WATERSHED MANAGEMENT USING MULTI-OBJECTIVE PROGRAMMING APPROACH-A CASE STUDY

By

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CERTIFICATE-I

This is to certify that the thesis entitled **"WATERSHED MANAGEMENT USING MULTI-OBJECTIVE PROGRAMMING APPROACH-A CASE STUDY"** submitted in partial fulfillment for the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water conservation Engineering** of the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of bonafide research work carried by **Sri Rati Ranjan Mohanty** under my chairmanship, direct supervision and guidance. No part of thesis has been submitted for any other degree or diploma.

The help and information availed in course of this investigation have been duly acknowledged by him.

Bhubaneswar

Date- 17-5-2014

(Dr. J. C. Paul)

CERTIFICATE-II

This is to certify that the thesis entitled **"WATERSHED MANAGEMENT USING MULTI-OBJECTIVE PROGRAMMING APPROACH-A CASE STUDY"** submitted in partial fulfillment of degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering** of Orissa University of Agriculture and Technology, Bhubaneswar by **Rati Ranjan Mohanty** has been approved by the student's advisory committee after an oral examination on the same in collaboration with the external examiner.

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Dedicated

to

MY PARENTS

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Rati Ranjan Mohanty.

Rati Ranjan Mohanty

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List of abbreviations

Abbreviations	Descriptions
Agril.	Agricultural
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
ASCO	Assistant Soil Conservation Officer
Asst.	Assistant
Cal	Calorie
cm	Centimetre
CAET	College of Agricultural Engineering and Technology
cc	Cubic Centimetre
CCA	Culturable Command Area
C^0	Degree Celsius
Contd.	Continued
Cum	Cubic Meter
Deptt.	Department
Div.	Division
DM	Decision Maker
E	East
Engg.	Engineering
Engr.	Engineer
eq^n	Equation
et al.	And others
etc.	Etceteras
Fig.	Figure
FSL	Full Supply Level
GCA	Gross Command Area
Govt.	Government
gm	Gram
GP	Goal programming
ha	Hectare
ha-cm	Hectare Centimetre
ha-m	Hectare Metre
ha-mm	Hectare Millimetre
HSJ	Hop Skip and Jump
hrs	Hours
IARI	Indian Agricultural Research Institute
i.e.	That is
IIT	Indian Institute of Technology
IE	Institution of Engineers
Inc.	Incorporated
ISAE	Indian Society of Agricultural Engineers
Jr	journal

Kcal	Kilo Calorie
kg	Kilogram
km	Kilometre
LP	Linear Programming
LPS	Litres per second
m	Metre
mm	Millimetre
M.Tech	Masters in Technology
Math	Mathematical
MOLP	Multi-Objective Linear Programming
MOP	Multi-objective Programming
Mop	Muriate of Potash
N	North
NPK	Nitrogen, Phosphorus, Potash
No.	Number
OUAT	Orissa University of Agriculture and Technology
Prog.	Programming
qt	Quintal
Rs	Rupees
S	South
Sempos	Sequential Multi-objective problem solving
Sq. km	Square kilometre
SSP	Single Super Phosphate
SWAMP	Storm Water Management Programme
t	ton
Trans.	Transaction
Univ.	University
Viz.	As per example
Vol.	Volume
WTCER	Water technology centre for Eastern region

Chapter-1

INTRODUCTION

INTRODUCTION

Agriculture is a term hard to imagine without two basic natural resources. The two natural resources are namely land and water. A country like India where population is increasing at an alarming rate and the main aim is to provide them food. Agriculture plays an important role not only by feeding to each person but also by contributing towards the country's growth. The question in front of us today is how to increase the production with such limited resources. Solution may be in different ways but their ultimate aim is to increase the productivity. That is to grow more crop per ha of land and also with per drop of water. According to statistics, by 2030 the population of India will be 1.6 billion by overcoming China. There are projections that demand for food grains would increase from 192 million tonnes in 2000 to 345 million tonnes in 2030 (ICAR *vision 2030*). So if we consider, the food grain production of 2013-14 (i.e. 257 million tonnes) from 2000, we are increasing at a rate of 5 million tonnes annually. In order to catch up the population of 2030, the food grain production is to be increased at the rate of 5.2 million tonnes per year from now on. As we have discussed, the land and water resource of India will remain same. Increase in production is not the only concern for us today, production along with the sustainable use of the resource is very important. Climate change is an important factor, which affects agricultural growth. So we have to check the pollution of these resources and also try to restore them in good condition. Sustainable agriculture is best described by, increase in agricultural production of a country without compromising the natural resources. In this context, rural people may be considered as the third resource because they are responsible for effective and sustained use of the resources of a particular area. So proper planning, management practices and efficient use of these resources are very much necessary, at present scenario. Available resources are to be used in such a way that, we will be able to get best out of them. Optimal utilization of available resources is very much necessary in order to meet the demand of the people. So we have to increase the production and other factors by taking resources as constraint. There may be several objectives as per the choice of decision maker (DM), which are to be selected as objective function. Those objective functions are to be treated with a set of constraint. As there are many objective functions, so it comes under multi-objective programming. The solution of these multi-objective programming equations will give rise to the optimum planning for that area. In this process, we are satisfactorily able to achieve the objectives within the boundary of constraint.

1.1 Watershed management

Watershed is a geo-hydrological unit draining at a common point by a system of streams. In other words, it may be defined as a divide separating one drainage basin from other. Watershed management implies the proper use of all land and water resources of a watershed for optimum production with minimum hazard to natural resources. It essentially deals with the integrated planning of the watershed for proper land use, treatment and for higher productivity from each unit land area. The different objectives of watershed management programme are:

- Proper land use.
- Soil conservation.
- Control damaging runoff.
- Manage and utilise the runoff for useful purposes.
- Control erosion and effect reduction in the sediment production.
- Flood protection.
- Enhancement of the ground water storage.
- Increase of food production.
- Appropriate use of the land resource of the watershed, thus developing forest and fodder resources.
- Improving socio-economic condition of the inhabitants.

Watershed management is a multidisciplinary activity which deals with following programmes

1. Conservation, up gradation and utilisation of natural resources like land, water, plant, animal and human resources in harmonies and integrated manner. This will aim at perpetual availability of food, fodder, fuel, fibre, timber and biomass for rural poor and also to meet the growing demands of human and live stock population through diversified land use.

2. Generation of massive employment and enhancing the regular employment facilities for ensuring livelihood security to the weaker section of the rural population like small and marginal farmers and landless labourers.

3. Improvement of production environment and restoration of ecological balance through scientific management of land and rain water such as in-situ moisture conservation, introduction of scientific production systems, network runoff management structures, recharging of ground water which will ensure the availability of water for the domestic consumption of the human and livestock, life saving irrigation and raising appropriate crops according to agro climatic potentialities.

4. Reduction of inequalities between irrigated and rainfed area. Stable production and healthy atmosphere will contribute towards better life in rural areas, reducing the problem of large scale migration from rural areas to the cities.

The above management activities are within the boundaries of a drainage basin, which includes agricultural lands, forest lands, grass lands and land deteriorated by erosion. Integrated planning of watershed helps in establishment and maintenance of the ecological balance and equilibrium between man and environment.

Before preparing the comprehensive watershed management plan, it is necessary to collect and analyze the rainfall data. The analysis of rainfall data helps in knowing the characteristics of rainfall, its occurrence and peak rate of runoff at different probability levels. The analysis of rainfall data is also used to assess the maximum water available from rainfall in kharif at different probability levels. The land use and land capability maps are to be analysed for planning of the cultivation practices and land treatments of the watershed. The existing water resources of the watershed should be assessed and the total need for life saving irrigation for crops in rabi season must be determined.

Watershed manager has to normally satisfy several basic objectives such as maximisation of food production, fodder production, fuel wood production, net income generation from field crops, labour employment generation and runoff water augmentation. These objectives are to be operated under a large number of system constraints such as land area, water availability, nutritional requirements of the people, food requirement, fodder requirement, fuel wood requirement, availability of labour force and area under water conservation structures.

A schematic diagram showing the components of watershed management is shown below:

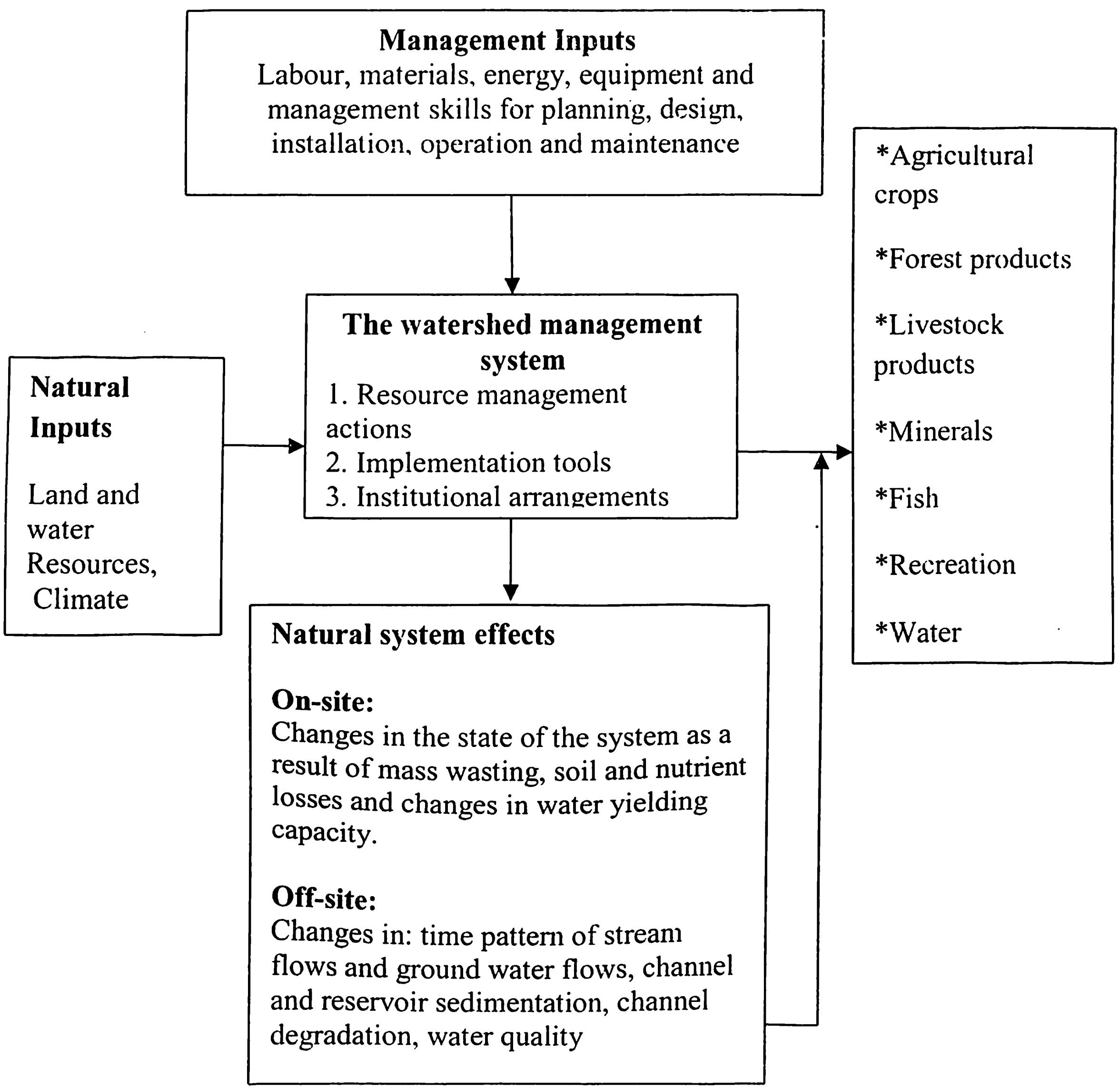

Fig 1.1 Components of watershed management

1.2 Multi-objective programming approach

Multi-objective programming approach has undergone a rapid development in various fields like industrial management, economic sector, agriculture and business sector etc. Multi-objective approach in agricultural resource management in command areas and watersheds involves multi criteria decision making and a comprehensive sophisticated work plan. In practice all the objectives in multi-objective problems cannot be optimised simultaneously, because of their inherent conflicts, therefore the planner has to find a compromise solution rather than an optimal solution.

Interactive techniques are used to find out the compromise solution in multi-objective problems, in which the DM has to interact with the computer directly with analyst as intermediary. The interactive process continues from one solution to other unless the DM is satisfied or further iteration cannot be possible by the solution procedure.

There are a number of interactive techniques used for land and water management planning problems. The step method is one of them. It is commonly used for its efficiency, simplicity, capacity to handle and accommodate problems of the size encountered. Further it uses the efficient simplex method which is familiar to the watershed planners. This interactive multi-objective model seeks to identify the best compromise solution to the decision maker with each solution reflecting the decision maker's preferences.

1.3 Problems of the watershed

The watershed selected for the study is in Begunia block of Khurda district. The name of the watershed is Mandakini Balinala watershed No.-1 micro watershed. It is located between Latitude: 20^0 18' N and Longitude: 85^0 62'' E. The distance of the watershed from district head quarter is 25 Kms. The major problems of the watershed are

1. Through the annual rainfall of the area is very high, water is available only in monsoon. There is a huge water crisis in other seasons.

2. The uplands are subjected to erosion, medium lands lack proper bunding and some parts of the lower lands are subjected to water logging.
3. Most of the inhabitants are poor with small land holdings. At present there is no assured water supply in rabi season so the people are unable to practise cultivation in rabi and looking for jobs elsewhere.
4. Present grain production is insufficient to meet the needs of the people.
5. Present fodder production is insufficient for the livestocks of the area.
6. Most of the area is barren, which can be bought under either grass land or forestry which may solve the fodder and fuel wood problem of the area.
7. The economic condition of the farmers is not good.

1.4 Objective of the study

Keeping all these problems of the watershed in view, a research project entitled "WATERSHED MANAGEMENT USING MULTI-OBJECTIVE PROGRAMMING APPROACH-A CASE STUDY" is under taken with the following objectives.

1. To analyze the rainfall data of the watershed.
2. To collect and analyse the land use and land capability map of the delineated watershed.
3. To develop an efficient compromise land allocation plan for different crops and plantation activities by judiciously utilizing the basic resources of the watershed using multi-objective programming approach.

Chapter-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This chapter deals with a brief review of the research work done in India and abroad on rainfall analysis, land use & land capability, watershed management, multi-objective programming and optimisation techniques, with particular reference to the different aspects of natural resource management and planning.

2.1 Frequency analysis of rainfall

The study of rainfall is stochastic in nature and is essential for forecasting of water availability of the area, crop planning, design of water harvesting structures and soil conservation structures. Analysis of rainfall data from single station is often unreliable, is not temporally or spatially consistent and should generally not be used for design purposes. A brief review of the analysis of rainfall data of the watershed is given below.

Senapati *et al.* (1979) analysed the annual maximum one day rainfall of Bhubaneswar and found that Gumbel or Log normal distribution can be used for prediction of annual maximum one day rainfall for a given recurrence interval.

Ray *et al.* (1980) analysed the weekly rainfall at Gopalpur and plotted weekly rainfall values of 70 years data on log normal probability paper using Weibull's formula. The authors found that the ratio of 100 year event to 2 year event is 2.0. The authors predicted weekly rainfall data at 10, 50, 80 percent levels of probability for crop planning and especially under dry land situation.

Aujla and Agnihotri (1985) used Gumbel distribution for analysis of dry spell with the daily rainfall data of Ludhiana, India.

Mohanty *et al.* (1999) analysed the annual maximum rainfall data for Amaravati district of Maharastra. In the analysis they have taken annual daily rainfall data for 30 years (1966 to 1995) and fitted these data to four different probability distribution functions i.e. Normal, Log normal, Extreme value type-I, Log Pearson type-III distribution and probable rainfall values for different return periods has been estimated. These estimated values have been compared with the values obtained by Weibull's Method. The analysis indicates that, the Log Pearson type-III distributions gives the closest fit to the observed data , hence it may be used to predict maximum rainfall, which will be a great importance for economic planning and design of small and medium hydraulic structures.

Sheng (2000) employed bivariate extreme value distribution, namely the Gumbel mixed model constructed from Gumbel marginal distributions to analyze the joint distribution of correlated storm peak (maximum rainfall intensity) and amount. Based on its marginal distributions, the joint distribution, the conditional probability distribution and the associated return periods can be deduced. Parameters of the bivariate distribution model are estimated based on its marginal distributions by the method of moments (MM). The usefulness of the model is demonstrated by using it to represent multivariate storm events at the Niigata meteorological station in Japan.

Chulsang *et al.* (2005) investigated the effect of global warming in the daily rainfall distribution using a mixed gamma distribution to estimate the change of rainfall quantities. A mixed distribution is used to overcome the limitation of conventional frequency analysis, which uses a continuous distribution, as this is not applicable for the assessment of the effects of global warming. It is summarized that even though the variation of daily rainfall distribution is high due to the variation of monthly rainfall amounts, the scale parameter and the wet probability of a mixed Gamma distribution are found to be closely related to the monthly rainfall amounts. On the other hand, the shape factor remains almost the same regardless of the monthly rainfall amount. The rainfall quantities are estimated using the daily rainfall data from June to September were found to be the most similar to those using the annual maximum data. Regardless of the increasing uncertainty as the return period becomes longer, flood risk is found to be increasing as a result of global warming.

Chin (2005) investigated the rainfall distribution characteristics of Chinanam plain area in Southern Taiwan , by using different statistical analyses such as Normal distribution, Log normal distribution, Extreme value type-I distribution and Log Pearson type-III distribution. A total of 178 stations having annual rainfall data over ten years were selected to perform frequency analysis. Results showed that the Log Pearson type-III distribution performed the best in probability distribution occupying 50% of the total station number.

Prasad *et al.* (2005) estimated the one day as well as the consecutive day's annual maximum rainfall of various return periods using various probability distribution and transformations. Five commonly used probability distribution functions (i.e. Normal, Log-Normal, Extreme value type-I, Pearson type-III and Log Pearson type-III) were tested by comparing the chi-square values. Two parameter log normal distribution was found to be the best fit frequency distribution function for the region. Simple regression models were developed for one day as well as 2 to 5-consecutive day's annual maximum rain fall for the region. Thein's U- static indicated that consecutive day's annual maximum rainfall model estimate was not statistically different from a 2-parameters log normal estimate.

Elsebaie (2012) conducted a study to derive the Intensity-duration-frequency curves of rainfall at Najran and Hafr Albatin regions in the kingdom of Saudi Arabia (KSA). For this, he conducted a frequency analysis by taking 34 years rainfall (1967-2001), using Gumbel and Log Pearson type-III distribution. The chi-square goodness-of-fit test was used to determine the best fit probability distribution. The results show that Gumbell distribution was best fitted than the Log Pearson type-III.

Teklu *et al.* (2013) conducted a regional frequency analysis based on the method of L-moments is performed from annual maximum series of extreme precipitation intensity to update Intensity–Duration-Frequency (IDF) curves for the city of Trondheim. Trend patterns and check for stationarity were demonstrated for a data from a target site based on both non-parametric Mann–Kendall and parametric regression tests. Selection of distributions was performed based on Z-statistics and Lmoment ratio diagrams. The results shows that different types of distributions fit to extreme precipitation events of different durations which shows that thorough selection of distributions is indispensable rather than fitting a single distribution for the whole durations.

2.2 Land use & Land capability

The two principal ways of increasing crop production are to develop new lands not now in production and to improve the productivity of present crop land. The development of new land is brought about primarily by drainage, irrigation and removal of shrubs, trees and rocks. The engineering phase mentioned apply primarily to those measures that will increase the efficiency of production on present arable land. A major challenge is to develop systems for greater precision in water and plant control so as to increase use efficiency of soil, water, energy resources and to improve the environment for humans.

Sheng (1972) suggested that land capability of land areas for sustaining crops differ depending on the purpose for which the land is to be used. The value of land capability assessment lies in identifying the risks attached to cultivating the land and in indicting the soil conservation measures which are required. Improvements to the classification rest on making the conservation recommendations more specific as in the case with treatment oriented scheme developed in Taiwan and tested in hilly islands in Jamaica.

Hannam (1980) had given a system of land capability classification that has been devised by the soil conservation service in New South Wales for the planning of urban land use with particular reference to erosion control.

Schwab *et al.* (1981) suggested that over population, decreased crop production, energy crisis and pollution (agricultural and industrial) problems in many countries are becoming much more serious. Compared to developed countries, under developed countries of the world have a higher population, much lower economic growth rate per capita and greater need for an increase in food production. The availability of tillable and pasture lands, which must produce most of our foods will require ever increasing soil and water conservation measures and more intensive land use to meet the future food demand of the people.

Morgan (1986) suggested that land use is varied from region to region, state to state and so also from country to country, which is dependent upon the geological structure, climate, hydrology, soils, vegetation, human and animal life. In passing from the macro to the micro scale, gradual changes occur in the dominant variable. As far as soil erosion is concerned, climate is dominant at the macro-scale but at the smaller scales, is fairly uniform over the size of the areas being considered, and soils and vegetation becomes important

The economics planning unit of Malaysia defined Class I land as that with potential for mineral development (Morgan, 1986) and is given in Table 2.1.

Table 2.1 Land capability classes recognized by the Economic planning unit, Malaysia

Class	Description
I	Land with high potential for mineral development
II	Land with a high potential for agricultural development with a wide range of crops.
III	Land with a moderate potential for agricultural development with a restricted range of crops, best used for crops with a wide range of soil tolerance
IV	Land with potential for productive forest development, best suited to commercial timber exploitation.
V	Land with little or no mineral, agricultural or forest development potential suitable for development as protective reserves for conservation, water catchments, game, recreation or similar purpose.

Dhruva Narayan *et al.* (1990) Suggested the land capability classification based on texture, depth of soil, slope and erosion status for the Indian conditions which are described in the form of a rating chart in table 2.2.

Murthy (1998) said that the lands are classified into eight classes. The first four classes are very good lands which can be cultivated safely and remaining four are considered to be unsuitable.

Table 2.2. Rating chart for land capability assessment.

Texture(T)			Depth(d)			Slope(S)			Erosion(E)		
Soil Texture Class	**Nota -tion**	**Land Capa -bility**	**Depth Of Soil, cm**	**Nota -tion**	**Capa -bility**	**Slope Class**	**Nota -tion**	**Capa bility**	**Class**	**Nota -tion**	**Cap -bility**
Sandy gravelly Sandy Loam	S	IV	Above 90 cm	d_6	I	0-1%	A	I	No Erosion Or slight	e_1	I,II
Loamy sand	Ls	III	45.0-90 cm	d_5	II	1-3%	B	II	Moderate or sheet erosion	E_2	III
Sandy loam	Sl		22.5-45 cm	D_4	III	3-5%	C	III	Severe erosion rills and gullies	E3	IV
Loam	L		7.5-22.5cm	D_3	IV	5-10%	D	II	Very severe erosion, deep ravines and gullies	E_4	V to VII
Silty loam	Sil		7.5cm or less	D_2	V to VI	10-15%	E	IV			
Silt	Si			D_1		15-25%	F	V			
Clay Loam	Cl	I				25-33%	G	VI			
Sandy Clay loam	Scl					33-50%	H	VII			
Silty clay loam	Sicl	II				Over 50%	I	VIII			
Sandy Clay	Sc	III									
Silty clay	Sic										
Clay	C										

Tefera and Geert (2010) conducted a study to determine the soil erosion problems and the factors that affect the adoption of soil and water conservation measures in Fincha watershed, Western Ethiopia. The study shows that the annual soil loss ranges between 24 to 160 Mg ha^{-1}. The soil erosion has a significant effect on the land capability. Due to this reason, they proposed integrated soil and water conservation planning at the watershed scale.

The above literature indicates that the land capability is dependent upon the physical characteristics such as soil type, depth, texture, land slope, erosion conditions, the purpose for which the land used and the national interest. For the watershed management program the land capability classification is based upon the soil type, texture, depth of soil, land slope and erosion status of which erosion condition has been given the top priority.

2.3 Watershed management

Watershed is defined as a geo hydrological unit draining to a common outlet. The overall management of the watershed is done under watershed management. A brief review of some of the watershed management works done in India and outside are given below.

Phadnawis *et al.* (1993) carried out work in Padalsinghi watershed, Beed district of Maharashtra for resource management in one rainfed watershed and concluded that productivity of tall traditionally grown crops like bajra, red gram etc have increased due to the resource management on watershed basis. The area under irrigation as well as the water table was increased due to construction of cement plugs, nala bunds and percolation tanks. The per capita income of farmers increased by large extend.

Agnitiotri *et al.* (1996) carried out a watershed management programme in a typically hilly watershed In Hoshiarpur, Shiwaliks, Punjab to demonstrate the minimization of soil erosion from the hills and flood problems, in the plain while boosting hill economy through development of hill resources with community participation.

Khatik *et al.* (1997) studied the impact of operational research project on agricultural production through integrated watershed management in Rabni watershed situated in Panchamal, a backward district in Gujarat. Under the integrated watershed management programme the area was treated with different soil and water conservation measures like land levelling, contour bunding, gully plug, check dam etc. The study revealed that the integrated watershed management programme increased the ground after recharge due to different soil conservation measures. The management programme gave a positive impact in increasing the cropping intensity in food grain production, fodder availability and animal population etc. in the watershed.

Nyonand *et al.* (1997) conducted watershed management work in Bagar-Ganiyar watershed in Mohindergarh district of Haryana to demonstrate the efficient management of soil and water resource for rehabilitation of degraded ecosystems. Regular monitoring of changes in watershed indicated that number of wells sprinkler sets and irrigated area increased with time. The demand of fertilizers, seeds, plant protection measures and agricultural implements increased with time which resulted in an increase in crop production by 20 to 25 percent. The watershed management programme provided about 22 percent higher employment opportunity in various sectors, income of village Panchayat increased three fold during the period.

Prasad *et al.* (1997) studied the impact of watershed management on runoff, water resource development and productivity of arable lands in Chhajawa watershed of Bara district in eastern Rajasthan and results indicate that integrated watershed development treatments such Provision of graded bunds, gully control structures etc halted the process of land degradation and improved the ground water recharge which could be successfully exploited and utilized for increasing the productivity of arable lands. The investment made recovered in 4 years indicating that the programme is economically viable.

Pande *et al.* (1998) conducted the watershed management programme in semi-arid tropics of Gujarat to examine the sustainability and equity issues. The results revealed that the net returns were not only by 2.3 to 2.4 times but also had fair distribution across the community. Watershed management further resulted in higher investment on farm assets ranging from two to five times with better distribution in post project period as compared to project period.

German *et al.* (2007) conducted a study in eastern African region to assess the impact 'participation' and 'integration' in watershed management. It shows that 'participation' in problem diagnosis and program implementation must move beyond community-level for a socially-disaggregated processes and explicit management of trade-offs to diverse groups. Secondly, 'integration' does not come about through implementation of parallel interventions, but rather through an explicit analysis of potential trade-offs and synergies of interventions to diverse system components, and strategies to define and reach systems-level goals.

Alemayehu *et al.* (2009) conducted a study to assess the impact of integrated watershed management system (IWSM) and to determine the land use and cover dynamics that is induced in upper Agula watershed, in semi-arid Eastern Tigray (Ethiopia). The results reveal significant modification and conversion of land use and cover of the watershed over the last four decades (1965–2005). A significant portion of the watershed was continuously under intensively cultivated (rainfed) land. The area under irrigation increased from 7 ha to 222.4 ha post-intervention. The area under dense forest increased from 32.4 ha to 98 ha. The study further shows that IWSM decreased soil erosion, increased soil moisture, reduced sedimentation and run off, set the scene for a number of positive knock-on effects such as stabilization of gullies and river banks, rehabilitation of degraded lands. IWSM also resulted in increased recharge in the subsurface water.

Samaras and Koutitas (2012) conducted a study to describe, an integrated approach to quantify the impact of watershed management on coastal morphology using numerical modeling in North Greece. The core of the proposed methodology refers to a coupled-calibration approach of the watershed and the coastal models, incorporating three scenarios of data availability regarding the parameters of interest (coastal morphology, overland sediment transport and coastal sediment transport). To support the applicability of this approach, a brief presentation of its successful application for an area in North Greece is also presented. The study retains the viewpoint of Integrated Coastal Zone Management and is deemed to provide an operational tool for future researchers and policy planners.

Chichackly *et al.* (2013) conducted a research to determine watershed-based storm water management plans that meet current total maximum daily load targets and also take into consideration anticipated changes in future precipitation patterns. They present a multi-scale, multi objective framework for generating a diverse family of storm water best management practice (BMP) plans for entire watersheds. The result helps to assess the relative trade-offs of alternative storm water BMP configurations.

Ghimire and Johnston (2013) conducted a study to assess the impact of Rain water harvesting (RWH) inside the watersheds within the Albemarle-Pamlico river basins in the South eastern USA. They summarize the design strategy of RWH and use of the Soil and Water Assessment Tool (SWAT) model to simulate baseline and RWH scenarios for urban and agricultural land uses. A high adoption rate (75–100%) of RWH throughout the watersheds reduced the downstream average monthly water yield up to 16%. A lower adoption rate (25%) reduced water yield approximately 6% for the Back Creek watershed (NC).

From the above study, it can be concluded that watershed management is an integrated approach, which comprises of proper land use, conservation of soil and water by adoption of programmes like afforestation, construction of different conservation structures. It also includes practice for enhancing socio-economic conditions of the inhabitants by increasing food, fodder, fuel wood production and simultaneously increasing the net return from the field crops.

2.4 Multi-Objective Models

Multiple objective programming (MOP) is related with planning problems in which several conflicting goals and objectives are to be optimised simultaneously. Most of the research studies for multi objective planning are based on linear programming and Goal programming approaches. Besides these there are some interactive approaches are also developed for analysis of MOP problems.

Senapati (1988) formulated a linear programming model to find optimum cropping patterns, subjected to land, water and labour constraints with the objective to maximise net return and production under various levels of canal release for assisting management. The model was applied to command area of distributary No. 6 of Kendrapara canal and recommended as a model for other canal commands of Orissa.

Jayshree (1994) developed an LP model incorporating the price fluctuations of yield, labour and fertiliser, to allocate land under different crops for Kharagpur block-I area, for the year 2001.In the study, comparison of the economics of the model allocations with the existing cropping pattern of the study area was done. In this model, it was found that net benefits obtained by the linear programming model without considering the price fluctuations seems to be exaggerated where as that given by the model considering price fluctuations results in reasonable and reliable estimates.

Beura (1998) developed multi objective approach for the planning for Mahanadi delta command. He developed a suitable cropping pattern based on the availability of surface and ground water for the command. The objective functions of his study are maximisation of production, maximisation of benefit, minimisation of labour under consideration of constraints like area, water, labour, fertiliser and capital. For the three objective functions, the cropping intensity comes to be 290, 290 and 225 respectively, where as the benefit-cost ratio are 2.06, 2.06 and 2.13:1 respectively.

Shirgure (1998) developed an interactive multi-objective linear programming approach to watershed planning for the Bishunpur watershed of Gumla district of Bihar. He took different objective functions such as maximisation of food production, fodder production, fuel wood production, labour employment generation, net income generation from field crops and runoff water augmentation. The above objectives were to be maximised under a set of resource constraints like land, water, labour and nutrients etc. The multi-objective planning for the watershed was analysed with an interactive technique (STEP method) and an efficient and compromise solution was generated by the preference of the decision maker in the interactive process. A comprehensive watershed work plan was proposed for optimal utilisation of land, water and human resources in the watershed.

Mohan and Jothiprakash (2000) formulated a fuzzy linear programming (FLP) model to derive optimal crop plans for an irrigation system with the aim, for conjuctive utilisation of water from surface reservoir and ground water aquifer and demonstrated with a case study at Sri Ram Sagar reservoir system in Andhra Pradesh. The results of FLP model were compared with classical LP model. The LP model maximises the net benefits from irrigation activities subjected to various physical economical and water availability constraints. The FLP model maximises the degree of satisfaction subjected to physical and economic constraints. The increase in the degree of satisfaction or truthness with increase in number of fuzzy variables was studied and the results were reported. It was found that the fuzziness in the ground water pumpage plays a prominent role in deriving the optimal operational strategies. From the optimal results it was found that the FLP model has resulted an optimal crop plan with a degree of truthness of 0.78 taking into account the fuzziness in different variables.

Jianbo *et al.* (2002) conducted a study for optimal utilization of red soil in the Qinghisan watershed, China. Techniques of system analysis and optimization were applied to this watershed develop planning model (QINGS) has been created. QINGS includes seven objectives, 32 activities and some constraints along with two scenarios i.e. three land use forms and two irrigation systems were available to the model for selection. The results obtained are shown to both watershed officers and local farmers to find out the best compromise solution. In this project, the net income was increased to 870000 Yuan from 265,000.

Kaur *et al.* (2004) carried out a research at Nagwan watershed situated in the Damodar-Barakar catchment in India. The aim of the study was not only to estimate the sediment yields under prevailing resource management systems but also designing a linear programming (LP) based optimized land use plan for soil loss reduction for the test watershed. The proposed spatial decision support system was validated on 9 years (1981-1983, 1985-1989 and 1991) of sediment data yield for the watershed. The result shows that not only decrease in sediment yield was about 14.61% but also an increase in its paddy and corn crop productivities by 2.80 and 68.14% respectively.

Paul *et al.* (2004) conducted a study, for the optimal crop planning in the Barapita nallah mini-watershed, Odisha using multi objective programming approach. In this study, the steps were taken for optimal utilization of land, water and human resources. The result indicates that benefit-cost ratio for the proposed plan was 1.3:1 and the cropping intensity was found to be 142% (kharif 86% and rabi 56%).

Ximing *et al.* (2004) applied a method based on compound, a model was proposed for regional water resources planning involving multiple decision makers. This method combines modelling techniques such as multi objective analysis and multi criteria and multi participant decision methods, and supports plan generation and evaluation, individual and group preference elicitation and negotiation taking aim at a consensus plan. The method demonstrated that computer models can be effective and useful for group decisions in water resources planning by facilitating information sharing, participative model development and learning processes.

Zografos and Oglethorpe (2004) examined the issues pertinent to the strategic planning and management of ecotourism. The use of Multi-criteria analysis in ecotourism is an innovative application of an existing methodology that has been traditionally employed in environmental planning and project appraisal to address conflicting stakeholder objectives over scarce natural resources. Using data from a case study of community-managed ecotourism in Ecuador, the paper demonstrates how this methodology can be usefully applied to integrate qualitative and quantitative research, consider stakeholder preferences in the decisions-making process and provide policy information helpful in conceptualizing the interplay of social and environmental objectives of sustainable tourism. In this way the methodology can help improve the participatory community management and planning of ecotourism as a livelihood economic activity.

Marineseu *et al.* (2005) suggested a timber allocation model using data envelopment analysis (DEA), was developed to test the capability of DEA to assist with multi criteria timber allocation decisions. The resulting DEA timber allocation model was able to allocate forest stands, referred to as stewardship units, to different forest products companies without the need for weighting or prioritizing the allocation criteria. The allocation procedure was demonstrated in a case considering two allocation criteria: profit and employment. The allocation generated by the model was compared with random, profit based and employment-based allocations. The results showed that the model was capable of producing practical solutions and balancing the two allocation criteria. However, adding other allocation criteria was complicated by procedural concerns. Despite its current limitations, the model opens the door to future applications of DEA in forest resource allocation problems.

Sheik and Khan (2005) presented a technique to generate optimal results during resource allocation. The whole procedure was discussed and solved. A new integer programming (IP) model was presented that supports the optimal allocation or useful resources in a university environment during the process of daily timetable generation keeping in view the priorities of both the teachers and administration.

Dmitri *et al.* (2006) develop new models of planning problems, based on the framework of Markov decision processes (MDPs), where the action sets are explicitly parameterized by the available resources. Given these models, they design algorithms based on linear and integer programming that simultaneously solve for optimal allocations of resources and strategies for acting in the stochastic environments. These algorithms then form the core of the mechanisms for allocating resources in cooperative as well as competitive multi agent settings. They showed analytically and empirically that the integrated approach leads to drastic (in many cases, exponential) improvements in computational efficiency over methods that consider the problems separately.

Massimo and Maurizio (2006) presented a lexicographic goal Programming (LGP) approach to define the best strategies for the maintenance of critical centrifugal pumps in an oil refinery. For each pump failure mode, the model allows to take into account the maintenance policy burden in terms of inspection or repair and in terms of the manpower involved, linking them to efficiency-risk aspects quantified as in FMECA methodology through the use of the classic parameters occurrence (O), severity (S) and detect ability (D), evaluated through an adequate application of the Analytic Hierarchy Process (AHP) technique. An extended presentation of the data and results of the case analyzed is proposed in order to show the characteristics and performance of this approach.

Mishra *et al.* (2006) adopted a fuzzy goal-programming model having multiple conflicting objectives and constraints pertaining to the machine-tool selection and operation allocation problem, and a new random search optimization methodology termed Quick Converging Simulated Annealing (QCSA) was used. The main feature of the proposed QCSA algorithm is that it outperforms genetic algorithm and simulated annealing approaches as far as convergence to the near optimal solution was concerned. Moreover, it is also capable of eluding local optima. Extensive experiments were performed on a problem involving real-life complexities, and some of the computational results were reported to validate the efficacy of the proposed algorithm.

Wang *et al.* (2006) conducted a study, to find out a preferable solution for the local agencies in Lake Qionghai watershed in china. The components of the study were agriculture, tourism, macroeconomics, cropland use, water supply, forest coverage, soil erosion and water pollution using an interval fuzzy multi objective programming (IFMOP). This study showed that the interval fuzzy multi objective programming for Lake Watershed system (IFMOPLWS) is a powerful tool for integrated watershed management planning and can provide a solid base for sustainable watershed management.

Romero and Rehman (2007) attempted to improve the awareness in the agricultural economics profession and the potential role that multiple criteria decision making (MCDM) techniques can play in analyzing problems involving several objectives. Important applications of the MCDM techniques to planning and management problems in fisheries, forestry, water and land resources are reviewed and some 150 applications are brought together to provide a unified source of reference.

William *et al.* (2007) applied an integrated multiple criteria decision making approach to the resource allocation problem. In the approach, the Analytic Hierarchy Process (AHP) was first used to determine the priority or relative importance of proposed projects with respect to the goals of the universities. Then the Goal Programming (GP) model incorporating the constraints of AHP priority, system and resource was formulated for selecting the best set of projects without exceeding the limited available resources. The projects include 'hardware' (tangible university's infrastructures), and 'software' (intangible effects that can be beneficial to the university, its members, and its students). In this paper, two commercial packages were used: Expert Choice for determining the AHP priority ranking of the projects and LINDO for solving the GP model.

Jha and Singh (2008) proposed a multi-objective model for the optimal allocation of resources like land, crop and water of Kosi irrigation system in Nepal. The model takes into account the use of both surface and ground water resources. Weighted goal programming technique is employed for optimal allocation of resources for a compromising solution to decision makers economic, health and environmental goals. The net return and cropping intensity of the planning was found to be Rs. 224.5 million and 270% respectively.

Sadeghi *et al.* (2009) conducted a research for optimization of land use in the Brimvand watershed of Iran. The aim of the study was to find out the most suitable land allocation to different land uses i.e. orchard, irrigated farming, dry farming and rangeland, targeting soil erosion minimization and benefit maximisation. The problem was then solved using the simplex method with the help of ADBASE software package and the optimal solution was ultimately determined. Additionally, sensitivity analysis was also conducted to recognize more effective land use in reducing soil erosion and increasing benefit. The results of the study revealed that the amount of soil erosion and benefit could, respectively reduce and increase to the tune of 7.9 and 18.6%.

Vivekanandan (2009) proposed a Goal programming approach to maximise the net return in Upper Indravati Irrigation Project. Three different cropping patterns of goal programming approach were adopted for optimizing, cropping pattern with available land and water resources. The model gives a net return of Rs. 2296×10^6. The total cropping intensity for three different cropping patterns was found to be 170,180 and 199% respectively.

Chen *et al.* (2011) conducted a study to determine the best environment-watershed plan by using a fuzzy decision support system in Taiwan. The fuzzy analytic hierarchy process (FAHP) method was used to determine the preference weightings of criteria for decision makers by subjective perception (natural language). It incorporated the decision maker's attitude towards the preference, overall performance value of each alternative can be obtained based on the concept of fuzzy multiple-criteria decision-making (FMCDM). The result was useful for destination planning and the sustainability of watershed tourism resources as well.

Rejani *et al.* (2011) proposed an optimal cropping pattern and ground water management plan for three blocks of Balasore district, Odisha. The study was undertaken for wet, normal and dry years to determine the optimal cropping pattern and net return for different seasons. The results of the study reveals that by adopting the optimal cropping pattern corresponding to wet, normal and dry years, the net annual return of the basin is increased to 257,167 and 112% respectively against the present net annual return.

Honghai and Altinakar (2013) conducted a research on multiobjective optimization of agricultural land-use management problems with uncertainty involved, in Goodwin Creek Experimental Watershed, in Northern Mississippi. For each trial land-use scenario, multiple objectives functions were constructed based on coupled simulation of annualized agricultural nonpoint source pollution model (AnnAGNPS) and the CCHE1D channel network model. The results show that it is a convenient way to introduce uncertainty related considerations into an optimization framework. More importantly, this approach allows for the development of a complex system of estimating the responses between management goals and miscellaneous environmental factors under uncertainty.

Zhou *et al.* (2013) conducted a research for industrial structure optimization problems under uncertainty, using inexact fuzzy multi-objective programming model (IFMOP) in South Four Lake watershed in Shandong province, China. The IFMOP model was formulated based on integration of an inexact linear programming (ILP), fuzzy flexible optimization (FFO), and multi-objective programming (MOP). The model can be used for supporting temporal and spatial optimization of industrial structure under a variety of environmental and socio-economic conditions. The results demonstrated that the model could help decision makers to generate stable and balanced industrial structure patterns, gain in-depth insights into effects of the uncertainties, and analyze trade-offs among economical objective, environmental protection and social demand.

The above literature review indicates that multi-objective models for optimal crop planning in command areas and watersheds have a better operational management on seasonal basis. Though some works have been done on multi-objective approach for optimal crop planning in canal command areas and tube well commands in Odisha, negligible work have been done in the field of optimisation of watershed management in Odisha. Now Govt. of India has given utmost importance for the development of watersheds in 12th plan under Integrated Watershed Management Programme (IWMP) scheme. The present study was undertaken for the management of such a watershed identified by soil conservation department of Govt. of Odisha. The prime aim is to maximise the different basic objectives like food, fodder, fuel wood, net income generation, labour employment generation and runoff water augmentation of the watershed using multi-objective programming approach.

Chapter-III

THEORETICAL DEVELOPMENT

THEORETICAL DEVELOPMENT

This chapter deals with the theoretical aspects that are considered during the development of the linear programming formulations for the project under consideration. Multi-objective programming (M.O.P.) involves optimization of two or more objective functions. The M.O.P. differs from the single objective optimization problem only in the expression of respective objective functions.

Watershed management involves a number of conflicting goals and objectives. These goals are to be treated with a set of operational constraints, in order to find the best compromise solution. In this present study a multi-objective mathematical model for the watershed was developed and analysed by an interactive step method.

3.1 Assumptions in the model

The following assumptions are made while formulating the multi-objective model.

1. The relationship between the variables in objective functions and the constraints are linear.
2. The soil and climate characteristics of the watershed are uniform throughout.
3. Planning is done for two seasons in a year, i.e. Kharif and Rabi season.
4. The water requirement in the kharif season is met from rainfall at different probability of occurrence and in rabi season assured water from ponds is provided.
5. The management practices of the land and cropping pattern is similar. Hence the yield and benefit under a particular crop is constant.
6. Time period of the crop is same in every year.

3.2 Mathematical programming model

3.2.1 Single objective models

The most commonly used optimization technique in any sphere of management is "linear programming technique". A linear programming model consists of a linear algebraic objective function and linear algebraic constraints. The general linear programming model can be defined as follows,

Maximise (minimise), $Z = \sum C_j x_j$ 3.1

Subjected to $\sum\sum a_{ij} x_j (\leq = \geq) b_j$ 3.2

$x_j \geq 0$ 3.3

For $i = 1, 2, 3, \ldots\ldots x$

$j = 1, 2, 3 \ldots\ldots n$

Here equation 3.1 is the objective function which is to be maximised or minimised under a set of constraints given by equation 3.2 and equation 3.3.

The equation given by 3.3 is known as non-negative constraints.

The most common method used to solve linear programming is simplex method. There are a number of standard computer programmes now a day available to solve the problems. A fig. showing ingredients of linear programming model is shown in fig 3.1.

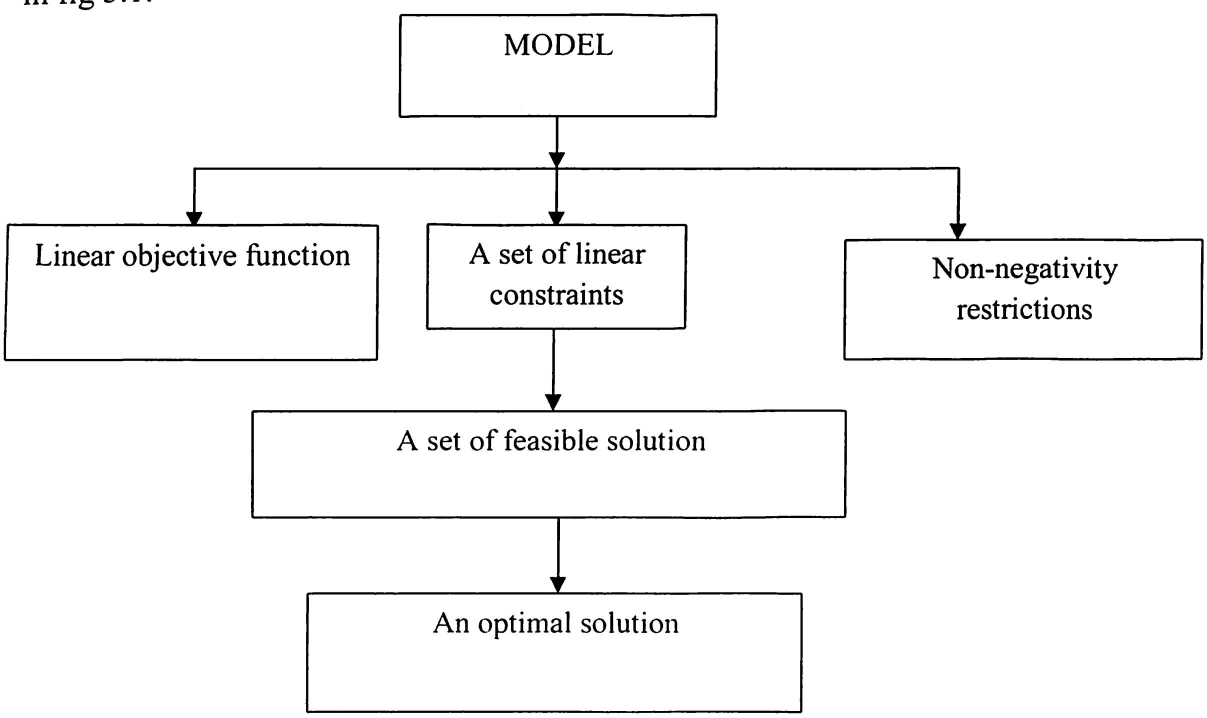

Fig. 3.1 Ingredients of a linear programming model

3.2.2 Multi-objective models

Multiple objective programming (MOP) model is a mathematical technique concerned with a problem, in which several functions are to be optimised simultaneously under a set of management and operational constraints.

The general description of a M.O.P. problem involving, p objectives, n decision variables and m constraints can be expressed as

Max $Z(x) = [Z_k(x)$, for k= 1, 2,...............p] 3.4

Subjected to: $g_i(x)$ (≤=≥) b, for i=1,2,.......m 3.5

and $x \geq 0$ 3.6

Where, Z is a vector valued function consisting of the objective functions $Z_k(x)$, for k=1,2,.........p and x is a vector consisting of decision variables, they are $x_1, x_2, x_3, \ldots\ldots x_n$.. Equation (3.5) is a set of constraints, defining the feasible regions of the decision variables.

If $Z_k(x)$ and $g_i(x)$ for i=1, 2,.........x and k=1, 2,............p are linear ,the MOP formulation is referred as multiple objective linear programming (MOLP).

The concept of optimal solution as used in single objective optimisation has a different interpretation in MOP. In MOP the compromise solution concept is more important than the optimal solution, because the solution which maximises one objective will not in general maximize the other objectives. Therefore a non-inferior solution is obtained by making trade-offs between the different objectives to improve and attain a satisfactory level for each objectives.

3.2.3 Classification of multi objective programming techniques

Multiple objective programming techniques have been classified into four major categories as follows.

I. Generating techniques:

- **i.** Weighting method.
- **ii.** Constraint method.

Step-1 **Construction of the pay off table**

I. All the 'p' individual maximisation problems are solved and optimal solutions for each of the 'p' objectives are found out.

II. Let the solution that maximises objective 'K' where K = 1,2,.......p be $X^k = (X_1^k, X_2^k, X_3^k \ldots\ldots X_n^k)$.

III. If there are alternative optima for any of these problems, then those solutions are chosen among the alternative optima that are non-inferior.

IV. The values of each objective, at each of the 'p' optimal solutions are computed. Let they are be $Z_1 (X^k), Z_2 (X^k), Z_3 (X^k) \ldots\ldots\ldots\ldots Z_n (X^k)$.
K = 1,2,3 ...p. which gives us p values of each of the 'p' objectives.

V. The 'p' values of each of the 'p' objectives are arranged in a table, in which the rows correspond to $X^1, X^2, X^3, \ldots\ldots\ldots\ldots X^p$ and the column are labelled by the objectives $Z_1 (X^k), Z_2 (X^k), Z_3 (X^k) \ldots\ldots\ldots\ldots Z_n (X^k)$.

Pay off table

Solution	**Objectives**			
	$Z_1 (x^k)$	$Z_2 (x^k)$	....	$Z_p(x^k)$
X^1	$Z_1(x^1)$	$Z_2(x^1)$	....	$Z_p(x^1)$
X^2	$Z_1(x^2)$	$Z_2(x^2)$	....	$Z_p(x^2)$
....				
....				
X^p	$Z_1 (x^p)$	$Z_2 (x^p)$	....	$Z_p (x^p)$

Step-2 From the pay off table, the maximum value & the minimum value for each individual optimisation of the k^{th} objective is found out. Let M_k be the maximum and n_k be the minimum value.

Step-3 From the objective function the value of normalising tem i.e. $\left[\sum (Cj^k)^2\right]^{\frac{-1}{2}}$ is computed, where Cj^k are the coefficients of the objective functions assuming that they are linear i.e.

$Z_k(x) = C_1^kX + C_2^kX + \ldots\ldots\ldots\ldots + C_n^kX$

$Cj^{k^2} = C_1^2 + C_2^2 + C_3^2 + \ldots\ldots\ldots + C_n^2$

$K = 1,2, \ldots\ldots\ldots p$

$j = 1,2, \ldots\ldots\ldots n$

Step-4 **Calculation of 'α' value**

$$\alpha_k \text{ (alpha)} = \frac{M_k - n_k}{M_k}\left[\sum (Cj^k)^2\right]^{\frac{-1}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

$\frac{M_k - n_k}{M_k}$ =Scaling term

$\left[\sum (Cj^k)^2\right]^{\frac{-1}{2}}$ = Normalising term

Step-5 **Computation of the weights W_k**

$$W_k = \frac{\alpha_k}{\sum \alpha_k} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

Step-6 from the values of W_k, the values which are zero or nearer to zero such objectives have already attained maximum value. For other objectives the compromise solution is to be obtained.

Step-7 Solve the linear programming

Minimise 'd' ……………….3.9

Subjected to $W_k [M_k - Z_k(x)] - d \leq 0$ ……………….3.10

For k= 1, 2, ……….p

$d \geq 0$ ……………….3.11

Step-8 Let the solution obtained be x(i). Then the value of each objective function is calculated.

Step-9 The above solution i.e. $Z_k [x(i)]$ is showed to the decision maker (DM)

I. If the D.M. is satisfied then the process will be stopped and the current solution is the best compromise solution.
II. If the D.M. is not satisfied, then some trade-offs are done and a new set of compromise solution may be obtained.
III. If the D.M. is not satisfied, then some other interactive techniques may be followed.

3.3 Multi objective watershed management

3.3.1 Objectives

The present study considered the following objectives for proper management of land and water resources of Mandakini Balinala watershed No.-1 of Begunia block of Khurda district (Odisha). The objectives are

1. Food production
2. Fodder production
3. Fuel wood production
4. Net income generation
5. Labour employment generation
6. Runoff water augmentation

1. Food production

As per Maslaw's theory, food ranks first among other objectives considered for land and water management problems. Therefore to meet the food demands of the people of the watershed, side by side to meet their nutritional requirement, different crops are proposed. Among the crops two cereals, two pulses and one oilseed crop is the preferred choice, basing on the requirement of the people. It is presumed that the existing water potential and created water potential will meet the future water demands of the crops that would be eventually taken in that area.

The objective function for maximization of food production is given by

$$\textbf{Max } Z_1(X) = \sum\sum y_{ij}\, x_{ij} \qquad \text{.................. 3.12}$$

Where, y_{ij} is the yield of j^{th} crop in i^{th} season in tons/ha.

x_{ij} is the area under j^{th} crop in i^{th} season in ha.

j= 1, 2, 3, 4, 5 represents upland paddy (paddy-I), medium land paddy (paddy-II), low land paddy (paddy-III), maize, arhar in kharif and

j=1, 2, 3 represents paddy-III, mustard and mung in rabi season.

2. Fodder production

The fodder production is to be maximised in order to meet the demand of the livestock in the watershed. Livestock management is considered as an important parameter in the process of integrated watershed management planning. The green fodder produced from the developed grass and the dry fodder produced from the cereal crops would meet the requirement of the bovine population of the watershed.

The objective function for maximisation of fodder production is given by

$$\textbf{Max } Z_2(X) = \sum\sum f_{ij}\, x_{ij} \qquad \text{................ 3.13}$$

Where, f_{ij} is the fodder yield from j^{th} crop or plantation in i^{th} season, tons/ha.

x_{ij} is the area under j^{th} crop/ plantation in i^{th} season in ha.

j=1, 2, 3, 4 represents paddy-I, paddy-II, paddy-III and maize in kharif.

and j=1 for paddy-III in rabi season.

j= 6, 7 represents hybrid napier bajra grass and subabool in kharif and 4, 5 represents the above in rabi season.

3. **Fuel wood production**

To meet the demands of fuel wood and other domestic uses of the people of the watershed, the plantation of fuel wood and timber trees are mostly necessary. For this purpose, the plantation crop subabool is preferred as it can serve the purpose of fuel wood and fodder for the livestock. It also utilises the wasteland and contributes to the economic upliftment of the individual farmers as well as the people in the watershed.

The objective function for the maximization of fuel wood production is given by

Max $Z_3(X) = \sum\sum w_{ij} x_{ij}$ 3.14

Where w_{ij} is the fuel wood production from j^{th} plantation in i^{th} season in t/ha.

x_{ij} represents area under fuel wood plantation in ha.

j=7 represents subabool plantation in kharif and 5 in rabi season.

4. **Net income generation from field crops and plantation**

Maximisation of net income from cereals, pulses and oilseed crops and plantation helps the farmers to boost their economic status. The farmers are provided with 12% interest loans for their agricultural inputs.

The objective function for the maximization of net income generation is

Max $Z_4(X) = \sum\sum N_{ij} x_{ij}$ 3.15

Where N_{ij} is the net income from j^{th} crop in i^{th} season in Rs/ha.

x_{ij} is area under jth crop/plantation in i^{th} season in ha.

j=1, 2, 3, 4, 5, 6, 7 represents paddy-I, paddy-II, paddy-III, maize, arhar, hybrid napier bajra grass and subabool in kharif and

j=1, 2, 3, 4, 5 represents paddy-III, mustard, mung, hybrid napier bajra grass and subabool in rabi season.

5. **Labour employment generation**

In order to boost the job prospects of the rural population like small, marginal farmers and landless labourers, generation of employment and enhancement of present employment facility is considered in this planning.

The objective function for the maximisation of labour employment generation is given by

$$\textbf{Max } Z_5(X) = \sum\sum L_{ij}\, x_{ij} \qquad \ldots\ldots\ldots\ldots\ 3.16$$

Where L_{ij} is the labour need of the j^{th} crop in i^{th} season in mandays/ha

x_{ij} is area under j^{th} crop in i^{th} season in ha.

j=1, 2, 3, 4, 5, 6, 7 represents crops like paddy-I, paddy-II, paddy-III, maize, arhar, hybrid napier bajra grass and subabool in kharif and

j=1, 2, 3, 4, 5 represents the crop like paddy-III, mustard, mung, hybrid napier bajra grass and subabool in rabi.

6. **Runoff water augmentation**

It is assumed that water requirement in kharif season is to be met from the rainfall at desired probability levels, where as the water requirement in rabi season is met from the storage structures. As the existing source of water in the watershed is insufficient to meet the demand of the crops, so an effort is made to augment (store) the runoff water in ponds for use by the crops in rabi season.

The objective function for maximisation of runoff water augmentation is given by

$$\textbf{Max } Z_6(X) = \sum C_j\, x_{ij} \qquad \ldots\ldots\ldots\ldots\ 3.17$$

Where C_j=capacity per unit ha i.e. ha-m/ha

x_j =Area under ponds in ha.

3.3.2 Constraints

1. Land

a. Total treatable watershed area

The area allocated for different land practices and treatments should be less than or equal to the total treatable area of the watershed.

$$\sum\sum x_{ij} + 2\sum x_j \leq 2AT \qquad \text{.......... 3.18}$$

Where, AT is the total treatable area of watershed, in ha.

The coefficient 2 is coming because the area used in both the seasons.

b. Total agricultural land

The area allocated for different field crops should be equal to or less than the total cultivable area of the watershed.

$$\sum\sum x_{ij} \leq 2AC \qquad \text{.......... 3.19}$$

Where, AC is the total cultivable area available for the field crops in the watershed in ha.

c. Total Forest and Gochar land

The land allocated for the grass cultivation and forestry plantation should be less than or equal to the total land available in the watershed for forest and grass cultivation.

$$\sum\sum x_{ij} + 2\sum x_j \leq 2AF \qquad \text{........ 3.20}$$

Where, AF is the total forest land, land to be used for grass and forestry cultivation which also include area required for ponds.

d. Total cultivable upland

Here in the present study crops proposed for upland are upland paddy (paddy-I), maize and arhar in kharif. So the total area allocated to these crops should be equal to or less than total cultivable upland.

$\sum x_j \leq$ **UA** **3.21**

Where, j=1, 4, 5 represents to the crops paddy-I, maize, arhar.

UA= total cultivable up land of the watershed.

e. Total cultivable medium land and low land of the watershed.

The crops proposed for medium land and low land are medium land paddy (paddy-II), arhar and low land paddy (paddy-III) respectively. The total area allocated to these crops should be less than or equal to the total cultivable medium land and low land respectively.

$\sum x_{ij} \leq$ **MA** **3.22**

Here j=2, 5 represents paddy-II and arhar,

When i=1 i.e. kharif season

and j= 2,3 represents mustard and mung

When i=2 i.e. rabi season.

MA=Total cultivable medium land

$\sum x_j \leq$ **LA** **3.23**

Here j=3 represents paddy-III

LA=Total cultivable low land

2. Water

The quantity of water needed for each crop and plantation should be less than or equal to the water resource available from rainfall and different storage structures. It was assumed that the water requirement in kharif will be met from the rainfall and during rabi it will be met from the water storage structures.

a. For kharif season

$\sum WR_{1j} x_{1j} \leq WR_e$ **3.24**

Where, WR_{1j} is the water requirement of j^{th} crop in kharif, m

x_{1j} is the area under j^{th} crop in kharif, ha

WR_e is the total water resource available at desired probability level (%P), ha-m.

b. For rabi season

$$\sum WR_{2j}x_{2j} \leq WR_e\ (tar) \qquad \text{........... 3.25}$$

Where, WR_{2j} is the water requirement of j^{th} crop in rabi, m

x_{2j} is the area under j^{th} crop in rabi, ha

WR_e (tar) is the total water made available from different storage structure i.e. ponds.

3. Nutritional requirements

For good health the basic source of nutrition is protein and calorie. The total nutritional component available from individual crops must be equal to or greater than the total requirement of people.

a. Protein

$$\sum\sum P_{ij}x_{ij} \geq PR \qquad \text{.......... 3.26}$$

Where, P_{ij} is the protein available from j^{th} crop in i^{th} season in kg/ha

x_{ij} is the area under j^{th} crop in i^{th} season in ha

PR is the total protein requirement of the people in kg.

b. Calorie

$$\sum\sum C_{ij}x_{ij} \geq CR \qquad \text{.......... 3.27}$$

Where, C_{ij} is the total calorie available from j^{th} crop in i^{th} season in Kcal/ha

x_{ij} is the area under j^{th} crop in i^{th} season in ha.

CR is the total calorie requirement of the people in Kcal.

4. **Labour**

The manpower required for cultivation of different crops should be less than or equal to labour force available in the watershed. The labour need by different crops monthly and total manpower available in a month is considered.

$$\sum\sum L_{ij}x_{ij} \leq LA \qquad \text{............ 3.28}$$

Where, L_{ij} is the labour need for j^{th} crop in every month in i^{th} season in mandays/ha.

x_{ij} is the area under j^{th} crop in i^{th} month in ha.

LA is the total labour force available in mandays.

5. **Fodder requirement**

The fodder available from the field crops (i.e. dry fodder) and plantation (i.e. green fodder) should be more than or equal to the requirement of the livestock population of the area.

a. **Field crops**

$$\sum\sum f_{ij}x_{ij} \geq FDR \qquad \text{............ 3.29}$$

b. **Plantation crops**

$$\sum\sum f_{ij}x_{ij} \geq FDR \qquad \text{............. 3.30}$$

Where, f_{ij} is the fodder available from j^{th} crop/plantation in i^{th} season in t/ha

x_{ij} is the area under j^{th} crop in ith season in ha.

FDR is the total fodder requirement of the livestock in the area, ton

6. **Fuel wood requirement**

The fuel wood produced from the plantation crops must be more than or equal to the fuel wood requirement of the people of the watershed.

$$\sum\sum W_{ij}x_{ij} \geq W_r \qquad \text{............ 3.31}$$

Where, W_{ij} is the wood available from j^{th} plantation in i^{th} season in t/ha

x_{ij} is the area under j^{th} crop in i^{th} season in ha.

W_r is bulk fuel wood need of the people, ton.

7. Food requirement

Total production of paddy, maize, arhar, mustard, mung should be greater than or equal to the actual demand of the total population in the watershed area.

a. Paddy requirement

$$y_{11}x_{11} + y_{12}x_{12} + y_{13}x_{13} + y_{21}x_{21} \geq Pd \qquad \text{........... 3.32}$$

Where, y_{11}, y_{12}, y_{13}, yield of paddy –I, paddy-II, paddy-III in kharif respectively, tons/ha.

y_{21} represents yield of paddy-III in rabi season, tons/ha.

x_{11}, x_{12}, x_{13}, x_{21} area under different paddy varieties in, ha.

Pd bulk requirement of paddy in tons

b. Maize requirement

$$y_{14}x_{14} \geq M_d \qquad \text{........... 3.33}$$

Where, M_d is the bulk need of maize, tons

c. Arhar requirement

$$y_{15}x_{15} \geq A_d \qquad \text{.......... 3.34}$$

Where, A_d s the bulk need of arhar, tons

d. Mustard requirement

$$y_{22}x_{22} \geq M_{sd} \qquad \text{......... 3.35}$$

Where, M_{sd} is the bulk requirement of mustard, tons.

e. Mung requirement

$$y_{23}x_{23} \geq M_{ng} \qquad \text{........... 3.36}$$

Where, M_{ng} is the bulk requirement of mung, tons.

8. Area under ponds

$$x_8 \geq A_{tar} \qquad \text{.......... 3.37}$$

Where, A_{tar} is the area required for proposed ponds in ha.

9. Non-negative constraints

Area under different crop/plantation, and reservoir should be either positive or zero, it should not be negative.

$$\sum\sum x_{ij} \geq 0 \qquad \text{.......... 3.38}$$

$$\sum x_j \geq 0 \qquad \text{...........3.39}$$

The above multi-objective watershed management model consists of six objectives, thirteen decision variables subjected to a set of constraints. Steps are taken to solve these multi objective problems using computer software and analyse the same by an interactive technique (step method).

Chapter-IV

DATA & METHODOLOGY

DATA AND METHODOLOGY

This chapter deals with a brief description of the watershed, existing resources, information about land use, land capability, rainfall and other details of the watershed. Also development of multi-objective programming model is done in this chapter. The various data collected and planning methodology followed for this study are discussed.

4.1 Watershed

4.1.1 Location

The watershed selected for this study is Mandakini Balinala watershed No.-1 micro watershed (code No.-0407010802020102) which lies in the Begunia block of Khurda district (Odisha). The watershed is located at a distance of 25 Kms. From district headquarter. The watershed has latitude: 20^0 18' N and longitude: 85^0 62"E.

4.1.2 General information

The Mandakini Balinala watershed No.-1 micro watershed comprises of two villages namely (i) Akhupadar (ii) Atharang with total geographical area of 506.67 ha. Out of this total area, the treatable area is 457 ha. The project area comes under the east and south eastern coastal plain agro climatic zone of the state. The average elevation of the area is 40 to 70 mts. from the mean sea level. The zone is generally flat with undulating and folded topography. The index map of the watershed is given in fig. 4.1.

4.1.3 Land use pattern

The total geographical area of the watershed is 506.67 ha, out of which 49.67 ha. comes under homestead, nallah, roads etc. So the total treatable area of the watershed is 457 ha. It is around 90.19% of the total area. Under agricultural land upland consists of 62.25 ha. which is the main foci of soil erosion as these are present in upper reaches of the watershed. The medium and low lands of the watershed are 199.85 and 20.12 respectively. The details are shown in table 4.1. The forest land which constitutes 39.75 ha is now completely depleted due to over exploitation. So these areas need fresh plantation and conservation practices. The gochar land constitutes 6.25 ha., this is almost barren. It needs treatment and proposed to be under fodder cultivation. The culturable wasteland constitutes 109.49 ha.

Culturable wasteland is about 21.60% of the total area. This area may be brought under different fuel wood plantation and fodder cultivation with proper treatment. Besides that un-culturable wasteland constitute 19.29 ha. The map showing land use pattern is given in fig. 4.2

Table 4.1 Land use pattern of the watershed.

Sl No.	Land use type	Area (ha.)	% of total Area
1.	i) Up land	62.25	12.28
	ii) Medium land	199.85	39.44
	iii) Low land	20.12	3.97
	Total cultivable land	**282.22**	**55.69**
2.	Forest land	39.75	7.84
3.	Gochar land	6.25	1.36
4.	Culturable wasteland	109.49	21.60
5.	Unculturable wasteland	19.29	3.80
6.	Home stead, Nallah ground, roads etc.	49.67	9.80
	Grand Total	**506.67**	**100**

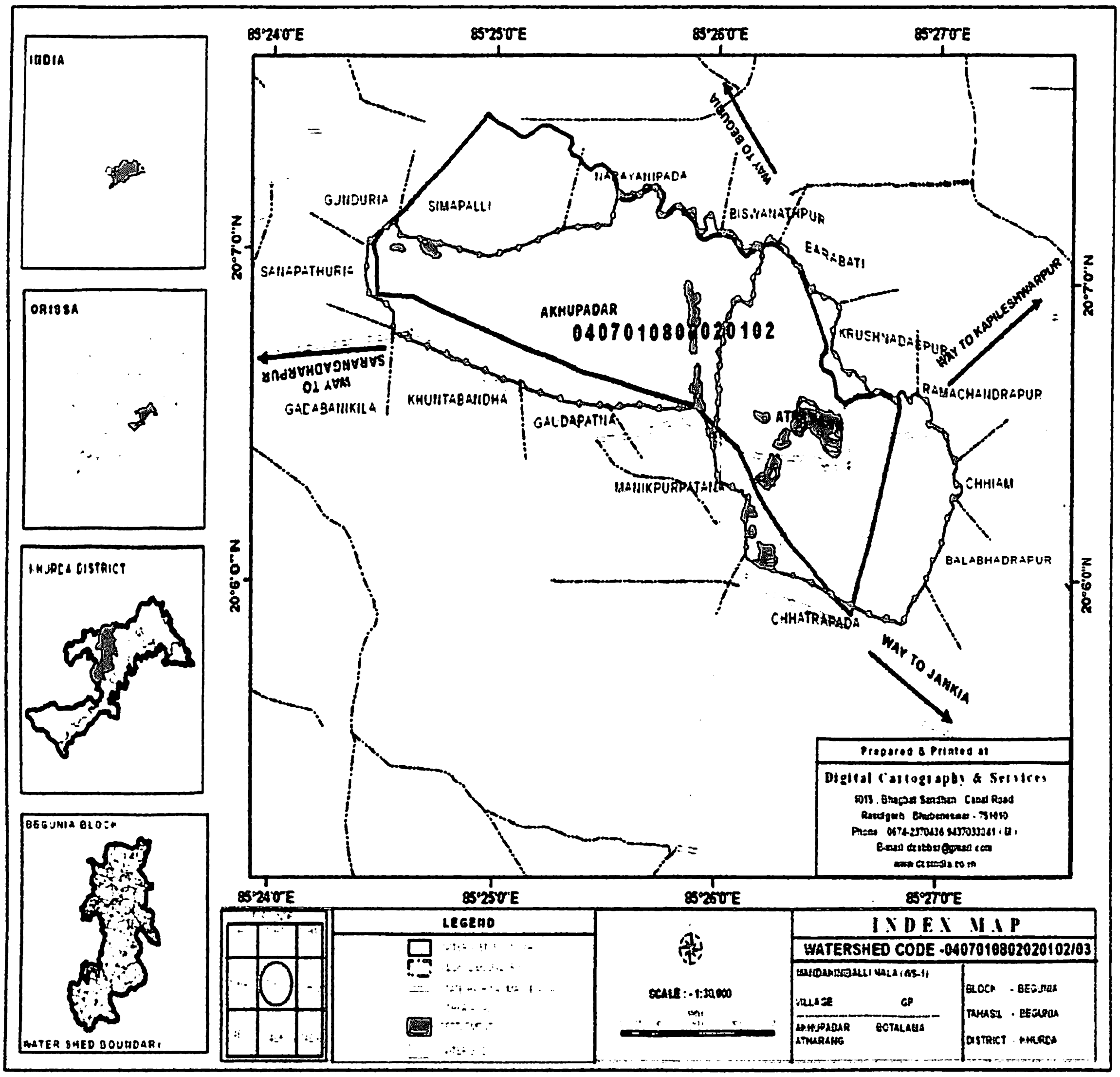

Fig 4.1. Index map of the watershed

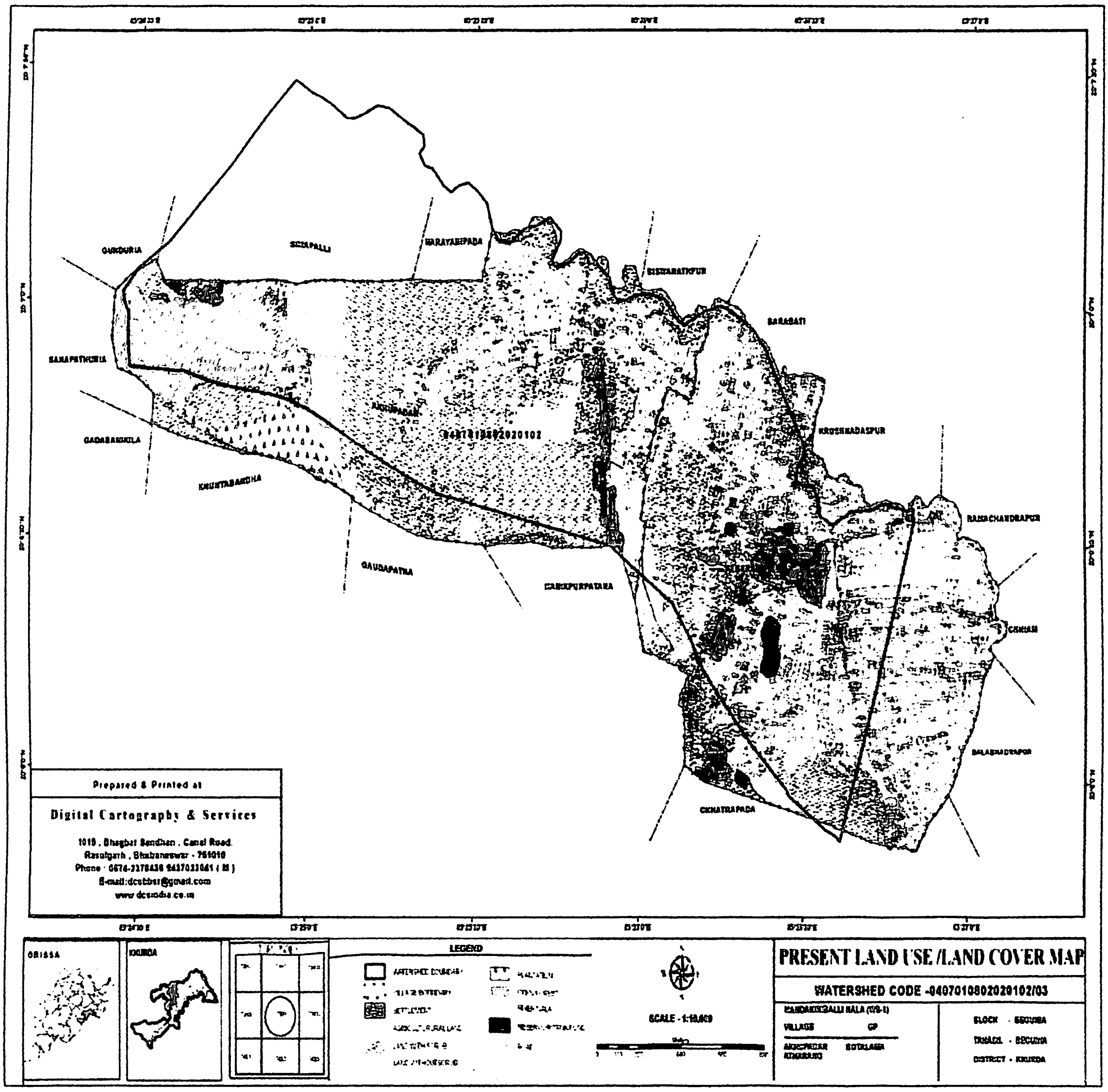

Fig 4.2 Land use pattern of the watershed

4.1.4 Soil type of the watershed

The soil type of the watershed is divided into major four groups namely gravely sandy loam, sandy loam, sandy clay loam and sandy clay. Due to weathering and leaching, soil is losing its natural status. Most of the unculturable lands are remain barren due to which soil losing its fertility and also erosion occurred. The soil type of the watershed (village wise) is given in table 4.2.

Table 4.2 Soil type of the watershed

Sl No.	Name of the village	Area under different soil types in 'ha'				Total
		Gravely sandy loam	Sandy loam	Sandy clay loam	Sandy clay	
1.	Akhupadar	30.22	9.29	64.53	127.51	231.55
2.	Atharang	34.06	13.90	48.90	128.59	225.45
	Total	64.28	23.19	113.43	256.10	457

4.1.5 Slope groups of the watershed

The slope at different parts of the watershed generally varies between 0-5% in arable land and more than 5% in some hilly terrains and forest lands. The area under different slope groups of the watershed is given in table 4.3 and the map showing different slopes are given fig. 4.3

Table 4.3 Slope groups of the watershed

Sl No.	Name of the village	Area under different slope groups in 'ha'				Total
		0-1%	1-3%	3-5%	5-7%	
1.	Akhupadar	39.14	51.85	90.21	50.35	231.55
2.	Atharang	61.85	108.21	55.39	-	225.45
	Total	100.99	160.06	145.60	50.35	457

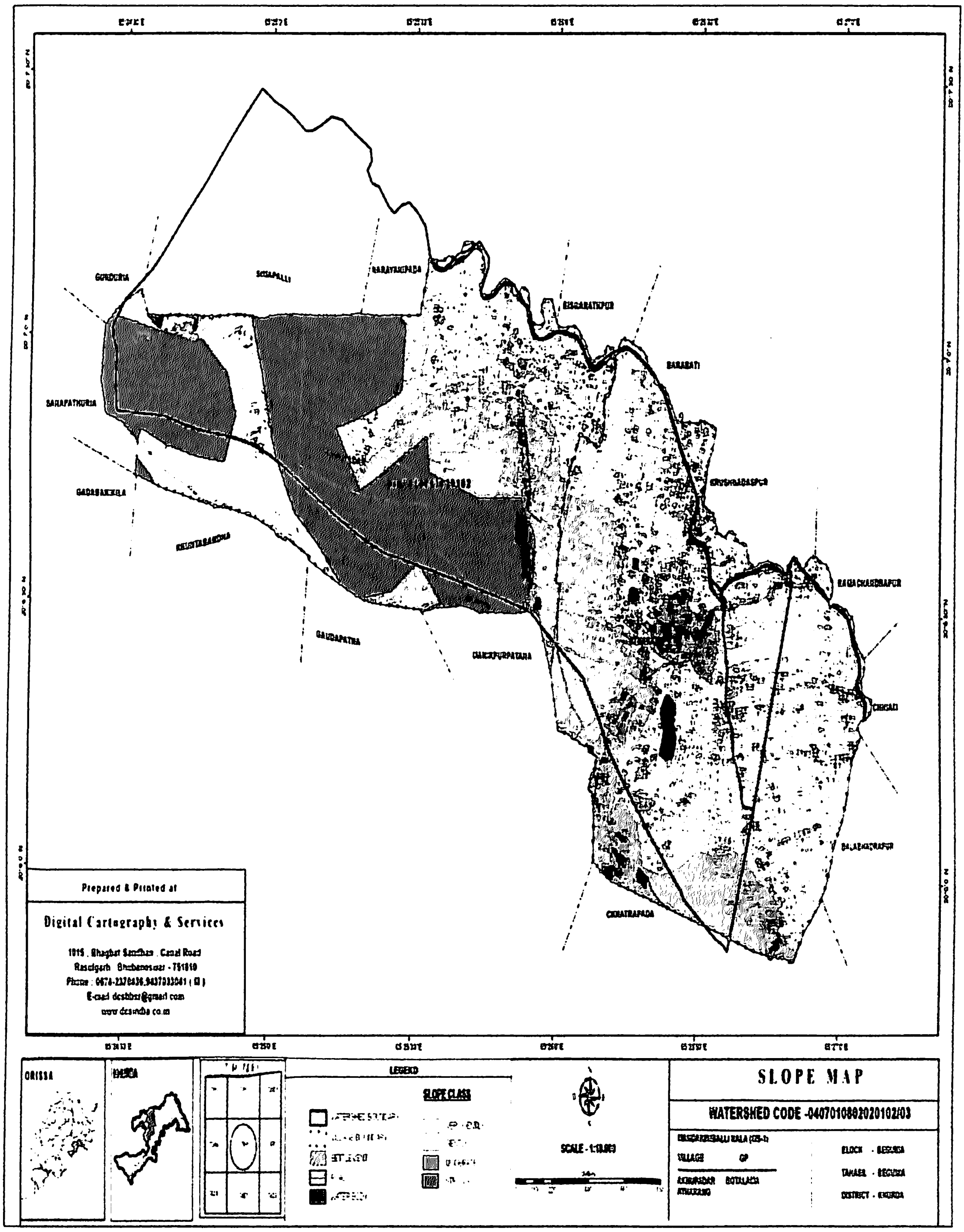

Fig 4.3 Slope map of the watershed

4.1.6 Soil erosion status of the watershed

The watershed is subjected to sheet and rill erosion mainly. At some places rills get wider and deeper giving the evidence of gully erosion. The erosion is distinguished from lower class i.e. e_1 to higher class e_4 for the watershed. (Classification based on Dhruva Narayan *et al.* 1990). The soil erosion status of the watershed is given in table 4.4

Table 4.4 Erosion status of the watershed

Sl No.	Name of the village	Area under different erosion classes in 'ha'				Total
		e_1	e_2	e_3	e_4	
1.	Akhupadar	80.25	60.62	50.98	39.70	231.55
2.	Atharang	75.82	80.64	40.28	28.71	225.45
	Total	156.07	141.26	91.26	68.41	457

4.1.7 Land capability classification of the watershed

The capability of different units of the watershed for sustaining crops depends on the characteristics like slope, soil type, soil depth and erosion status of the watershed. Basing on these criteria land capability is decided and it varies between class-II to class-VII. The land capability classification of the watershed is given in table 4.5.

Table 4.5 Land capability classification of the watershed

Sl No.	Name of the village	Area under different land capability class in 'ha'					Total
		II	III	IV	VI	VII	
1.	Akhupadar	68.82	30.38	8.26	101.26	22.83	231.55
2.	Atharang	33.10	134.97	6.69	45.26	5.43	225.45
	Total	101.92	165.35	14.95	146.52	28.26	457

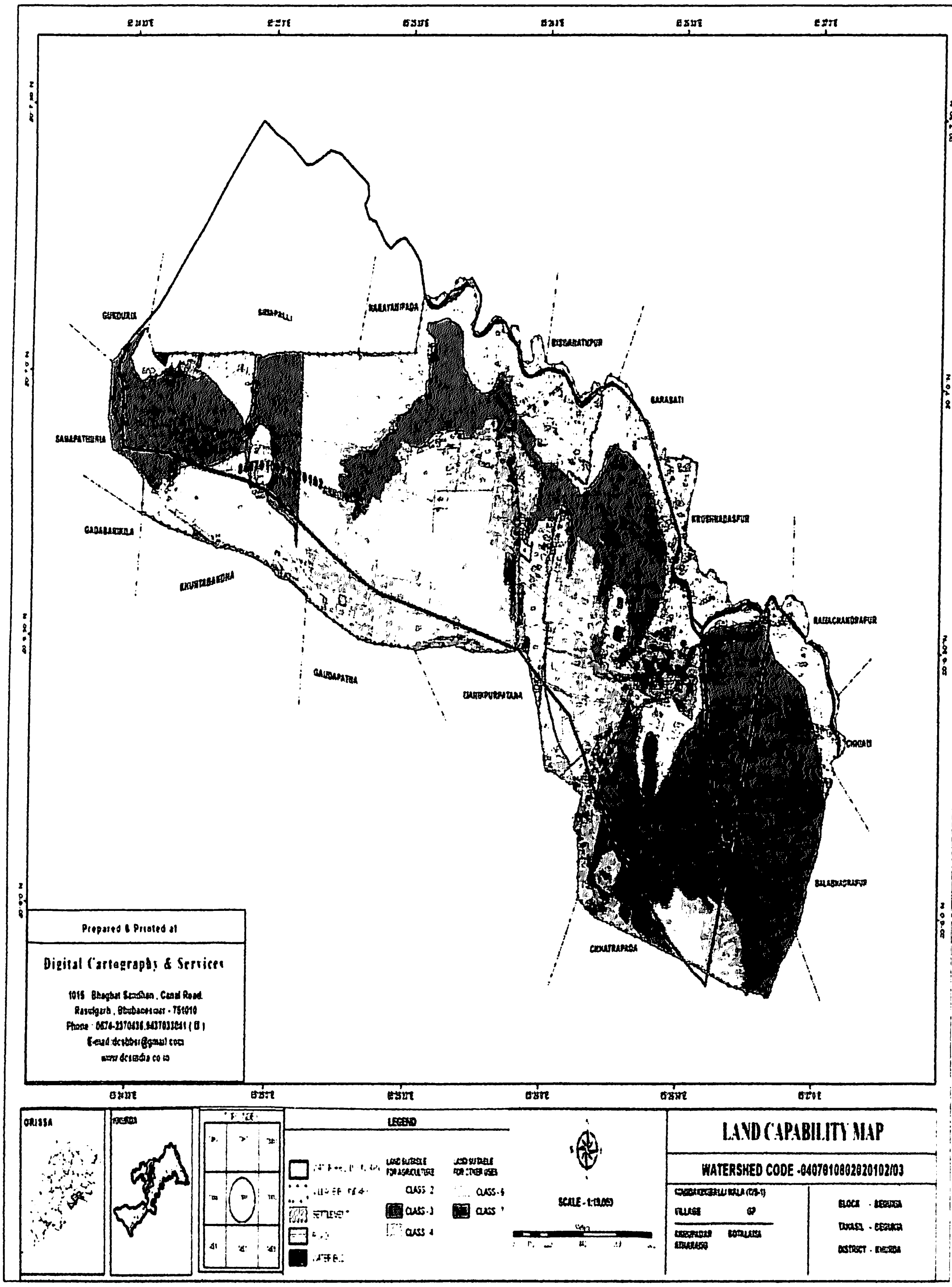

Fig 4.4 Land capability map of the watershed

4.1.8 Agricultural practices

The main crop grown in the watershed is paddy. However in kharif, maize and arhar are grown in some areas. In rabi season, crops like mustard, mung and low land paddy are grown in some area. Due to lack of irrigation facility, crops grown in limited areas in rabi season. Most of the rainfall in monsoon flow as runoff and ultimately lossed due to limited storage structures. This causes moisture deficit in upland and medium land areas. The area under crop cover is more in kharif than rabi season.

The present land use pattern of the watershed and areas that can be brought under cultivation in future is given in table 4.6.

Table 4.6 Area under crops in kharif and rabi season

Category of Land	Total Cultivable area in ha	Presently under agriculture in 'ha'		Can be utilised in future in 'ha'	
		Kharif	Rabi	Kharif	Rabi
Upland	62.25	39.93	-	62.25	-
Medium land	199.85	135.27	90.14	199.85	199.85
Low land	20.12	20.12	15.71	20.12	20.12
Total	282.22	195.32	105.85	282.22	219.97

4.1.9 Socio-economic and population

The socio-economic study reveals that most of the people in the watershed have poor economic status. They are annual income is very low. Most of the farmers have very less land holding i.e. within one hectare. They come under small and marginal farmer's category. Moreover the land is very much fragmented and scattered. Most of the people depend upon the agriculture for their income, though some of them are engaged in other activities like industrial worker, smithy and pottery etc. Productivity is less in the area due to lack of irrigation facility, agricultural inputs, traditional farming system, and restricted use of improved technology. The population details of the watershed as per the 2011 census and the forecasted population for the year 2018 is given in table 4.7. Nearly 40-50% of the population are engaged as agricultural labourers.

Table 4.7 Population Details of the watershed

Sl No.	Name of the village	Population details of the watershed as per 2011 census	Population forecasted for 2018*
1	Akhupadar	303	357
2.	Atharang	667	788
	Total	970	1145

*Annual population growth is taken as 2.1%

Table 4.8 Category wise distribution of population

Sl No.	Name of the village	Male	Female	Children	Total
1.	Akhupadar	177	155	25	357
2.	Atharang	385	336	67	788
	Total	562	491	92	1145

4.1.10 Livestock population of the watershed

For the economic upliftment of the people in watershed livestock plays an important role. To estimate the total fodder requirement of the watershed, knowledge of livestock population is utmost necessary. The village wise livestock population of the watershed is given in the table 4.9

Table 4.9 Livestock population of the watershed

Sl No.	Name of the village	Livestock Population(Nos.)				
		Cow	**Bullock**	**Buffalo**	**Sheep**	**Goat**
1.	Akhupadar	25	22	3	8	22
2.	Atharang	78	72	6	17	26
	Total	103	94	9	25	48

4.1.11 Climate of the watershed

The climate of the watershed area is hot and dry sub humid. The mean maximum temperature is 40.5^{0}c during the month April and may and the mean minimum temperature is 14.6^{0}c during the month of December and January. The average annual rainfall is 1499.29 mm and the portion of rainfall received during the monsoon (June - September) constitutes about 70-75% of the total annual rainfall. As such irrigation becomes extremely momentous not only for overcoming the enigma of moisture stress for the rest part of the year, but also at the time of failure of monsoon.

4.1.12 Existing water source of the watershed

In the watershed area two types of surface water structures are available.

1. Dugout pond constructed by soil conservation department.

2. Dugout pond owned by village panchayat

From these two water sources, small patches of land have been covered in rabi season. Therefore, it is necessary to quantify the water available for its reuse to rabi season crops.

4.1.12.1 Pond No.1

The inside dimensions, side slope and the depth from bottom up to the crest level of the spillway were measured for quantifying the storage volume. The storage capacity of the water harvesting pond no.1 up to crest level was estimated following trapezoidal rule. Assuming 20% as losses occurred due to evaporation, seepage and percolation, the rest 80% is considered as utilizable water for irrigation purpose.

4.1.12.2. Pond No.2

The dimensions of the second pond are collected to estimate the capacity of the pond. The capacity of the pond was quantified at different depths taking contour interval of 0.5 m through trapezoidal rule. A water depth of 1.5m is kept as dead storage for bathing and other purposes of the people and the domestic animals. The storage volume between the crest level of the spillway and the dead storage level was considered to be available for crop use. Net quantity of water available for its utilization is obtained after satisfying the unavoidable losses (assumed 20%).

4.1.13 Collection and analysis of Rainfall data

The monthly rainfall data for the watershed was collected from OUAT metrological laboratory, Bhubaneswar for 29 years i.e. from 1978 to 2007, which is given in appendix-C.I. These rainfall data has been fitted into five different probability distribution functions i.e. Normal, Log Normal, Gumbel extreme value maximum, Log Pearson type-III and Weibull and probable rainfall values are obtained according to their best fit distribution. The probability analysis of the rainfall is carried out with the help of "FLOOD" software.

4.1.13.1 Types of Probability distribution functions

1. Normal Distribution

A normal distribution is given by

$$f(x, \mu, \sigma)=\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad \text{.......... 4.1}$$

Where, μ and σ are mean and standard deviation of the variate 'x' respectively.

2. Log normal Distribution

The probability density function of a log-normal distribution is:

$$f(x, \mu, \sigma)= \frac{1}{x\sigma_y\sqrt{2\pi}} e^{\frac{-(\ln x-\mu_y)^2}{2\sigma_y^2}}, x > 0 \qquad \text{.......... 4.2}$$

Where y=logx, μ_y and σ_y are the mean and standard deviation of variate respectively.

3. Gumbel Extreme Value Maximum

The probability distribution function of this distribution is given by

$$f(x)=\frac{1}{\alpha} e^{[\frac{-(x-\mu)}{\alpha} -e^{\frac{-(x-\mu)}{\alpha}}]} \qquad \text{.......... 4.3}$$

Where $\alpha=\frac{\sqrt{\sigma Sx}}{\pi}$, $U=x^{`}-0.57772\alpha$

$x^{`}$ and S_x are mean and standard deviation of variate x respectively.

4. **Log Pearson Type-III Distribution**

The probability distribution function of this distribution is given by

$$f(x)=\frac{\lambda^{\beta}(y-\varepsilon)^{\beta-1}}{x\{\beta\}} e^{-\lambda(\tau-t)} \qquad \text{........4.4}$$

Where $\lambda = \frac{Sy}{\sqrt{\beta}}, \ \beta = \left[\frac{2}{Cs(y)}\right]^2$

$\varepsilon = y^{`} - s_y\sqrt{\beta}$ and $y=\log x$

Where y', s_y and $c_s(y)$ are the mean, standard deviation and skewness coefficient of variate respectively.

5. **Weibull's Distribution**

The probability distribution of this distribution is given by

$$f(x) = \{\frac{k}{\lambda}(\frac{x}{\lambda})^{k-1} \times e^{(-\frac{x}{\lambda})^{k}}\} \qquad \text{........ 4.5}$$

Where k>0 is the shape parameter and λ>0 is the scale parameter.

All the five probability functions are taken while checking for the best fit distribution. Then depending upon the RMSE value and Mean error value, the best distribution for a particular month of 29 years is tested, using the "FLOOD" software. The results obtained are shown in the results and discussions section.

4.2 Land and Water management plan for the watershed.

Successes of any project depend on its integrated work plan. The planning should be such that it includes the details of the land treatment measures, their design, operation and maintenance of the measures. The different categories of land and their main treatment programme are briefed below.

I. Arable land | **Suggested Treatment Programmes**

It includes

a. Eroded up land

b. Weakly bunded medium land

c. Some portion of low land that are subjected to water logging.

1. Crop with specified rotation
2. Contour bunding and graded bunding
3. Strip cropping
4. Conservation farming
5. Provision of disposal system from one field to another field.
6. Crop demonstrations.
7. Reclamation of waterlogged area.

II. Non arable land | **Suggested Treatment Programmes**

It includes

a. Area under forest

b. Culturable wasteland

c. Hills

d. Hill slopes

e. Pediments

f. Gochar

1. Forestry promotion
2. Horticultural development
3. Pasture development
4. Breaking of slopes by terracing
5. Reclamation of wastelands

III. Natural drainage line | **Suggested treatment Programmes**

It includes the natural drains of the watershed which carries runoff to the outlet point.

1. Gully control structures.
2. Construction of runoff harvesting Structures
3. Renovation of tanks.

4.2.1 Suggested measures for the slope groups of the watershed

From the table 4.3 the lands covered under different slope groups are distinguished and appropriate measures for each slope group are recommended below in table 4.10.

Table 4.10 Suggested measures for different slope groups of the watershed

Slope groups (%)	Area in ha	Suggested land measures
0-1%	100.99	Any crop with crop rotation, contour farming
1-3	160.06	Some specified low duty crops with intensive agronomical measures such as strip cropping, contour bunding with some areas under pasture grasses
3-5	145.60	Pasture with control grazing, forestry with restricted cutting, contour trenching and terracing
5-7	50.35	Forest plantation with restricted cutting of trees

4.3 Development of multi-objective model

A Multiple objective programming model has been developed for optimum allocation of land and water to different activities of agriculture and forestry in the watershed. The proposed crops in the planning are paddy, maize, arhar in kharif and paddy, mustard and mung in rabi season. Besides this there was a proposal for hybrid napier bajra grass as a fodder and subabool as a forestry crop for the watershed throughout the year.

The decision variables are x_{ij}, that is the area under j^{th} crop in i^{th} season.

j= 1,2,3,4,5,6,7 represents upland paddy (paddy-I), medium land paddy (paddy-II), lowland paddy (paddy-III), maize, arhar, hybrid napier bajra grass and subabool in kharif season (i=1)

j= 1, 2, 3, 4, 5 represents paddy-III (lowland), mustard, mung, hybrid napier bajra grass and subabool in rabi season. (i=2)

4.3.1 Multiple objective functions

For the watershed management programme six basic objectives have been taken in the model. They are maximisation of food production, maximisation of fodder production, maximisation of fuel wood and timber production, maximization of net income generation from field crops, maximisation of labour employment generation and maximisation of runoff water augmentation. These objectives aim at improving the status of the farmers and ensure judicious utilization of land, water and human resources of the watershed. There are 13 variables taken in the MOP model they are listed in table 4.11.

Table-4.11 Variables with their notations

Sl No.	Variables	Used for the crop in 'ha'
A.	Kharif	
1.	x_{11}	Area under up land paddy(paddy-I)
2.	x_{12}	Area under medium land paddy(paddy-II)
3.	x_{13}	Area under low land paddy(paddy-III)
4.	x_{14}	Area under maize
5.	x_{15}	Area under arhar
6.	x_{16}	Area under hybrid napier bajra grass
7.	x_{17}	Area under subabool plantation
B.	Rabi	
1.	x_{21}	Area under low land paddy(paddy-III)
2.	x_{22}	Area under mustard
3	x_{23}	Area under mung
4.	x_{24}	Area under hybrid napier bajra grass
5.	x_{25}	Area under subabool plantation
	x_8	Are under ponds

I. Food Production

Food is one of the basic needs of human being. So maximisation of food production is considered as one of the prime objectives, which will help in achieving the self sufficiency of the food grains for the people of the watershed. The yield of the different field crops in tons/ha is given in table-4.12. These values are used for fixing the objective function.

Table 4.12 **Grain, fodder, fuel wood yield of different crops and plantation**

Sl No.	Crop/plantation	Variable name	Grain yield (tons/ha)	Fodder Yield (tons/ha)	Fuel wood yield (tons/ha)
A.	**Kharif**				
1.	Up land paddy(paddy-I)	x_{11}	2.6	6.5	-
2.	Medium land paddy(paddy-II)	x_{12}	3.2	7.1	-
3.	Low land paddy(paddy-III)	x_{13}	3.7	8.0	-
4.	Maize	x_{14}	4.0	2.0	-
5.	Arhar	x_{15}	1.8	-	-
6.	Hybrid napier bajra grass	x_{16}	-	30.0	-
7.	Subabool	x_{17}	-	7.0	10.0
B.	**Rabi**				
1.	Low land paddy(paddy-III)	x_{21}	4.3	8.5	-
2.	Mustard	x_{22}	1.5	-	-
3.	Mung	x_{23}	1.0	-	-
4.	Hybrid napier bajra grass	x_{24}	-	20.0	-
5.	Subabool	x_{25}	-	3.0	10.0

The objective function for maximisation of food production is expressed as

$$Z_1(x) = 2.6x_{11}+3.2x_{12}+3.7x_{13}+4x_{14}+1.8x_{15}+4.3x_{21}+1.5x_{22}+x_{23} \quad \text{.................} 4.6$$

II. Fodder Production

Fodder is inevitable for the livestock population of the watershed. Keeping in view, the fodder requirement of the livestock's of the watershed, which is an important component of farming is to be maximized. The fodder yield from different crops and plantation crops are given in table-4.12.

The objective function for maximisation of fodder production is given by

$$Z_2(x) = 6.5x_{11}+7.1x_{12}+8x_{13}+2x_{14}+30x_{16}+7x_{17}+8.5x_{21}+20x_{24}+3x_{25} \quad \text{................} 4.7$$

III. Fuel wood Production

Fuel wood and timber is essential for the livelihood of the rural people. To satisfy the requirement of the people and also to utilise the culturable wasteland for the purpose of plantation activities, the objective function for the maximisation of the fuel wood production is considered in the planning. The fuel wood yield from the plantation trees is given in table-4.12.

The objective function for maximisation of fuel wood production is given by

$$Z_3(x) = 10x_{17} + 10x_{25} \quad \text{........... 4.8}$$

IV. Net income generation from field crops

Most of the people of the watershed are small and marginal farmers. They depend on agriculture for their livelihood. So to improve the economic condition of the farmers, it is necessary to get more income from the field crops. This will be achieved by providing basic agricultural inputs such as seed, fertiliser, pesticides and loans at a reasonable interest rate (12%) to the farmers. The details of the inputs, investment cost, net return per hectare of land is presented in appendix B_I to B_X .The net return from various crops and plantation activities are given in table 4.13. The objective function for maximisation of net income generation from field crops is given by

$$Z_4(x) = 9671x_{11}+11202x_{12}+11838x_{13}+15618x_{14}+48673x_{15}+10800x_{16}+6980x_{17}$$

$$+16916x_{21}+15213\, x_{22}+24740\, x_{23}+7200\, x_{24}+4980\, x_{25} \quad \text{.............. 4.9}$$

V. Labour Employment Generation

The objective of maximisation of labour employment is considered in the plan to ensure livelihood security to the weaker section of the rural population like small and marginal farmers and landless labourers. So the aim is to utilise the existing human resources and provide employment to maximum number of people that may be possible.

The total labour need for different crops and plantation for the entire season are given in table 4.13.So taking into consideration the total labour required by crops in mandays, the objective function for maximisation of labour employment generation is given by

$$\mathbf{Z_5(x)= 102x_{11} + 132x_{12} + 165x_{13} + 160x_{14} + 93x_{15} + 60x_{16} + 185x_{17} + 165x_{21} + 100x_{22} + 65x_{23} + 90x_{24} + 185x_{25}} \quad \text{.............}\mathbf{4.10}$$

Table 4.13 Net income and labour requirement of field crops.

Sl No.	Crop/plantation	Variable name	Net income (Rs./ha)	Labour required (Mandays/ha)
A.	**Kharif**			
1.	Up land paddy(paddy-I)	x_{11}	9671	102
2.	Medium land paddy(paddy-II)	x_{12}	11202	132
3.	Low land paddy(paddy-III)	x_{13}	11838	165
4.	Maize	x_{14}	15618	160
5.	Arhar	x_{15}	48673	93
6.	Hybrid napier bajra grass	x_{16}	10800	60
7.	Subabool	x_{17}	6980	185
B.	**Rabi**			
1.	Low land paddy(paddy-III)	x_{21}	16916	165
2.	Mustard	x_{22}	15213	100
3.	Mung	x_{23}	24740	65
4.	Hybrid napier bajra grass	x_{24}	7200	90
5.	Subabool	x_{25}	4980	185

VI. Run off water augmentation

To meet the water requirements of the crops and plantation, it is essential to store as much as water possible for use in rabi season. So the objective for maximisation of the stored volume of water in ponds are considered and mathematically expressed as below. The details, of the determination of capacity of pond and also the capacity per unit area are given in appendix- D-II.

$$Z_6(x) = 3x_8 \qquad \text{.................. 4.11}$$

4.3.2 Constraints of Multi objective model

1. Land area

The total watershed area is 506.67 ha., out of which 49.67 ha comes under homestead land, nallah, roads etc. so the net area allocated to different crops/ plantation activities should not exceed 457 ha i.e. the treatable area of the watershed.

So, $x_{11}+ x_{12}+ x_{13}+ x_{14}+ x_{15}+ x_{16}+ x_{17}+ x_8 \leq 457$ 4.12

$x_{21}+ x_{22}+ x_{23}+ x_{24}+ x_{25}+ x_8 \leq 457$ 4.13

From the land capability classification it is shown that 282.22 ha land is suitable for agriculture. So the land allocated to field crops should be less than or equal to 282.22.

So $x_{11}+ x_{12}+ x_{13}+ x_{14}+ x_{15} \leq 282.22$ 4.14

Similarly in rabi season total land cultivable is limited to sum of medium land and low land i.e. 219.97

$x_{21}+ x_{22}+ x_{23} \leq 219.97$ 4.15

Out of 282.22 ha. of arable land, 62.25 ha is under up land, 199.85 ha is medium land and 20.12 ha is low land.

In upland the crops suggested is up land paddy, maize, arhar and in medium land the crops suggested are medium land paddy and arhar. Similarly in low land, low land paddy is suggested. So the respective constraints equations are as below

$x_{11}+ x_{14}+ x_{15} \leq 62.25$ 4.16

$x_{12}+ x_{15} \leq 199.85$ 4.17

$x_{13} \leq 20.12$ 4.18

Similarly in rabi season the total medium land is distributed between mustard and mung and the low land is to be cultivated with low land paddy. The respective constraints are shown below

$x_{22}+x_{23} \leq 199.85$ 4.19

$x_{21} \leq 20.12$ 4.20

The total land under degraded forest, gochar, culturable and unculturable wasteland which can be bought under plantation, fodder and also for making the water storage structures is 174.78. So the constraints equations are

$x_{16}+ x_{17}+ x_8 \leq 174.78$ 4.21

$x_{24}+ x_{25}+ x_8 \leq 174.78$ 4.22

As subabool and hybrid napier bajra grass is grown in both seasons, so total area cultivated in kharif season must be equal to the total area in rabi season.

$x_{16}- x_{24} = 0$ 4.23

$x_{17}- x_{25} = 0$ 4.24

2. Water

The total quantity of water needed by different crops/plantation should be less than or equal to the total volume of water available from rainfall in kharif season at the desired probability level and from different storage structures in rabi season. The water requirement of the crops/plantation is given in table 4.14. The magnitude of rainfall at different probability levels and water available from ponds are given in appendix, C-II.

Table 4.14 Water requirement of different crops in terms of depth (m)

Sl No.	Crop/plantation	Variable name	WR(in 'm')
A.	**Kharif**		
1.	Up land paddy(paddy-I)	x_{11}	1.20
2.	Medium land paddy(paddy-II)	x_{12}	1.20
3.	Low land paddy(paddy-III)	x_{13}	1.00
4.	Maize	x_{14}	0.45
5.	Arhar	x_{15}	0.35
6.	Hybrid napier bajra grass	x_{16}	0.40
7.	Subabool	x_{17}	0.35
B.	**Rabi**		
1.	Low land paddy(paddy-III)	x_{21}	1.00
2.	Mustard	x_{22}	0.40
3.	Mung	x_{23}	0.40
4.	Hybrid napier bajra grass	x_{24}	0.20
5.	Subabool	x_{25}	0.10

The required constraint equations are as below:

i) $1.2x_{11}+1.2x_{12}+x_{13}+0.45x_{14}+0.35x_{15}+0.4x_{16}+0.35x_{17} \leq 306$ ha-m 4.25

(70% probability level)*

ii) $x_{21}+0.4x_{22}+0.4x_{23}+0.2x_{24}+0.1x_{25} \leq 127$ ha-m 4.26

*A rough guide for estimating effective rainfall has been developed by U.S. Bureau of reclamation for arid and semi-arid regions (1969) in which the mean seasonal precipitation of transpiration/precipitation ratio method based on extensive field basis has been used for the determination. Rainfall values of 70% probability levels are considered in calculation for irrigation planning.

3. Nutritional requirement

Protein and calorie are two main nutrients required by a man for better health. The quantity of food produced from different crop should meet the minimum nutritional requirements of the people. The recommended nutritional requirements per day per person of different age groups and the protein and calorie content of the crops are given in table 4.15 and table 4.16.The details of the nutritional requirements, the nutrient available per ha of area from different crops are shown in appendix A-II and A-V.

Table 4.15 Nutritional requirements of different age groups/day.

Sl No.	Age group	Protein(gms)	Calories(Cal.)
1.	Male	70	3000
2.	Female	55	2400
3.	Children	40	2200

Table 4.16 Protein and Calorie contents of the crops

Sl No.	Crop	Protein(gms/kg)	Calories(Cals/kg)
1.	Paddy	68	3450
2.	Maize	85	3430
3.	Arhar	245	3480
4.	Mustard	200	2917
5.	Mung	240	3240

A. Protein Constraint

The total protein need of the people of the watershed is 25,556 Kg. for one year as determined in appendix A-II. Therefore, the total protein available from different crops must be greater than or equal to the total requirement.

$$177x_{11}+218x_{12}+252x_{13}+340x_{14}+441x_{15}+292x_{21}+300x_{22}+240x_{23} \geq 25,556 \quad \text{....} \quad 4.27$$

B. Calorie Constraint

The total calorie need of the people of the watershed for one year is 11,19,378 Kcal as determined in appendix A-II. Therefore the total calorie available from different crops must be greater than or equal to the total requirement.

$$8970x_{11}+11040x_{12}+12765x_{13}+13720x_{14}+6264x_{15}+14835x_{21}+$$
$$4376x_{22}+3240x_{23} \geq 1119378 \quad \text{...........} 4.28$$

4. Labour requirement

Labour requirement for different crops, month wise is given in appendix-B XI. The kharif season is taken from June to October and rabi from December to April. The labour requirement by the plantation and fodder crops is taken throughout the year. The labour required by different crops in a particular month should be less than or equal to the available labour of the watershed in that month. Assume that maximum 50% of the population can be engaged as labourers for agricultural practices. So the no. of people available as labourers in a day is 572.

Total mandays available in a month= 572 * 30 = 17160

Taking into consideration the labour requirement by different crops and total labour available for the watershed, the constraint equations are given below

Jun $30x_{11}+30x_{12}+30x_{13}+35x_{14}+15x_{15}+25x_{16}+20x_{17} \leq 17160$ 4.29

Jul $20x_{11}+35x_{12}+35x_{13}+30x_{14}+20x_{15}+10x_{16}+10x_{17} \leq 17160$ 4.30

Aug $15x_{11}+20x_{12}+30x_{13}+15x_{14}+10x_{15}+10x_{16}+30x_{17} \leq 17160$ 4.31

Sep $7x_{11}+12x_{12}+30x_{13}+20x_{14}+23x_{15}+5x_{16}+25x_{17} \leq 17160$ 4.32

Oct	$30x_{11}+35x_{12}+40x_{13}+60x_{14}+25x_{15}+10x_{17} \leq 17160$	.... 4.33
Nov	$10x_{16}+110x_{17} \leq 17160$	.... 4.34
Dec	$30x_{21}+20x_{22}+10x_{23}+10x_{24}+20x_{25} \leq 17160$	.... 4.35
Jan	$35x_{21}+15x_{22}+10x_{23}+10x_{24}+20x_{25} \leq 17160$	.... 4.36
Feb	$30x_{21}+10x_{22}+10x_{23}+15x_{24}+15x_{25} \leq 17160$	.... 4.37
Mar	$30x_{21}+25x_{22}+10x_{23}+15x_{24}+10x_{25} \leq 17160$	.... 4.38
Apr	$40x_{21}+30x_{22}+25x_{23}+10x_{24}+10x_{25} \leq 17160$	.... 4.39
May	$30x_{24}+90x_{25} \leq 17160$	.... 4.40

5. Bulk Requirement

The total quantity of food, fodder and fuel wood required per year by the people and livestock of the watershed is given in table 4.17

Table 4.17 Estimated food, fodder and fuel wood requirement of the watershed

S No.	Items	Estimated quantity(tons)
1.	Food requirements	
i.	Paddy	174
ii.	Maize	71.3
iii.	Arhar	18
iv.	Mustard	17.2
v.	Mung	15.14
2.	Fodder requirement	1940
3.	Fuel wood requirement	1755

I. Food Requirement

Food produced under each category of food should be more than the food requirement.

i. Paddy

The total requirement of the paddy for the watershed in one year is estimated as 174 tons. So yield of paddy is greater than or equal to the need.

$$2.6x_{11}+3.2x_{12}+3.7x_{13}+4.3x_{21} \geq 174 \qquad \text{........... 4.41}$$

ii. **Maize**

The total requirement of maize is 71.3 tons. So the total yield of maize should be greater than or equal to 71.3 tons

$$4x_{14} \geq 71.3 \qquad \text{.......... 4.42}$$

iii. **Arhar**

The total requirement of arhar is estimated as 18 tons. So the total yield of arhar should be more than or equal to the estimated value.

$$1.8x_{15} \geq 18 \qquad \text{.......... 4.43}$$

iv. **Mustard**

The total requirement of mustard is estimated as 17.2 tons. So the total yield of mustard should be greater than or equal to 17.2 tons.

$$1.5x_{22} \geq 17.2 \qquad \text{.......... 4.44}$$

v. **Mung**

The total requirement of mung is estimated as 15.14 tons. So the total yield of mung should be greater than or equal to 15.14 tons.

$$x_{23} \geq 15.14 \qquad \text{.......... 4.45}$$

II. **Fodder Requirement**

The total quantity of fodder available from different crops and plantation should be greater than or equal to the total requirement of the livestock of the watershed i.e. 970 tons each green and dry fodder as given in appendix-A III.

Dry fodder

$$6.5x_{11}+7.1x_{12}+8x_{13}+2x_{14}+8.5x_{21} \geq 970 \qquad \text{.......... 4.46}$$

Green fodder

$$30x_{16}+7x_{17}+20x_{24}+3x_{25} \geq 970 \quad \text{.......... 4.47}$$

III. Fuel wood Requirement

The total fuel wood requirement of the watershed is 1755 tons as given in appendix A.IV. So the total fuel wood available from plantation crops should be greater than or equal to 1755 tons.

$$10x_{17}+10x_{25} \geq 1755 \quad \text{.......... 4.48}$$

6. Area required for ponds

The total area needed for constructing the required number of ponds should be greater than or equal to 40.39 ha. i.e. the area required to augment the quantity of water needed for irrigation purpose in rabi season as given in appendix-D II.

$$x_8 \geq 40.39 \quad \text{.......... 4.49}$$

7. Non negative Constraints

All the variables should be either greater than or equal to zero. (Should be non-negative). So the constraint equations are

$x_{11} \geq 0$, $x_{12} \geq 0$, $x_{13} \geq 0$, $x_{14} \geq 0$, $x_{15} \geq 0$, $x_{16} \geq 0$,
$x_{17} \geq 0$, $x_{21} \geq 0$, $x_{22} \geq 0$, $x_{23} \geq 0$, $x_{24} \geq 0$, $x_{25} \geq 0$,
$x_8 \geq 0$

These six objective functions along with thirty eight constraints are inputted in the Quick Statistical Business software (QSB) software to find out the required solutions.

Chapter-V

RESULTS & DISCUSSIONS

RESULTS AND DISCUSSIONS

This chapter deals with analysis of the rainfall data, the measures suggested for land and water management plan, land allocated to different crops by judiciously utilising the natural resources with the help of multi-objective approach. Multi-objective watershed plan with six objectives is studied and finally a compromise solution is obtained using the step method. The details of the objective functions with constraints are given in chapter IV. The results of the study are discussed in following paragraphs.

5.1 Rainfall analysis

In the proposed multi-objective model, the assumption was that water requirement in kharif was met from rainfall and water requirement in rabi season was met from water harvesting structures. So the water available from the rainfall at different probability level was estimated. The monthly rainfall data of 29 years were collected. The collected data was tested with different probability distribution functions, in order to find out the best fit probability distribution function. The probability distribution functions considered during the study were Normal distribution, Log normal distribution, Gumbel maximum, Log Pearson type-III and Weibull distribution. The different probability distribution functions along with their formulae are discussed in 4.1.13. The rainfall data was analyzed using 'FLOOD' software. The best fit function was determined basing upon chi-square goodness of fit test. The probability function, which has least mean error, was selected as best fit distribution. The distribution function best fit for different months along with their RMSE value and mean error are given in table 5.1.

After that, the rainfall values at different probability level were calculated, using the same 'FLOOD' software. Monthly variation of rainfall at different probability levels were estimated and are given in table 5.2. The rainfall values at different probability level are shown graphically in fig 5.1 to 5.3.

Table 5.1 Best fit probability distribution function for different months.

Month	Best fit distribution	Corresponding RMSE value	Corresponding Mean error
January	Log Pearson type-III	0.04204	0.03591
February	Gumbel max.	0.05128	0.0357
March	Log Pearson type-III	0.03747	0.03043
April	Weibull	0.03763	0.02864
May	Log normal	0.02796	0.0221
June	Log Pearson type-III	0.02643	0.02243
July	Gumbel max.	0.03483	0.02646
August	Weibull	0.03961	0.03442
September	Gumbel max.	0.05466	0.04518
October	Log normal	0.04245	0.03711
November	Log pearson type-III	0.03474	0.02855
December	Log pearson type-III	0.06191	0.05398

Table 5.2 Expected month wise rainfall (mm) at different probability levels

	Probability level (%)								
Month	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**
Jan	-	-	-	-	-	6.78	15.33	27.97	50.62
Feb	0	0	0	11.08	19.30	27.02	35.38	45.76	61.80
Mar	0	0.69	3.11	6.32	10.78	17.17	26.95	43.72	80.50
Apr	3.02	7.80	13.12	19.18	26.28	34.89	45.90	61.31	87.39
May	20.54	30.27	40.04	50.84	63.57	79.49	100.96	133.56	196.96
Jun	108.70	129.34	146.94	164.11	182.17	202.46	227.05	260.13	315.19
Jul	167.57	205.63	236.48	265.50	295.16	327.60	365.78	415.62	495.38
Aug	193.76	247.35	288.13	323.86	357.68	391.68	428.08	470.48	528.64
Sep	126.75	156.72	181.01	203.85	227.21	252.74	282.80	322.04	384.84
Oct	40.18	57.36	74.14	92.33	113.34	139.14	173.28	224.04	320.00
Nov	0	0	1.60	4.62	9.43	16.92	28.94	49.96	95.21
Dec	0	0	0	0	0	0	3.81	8.04	15.93

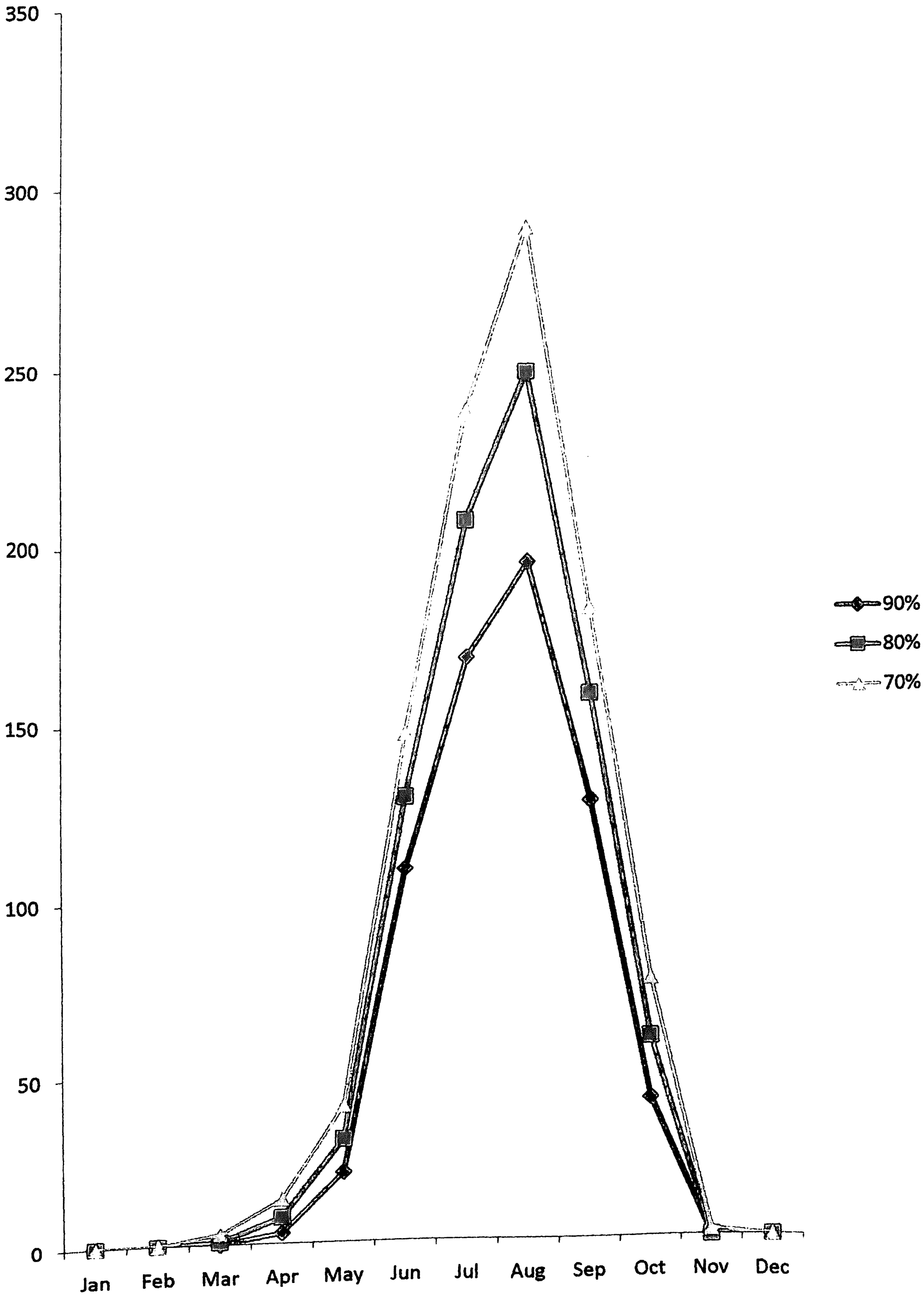

Fig 5.1 Monthly variation of rainfall at 90%, 80% and 70% probability levels

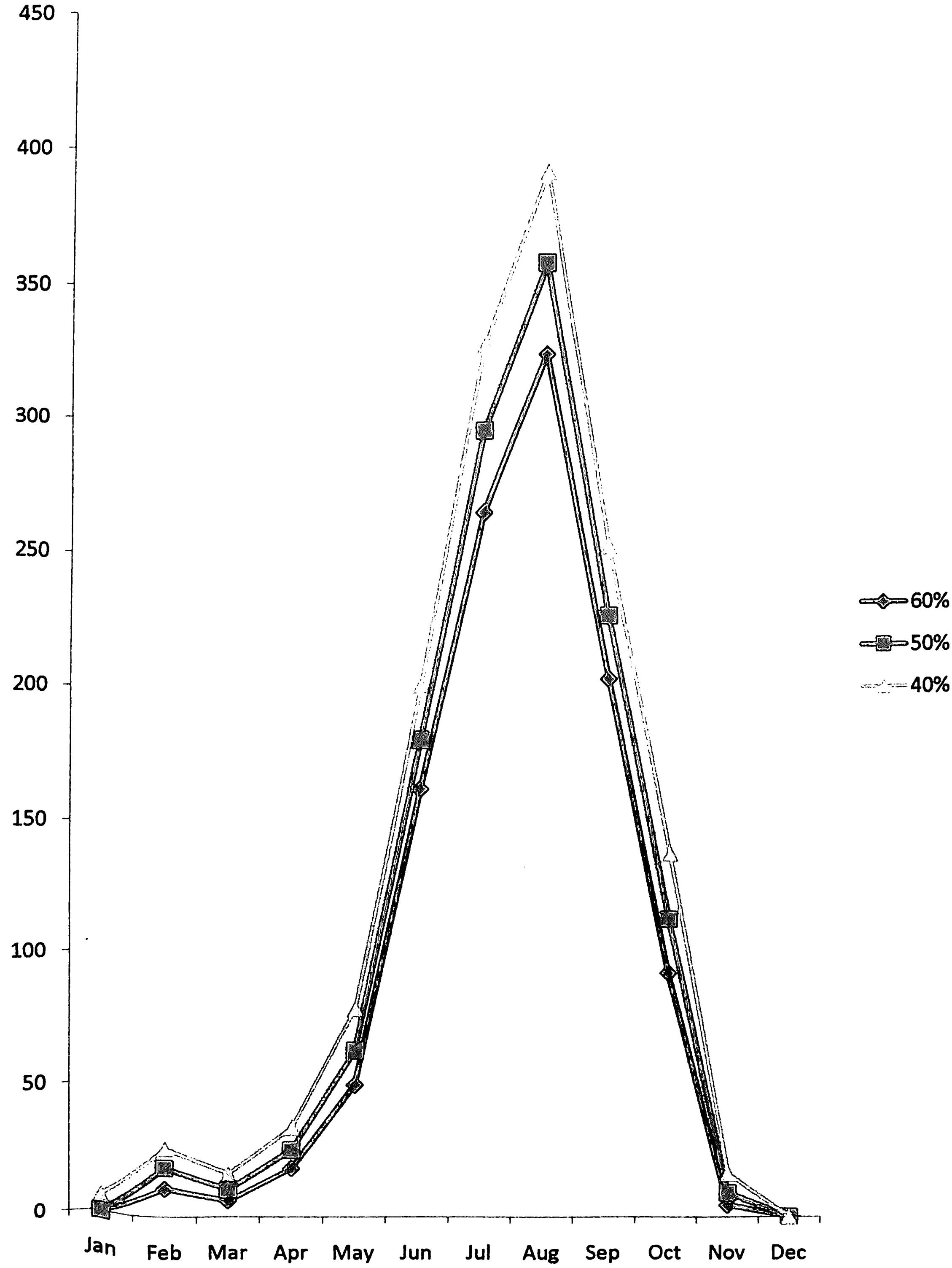

Fig 5.2 Monthly variation of rainfall at 60%, 50% and 40% probability levels

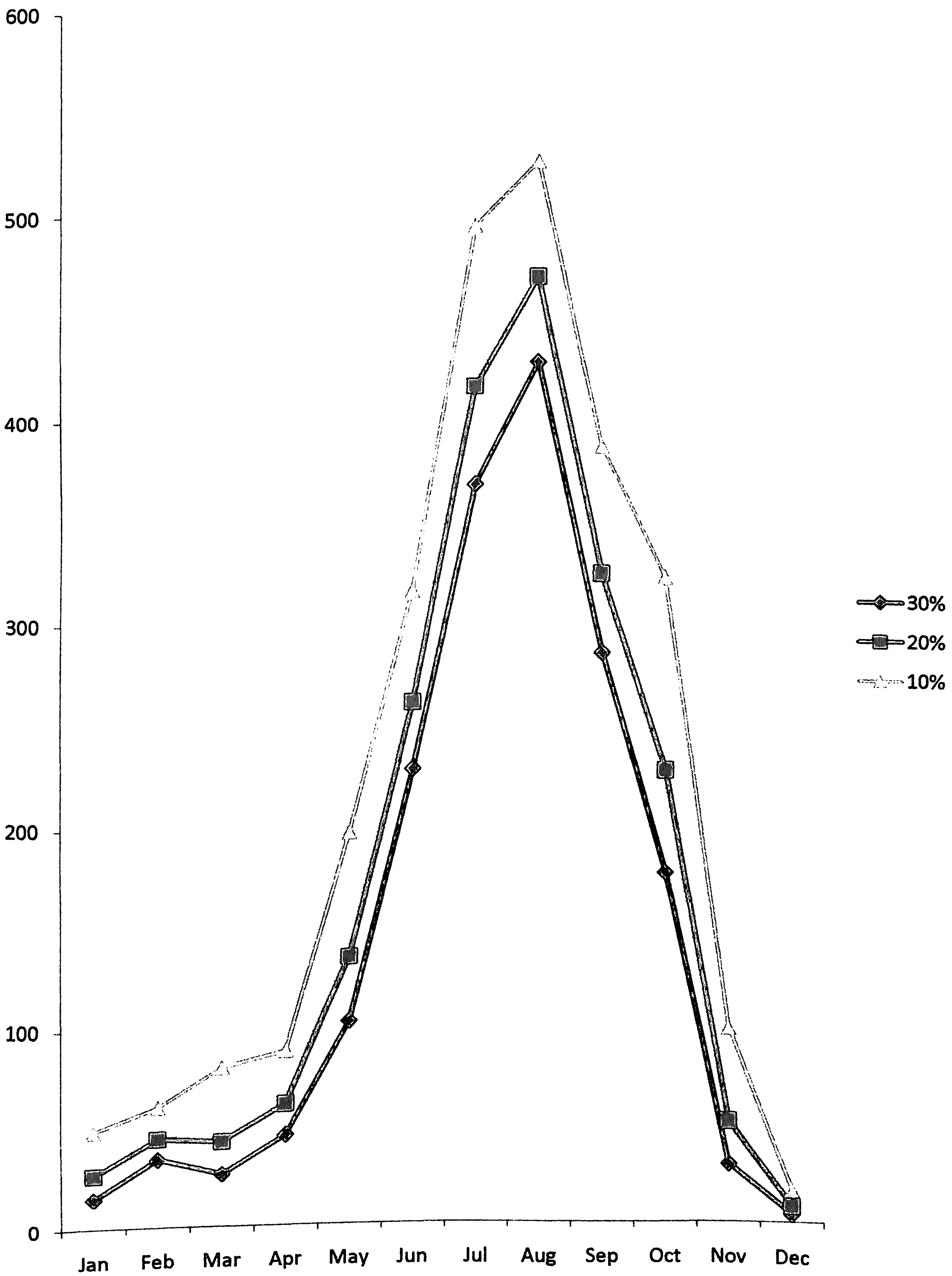

Fig 5.3 Monthly variation of rainfall at 30%, 20% and 10% probability levels

5.2 Watershed treatments

To conserve the basic resources i.e. land and water of the watershed and also to increase the productivity in watershed, different treatment practices are proposed.

5.2.1 Cultivation practices for different slope groups.

The slope of the culturable lands of watershed varies between0 to 5%. The degraded forests need renovation and afforestation, in wastelands and gochars. The grass lands needs controlled grazing. In the culturable wasteland some portion may be under plantation and some portion under fodder crop.

The proposed cultivation practices are presented in table 5.3

Table 5.3 Suggested cultivation practices

Slope group (%)	**Area(ha)**	**Proposed cultivation practices**
0-1	100.99	Any crop with proper crop rotation and green manuring to maintain soil fertility.
1-3	160.06	Some specified low duty crops with agronomical measures such as strip cropping and contour farming.
3-5	145.60	Grass land and forestry with controlled grazing and limited cutting of forestry trees.

Along with these measures, crop rotation and improved varieties of different crops should be grown in that watershed. The improved varieties grown in that watershed should be suitable for the climate of the watershed. The improved varieties not only increase the yield but also farmers will be more benefited from the crops.

In the watershed management programme some crop rotation and improved varieties of the crops are taken. The suggested crops along with their varieties are given in table 5.4.

Table 5.4 Suggested crop varieties for different types of land.

Sl No.	Type of land	Crops suggested	Varieties	Follow-up crop
1.	Upland(Plain)	Paddy	Hira Parijat Kalinga-III	Niger Mustard
		Maize	Ganga-5 Decan-103	Niger Mustard
		Maize + Arhar	Ganga-5 UPAS-120	Mustard Sesamum
2.	Slopy agricultural land(contoured lands)	Mixed cropping	Maize/jawar Arhar + cowpea Arhar + Biri + Ragi	Mustard Sesamum
3.	Medium land	Paddy	Annapurna Cavery Parijat	Mung Mustard
		Arhar + Ragi	UPAS-120 Dibyasinga	Mung Mustard
4.	Low land	Paddy	Swarna Jagannath Jajati	Sesamum Mung

5.3 Land allocation plan using multi-objective approach

The multi-objective functions along with the various constraints were formulated. The equations are solved and analyzed by an interactive technique i.e. step method. The optimal solution is obtained for each objective function considering the resource constraints and requirement of the people. From the sets of optimal solution, a compromise solution for allocation of land under different crops and plantation is found out in kharif and rabi seasons.

5.3.1 Optimal solutions for the objective functions

The six objective functions along with thirty eight constraints were solved for maximisation separately using Quick Statistical Business (QSB) software. There is a feasible solution for each objective function. From the feasible solution the optimal solution for each function is obtained considering the other alternative optima which are non-inferior. The set of optimal solution is given in table 5.5.

Table 5.5 Optimal value under different objective functions

Crop variables	Area allocation under different objectives in ha					
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
x_{11}	0	0	0	0	0	0
x_{12}	182.04	187.49	100.08	155.43	175.52	100.08
x_{13}	20.12	20.12	20.12	20.12	20.12	20.12
x_{14}	52.25	17.825	17.82	17.83	52.25	17.82
x_{15}	10	10	10	10.00	10.00	10
x_{16}	24.25	24.25	24.25	24.25	24.25	24.25
x_{17}	87.75	110.14	110.14	110.14	110.14	87.75
x_{21}	20.12	20.12	20.12	20.12	20.12	20.12
x_{22}	184.71	11.46	11.46	11.47	184.71	11.46
x_{23}	15.14	15.14	15.14	15.14	15.14	15.14
x_{24}	24.25	24.25	24.25	24.25	24.25	24.25
x_{25}	87.75	110.14	110.14	110.14	110.14	87.75
x_8	40.39	40.39	40.39	40.39	40.39	40.39
Optimal value of objective	**Z_1=1262 tons**	**Z_2=4012 tons**	**Z_3=2202 tons**	**Z_4=Rs.5387503/-**	**Z_5=102942 Mandays**	**Z_6=121.17 ha-m**

5.3.2 Pay-off table

After finding out six set of optimal solution they are to be put in the expression for the objective functions. In the construction of pay-off table, the rows correspond to the optimal solution and the columns are labelled by the objectives.

Table-5.6 Pay-off table

Objective function → / Optimal solution ↓	$Z_1(x)$ ton	$Z_2(x)$ ton	$Z_3(x)$ ton	$Z_4(x)$ in Rs.	$Z_5(x)$ Mandays	$Z_6(x)$ ha-m
X_1^*	1262	3819	1755	8591125	95520	121.17
X_2	882	4012	2202	5746614	81690	121.17
X_3	602	3392	2202	4767348	70151	121.17
X_4	779	3785	2202	5387503	77457	121.17
X_5	1241	3996	2202	8785756	102942	121.17
X_6	602	3168	1755	4499564	61866	121.17

X_1^* - optimal solution set for objective function Z_1 i.e. (x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{21}, x_{22}, x_{23}, x_{24}, x_{25}, x_{8}.)

The coefficient of different objective functions are selected .From the coefficient of objective functions the value of $[\sum (C_j^k)^2]^{\frac{-1}{2}}$ (normalising term) is calculated and given at table 5.7.

Table 5.7 Calculation of normalising term $[\sum (C_j^k)^2]^{-\frac{1}{2}}$

Objective Function	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_8	$\sum (C_j^k)^2$	$[\sum (C_j^k)^2]^{-\frac{1}{2}}$
Z_1	2.6	3.2	3.7	4	1.8	0	0	4.3	1.5	1	0	0	0	71.67	0.1181
Z_2	6.5	7.1	8	2	0	30	7	8.5	0	0	20	3	0	1590.91	0.0250
Z_3	0	0	0	0	0	0	10	0	0	0	0	10	0	200	0.0707
Z_4	9671	11202	11838	15618	48673	10800	6980	16916	15213	24740	7200	4980	0	4343788967	0.0000151
Z_5	102	132	165	160	93	60	185	165	100	65	90	185	0	210902	0.00217
Z_6	0	0	0	0	0	0	0	0	0	0	0	0	3	9	0.3333

After calculation of the normalising term the value of scaling term $\frac{M_k - n_k}{M_k}$ is calculated, and the multiplication of the normalising term with scaling term will give the value of 'α_k'. The calculation of 'α_k' is given in table 5.8.

Table-5.8 Calculation of 'α_k'

Objective function	Maximum value of objective function M_k	Minimum value of objective function n_k	$\frac{M_k - n_k}{M_k}$	$[\sum (C_j^k)^2]^{-\frac{1}{2}}$	α_k
$Z_1(x)$	1262	602	0.522	0.1181	0.0617
$Z_2(x)$	4012	3168	0.210	0.0250	0.0052
$Z_3(x)$	2202	1755	0.202	0.0707	0.0143
$Z_4(x)$	8785756	4499564	0.487	0.0000151	0.0000073
$Z_5(x)$	102942	61866	0.399	0.00217	0.000878
$Z_6(x)$	121.17	121.17	0	0.3333	0

From the values of 'α_k' the values of initial set of weights (W_k) are calculated and tabulated in table 5.9.

Table 5.9 Calculation of 'W_k' (Initial set of weights)

Objective Function	Value of α_k	Value of 'W_k'($W_k = \frac{\alpha_k}{\sum \alpha_k}$)
$Z_1(x)$	0.0617	0.751
$Z_2(x)$	0.0052	0.063
$Z_3(x)$	0.0143	0.174
$Z_4(x)$	0.0000073	0.000088
$Z_5(x)$	0.000878	0.01069
$Z_6(x)$	0	0
	$\sum \alpha_k = 0.08208$	**$\sum W_k = 0.999 \approx 1$**

The above values of weights are used to derive the first compromise solution, by minimising the deviation from the optimal solution. The objectives having largest difference between maximum and minimum value of objective functions are assigned with larger weights.

From the above calculation the sixth objective having weight equal to zero, has already attain the optimal value. There is no necessity for calculation of compromise solution for this objective.

5.3.3 First compromise solution

Simultaneous optimisation of all the six objectives is not possible, that is why the compromise solution is obtained by the initial set of weights as calculated in table No. 5.9.

From the table 5.9 it is clear that the objectives Z_1, Z_2 and Z_3 exhibit larger relative variation in their maximum and minimum values. Therefore larger weights are assigned to these objective functions. The compromise solution is obtained for objectives one to five except objective No. 6.

The first compromise solution will be obtained by solving the following linear programming.

Minimise the deviation'd' **5.1**

Subjected to –

$W_k [M_k - Z_k(x)] - d \leq 0$

or, $W_k M_k - W_k Z_k(x) - d \leq 0$

or, $W_k Z_k(x) + d - W_k M_k \geq 0$

or, $W_k Z_k(x) + d \geq W_k M_k$ **5.2**

(This is the required constraint equation)

$d \geq 0$ **5.3**

Now the requisite equations are

Minimise'd' **5.4**

S. t.

$$0.751\,(2.6\,x_{11} + 3.2\,x_{12} + 3.7\,x_{13} + 4\,x_{14} + 1.8\,x_{15} + 4.3\,x_{21} + 1.5\,x_{22} + x_{23}) + d \geq 0.751 \times 1262$$

$$\text{or, } 1.952\,x_{11} + 2.403\,x_{12} + 2.778\,x_{13} + 3.004\,x_{14} + 1.351\,x_{15} + 3.229\,x_{21} + 1.126\,x_{22} + x_{23} + d \geq 947 \quad \text{.......... 5.5}$$

$$0.063\,(6.5\,x_{11} + 7.1\,x_{12} + 8\,x_{13} + 2\,x_{14} + 30\,x_{16} + 7\,x_{17} + 8.5\,x_{21} + 20x_{24} + 3\,x_{25}) + d \geq 0.063 \times 4012$$

$$\text{or, } 0.409\,x_{11} + 0.447\,x_{12} + 0.504\,x_{13} + 0.126\,x_{14} + 1.89\,x_{16} + 0.441\,x_{17} + 0.535\,x_{21} + 1.26\,x_{24} + 0.189\,x_{25} + d \geq 252 \quad \text{........... 5.6}$$

$$0.174(10\,x_{17} + 10\,x_{25}) + d \geq 0.174 \times 2202$$

$$\text{or, } 1.74\,x_{17} + 1.74\,x_{25} + d \geq 383 \quad \text{.......... 5.7}$$

$$0.000088\,(9671\,x_{11} + 11202\,x_{12} + 11838\,x_{13} + 15618\,x_{14} + 48673\,x_{15} + 10800\,x_{16} + 6980\,x_{17} + 16916\,x_{21} + 15213\,x_{22} + 24740\,x_{23} + 7200\,x_{24} + 4980\,x_{25}) + d \geq 0.000088 \times 8785756$$

$$\text{or, } 0.851\,x_{11} + 0.985\,x_{12} + 1.041\,x_{13} + 1.374\,x_{14} + 4.283\,x_{15} + 0.950\,x_{16} + 0.614\,x_{17} + 1.488\,x_{21} + 1.338\,x_{22} + 2.177\,x_{23} + 0.633\,x_{24} + 0.438\,x_{25} + d \geq 773 \quad \text{........... 5.8}$$

$$0.01069(102\,x_{11} + 132\,x_{12} + 165\,x_{13} + 160\,x_{14} + 93\,x_{15} + 60\,x_{16} + 185x_{17} + 165\,x_{21} + 100\,x_{22} + 65\,x_{23} + 90\,x_{24} + 185\,x_{25}) + d \geq 0.01069 \times 102942$$

$$\text{or, } 1.090\,x_{11} + 1.411\,x_{12} + 1.763\,x_{13} + 1.710\,x_{14} + 0.994\,x_{15} + 0.641\,x_{16} + 1.977x_{17} + 1.763\,x_{21} + 1.069\,x_{22} + 0.694\,x_{23} + 0.962\,x_{24} + 1.977\,x_{25} + d \geq 1100 \quad \text{........... 5.9}$$

$$d \geq 0 \quad \text{.........5.10}$$

Solving equations 5.4 to 5.10 the first compromise solution set is obtained. These compromise solution set gives new function values. The percentage difference between these compromise value and optimum value is calculated. These values will help in deciding the achievement levels and trade off between different objectives. The solution of the above equation gives the value of the variable as

x_{11}	=	0	x_{21}	=	20.12
x_{12}	=	175.52	x_{22}	=	184.71
x_{13}	=	20.12	x_{23}	=	15.14
x_{14}	=	52.25	x_{24}	=	24.25
x_{15}	=	10.00	x_{25}	=	110.14
x_{16}	=	24.25	x_{8}	=	40.39
x_{17}	=	110.14	d	=	4.6

Putting these values, the 1st compromise solution for different objectives is obtained. The differences in percentage of 1st compromise solution from the maximum value are given in table 5.10.

Table 5.10 First compromise solution

Objective function	Maximum value	First compromise solution	% difference from maximum value
$Z_1(x)$	1262	1241*	1.66
$Z_2(x)$	4012	3996*	0.39
$Z_3(x)$	2202	2202*	0
$Z_4(x)$	8785756	8785756*	0
$Z_5(x)$	102942	102942*	0
$Z_6(x)$	121.17	121.17*	0

*Satisfactorily achieved objectives

If the percentage difference between first compromise solution and maximum value is within 5% then the objective function is considered to be satisfactorily achieved.

From the above table it is observed that the objectives 3, 4, 5 and 6 have been satisfactorily achieved the maximum value whereas objectives 1 and 2 are within the permissible range. Decision maker (here the author) is satisfied with this solution, so no need of further iteration.

So from the above solution, the DM believed that if the land is put under the following crops and plantation activities taken with desired inputs, the achievement levels will be satisfactorily.

Table 5.11 Land allocation proposals for the watershed

Kharif	
1.Paddy (medium land)	175.52ha
2.Paddy(low land)	20.12ha
3.Maize	52.25ha
4.Arhar	10.00ha
5.Hybrid napier bajra grass	24.25ha
6.Subabool	110.14ha
Total	**392.28ha**
Rabi	
1.Paddy(low land)	20.12ha
2.Mustard	184.71ha
3.Mung	15.14ha
4.Hybrid napier bajra grass	24.25ha
5.Subabool	110.14ha
Total	**354.36ha**
Grand total	**746.64ha**

Achievement level of the selected objectives

1. Food production = 1241 ton
2. Fodder production = 4012 ton
3. Fuel wood production = 2202 ton
4. Net income from field crops = Rs. 87,85,756
5. Labour employment generation =102942 Mandays
6. Run off volume augmentation =121.17 ha-m

5.3.4 Food grain production

Food grain production from different crops based on the feasible land allocation plan is given in table 5.12. It is found that the percent increase of food grains of paddy and maize as per land allocation plan is more than 100 percent and the highest being obtained from the mustard(1510.46 percent), whereas the other crops just meeting the requirement of the people of the watershed.

Table 5.12 Food grain productions in the watershed

Sl No.	Crop	Food grain requirement in the watershed(ton)	Food grain achieved in the watershed(ton)	Percent increase over requirement
1.	Paddy	179	722	303.35
2.	Maize	71.3	209	193.12
3.	Arhar	18	18	-
4.	Mustard	17.2	277	1510.46
5.	Mung	15.14	15.14	-
	Total	300.64	1241.14	312.83

The result of requirement vs. achievement of different food grains inside the watershed is shown graphically in fig No. 5.4.

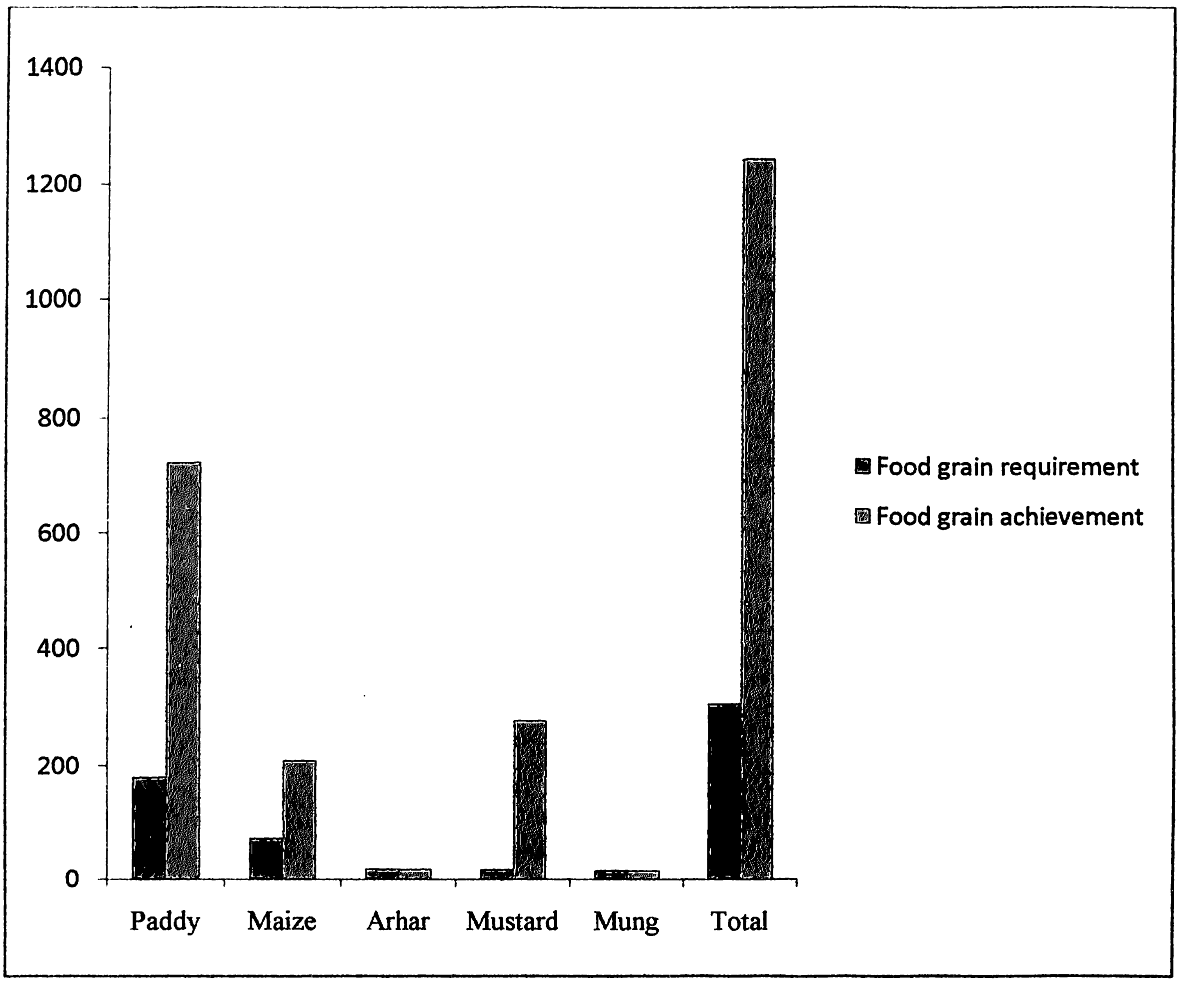

Fig 5.4. Food grain requirement vs. Food grain achievement

5.3.4.1 Achievement of calorie and protein

The total calorie and protein available from different field crops as per land allocation plan are estimated and the values are presented in table 5.13. The table showed that the calorie and protein requirements are sufficiently more than the requirements for the people of the watershed.

Table 5.13 Achievement of calorie and protein

Sl No.	Nutrients	Nutrient requirement in the watershed	Total nutrient achievement in the watershed	Percent increase over requirement
1.	Calorie	1119378.00Kcal	4129907.00Kcal	268.94
2.	Protein	25556.00kg	130430.00kg	410.36

The result of calorie requirement for the people of the watershed vs. calorie achievement is shown graphically in fig 5.5. and the protein requirement vs. achievement is given in fig 5.6.

5.3.5 Fodder and fuel wood production in the watershed

The fodder and fuel wood production from different crop activities are presented in table 5.14.

Table 5.14 Fodder and fuel wood achievement in the watershed

Sl No.	Materials	Requirement (tons)	Dry fodder achieved (tons)	Green fodder achieved (tons)	Fuel wood Achieved (tons)	Total	Percent Increase Over require-ment
1.	Fodder	1940	1682.67	2313.90		3996.57	106
2.	Fuel wood	1755	-	-	2202	2202	25.47

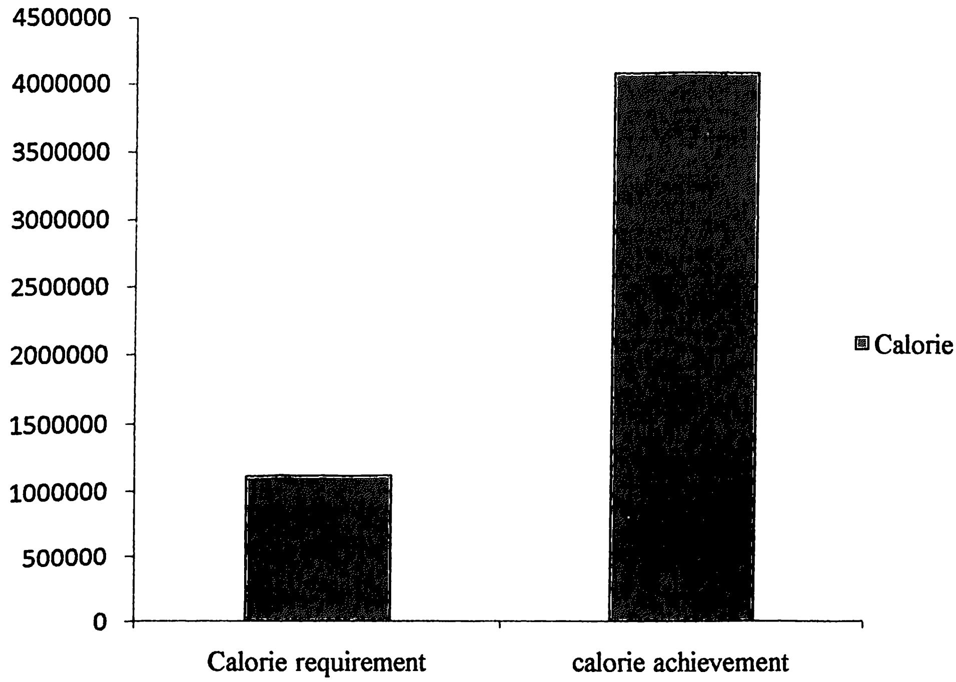

Fig. 5.5 Calorie requirement vs. Calorie achievement

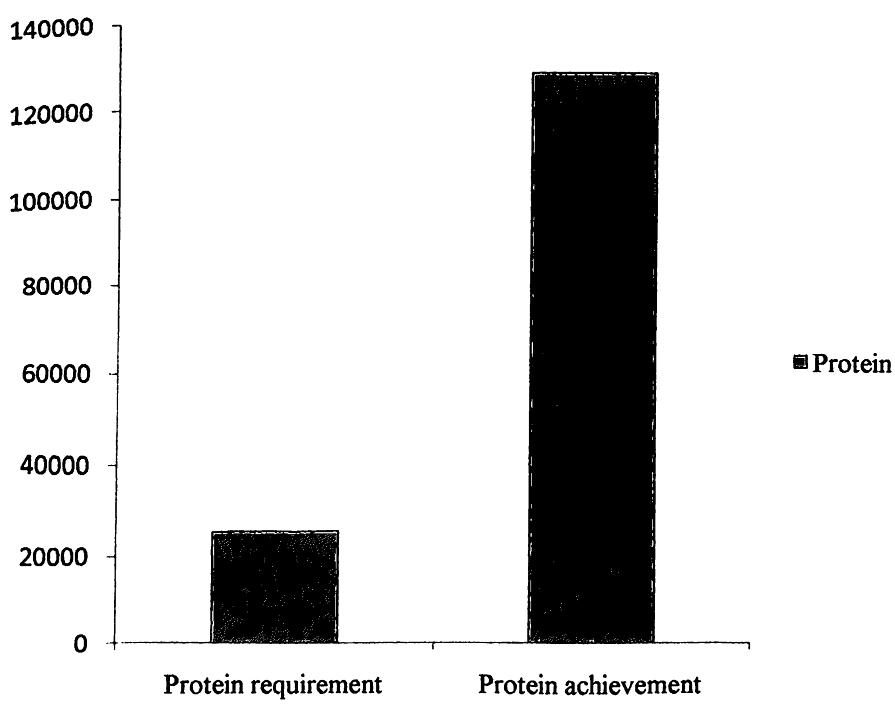

Fig 5.6 Protein requirement vs. Protein Achievement

The fodder requirement vs. achievement is shown graphically in fig 5.7 and fuel wood requirement vs. achievement is shown in fig 5.8

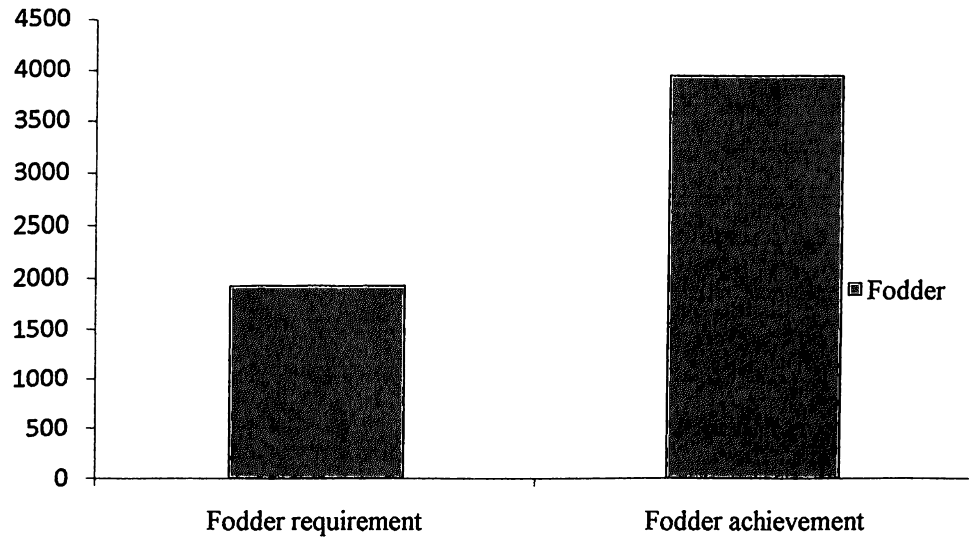

Fig 5.7 Fodder requirement vs. Fodder achievement

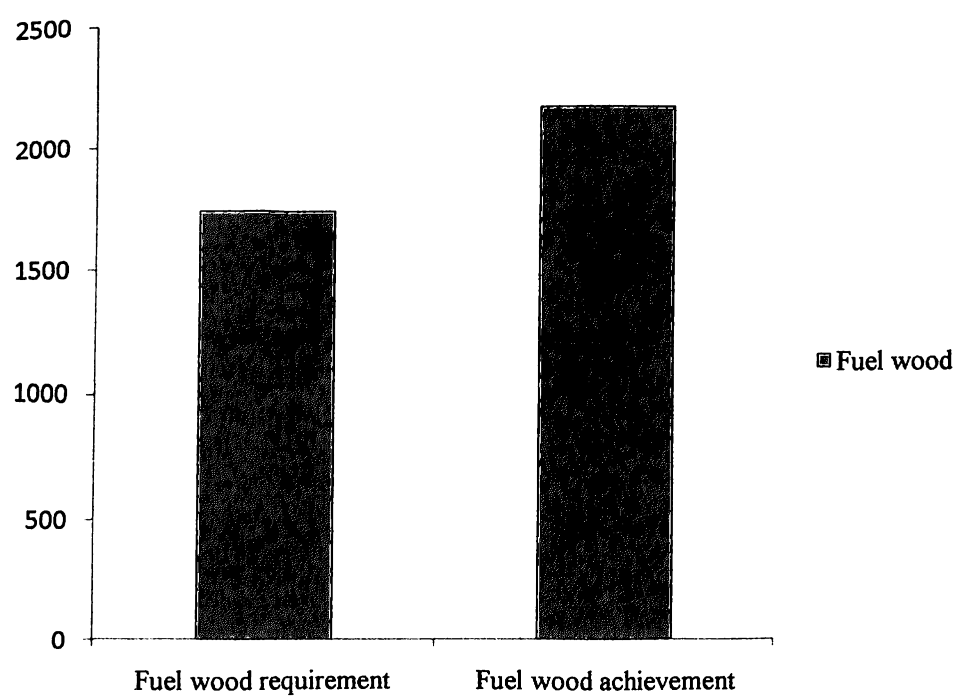

Fig 5.8 Fuel wood requirement vs. Fuel wood achievement

5.3.6 Economics of the proposed planning

The compromised land allocation plan obtained for different crops was found out. The economics of the suggested crops in compromised land allocation planning is given in table 5.15.

Table5.15 Economics of the suggested crops in compromised land allocation planning

Sl No.	Crop	Area Allocated (ha)	Cost of Produce Per 'ha' in Rs.	Total cost of produce (Rs.)	Cost per 'ha' in Rs.	Total cost of production (Rs.)	Net benefit	B-C ratio
1.	**Kharif**							
1.	Medium land paddy	175.52	49020	8603990.40	37818	6637815.36	1966175.04	
2.	Low land paddy	20.12	56470	1136176.40	44632	897995.84	238180.56	
3.	maize	52.25	53400	2790150.00	37782	1974109.50	816040.50	
4.	arhar	10.00	77400	774000.00	28727	287270.00	486730.00	
5.	hybrid napier bajra grass	24.25	45000	1091250.00	34200	829350.00	261900.00	
6.	subabool	110.14	43250	4763555.00	36270	3994777.80	768777.20	
	Total	**392.28**		**19159121.80**		**14621318.50**	**4537803.30**	**1.31**
2	**Rabi**							
1.	Low land paddy	20.12	64830	1304379.60	47914	964029.68	340349.92	
2.	mustard	184.71	45000	8311950.00	29787	5501956.77	2809993.23	
3.	mung	15.14	45000	681300.00	20260	306736.40	374563.60	
4.	hybrid napier bajra grass	24.25	30000	727500.00	22800	552900.00	174600.00	
5.	subabool	110.14	41750	4598345.00	36770	4049847.80	548497.20	
	Total	**354.36**		**15623474.6**		**11375470.65**	**4248003.95**	**1.37**
	Grand total (Kharif + Rabi)	**746.64**		**34782596.40**		**25996789.15**	**8785807.25**	**1.33**

5.3.6.1 Comparison of economics of existing and proposed planning

A comparative study between the existing land allocation plan and the proposed plan is given in table 5.16.The benefit-cost ratio for the proposed plan is found to be 1.33 where for the existing plan, it is 1.08. Similarly the cropping intensity for the proposed planning is 163.37%, with comparison to 108.81% for the existing one. The benefit for the proposed planning is Rs. 34782596.40 as compared to Rs. 12234250. The benefit-cost ratio of the proposed plan is 1.33, which indicates the economic viability of the programme.

Table 5.16 Comparison of economics of the existing and proposed land allocation planning

Plans	Investment on farming system(10^3Rs.)	Return (10^3 Rs.)	Benefit-cost ratio	Percentage of area cultivated during		Cropping intensity (%)
				Kharif	Rabi	
Existing	11328.009	12234.250	1.08	69.21	39.60	108.81
Proposed	25996.789	34782.596	1.33	85.83	77.54	163.37

5.3.7 Resource utilization pattern in compromise land allocation planning.

Watershed development activity is a multi disciplinary programme in which several objectives are to be fulfilled simultaneously. The comprehensive development of a basin is to make productive use of all its natural resources in a planned way for economic development and conservation of land and water resources. The resource utilisation pattern and net return for the compromise land allocation planning is given in table 5.17.

Table 5.17 **Resource utilisation pattern and Net return for the compromise land allocation planning**

Sl No.	Resource	Resource utilisation in the improved planning		
		Kharif	Rabi	Total
1.	Land	392.28 ha	354.36 ha	746.64ha
2.	Water	306 ha-m	116 ha-m	422ha-m
3.	Labour	57609 mandays	45333 mandays	102942mandays
4.	Total crop activities			
	1)Investment	Rs.14621318.50	Rs. 11375470.65	Rs. 25996789.15
	2)Benefit	Rs.19159121.80	Rs. 15623474.60	Rs. 34782596.40
	3)Net profit	Rs. 4537803.3 (1.31)	Rs. 4248003.95 (1.37)	Rs. 8785807.25 (1.33)

From the results obtained for maximisation of different objectives, maximisation of production of food, fodder, fuel wood is more compromising to the policies of the government, because government is interested in maximum production. Similarly the maximisation of benefit is beneficial to the farmers. Maximisation of labour employment is best suited to the unemployment status of the area and economic status of the watershed. It is left to the Govt. and the people of the watershed either to adopt compromise solution or one of the optimal solutions described earlier, as per their own option depending upon the situation.

Chapter-VI

SUMMARY & CONCLUSION

SUMMARY AND CONCLUSION

The present study aims at proper management of the Mandakini Balinala watershed No.-1, considering six basic objectives. The multi objective model comprises objectives like maximisation of food, fodder, fuel wood, net income generation from field crops, labour employment generation and runoff water augmentation. These objectives were solved under a set of 38 resource constraints and requirement of the people and the livestock in the watershed.

The management plan also includes some biological measures proposed for future development of the watershed. In biological measures, the management plan consists of proper agricultural inputs, improved varieties of crops, crop rotation and fertilizer management.

The multi objective mathematical model was formulated and the solution was obtained by one computer software package Quick Statistical Business software (QSB). The solution was analyzed with an interactive technique known as step method. By this method a compromised land allocation plan under different crops and plantation activities was obtained.

Basing on the research study the following conclusions are drawn.

1. Various biological measures have been suggested for the watershed depending upon the soil, slope and land capability of the area.
2. As watershed management involves multi-disciplinary activities with special objectives like food, fodder, fuel wood production, maximisation of net income from field crops etc. Multi objective approach is found to be suitable approach for watershed management programme.
3. Among different methods and interactive techniques, the step method is found to be best suited method to derive the compromise solution in watershed

management programme, because it can accommodate the problems encountered and is easy to understand.

4. The compromise solution developed will help the decision maker to generate new compromise solution by judging satisfactory objectives.

5. The optimal land allocation plan in ha for kharif and rabi season obtained was as follows.

Kharif		Rabi	
1.Paddy (medium land)	175.52ha	1.Paddy(low land)	20.12ha
2.Paddy(low land)	20.12ha	2.Mustard	184.71ha
3.Maize	52.25ha	3.Mung	15.14ha
4.Arhar	10.00ha	4.Hybrid napier bajra grass	24.25ha
5.Hybrid napier bajra grass	24.25ha	5.Subabool	110.14ha
6.Subabool	110.14ha		
Total	**392.28ha**	**Total**	**354.36ha**

6. Besides this the area under ponds is 40.39 ha.

7. The optimal value of different objectives obtained in the model is given below.

I.	Food production	=	1241 ton
II.	Fodder production	=	4012 ton
III.	Fuel wood production	=	2202 ton
IV.	Net income from field crops	=	Rs. 87,85,756
V.	Labour employment generation	=	102942 Mandays
VI.	Run off volume augmentation	=	121.17 ha-m

8. The cropping intensity of the proposed planning is found to be 163.37% against the existing cropping intensity of 108.81%

9. The cost economics of the crops suggested in the proposed planning has been calculated and it has been found that the total benefit is Rs. 34782596/- against the existing total benefit of Rs.12234250/-, which shows increase in total benefit of 184.30%.

10. The benefit-cost ratio of the proposed planning in kharif season is 1.31 and in rabi season, it is 1.37. The resultant benefit-cost ratio of the planning is 1.33, which shows the economic viability of the proposed programme.

11. The planning shows that, total land resources utilised in both the season is 746.64ha and total water resources utilised in both the season is 422ha-m.

12. The results obtained from maximisation of production and maximisation of income appears to be more compromising and beneficial to government and to the farmers as the farmer is interested in maximum income from his crops and government has the aim for maximum production of food grains and fodder from unit land area.

It is hoped that this compromise land allocation plan along with suggested land treatment measures, if implemented will help to boost the standard of living of the people of the watershed.

SUGGESTIONS FOR FUTURE WORK

The following are the suggestions for future work that may be carried out in related research work.

1. Multi objective model developed here can be compared with other methods like goal programming, fuzzy set programming, HSJ method, weighting method for watershed management programmes.
2. Interactive approach (step method) studied here can be applied to other water resources related problems.
3. A software for step method may be developed in the solution of multi-objective problems.
4. Similar management plans may be prepared for other watershed.
5. PRA (Participatory Rural Appraisal) technique and rėmote sensing technique may be applied to select the site for different soil and water conservation structures.

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APPENDICES

APPENDIX-A.I

CALCULATION OF FOOD REQUIREMENT

Per capita food requirement

$$F_n = \frac{MF_nN_m + FF_nN_f + CF_nN_c}{\text{Total population}}$$

MF_n, FF_n, CF_n are the food requirements of male, female and children respectively in gms/day. N_m, N_f, N_c are the number of male, female and children respectively.

Total food requirement in quintals = $F_n \times$ total population $\times$ 365

1. Paddy, $F_n = \dfrac{450\times562+400\times491+300\times92}{1145}$ =416.50 gms/person/day

   Paddy requirement for the total watershed = $\dfrac{416.50\times1145\times365}{1000000}$ =174 ton

2. Maize, $F_n = \dfrac{200\times562+150\times491+100\times92}{1145}$ = 170.52 gms/person/day

   Maize requirement of the watershed = $\dfrac{170.52\times1145\times365}{1000000}$ =71.3 tons

3. Arhar, $F_n = \dfrac{50\times562+40\times491+25\times92}{1145}$ = 43.70 gms/person/day

   Arhar requirement of the watershed = $\dfrac{43.70\times1145\times365}{1000000}$ = 18 tons

4. Mustard, $F_n = \dfrac{50\times562+35\times491+20\times92}{1145}$ = 41.15 gms/person/day

   Mustard requirement of the watershed = $\dfrac{41.15\times1145\times365}{1000000}$ = 17.2 tons

5. Mung, $F_n = \dfrac{40\times562+35\times491+20\times92}{1145}$ = 36.24 gms/person/day

   Mung requirement of the watershed = $\dfrac{36.24\times1145\times365}{1000000}$ =15.14 tons

SUMMARY

Sl No.	Food requirement	Estimated quantity(tons)
1.	Paddy	174
2.	Maize	71.3
3.	Arhar	18
4.	Mustard	17.2
5.	Mung	15.14

APPENDIX- A.II
CALCULATION OF NUTRITIONAL REQUIREMENT

1. **Calorie Need:**

Calorie need/person/day(C)

$$C = \frac{C_m \times N_m + C_f \times N_f + C_c \times N_c}{\text{Total population}}$$

Where C_m, C_f and C_c are the calorie need of the male, female and children respectively. Total calorie need of the people (CP)

$$CP = C \times \text{population} \times \text{days}$$

$$C = \frac{3000 \times 562 + 2400 \times 491 + 2200 \times 92}{1145} = 2678.42 \text{ cal/person/day}$$

Total calorie need of the people of the watershed = 2678.42×1145×365/1000

= 1119378 Kcal

2. **Protein need:**

Protein need/person/day (P)

$$P = \frac{P_m \times N_m + P_f \times N_f + P_c \times N_c}{\text{Total population}}$$

Where P_m, P_f and P_c are the protein need of the male, female and children respectively. Total protein need of the people (PP)

$$PP = P \times \text{population} \times \text{days}$$

$$P = \frac{70 \times 562 + 55 \times 491 + 40 \times 92}{1145} = 61.15 \text{ gms/person/day}$$

Total protein need of the people of the watershed = 61.15 × 1145 × 365/1000=25556 kg

APPENDIX-A.III

CALCULATION OF FODDER REQUIREMENT OF LIVESTOCKS IN THE WATERSHED

Sl No.	Animals	Body weight of animal(qt)	No. of animals	Feed rate per qt of body weight (kg/day)	Fodder requirement (kg/day)
1.	Bullock	4.5	94	3.0	1269
2.	Cow	4.0	103	2.7	1112.4
3.	Buffaloes	6.0	9	3.5	189
4.	Sheep	0.7	25	2.5	43.75
5.	Goat	0.45	48	2.0	43.92
	Total				**2658.07 kg/day**

Total fodder requirement in a year = 2658.07 × 365/1000 = 970 ton (each green and dry fodder)

APPENDIX- A. IV

CALCULATION OF FUEL WOOD REQUIREMENT

Total numbers of families in the watershed as per the village are given below

Sl No.	Name of the village	No. of Family
1.	Akhupadar	63
2.	Atharang	132
	Total	195

Assuming the average family consumption of fuel wood as 750 kg/family/month, the total annual fuel wood requirement is

$$= 750 \times 195 \times 12/1000 = 1755 \text{ ton}$$

APPENDIX- A. V

NUTRIENTS AVAILABLE PER ha OF LAND UNDER DIFFERENT CROPS

A. Protein

Sl No.	Crop	Yield(ton/ha)	Protein available	
			gm/kg	kg/ha
i.	**Kharif**			
1.	Paddy-I	2.6	68	177
2.	Paddy-II	3.2	68	218
3.	Paddy-III	3.7	68	252
4.	Maize	4.0	85	340
5.	Arhar	1.8	245	441
ii.	**Rabi**			
1.	Paddy-III	4.3	68	292
2.	Mustard	1.5	200	300
3.	Mung	1.0	240	240

B. Calorie

Sl No.	Crop	Yield(ton/ha)	Calorie available	
			Cal/kg	Kcal/ha
i.	**Kharif**			
1.	Paddy-I	2.6	3450	8970
2.	Paddy-II	3.2	3450	11040
3.	Paddy-III	3.7	3450	12765
4.	Maize	4.0	3430	13720
5.	Arhar	1.8	3480	6264
ii.	**Rabi**			
1.	Paddy-III	4.3	3450	14835
2.	Mustard	1.5	2917	4376
3.	Mung	1.0	3240	3240

APPENDIX- B.I

COST OF CULTIVATION AND NET RETURN OF PADDY (UP LAND)-KHARIF (BROADCASTED)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	80 kg/ha	Rs. 15/kg	1200.00
2.	Cost of seed treating chemical	2gm/kg	Rs. 1.60/gm	256.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	60kg	Rs.12.70/kg	762.00
ii)	P_2O_5	30kg	Rs.37.50/kg	1125.00
iii)	K_2O	30kg	Rs. 20.80/kg	624.00
5.	Micro nutrient			500.00
6.	Cost of PP chemicals	2 Nos.	Rs. 400/No.	800.00
7.	Weedicide	1kg	Rs. 400/kg	400.00
8.	Tractor operation	11 hrs.	Rs. 400/hr	4400.00
9.	Bullock labour	5 Nos.	Rs. 150/Nos.	750.00
10.	Human labour	102 MD	Rs. 150/MD	15300.00
11.	Irrigation	-	-	-
12.	Total investment			29117.00
13.	Interest on investment	6 month	12%	1747.00
14.	Land revenue			25.00
15.	Total cost of cultivation			30889.00
16.	Total yield			
	Grain	26 qt	Rs. 1310/qt	34060.00
	Straw	65 qt	Rs. 100/qt	6500.00
17.	Gross income			40560.00
18.	Net return(Sl No.17-Sl No.15)			**9671.00**

APPENDIX- B.II

COST OF CULTIVATION AND NET RETURN OF PADDY (MEDIUM LAND)- KHARIF (BROADCASTED)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	80 kg/ha	Rs. 15/kg	1200.00
2.	Cost of seed treating chemical	2gm/kg	Rs. 1.60/gm	256.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	80kg	Rs.12.70/kg	1016.00
ii)	P_2O_5	40kg	Rs.37.50/kg	1500.00
iii)	K_2O	40kg	Rs. 20.80/kg	832.00
5.	Micro nutrient			500.00
6.	Cost of PP chemicals	2 Nos.	Rs. 400/No.	800.00
7.	Weedicide	1kg	Rs. 400/kg	400.00
8.	Tractor operation	14 hrs.	Rs. 400/hr	5600.00
9.	Bullock labour	5 Nos.	Rs. 150/Nos.	750.00
10.	Human labour	132 MD	Rs. 150/MD	19800.00
11.	Irrigation	-	-	-
12.	Total investment			35654.00
13.	Interest on investment	6 month	12%	2139.00
14.	Land revenue			25.00
15.	Total cost of cultivation			37818.00
16.	Total yield			
	Grain	32qt	Rs. 1310/qt	41920.00
	Straw	71 qt	Rs. 100/qt	7100.00
17.	Gross income			49020.00
18.	Net return(Sl No.17-Sl No.15)			**11202.00**

APPENDIX- B.III

COST OF CULTIVATION AND NET RETURN OF PADDY (LOW LAND)-KHARIF (BROADCASTED)

Unit- 1 ha.

Sl No.	**Components**	**Unit**	**Rate (Rs.)**	**Total(Rs.)**
1.	Cost of seed	60 kg/ha	Rs. 15/kg	900.00
2.	Cost of seed treating chemical	2gm/kg	Rs. 1.60/gm	192.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	84kg	Rs.12.70/kg	1066.80
ii)	P_2O_5	44kg	Rs.37.50/kg	1650.00
iii)	K_2O	42kg	Rs. 20.80/kg	873.00
5.	Micro nutrient			500.00
6.	Cost of PP chemicals	2 Nos.	Rs. 400/No.	800.00
7.	Weedicide	1kg	Rs. 400/kg	400.00
8.	Tractor operation	18 hrs.	Rs. 400/hr	7200.00
9.	Bullock labour	5 Nos.	Rs. 150/Nos.	750.00
10.	Human labour	165 MD	Rs. 150/MD	24750.00
11.	Irrigation	-	-	-
12.	Total investment			42082.00
13.	Interest on investment	6 month	12%	2524.00
14.	Land revenue			25.00
15.	Total cost of cultivation			44632.00
16.	Total yield			
	Grain	37qt	Rs. 1310/qt	48470.00
	Straw	80 qt	Rs. 100/qt	8000.00
17.	Gross income			56470.00
18.	Net return(Sl No.17-Sl No.15)			**11838.00**

APPENDIX- B.IV

COST OF CULTIVATION AND NET RETURN OF MAIZE(KHARIF)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	15 kg/ha	Rs. 40/kg	600.00
2.	Cost of seed treating chemical	2gm/kg	Rs. 1.60/gm	72.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	80kg	Rs.12.70/kg	1016.00
ii)	P_2O_5	40kg	Rs.37.50/kg	1500.00
iii)	K_2O	40kg	Rs. 20.80/kg	832.00
5.	Micro nutrient	-	-	-
6.	Cost of PP chemicals	2 Nos.	Rs. 400/No.	800.00
7.	Weedicide	1kg	Rs. 600/kg	600.00
8.	Tractor operation	8 hrs.	Rs. 400/hr	3200.00
9.	Bullock labour	-	-	-
10.	Human labour	160 MD	Rs. 150/MD	24000.00
11.	Irrigation	-	-	-
12.	Total investment			35620.00
13.	Interest on investment	6 month	12%	2137.00
14.	Land revenue			25.00
15.	Total cost of cultivation			37782.00
16.	Total yield			
	Grain	40qt	Rs. 1310/qt	52400.00
	Straw	20 qt	Rs. 50/qt	1000.00
17.	Gross income			53400.00
18.	Net return(Sl No.17-Sl No.15)			**15618.00**

APPENDIX- B.V

COST OF CULTIVATION AND NET RETURN OF ARHAR(KHARIF)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	20 kg/ha	Rs. 25/kg	500.00
2.	Cost of seed treating chemical	3gm/kg	Rs. 1.60/gm	96.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	20kg	Rs.12.70/kg	254.00
ii)	P_2O_5	40kg	Rs.37.50/kg	1500.00
iii)	K_2O	20kg	Rs. 20.80/kg	416.00
5.	Micro nutrient			1000.00
6.	Cost of PP chemicals	2 Nos.	Rs. 500/No.	1000.00
7.	Weedicide	0.75kg	Rs. 600/kg	450.00
8.	Tractor operation	5 hrs.	Rs. 400/hr	2000.00
9.	Bullock labour	3 Nos.	Rs. 150/Nos.	450.00
10.	Human labour	93 MD	Rs. 150/MD	13950.00
11.	Irrigation	-	-	-
12.	Total investment			24616.00
13.	Miscellaneous		10%	2461.60
14.	Interest on investment	6 month	12%	1264.65
15.	Land revenue			25.00
16.	Total cost of cultivation			28727.00
17.	Total yield			
	Grain	18qt	Rs. 4300/qt	77400.00
18.	Gross income			77400.00
19.	Net return(Sl No.18-Sl No.16)			**48673.00**

APPENDIX- B.VI

COST OF CULTIVATION AND NET RETURN OF PADDY (LOW LAND)- RABI (TRANSPLANTED)

Unit- 1 ha.

Sl No.	**Components**	**Unit**	**Rate (Rs.)**	**Total(Rs.)**
1.	Cost of seed	60 kg/ha	Rs. 15/kg	900.00
2.	Cost of seed treating chemical	3gm/kg	Rs. 1.60/gm	288.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Chemical Fertilizer			
i)	N	84kg	Rs.12.70/kg	1066.80
ii)	P_2O_5	44kg	Rs.37.50/kg	1650.00
iii)	K_2O	42kg	Rs. 20.80/kg	873.00
5.	Micro nutrient			500.00
6.	Cost of PP chemicals	2 Nos.	Rs. 400/No.	800.00
7.	Weedicide	1kg	Rs. 400/kg	400.00
8.	Tractor operation	18 hrs.	Rs. 400/hr	7200.00
9.	Bullock labour	5 Nos.	Rs. 150/No.	750.00
10.	Human labour	165 MD	Rs. 150/MD	24750.00
11.	Irrigation	15 Nos.	Rs. 200/No.	3000.00
12.	Total investment			45178.00
13.	Interest on investment	6 month	12%	2710.70
14.	Land revenue			25.00
15.	Total cost of cultivation			47914.00
16.	Total yield			
	Grain	43qt	Rs. 1310/qt	56330.00
	Straw	85 qt	Rs. 100/qt	8500.00
17.	Gross income			64830.00
18.	Net return(Sl No.17-Sl No.15)			**16916.00**

APPENDIX- B.VII

COST OF CULTIVATION AND NET RETURN OF MUSTARD (RABI)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	10kg/ha	Rs. 30/kg	300.00
2.	Cost of seed treating chemical	3gm/kg	Rs. 1.60/gm	48.00
3.	Farm yard manure	5MT	Rs. 600/MT	3000.00
4.	Bio-fertilizer			200.00
5.	Chemical Fertilizer			
i)	N	60kg	Rs.12.70/kg	762.00
ii)	P_2O_5	30kg	Rs.37.50/kg	1125.00
iii)	K_2O	30kg	Rs. 20.80/kg	624.00
6.	Micro nutrient			1000.00
7.	Cost of PP chemicals	2 Nos.	Rs. 500/No.	1000.00
8.	Weedicide	0.78kg	Rs. 600/kg	468.00
9.	Tractor operation	8hrs.	Rs. 400/hr	3200.00
10.	Bullock labour	3Nos.	Rs. 150/Nos.	450.00
11.	Human labour	100 MD	Rs. 150/MD	15000.00
12.	Irrigation	3 Nos.	Rs. 300/Nos.	900.00
13.	Total investment			28077.00
14.	Interest on investment	6 month	12%	1684.62
15.	Land revenue			25.00
16.	Total cost of cultivation			29787.00
17.	Total yield			
	Grain	15qt	Rs. 3000/qt	45000.00
	Straw	-	Rs. 100/qt	-
18.	Gross income			45000.00
19.	Net return(Sl No.18-Sl No.16)			**15213.00**

APPENDIX- B.VIII

COST OF CULTIVATION AND NET RETURN OF MUNG (RABI)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of seed	25kg/ha	Rs. 30/kg	750.00
2.	Cost of seed treating chemical	3gm/kg	Rs. 1.60/gm	120.00
3.	Farm yard manure	3MT	Rs. 600/MT	1800.00
4.	Chemical Fertilizer			
i)	N	20kg	Rs.12.70/kg	254.00
ii)	P_2O_5	40kg	Rs.37.50/kg	1500.00
iii)	K_2O	20kg	Rs. 20.80/kg	416.00
5.	Micro nutrient	-	-	-
6.	Cost of PP chemicals	2 Nos.	Rs. 500/No.	1000.00
7.	Weedicide	0.75kg	Rs. 600/kg	450.00
8.	Tractor operation	5hrs.	Rs. 400/hr	2000.00
9.	Bullock labour	3Nos.	Rs. 150/Nos.	450.00
10.	Human labour	65 MD	Rs. 150/MD	9750.00
11.	Irrigation	2 Nos.	Rs. 300/No.	600.00
12.	Total investment			19090.00
13.	Interest on investment	6 month	12%	1145.40
14.	Land revenue			25.00
15.	Total cost of cultivation			20260.00
16.	Total yield			
	Grain	10qt	Rs. 4500/qt	45000.00
	Straw	-	-	-
17.	Gross income			45000.00
18.	Net return(Sl No.17-Sl No.15)			**24740.00**

APPENDIX- B.IX

COST OF CULTIVATION AND NET RETURN OF HYBRID NAPIER BAJRA GRASS THROUGHOUT THE YEAR-(KHARIF & RABI)

Unit- 1 ha.

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Cost of planting	40000 slips/ha	Rs. 0.40/slips	16000.00
2.	Farm yard manure	8MT	Rs. 600/MT	4800.00
3.	Chemical Fertilizer			4000.00
4.	Tractor operation	7hrs.	Rs. 400/hr	2800.00
5.	Bullock labour	2Nos.	Rs. 200/Nos.	400.00
6.	Plant protection	4Nos.	Rs. 500/No.	2000.00
7.	Human labour	150 MD	Rs. 150/MD	22500.00
8.	Irrigation			4500.00
9.	Total investment			57000.00
10.	Total yield			
	Fodder	500qt	Rs. 150/qt	75000.00
11.	Gross income			75000.00
12.	Net return(Sl No.11-Sl No.9)			**18000.00**

Season wise Net return from the grass

Season	Yield	Price
Kharif	30	10800
Rabi	20	7200
Total		**18000**

APPENDIX-B.X

COST OF CULTIVATION AND NET RETURN FROM THE SUBABOOL PLANTATION THROUGHOUT THE YEAR (KHARIF & RABI)

UNIT-1 ha

Sl No.	Components	Unit	Rate (Rs.)	Total(Rs.)
1.	Site preparation including soil work	80MD	Rs. 150/MD	12000.00
2.	Alignment & staking	60MD	Rs. 150/MD	9000.00
3.	Cost of plants	5500 Nos.	Rs. 3/No.	16500.00
4.	Planting and gap filling	70MD	Rs. 150/MD	10500.00
5.	Weeding, mulching etc.	80MD	Rs. 150/MD	12000.00
6.	Cost of insecticides	.		440.00
7.	Protection and fencing	80MD	Rs. 150/MD	12000.00
8.	Irrigation	2 Nos.	Rs. 300/No.	600.00
9.	Total investment			73040.00
10.	Total yield			
	Fuel wood	20t/yr	Rs. 4000/t	80000.00
	Leafs	100qt/yr	Rs. 50/qt	5000.00
11.	Gross income			85000.00
12.	Net return(Sl No.11-Sl No.9)			**11960.00**

Season wise Net return from the Subabool plantation

Sl No.	Season	Yield(t/ha)		Total
		Fodder	Fuel wood	
1.	Kharif	7	10	6980
2.	Rabi	3	10	4980
	Total			**11960**

APPENDIX-B.XI

MONTH WISE LABOUR REQUIREMENT OF DIFFERENT CROPS PROPOSED IN THE WATERSHED

Month▸	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Crop▾												
1.Kharif												
Paddy-I	-	-	-	-	-	30	20	15	7	30	-	-
Paddy-II	-	-	-	-	-	30	35	20	12	35	-	-
Paddy-III	-	-	-	-	-	30	35	30	30	40	-	-
Maize	-	-	-	-	-	35	30	15	20	60	-	-
Arhar	-	-	-	-	-	15	20	10	23	25	-	-
2.Rabi												
Paddy-III	35	30	30	40	-	-	-	-	-	-	-	30
Mustard	15	10	25	30	-	-	-	-	-	-	-	20
Mung	10	10	10	25	-	-	-	-	-	-	-	10
Hybrid napier bajra grass	10	15	15	10	30	25	10	10	5	-	10	10
Subabool	20	15	10	10	90	20	10	30	25	10	110	20

Total labour requirement of different crops

Paddy -I	**Paddy -II**	**Paddy -III**	**Maize**	**Arhar**	**Paddy -III**	**Mustard**	**Mung**	**Hybrid Napier Bajra grass**	**Subabool**
102	132	165	160	93	165	100	65	150	370

APPENDIX-C.I

MONTHLY RAINFALL DATA (in mm) FOR THE WATERSHED AREA

FROM 1978 TO 2007

Month Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	0	8.3	43.2	22.9	97.3	91.9	199.2	211.7	215.8	138.3	3.4	24.9
1979	0	40.8	1.3	85	34.1	110.2	237.7	368.8	229.8	94.2	1.8	4.3
1980	0	26	27.7	0.2	70.1	389.1	404.3	258.1	401.3	123.6	0.1	10.2
1981	29.5	8.2	165.8	20.4	113	103.6	210.8	389.6	241.7	31.3	0	19.6
1982	1.8	48.8	23.3	35.9	61.6	293.5	213.4	441.5	218.9	39.6	19.6	0
1983	0	108.9	10.7	44.4	45.3	199.9	360.9	537.2	299.4	173.6	3.3	11.4
1984	0	26.1	0	17.4	23.9	234	507.6	557.4	215.8	55.7	0	0
1985	10	33.5	2.8	7.2	28.3	147.6	399.7	402.7	343	220.8	0	0
1986	32	27.5	6.6	55.7	67.7	267.7	393.3	288.7	273.8	187.5	173.9	8.4
1987	5.4	0	10.2	19.4	56.2	91.7	291.6	255.8	111	124.9	105.9	3.8
1988	0	7.4	6.2	34.2	84.3	195.7	381.2	142.3	271.1	89	0	0
1989	0	0	4.2	4.7	156.6	231.6	129.5	365.1	162.5	41.2	0	1.1
1990	0	59.8	119.5	130.7	124.9	210.6	289.5	468.5	238.1	165.2	24.6	2
1991	60.9	60.6	39.1	16.5	13.6	160.9	500.6	307.2	127	104.7	79.9	3
1992	20.5	54.9	0	11	251.4	138.2	354	356.3	225.9	163.9	1.3	0
1993	0	0	9.7	90.6	55.7	284.8	241.4	456.7	195.3	79.3	14.2	0
1994	0	33.6	0.8	21.9	17.9	168.9	238	489.3	251.17	149.3	5.6	0
1995	32	52.5	21.6	11.4	703.9	132.2	176.4	195.1	240.2	335	183.5	0
1996	83.5	4.6	0	17.2	41.5	134.5	141.5	227.9	67	109.2	16.3	0
1997	67.5	8	54.6	135.5	16.3	184	191.9	534.6	348.6	32.3	9.4	27.7
1998	26.4	20.9	67.3	77.8	40.5	164.4	341.5	163.5	239.1	306.6	93.5	0
1999	1.5	0	0	0	189	173.8	262.6	445.8	238.6	745.5	19.3	0
2000	0	35.8	0	52.8	92.8	298.5	424.1	221.6	97.9	42.5	0.8	0
2001	0	0	71.3	6.5	88.3	437.4	797.7	450.6	144.3	160.8	61.8	0
2002	45.7	0	3.8	7.9	114.5	216.7	353.9	514.4	181.7	48	27.2	0
2003	0	9.6	28.2	2.8	16.8	313.9	355.5	387.5	297.1	462.6	9.2	22.3
2004	8.1	3.3	0.8	101.1	30.7	133.4	265.8	294.4	164.4	205	0	0
2005	16.3	0	56.9	45.2	59.4	101.4	255.7	161.6	527.3	30.7	56.4	0
2006	0	0	21.3	18.6	98.9	230.4	424.2	567.3	242.5	102.9	12.2	0
2007	0	69.9	0	34.9	113.3	162.8	183.8	346.4	535.3	130.5	15.9	0

APPENDIX-C.II

TOTAL WATER AVAILABLE FROM RAINFALL IN KHARIF AND FROM W.H.S. IN RABI SEASON

The kharif season is taken from June to October. The total rainfall (monsoon) during this period at 70% probability levels are calculated from table 5.2

Month	70%
Jun	146.94
July	236.48
August	288.13
September	181.01
October	74.14
Total	**926.7mm**

Sl No.	Probability level (%)	Total rainfall (cm)	Runoff coeff. of the area	Runoff produced in(cm)	Effective rainfall useable to crops(cm)
1.	70	92.67	0.276	25.57	67.1

Total water available in kharif (from rainfall) = Treatable area (ha) × Rainfall (m)

= 457 × 0.67 = 306 ha-m

Water requirement by the crops during rabi:

Water available during rabi season for irrigation to rabi cops is equal to

Area under rabi crops proposed = (total available cultivable medium land + total available low lands) + (forest/plantation +gochar + cultivable and uncultivable waste lands)

= 199.85 + 20.12 + 39.75 + 6.25 + 109.49 + 19.29 = 398 ha.

Water requirement of low land paddy during rabi = 100 cm

Average water requirement of the mustard and mung in rabi season = 40 cm & average water requirement of the fodder crops and plantation crops in rabi season = 15 cm.

Therefore total quantity of water to be stored in existing tanks, nala and proposed water harvesting ponds = (1× 20.12 + 0.4 × 199.85 + 0.15 × 174.78) = 127 ha.m

APPENDIX-D.I

DETERMINATION OF CAPACITY OF THE EXISTING PONDS AND NALA BUNDING

A. POND No. 1:

The dimensions of the pond are,

Top dimension = 50 × 50m

Side slope = 1:1.5(V: H)

Depth up to crest level = 2.5 m

Depth over crest level = 0.5m

Bottom dimensions of the pond = [{50.0 - (2 × 1.5 ×3.0)} m × {50.0 – (2 × 1.5 × 3)} m]

= 41.0 m × 41.0 m

Top dimensions of the pond at crest level

= [{50.0 - (2 × 1.5 ×0.5)} m × {50.0 – (2 × 1.5 × 0.5)}]

= 48.5 m × 48.5 m

Capacity of the pond by Trapezoidal rule, Q_1 = 0.50 ha.m

Assuming 20% loss due to seepage, percolation and evaporation, water available for irrigation, V_1 = 0.40 ha.m

B. Pond No.2:

The dimensions of the pond are

Top dimension = 95 × 95m

The volume of water stored (Q_2) at different depths at 0.5m interval is found out by trapezoidal rule,

= Σ [1/2 (ΣArea between two contours) × (contour interval)]

From the stage-storage curve,

Storage volume at 4.5m depth = 3.52 ha.m

Storage volume at 1.5m depth = 1.05 ha.m

Storage volume available for utilisation = (3.52-1.05) ha.m = 2.47 ha.m

Considering 20% losses, volume available for irrigation, $V_2 = 2.47 \times 0.8$ ha.m = 1.98 ha.m

C. **Nala bunding:**

Average top width of drainage nala = 7.5m

Average bottom width of nala = 6.0m

Average depth of nala = 3.0m

Nala bunding will be done at 2.0km and 3.0km away from head reach.

Therefore, water spreading length for 1st bund is 2.0km and between 1st and 2nd bund is 1.0km

The volume of water stored in between head reach and 1st bund,

$V_3 = ½[(7.5m + 6.0m)] \times 3.0m \times 2000.0m = 4.05$ ha.m

The volume of water stored between the 1st and 2nd bund,

$V_4 = 1/2[(7.5m+6.0m)] \times 1000.0m = 2.03$ ha.m

The total volume of water to be stored in nala at the end of rainy season will be

$V = V_3 + V_4 = 4.05 + 2.03 = 6.08$ ha.m

After loss the quantity of water available from the nala bunding = 4.86 ha.m

Total quantity of water available from the existing ponds and nala bunding is

0.40 + 1.98 + 4.86 = 7.24 ha.m

APPENDIX-D.II

AREA REQUIRED FOR CONSTRUCTION OF PONDS

i) Total water required to meet the need of crops and plantations during rabi season

= 127 ha.m

Total volume of water available from the existing ponds and nala bunds = 7.24 ha.m

Total volume of water to be stored from runoff = 127 ha.m – 7.24 ha.m = 119.76 ha.m

No. of ponds proposed = 35

Capacity of each pond assuming 20% losses = (119.76 × 1.2)/35 = 4.10 ha.m

Dimension of each pond, T = 103m × 103m

Capacity per unit ha for WHS

ii) Total area to be utilized for water storage ponds, nala etc.

= Top area of (pond no.1 + pond no.2 + drainage nala + 35 Nos. of proposed water harvesting ponds)

= [(50 × 50) + (95 × 95) + (7.5 × 3000) + (35 × 103 × 103)

= 40.39 ha

Therefore, capacity per unit area = 119.76/40.39 = 3 ha-m/ha

APPENDIX- E.I

SUMMARY OF OBJECTIVE FUNCTONS

Objective function / Varables	Food production $Z_1(x)$	Fodder production $Z_2(x)$	Fuel wood production $Z_3(x)$	Net income generation $Z_4(x)$	Labour employment generation $Z_5(x)$	Runoff water augmentation $Z_6(x)$
x_{11}	2.6	6.5	0	9671	102	0
x_{12}	3.2	7.1	0	11202	132	0
x_{13}	3.7	8	0	11838	165	0
x_{14}	4	2	0	15618	160	0
x_{15}	1.8	0	0	48673	93	0
x_{16}	0	30	0	10800	60	0
x_{17}	0	7	10	6980	185	0
x_{21}	4.3	8.5	0	16916	165	0
x_{22}	1.5	0	0	15213	100	0
x_{23}	1	0	0	24740	65	0
x_{24}	0	20	0	7200	90	0
x_{25}	0	3	10	4980	185	0
x_8	0	0	0	0	0	3