')))
          =L= (SUM(CTYPE,CREDIT(T,'IC',H))
          +SUM(L,LIVSALE(T,L,H)$SALE(L)*PRICEL(L)$SALE(L))
          +SUM(S,LABNFM(T,H,S)*OFMWAGE)
          +SUM(S,LABOUT(T,H,S)*HINWAGE)
          +SUM(C,XSELCROP(T-1,C,H)*PRICES(C,'FARMPR'))
          +SUM(C,XSTOREDS(T,C,H)*PRICES(C,'FARMPR'))
        +SUM((LANDT,SOILT),RENTOUT(T,LANDT,SOILT,H)
        *LANDPRICE(LANDT,SOILT,'LANDRV'))
          + MILKSALE(T,H)*MILKPR);
```

```
INCREDITEQ(T,H).. SUM(FERT,FERTBUY(T,FERT,H)*FERTPR(FERT,'FPRICE'))
         + SUM(C,XBUYSED(T,C,H)*PRICES(C,'SPRICE'))
         =L= SUM(CTYPE,CREDIT(T,'GC',H));
```

***------------------------------Fertiliser------------------------------**

```
FERTUSE(T,NP,H).. SUM((C,LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
         *FERTZ(NP,FERTL))=E=SUM(FERT,FERTNUT(FERT,NP)*FERTBUY(T,FERT,H))
         +MANUSE(T,H)*0.6*MANNUT(NP,'MANCOM')
         +MANUSE(T-1,H)*0.4*MANNUT(NP,'MANCOM');
```

*fertilizer used in the crop production by each HH = amount of fertilizer bought by each HH + manure applied

***----------------------Fertilizer nutrients N and P supply-------------**

```
FERTNPEQ(T,C,LANDT,SOILT,NP,H).. SUM((FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
         *FERTZ(NP,FERTL))=E=FERTNP(T,C,LANDT,SOILT,NP,H);
```

***-------------------------Livestock feed requirement-------------------**

```
FEEDBAL(T,H).. SUM((C,LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
         *(CROPYL(T,C,LANDT,SOILT,FERTL,CL,H))*CROPSY(C,'SYIELD'))
         +DMRESID*XCRESID(T,H)=G=SUM(L,LIVPROD(T,L,H)*DRYMREQ(L,'DM'))
         +SUM(L,LIVREAR(T,L,H)$RA(L)*DRYMREQ(L,'DM')$RA(L));
```

* The amount of dry mater crop production + the dry matter purchased by each HH >or = amt of dry matter required for livestock rearing in each year for each HH

***------------Production and use of animal manure-----------------------**

```
DMANUREEQ(T,H)..DMANURE(T,H)=E=SUM(L,LIVPROD(T,L,H)*MANPYPA(L))
         +SUM(L,LIVREAR(T,L,H)$RA(L)*MANPYPA(L)$RA(L))
         +SUM(L,LIVBUY(T,L,H)$RA(L)*MANPYPA(L)$RA(L))
         +SUM(L,LIVREAR(T-1,'MALECAL',H)*MANPYPA('MALECAL'))
         +SUM(L,LIVREAR(T-2,'MALECAL',H)*MANPYPA('MALECAL'))
         +SUM(L,LIVREAR(T-1,'FEMALECAL',H)*MANPYPA('FEMALECAL'))
         +SUM(L,LIVREAR(T-2,'FEMALECAL',H)*MANPYPA('FEMALECAL'))
         +SUM(L,LIVREAR(T-1,'BUMALC',H)*MANPYPA('BUMALC'))
         +SUM(L,LIVREAR(T-2,'BUMALC',H)*MANPYPA('BUMALC'))
         +SUM(L,LIVREAR(T-1,'BUFEMC',H)*MANPYPA('BUFEMC'))
         +SUM(L,LIVREAR(T-2,'BUFEMC',H)*MANPYPA('BUFEMC'));

MANUREEQ(T,H).. MANUSE(T,H)=L=DMANURE(T,H);
```

***--------------------- Soil erosion and soil depth---------------------**

```
EROSCREQ(T,LANDT,SOILT,H)..
        SUM((C,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
        *EROS(C,CL,'EROSL'))=E=TEROSCR(T,LANDT,SOILT,H);

SOILEREQ(T,LANDT,SOILT,H).. TSOILER(T,LANDT,SOILT,H)
        =E=TEROSCR(T,LANDT,SOILT,H);

TEROSWEQ(T).. TEROSW(T)
        =E=SUM((LANDT,SOILT,H),TSOILER(T,LANDT,SOILT,H));

AVEROSEQ(T,LANDT,SOILT,H).. AVSEROS(T,LANDT,SOILT,H)
        =E=TSOILER(T,LANDT,SOILT,H)/LANDAV(LANDT,SOILT,H);

CUMSECO1(T,LANDT,SOILT,H)$(ORD(T)EQ1).. CUMSEROS(T,LANDT,SOILT,H)$(ORD(T)EQ 1)
          =E=AVSEROS(T,LANDT,SOILT,H)$(ORD(T)EQ 1);

CUMSECO2(T,LANDT,SOILT,H).. CUMSEROS(T,LANDT,SOILT,H)
        =E=CUMSEROS(T-1,LANDT,SOILT,H)+AVSEROS(T,LANDT,SOILT,H);

DEPTHEQ(T,LANDT,SOILT,H).. DEPTH(T,LANDT,SOILT,H)
        =E=SDEPTH(SOILT,LANDT)-0.01*CUMSEROS(T,LANDT,SOILT,H);
```

*0.01 is the conversion factor i.e., 100 tons of soil eroded from 1 ha field will decrease the soil depth by 1cm

```
CDEPTHEQ(T,LANDT,SOILT,H).. CDEPTH(T,LANDT,SOILT,H)
        =E=SDEPTH(SOILT,LANDT)-DEPTH(T,LANDT,SOILT,H);
```

***-----------Change in crop yield after erosion and fertilizer application-------**

```
CROPYLEQ(T,C,LANDT,SOILT,FERTL,CL,H)..
        CROPYL(T,C,LANDT,SOILT,FERTL,CL,H)=E=(ACROPYL(C,LANDT,SOILT)
        -YIELDRED(C,LANDT,SOILT)*CDEPTH(T,LANDT,SOILT,H)
        +FERTZ('NITRO',FERTL)*FERTRESP(C,'NRESP')+(FERTZ('NITRO',FERTL)
        *FERTZ('NITRO',FERTL))*FERTRESP(C,'NSQRESP')
        +FERTZ('PHOS',FERTL)*FERTRESP(C,'PRESP')
        +(FERTZ('PHOS',FERTL)*FERTZ('PHOS',FERTL))*FERTRESP(C,'PSQRESP'))
        *VARCOEF(C,'YMULTI');
```

*crop yield = Intercept of production function (controlled for N, P and soil depth) - yield reduction due to change in soil depth + increase in yield by the application of nutrients (N and P)

***--------------------Livestock equations-------------------------------**

```
KEEPLIV(TFIRST,L,H).. LIVPROD(TFIRST,L,H)=E=LIVBIN(L,H)
        +LIVBUY(TFIRST,L,H)$PA(L)-LIVSALE(TFIRST,L,H)$SALE(L)
```

```
        -CONSOWNA(TFIRST,L,H)$SA(L);

KEEPBUL(T+1,H).. LIVPROD(T+1,'BULLOCK',H)=E=0.80*LIVPROD(T,'BULLOCK',H)
        +LIVBUY(T+1,'BULLOCK',H)+LIVPROD(T,'BULL',H);

KEEPCOW(T+1,H).. LIVPROD(T+1,'COW',H)=E=0.80*LIVPROD(T,'COW',H)
        +LIVBUY(T+1,'COW',H)+LIVPROD(T,'HEIFERS',H);

KEEPBULL(T+1,H).. LIVPROD(T+1,'BULL',H)=E=0.9*LIVREAR(T-2,'MALECAL',H)
        +LIVBUY(T+1,'BULL',H)-LIVSALE(T+1,'BULL',H);

KEEPHF(T+1,H).. LIVPROD(T+1,'HEIFERS',H)
        =E=0.9*LIVREAR(T-2,'FEMALECAL',H)
        +LIVBUY(T+1,'HEIFERS',H)-LIVSALE(T+1,'HEIFERS',H);

*20% of the bullocks and cows are replaced every year
*It may require at least three years for calves to become bulls and heifers
*This implies it may require up to four years for claves to become cows and bullocks
*10% of the claves may die before they become bulls and heifers

*--------------------------Buffaloes-----------------------------------

KEEPBUF(T+1,H).. LIVPROD(T+1,'SHEBUFF',H)
        =E=0.80*LIVPROD(T,'SHEBUFF',H)+LIVBUY(T+1,'SHEBUFF',H)
        +LIVPROD(T,'BUHEIFER',H);

KEEPBUFBULOK(T+1,H).. LIVPROD(T+1,'BUFBULLOCK',H)
        =E=0.80*LIVPROD(T,'BUFBULLOCK',H)
        +LIVBUY(T+1,'BUFBULLOCK',H)+LIVPROD(T,'BUFBULL',H);

KEEPBUFBULL(T+1,H).. LIVPROD(T+1,'BUFBULL',H)
        =E=0.9*LIVREAR(T-2,'BUMALC',H)+LIVBUY(T+1,'BUFBULL',H)
        -LIVSALE(T+1,'BUFBULL',H);

KEEPBHF(T+1,H).. LIVPROD(T+1,'BUHEIFER',H)
        =E=0.9*LIVREAR(T-2,'BUFEMC',H)
        +LIVBUY(T+1,'BUHEIFER',H)-LIVSALE(T+1,'BUHEIFER',H);

*--------------------------------Sheep---------------------------------

KEEPEW(T+1,H).. LIVPROD(T+1,'SHEEPEW',H)
        =E=0.77*LIVPROD(T,'SHEEPEW',H)
        +LIVBUY(T+1,'SHEEPEW',H)+0.8*LIVREAR(T-2,'FEMLAMB',H);

KEEPRAM(T+1,H).. LIVPROD(T+1,'SHEEPRAM',H)
        =E=0.95*LIVPROD(T,'SHEEPRAM',H)+LIVBUY(T+1,'SHEEPRAM',H)
        +0.9*LIVBUY(T,'MLAMB',H)+0.8*LIVREAR(T-2,'MLAMB',H)
        -LIVSALE(T+1,'SHEEPRAM',H)-CONSOWNA(T+1,'SHEEPRAM',H);
```

```
*--------------------------Goat---------------------------------------

KEEPDOE(T+1,H).. LIVPROD(T+1,'GOATDOE',H)
        =E=0.77*LIVPROD(T,'GOATDOE',H)+LIVBUY(T+1,'GOATDOE',H)
        +0.8*LIVREAR(T-2,'KIDFEM',H);

KEEPBUK(T+1,H).. LIVPROD(T+1,'GOATBUCK',H)
        =E=0.95*LIVPROD(T,'GOATBUCK',H)+LIVBUY(T+1,'GOATBUCK',H)
        +0.9*LIVBUY(T,'KIDMALE',H)+0.8*LIVREAR(T-2,'KIDMALE',H)
        -LIVSALE(T+1,'GOATBUCK',H)-CONSOWNA(T+1,'GOATBUCK',H);

*23% of the ewes and does had to be replaced every year
*It may require up to two year for lambs and kids to become ewes and does
*20% of the lambs and kids may die in the process of rearing
*the death rate for rams and bucks is 5%
*20% of the male kids and lambs may die in
*the process of rearing (10% die in one year)

*---------------------------Hen---------------------------------------

KEEPHEN(T+1,H).. LIVPROD(T+1,'HEN',H)
        =E=0.75*LIVPROD(T,'HEN',H)+LIVBUY(T+1,'HEN',H)
        +LIVREAR(T,'FEMCHICKEN',H);

*---------------------calf Balance------------------------------------

MCCALFB(T,H).. LIVREAR(T,'MALECAL',H)+LIVSALE(T,'MALECAL',H)
        =E=0.33*LIVPROD(T,'COW',H);

FCCALFB(T,H).. LIVREAR(T,'FEMALECAL',H)+LIVSALE(T,'FEMALECAL',H)
        =E=0.33*LIVPROD(T,'COW',H);

BUMALCB(T,H).. LIVREAR(T,'BUMALC',H)+LIVSALE(T,'BUMALC',H)
        =E=0.25*LIVPROD(T,'SHEBUFF',H);

BUFEMCB(T,H).. LIVREAR(T,'BUFEMC',H)+LIVSALE(T,'BUFEMC',H)
        =E=0.25*LIVPROD(T,'SHEBUFF',H);

*The calving rate of a cow is 66% (i.e. cow calves every 1.5 years)
*The calving rate of a buffaloes is 50% (i.e. cow calves every second years)
*The sex ratio of the calves is 50%

*----------------------Lamb balance-----------------------------------

MLAMBB(T,H).. LIVREAR(T,'MLAMB',H)+CONSOWNA(T+1,'MLAMB',H)
        +LIVSALE(T,'MLAMB',H)=E=0.75*LIVPROD(T,'SHEEPEW',H);

FEMLAMBB(T,H).. LIVREAR(T,'FEMLAMB',H)+CONSOWNA(T+1,'FEMLAMB',H)
        +LIVSALE(T,'FEMLAMB',H)=E=0.75*LIVPROD(T,'SHEEPEW',H);
```

*sheep ewe lambs 3 times in 2 consecutive years (i.e. one time in 0.67 years)
*lambing rate for sheep ewe is 150%
*The sex ratio is 50%
* The litter size for sheep is 1

***-------------------------Kids Balance----------------------------------**

```
KIDMALB(T,H).. LIVREAR(T,'KIDMALE',H)+CONSOWNA(T+1,'KIDMALE',H)
        +LIVSALE(T,'KIDMALE',H)=E=0.75*LIVPROD(T,'GOATDOE',H);

KIDFEMB(T,H).. LIVREAR(T,'KIDFEM',H)+CONSOWNA(T+1,'KIDFEM',H)
        +LIVSALE(T,'KIDFEM',H)=E=0.75*LIVPROD(T,'GOATDOE',H);
```

*The lambing rate for doe is also 150%
* The sex ratio is 50%
* The litter size is average 1.66 kids

***-----------------------------chicken Balance---------------------------**

```
FCHICKENB(T,H).. LIVREAR(T,'FEMCHICKEN',H)+LIVSALE(T,'FEMCHICKEN',H)
          +CONSOWNA(T+1,'FEMCHICKEN',H)+EGGSOWN(T,H)
          =E= 0.5*12*LIVPROD(T,'HEN',H);

MCHICKENB(T,H)..LIVREAR(T,'MALCHICKEN',H)+LIVSALE(T,'MALCHICKEN',H)
          +CONSOWNA(T+1,'MALCHICKEN',H)+EGGSOWN(T,H)
          =E=0.5*12*LIVPROD(T,'HEN',H);
```

*A hen can hatch 25 chickens in a year.
*Mortality rate of chicken is 50%

***---------------Cow, bullock and buffaloes replacement-----------------**

```
COWREPL(T,H).. 0.20*LIVPROD(T,'COW',H)=L=LIVREAR(T,'FEMALECAL',H)
        +LIVBUY(T,'FEMALECAL',H)+LIVPROD(T,'HEIFERS',H);

BULREPL(T,H).. 0.20*LIVPROD(T,'BULLOCK',H)=L=LIVREAR(T,'MALECAL',H)
        +LIVBUY(T,'MALECAL',H)+LIVPROD(T,'BULL',H);

BUFREPL(T,H).. 0.20*LIVPROD(T,'SHEBUFF',H)=L=LIVREAR(T,'BUFEMC',H)
        +LIVBUY(T,'BUFEMC',H)+LIVPROD(T,'BUFEMC',H);
```

*The replacement rate for cow, buffaloes and bullocks is 20%

***----------------------------Ewe and doe replacement-------------------**

```
EWEREPL(T,H).. 0.23*LIVPROD(T,'SHEEPEW',H)
          =L=LIVREAR(T,'FEMLAMB',H)+LIVBUY(T,'FEMLAMB',H);
```

```
DOEREPL(T,H).. 0.23*LIVPROD(T,'GOATDOE',H)
          =L=LIVREAR(T,'KIDFEM',H)+LIVBUY(T,'KIDFEM',H);

*The replacement rate for ewe and doe is 23%(i.e. culling rate is 13% and death rate is 10%)

*--------------------------Milk production equation--------------------

MILKPRODEQ(T,L,H)$ML(L)..LIVPROD(T,L,H)$ML(L)*AMILKP(L)$ML(L)*PLIV
          =E=MILKPROD(T,L,H)$ML(L);

MILKBAL(T,H).. MILKCONS(T,H)+MILKSALE(T,H)
          =E=SUM(L,MILKPROD(T,L,H)$ML(L));

*------------------------HH Consumption Requirement--------------------

CONSNUT(NUT,T,H).. SUM(C,XCONS(T,C,H)*CROPNUT(C,NUT))
            +SUM(C,XSTOREDC(T,C,H)*CROPNUT(C,NUT))
            +SUM(C,XBUYCON(T,C,H)*CROPNUT(C,NUT))
            +SUM(L,CONSOWNA(T,L,H)*LIVNUT(L,NUT)$SA(L))
            +SUM(L,CONSPURA(T,L,H)*LIVNUT(L,NUT)$SA(L))
            +SUM(PAP,BUYANIP(T,PAP,H)*ANPRICE(PAP,NUT))
          +MILKCONS(T,H)*MILKNCOM('NUT','MILKN')
            +EGGSOWN(T,H)*EGGNCOM('NUT','EGGSNU')
            =G=NUTRQY(NUT,T,H);

*-------------------Consumption of own animals------------------------

CONSRBE(TFIRST,L,H)$RB(L)..CONSOWNA(TFIRST,L,H)
            =L=LIVBIN(L,H)$RB(L)-LIVSALE(TFIRST,L,H)$RB(L);

*--------------------Constraint equation for intercrops----------------

PPAREAEQ(T,C,LANDT,SOILT,FERTL,CL,H)..
          XCROP(T,'PP-SOR',LANDT,SOILT,FERTL,CL,H)
          =E=XCROP(T,'SOR-PP',LANDT,SOILT,FERTL,CL,H);

MAZAREAEQ(T,C,LANDT,SOILT,FERTL,CL,H)..
          XCROP(T,'PP-MAZ',LANDT,SOILT,FERTL,CL,H)
          =E=XCROP(T,'MAZ-PP',LANDT,SOILT,FERTL,CL,H);

*------------------Summing up of certain computed variables-------

ACULTEQ(T,LANDT).. SUM((C,H,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
          =E=ACULT(T,LANDT);

ACULTSEQ(T,SOILT).. SUM((C,H,LANDT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
          =E=ACULTS(T,SOILT);
```

```
ACULTHEQ(T,H).. SUM((C,LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
       =E=ACULTH(T,H);

CROPAHEQ(T,C,H).. SUM((LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
       =E=CROPAH(T,C,H);

TACULTEQ(T)..
      SUM((C,LANDT,SOILT,FERTL,CL,H),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
      =E=TACULT(T);

TCROPSEQ(T,C,SOILT).. SUM((LANDT,FERTL,CL,H),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
      =E=TCROPS(T,C,SOILT);

TCROPLEQ(T,C,LANDT)..
      SUM((SOILT,FERTL,CL,H),XCROP(T,C,LANDT,SOILT,FERTL,CL,H))
      =E=TCROPL(T,C,LANDT);

TPRODEQ(T,C,H).. TPROD(T,C,H)
      =E=SUM((LANDT,SOILT,FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
      *CROPYL(T,C,LANDT,SOILT,FERTL,CL,H));

TPRODWEQ(T,C).. TPRODW(T,C)
      =E=SUM((LANDT,SOILT,FERTL,CL,H),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
      *CROPYL(T,C,LANDT,SOILT,FERTL,CL,H));

TLABONFEQ(T,H).. TLABONF(T,H)=E=SUM(S,LABONF(T,H,S));
TLABNFMEQ(T,H).. TLABNFM(T,H)=E=SUM(S,LABNFM(T,H,S));
TLABHINEQ(T,H).. TLABHIN(T,H)=E=SUM(S,LABHIN(T,H,S));
TLABOUTEQ(T,H).. TLABOUT(T,H)=E=SUM(S,LABOUT(T,H,S));

CULTKAREQ(T).. SUM((C,LANDT,SOILT,FERTL,CL,H),
      XCROP(T,C,LANDT,SOILT,FERTL,CL,H)$KAR(C))
      =E=KARAREACUL(T);
CULTRABEQ(T).. SUM((C,LANDT,SOILT,FERTL,CL,H),
      XCROP(T,C,LANDT,SOILT,FERTL,CL,H)$RAB(C))
      =E=RABAREACUL(T);
INCOMEPHEQ(T,H).. INCOME(T,H)/THHN(T,H)=E=INCOMEPH(T,H);

INCOMEPCAPEQ(T,H).. INCOME(T,H)/TCONSUNIT(T,H)=E=INCOMEPCAP(T,H);

CROPRESYEQ(T,C,LANDT,SOILT,H).. CROPRESY(T,C,LANDT,SOILT,H)
      =E=(SUM((FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
      *CROPYL(T,C,LANDT,SOILT,FERTL,CL,H))*PRICES (C,'RESIY'));

CROPYEQ(T,C,LANDT,SOILT,H)..CROPY(T,C,LANDT,SOILT,H)
      =E= SUM((FERTL,CL),XCROP(T,C,LANDT,SOILT,FERTL,CL,H)
      *CROPYL(T,C,LANDT,SOILT,FERTL,CL,H));
```

```
MODEL KOTHAPALLY /ALL/;

OPTION ITERLIM=50000;
OPTION RESLIM=900000;
OPTION LIMROW=0;
OPTION LIMCOL=0;

OPTION NLP=CONOPT2;
set Rtnwtv 0.000000006;
set Rtmaxv 5.56E+15;
```

SOLVE KOTHAPALLY USING NLP MAXIMISING DISINC;

```
*----------------------------------------------------------------------

XTCONS.L(T,C,H)=XCONS.L(T,C,H)+XBUYCON.L(T,C,H)+XSTOREDC.L(T,C,H);

XTSELL.L(T,C,H)=XSELCROP.L(T,C,H)+XSTOREDS.L(T,C,H);

LIVINC.L(T,H)=SUM(L,LIVSALE.L(T,L,H)$SALE(L)*PRICEL(L)$SALE(L))
          + MILKSALE.L(T,H)*MILKPR ;

CROPINC.L(T,H)=SUM(C,XSELCROP.L(T,C,H)*PRICES(C,'FARMPR'))
          +SUM(C,XSTOREDS.L(T,C,H)*PRICES(C,'FARMPR'));

TCAREA.L(T,C)=SUM(H,CROPAH.L(T,C,H));
NFMINC.L(T,H)=TLABNFM.L(T,H)* OFMWAGE;
WAGEINC.L(T,H)=TLABOUT.L(T,H)*HINWAGE;

CROPCULLAND.L(T,C,LANDT,H)=
          SUM((SOILT,FERTL,CL),XCROP.L(T,C,LANDT,SOILT,FERTL,CL,H));

AVSERWAT.L(T)=TEROSW.L(T)/422.59;

AVSER.L(T,LANDT,SOILT)=
          SUM(H,TSOILER.L(T,LANDT,SOILT,H))/SUM((C,FERTL,CL,H),
          XCROP.L(T,C,LANDT,SOILT,FERTL,CL,H));

LABCONS.L(T,H)=
          SUM((C,LANDT,SOILT,FERTL,CL),XCROP.L(T,C,LANDT,SOILT,FERTL,CL,H)
          *EROS(C,CL,'CONLAB'));

CSDEPTH.L(LANDT,SOILT,H)= SDEPTH(SOILT,LANDT)DEPTH.L('10',LANDT,SOILT,H);

AVGCROPASM.L(T,C,LANDT,'SMALL')=
          CROPCULLAND.L(T,C,LANDT,'SMALL')/THHN(T,'SMALL');
AVGCROPAMD.L(T,C,LANDT,'MEDUM')=
          CROPCULLAND.L(T,C,LANDT,'MEDUM')/THHN(T,'MEDUM');
```

```
AVGCROPALG.L(T,C,LANDT,'LARGE')=
          CROPCULLAND.L(T,C,LANDT,'LARGE')/THHN(T,'LARGE');

*-------------------------------------------------------------------

CONNUT.L(T,NUT,H)= SUM(C,XCONS.L(T,C,H)*CROPNUT(C,NUT))
            +SUM(C,XSTOREDC.L(T,C,H)*CROPNUT(C,NUT))
            +SUM(C,XBUYCON.L(T,C,H)*CROPNUT(C,NUT))
            +SUM(L,CONSOWNA.L(T,L,H)*LIVNUT(L,NUT)$SA(L))
            +SUM(L,CONSPURA.L(T,L,H)*LIVNUT(L,NUT)$SA(L))
          +SUM(PAP,BUYANIP.L(T,PAP,H)*ANPRICE(PAP,NUT))
          +MILKCONS.L(T,H)*MILKNCOM('NUT','MILKN')
          +EGGSOWN.L(T,H)*EGGNCOM('NUT','EGGSNU');
```

***----------------Nutrient balance in the watershed-----------------------**

```
CROPCUL.L(T,C,LANDT,SOILT,H)=
          SUM((FERTL,CL),XCROP.L(T,C,LANDT,SOILT,FERTL,CL,H));

NUTAPP.L(T,C,NP)=SUM((LANDT,SOILT,H),FERTNP.L(T,C,LANDT,SOILT,NP,H));

NUTPHA.L(T,C,NP)=
          NUTAPP.L(T,C,NP)/SUM((LANDT,SOILT,FERTL,CL,H),
          XCROP.L(T,C,LANDT, SOILT,FERTL,CL,H));

NUTINF.L(T,NP)= SUM(C,NUTPHA.L(T,C,NP)*TCAREA.L(T,C))
            +SUM(C,NITROFIX(C,NP)*TCAREA.L(T,C))
          +SUM((LANDT,SOILT,H),LANDAV(LANDT,SOILT,H))*NUTDEP(NP)
          +SUM(H,MANUSE.L(T,H))*NMANU ('POT');

NUTOUTF.L(T,NP)=
          SUM((C,LANDT,SOILT,H),CROPY.L(T,C,LANDT,SOILT,H)*NPKCONH(C,NP))
            +SUM((C,LANDT,SOILT,H),CROPRESY.L(T,C,LANDT,SOILT,H)
          *NPKCONR(C,NP))+TEROSW.L(T)*NLEROS(NP)+LEACH(NP);

NUTBAL.L(T,NP)=NUTINF.L(T,NP)-NUTOUTF.L(T,NP);
```

***---**