

# **Optimal land and water use planning for Koraput district in Eastern Ghat region of Odisha**

*A thesis submitted to the  
Orissa University of Agriculture and Technology  
In partial fulfilment of the requirements for the degree of  
Doctor of philosophy in Agricultural Engineering  
(Soil and Water Conservation Engineering)*

*By*

**BHUPENDRA SINGH NAIK**  
**Adm. No. 01SWCE/Ph.D./2011**



**DEPARTMENT OF SOIL & WATER CONSERVATION ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING & TECHNOLOGY  
ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
BHUBANESWAR-751003, ODISHA  
2016**



**ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY  
BHUBANESWAR-3**

**Dr. J. C. Paul**  
Associate Professor

**Bhubaneswar**  
Date:

## **CERTIFICATE - I**

This is to certify that the thesis entitled “**Optimal land and water use planning for Koraput district in Eastern Ghat region of Odisha**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in AGRICULTURAL ENGINEERING (Soil and Water Conservation Engineering)** to the Orissa University of Agriculture and Technology is a faithful record of *bona fide* and original research carried out by **SRI BHUPENDRA SINGH NAIK** (Adm. No. 01 SWCE/ Ph.D./ 11) under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigations have been duly acknowledged.

**CHAIRMAN  
ADVISORY COMMITTEE**



**ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY  
BHUBANESWAR-3**

## CERTIFICATE – II

This is to certify that the thesis entitled “**Optimal land and water use planning for Koraput district in Eastern Ghat region of Odisha**” submitted by **BHUPENDRA SINGH NAIK** (Adm. No. 01 SWCE/ Ph.D./ 11) to the Orissa University of Agriculture and Technology, Bhubaneswar, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in AGRICULTURAL ENGINEERING (SOIL AND WATER CONSERVATION ENGINEERING)** has been approved by the Student’s advisory committee and the external examiner.

### ADVISORY COMMITTEE

**Chairman :**     **Dr. J. C.Paul,**  
Associate Professor

\_\_\_\_\_

**Members :** 1. **Dr. B. Panigrahi,**  
Prof. and Head

\_\_\_\_\_

2. **Dr. B. C. Sahoo,**  
Associate Professor

\_\_\_\_\_

3. **Dr. M. K. Mahanti**  
Prof. and Head,  
Dept. of Mathematics, CBSH

\_\_\_\_\_

External Examiner

\_\_\_\_\_  
(Name & designation)

# ACKNOWLEDGEMENTS

At the outset I would like to express my profound gratitude to Dr. J.C. Paul, Chairman of the advisory committee and Associate Professor, Department of Soil and Water Conservation Engineering, CAET, OUAT, Bhubaneswar for his constant support, encouragement, invaluable guidance and close supervision throughout the course of research and preparing this dissertation.

I am ever grateful to Dr B. Panigrahi, Professor and Head, Department of Soil and Water Conservation Engineering, CAET, OUAT for his continuous encouragement, moral support and guidance. Without him it could not have been possible to complete this work in its present form.

I am deeply indebted to Dr. B. C. Sahoo, Associate Professor, Department of Soil and Water Conservation Engineering, CAET and Dr. M. K. Mahanti, Professor and Head, Department of Mathematics, College of Basic Science and Humanities, OUAT, Bhubaneswar and members of my advisory committee for their valuable guidance, constructive criticism, showing keen interest and helping in research work, useful suggestions and critically reviewing the dissertation.

I express my deep regards to Dr. Md. Khalid Khan, Dean, CAET, OUAT, Bhubaneswar for providing me all the facilities and assistances for carrying out the research work.

My sincere thanks are due to Dr. S. C. Senapati, Professor, Er. C. R. Subudhi, Associate Professor, Dr. N. Sahoo, Associate Professor, Dr. B. P. Behera, Associate Professor and Dr. A. P. Sahu, Associate Professor, Department of Soil and Water Conservation Engineering, CAET, OUAT for their valuable help and moral support during the entire period of research work.

I also thank all the staffs of Department of Soil and Water Conservation Engineering for their help during the period of study.

I take this opportunity to appreciate Dr. Dwitikrishna Panigrahi, Assistant Agriculture Engineer, Govt. of Odisha and Sri Lalit Kumar Mohanty, Senior Scientist, KVK, Kendrapada (Odisha) for their informative feedbacks related to my research work and friendly response in clarifying my doubts as and when needed.

I am highly thankful to my esteemed organisation “Indian council of Agricultural Research” and thank Dr. P. K. Mishra, Director, Dr. V. N. Sharda, Member, ASRB, New Delhi, and Ex-Director, ICAR- IISWC, Dehradun, and Dr. M. Madhu, Head, ICAR- IISWC, Research Centre, Sunabeda, Koraput for allowing me the study leave for pursuing Ph.D. and extending all possible help during the study period. I also thank Dr. A. Raizada, Head, ICAR- IISWC, Research Centre, Bellary (Karnataka) for his support and encouragement to complete this task.

Though my father is no more but I do believe his heavenly blessings are always there with me for this big achievement. I thank my mother, family members, mother-in-law, father-in-law and all relatives for their great support to reach this level.

There are no words to express my feelings to my beloved wife Smt. Bhumisuta for extending me the unconditional love, care, motivation and support. She took utmost care of the family facing all the difficulties during my absence. Special thanks and appreciations to my daughter Rajita and son Ramit for missing me and bearing all pain in my absence. I strongly appreciate them for their sacrifices, endurance and cheering me up during hardships.

I thank all my friends, colleagues and well wishers for encouraging and supporting me to complete this difficult assignment.

Last but most of all, I would like to pray Lord Jagannath, for blessing me with wonderful life and strength to achieve my goals.

Date  
Bhubaneswar

(Bhupendra Singh Naik)

# CONTENTS

Chapter	Particulars	Page
	<b>CERTIFICATE-I</b>	i
	<b>CERTIFICATE-II</b>	ii
	<b>ACKNOWLEDGEMENTS</b>	iii-iv
	<b>LIST OF TABLES</b>	v
	<b>LIST OF FIGURES</b>	vi
	<b>SYMBOLS AND ABBREVIATIONS USED</b>	vii-xi
	<b>ABSTRACT</b>	xii-xiii
<b>I</b>	<b>INTRODUCTION</b>	1-6
<b>II</b>	<b>REVIEW OF LITERATURE</b>	7-54
	2.1 Land degradation due to agricultural practices	7
	2.2 Land and water management	9
	2.3 Food requirement for nutritional sufficiency	11
	2.4 Estimation of evapotranspiration	14
	2.5 Determination of effective and dependable rainfall	17
	2.6 Estimation of soil loss	19
	2.6.1 Universal Soil Loss Equation	20
	2.6.2 Factors of Universal Soil Loss Equation	25
	2.7 Mathematical modeling for resource allocation in agriculture	43
	2.7.1 Linear programming	43
	2.7.2 Goal programming	44
	2.7.3 Application of linear / goal programming in agriculture	44
<b>III</b>	<b>MATERIALS AND METHODS</b>	55-80
	3.1 Description of the study area	55
	3.1.1 General features	55
	3.1.2 Climate	55
	3.1.3 Soil	56
	3.1.4 Topography	58
	3.1.5 Drainage	58

<b>Chapter</b>	<b>Particulars</b>	<b>Page</b>
3.1.6	Forest	58
3.1.7	Shifting cultivation	59
3.1.8	Land use	59
3.1.9	Irrigation potential	60
3.1.10	Socio-economic features	60
3.2	Data collection	62
3.3	Climatic data analysis	63
3.3.1	Effective rainfall	63
3.3.2	Water resource potential	63
3.3.3	Reference crop evapotranspiration	64
3.3.4	Crop coefficient	65
3.3.5	Climatic index	65
3.3.6	Selection of cropping period	66
3.4	Return from agriculture	67
3.5	Food requirement	68
3.6	Soil loss from agricultural land	69
3.7	Formulation of mathematical models	71
3.7.1	Constraint structures	72
3.7.2	Solution of linear programming models	80
<b>IV</b>	<b>RESULTS AND DISCUSSION</b>	<b>81-105</b>
4.1	Effective rainfall, evapotranspiration and climatic index	81
4.2	Initial crop coefficient, dependable climatic index and water balance	83
4.3	Selection of cropping period	84
4.4	Investment and return from agriculture	87
4.4.1	Present status of agriculture	87
4.4.2	Based on standard package of practices, and suggested cropping patterns	90
4.5	Projected population	91
4.6	Food requirement	91
4.7	Soil loss from agricultural land	93
4.7.1	Existing cropping pattern	93

<b>Chapter</b>	<b>Particulars</b>	<b>Page</b>
4.7.2	Suggested cropping pattern	93
4.8	Water resource potential	98
4.8.1	Water availability during <i>kharif</i>	98
4.8.2	Water availability during <i>rabi</i>	99
4.9	Mathematical models for land and water use optimisation	100
4.9.1	Solution of models	101
4.9.2	Comparison of model solution with present status of agriculture	103
<b>V</b>	<b>SUMMARY AND CONCLUSIONS</b>	106-110
	<b>SUGGESTIONS FOR FUTURE WORK</b>	111
	<b>REFERENCES</b>	xiv-xxxv
	<b>APPENDICES</b>	xxxvi-lxx
	<b>LIST OF PUBLICATIONS</b>	lxxi
	<b>CURRICULUM VITAE</b>	lxxii

# LIST OF TABLES

Table	Title	Page
3.1	Area covered under major soils in Koraput district	56
3.2	Land use pattern of the Koraput district	60
3.3	Prevailing cropping pattern ( <i>Kharif &amp; Rabi</i> ) and productivity scenario in Koraput district	61
3.4	Recommended dietary allowance (RDA) for Indian adult male and female	68
3.5	Edible portion, local affinity and requirement towards seed, feed & losses of food items	69
3.6	Values of crop management factor 'C'	71
4.1	Month wise values of initial crop coefficient ( $K_{cini}$ )	83
4.2	Proposed cropping sequences for Koraput district	85
4.3	Food requirement as per RDA for the projected population of Koraput district during 2021	92
4.4	Estimated soil losses from crop lands under existing cropping pattern of Koraput district	94
4.5	Soil loss from single cropped land under suggested cropping pattern	95
4.6	Soil loss from double cropped land under suggested cropping pattern	96
4.7	Month wise best fit probability distributions of rainfall	98
4.8	Expected month wise rainfall (mm) at different probability levels	99
4.9	Month wise best fit probability distributions of runoff	100
4.10	Expected month wise runoff (mm) at different probability levels	100
4.11	Allocation of area for different cropping patterns as suggested by Goal programming	102
4.12	Summary of constraints of Goal programming	103
4.13	Comparison of the model results with the existing agricultural situation	104

# LIST OF FIGURES

Figure	Title	Page
3.1	Location of Koraput district	57
3.2	Average $K_{c\ ini}$ as related to the level of $ET_o$ and the mean wetting interval during the initial growth stage for small infiltration depths	66
3.3	Average $K_{c\ ini}$ as related to the level of $ET_o$ and the mean wetting interval during the initial growth stage for large infiltration depths	67
4.1	Trend of annual effective rainfall, reference crop evapotranspiration ( $ET_o$ ) and climatic index ( $C_i$ ) of Koraput district	82
4.2	Trend of monthly effective rainfall, reference crop evapotranspiration ( $ET_o$ ) and climatic index ( $C_i$ ) of Koraput district	82
4.3	Month wise trend of dependable climatic index ( $C_i$ ) and initial crop coefficient ( $K_{cini}$ ) of Koraput district	84
4.4	Suggested crop schedule for Koraput district	88
4.5	Present cropping pattern in Koraput district	89
4.6	Present investment and net returns from crops	89
4.7	Investment and net returns from crops as per standard package of practices	90
4.8	Cost of cultivation of suggested cropping patterns	91
4.9	Net returns of suggested cropping patterns	91
4.10	Comparison of soil loss from single and double cropped lands under existing cropping pattern and suggested cropping pattern	98
4.11	Investment, gross return and net return from present cropping pattern and suggested cropping pattern	105
4.12	Soil loss from present cropping pattern and suggested cropping pattern	105

## SYMBOLS AND ABBREVIATIONS USED

$a_g$	Area of crop sequence with perennial grass cover
$a_{gn}$	Area of crop sequence, where ginger is taken
$a_i$	Area of $i^{\text{th}}$ crop sequence set
$a_{i_1}$	Area of $i_1^{\text{th}}$ crop sequence in upland areas
$a_{i_2}$	Area of $i_2^{\text{th}}$ crop sequence in medium land areas
$a_{i_3}$	Area of $i_3^{\text{th}}$ crop sequence in up and medium land areas
$a_{i_4}$	Area of $i_4^{\text{th}}$ crop sequence in medium and low land areas
$a_{i_5}$	Area of $i_5^{\text{th}}$ crop sequence in assured irrigated areas
$a_{i_6}$	Area of $i_6^{\text{th}}$ crop sequence
$a_{i_7}$	Area of $i_7^{\text{th}}$ crop sequence
$a_{i_8}$	Area of $i_8^{\text{th}}$ crop sequence set, where rice is taken
$a_{i_9}$	Area of $i_9^{\text{th}}$ crop sequence set, where ragi is taken
$a_{i_{10}}$	Area of $i_{10}^{\text{th}}$ crop sequence set, where maize is taken
$a_{i_{11}}$	Area of $i_{11}^{\text{th}}$ crop sequence set, where mung is taken
$a_{i_{12}}$	Area of $i_{12}^{\text{th}}$ crop sequence set, where black gram is taken
$a_{i_{13}}$	Area of $i_{13}^{\text{th}}$ crop sequence, where arhar is taken
$a_{i_{14}}$	Area of $i_{14}^{\text{th}}$ crop sequence, where <i>kulthi</i> is taken
$a_{i_{15}}$	Area of $i_{15}^{\text{th}}$ crop sequence, where groundnut is taken
$a_{i_{16}}$	Area of $i_{16}^{\text{th}}$ crop sequence set, where niger is taken
$a_{i_{17}}$	Area of $i_{17}^{\text{th}}$ crop sequence, where mustard is taken
$a_{i_{18}}$	Area of $i_{18}^{\text{th}}$ crop sequence, where vegetables is taken in <i>kharif</i>
$a_{i_{19}}$	Area of $i_{19}^{\text{th}}$ crop sequence, where vegetable is taken in <i>rabi</i>
$a_{tr}$	Area of crop sequence, where turmeric is taken
A	Average soil loss
Agri.	Agriculture
Agron.	Agronomy
$A_i$	Total cultivable area in assured irrigated areas
$A_m$	Total cultivable area in medium land
$A_{ml}$	Total cultivable area in medium and low land areas

$A_t$	Total cultivable area
$A_u$	Total cultivable area in upland
$A_{um}$	Total cultivable area in upland and medium land areas
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
C	Crop management factor of USLE
CAET	College of Agricultural Engineering and Technology
CACP	Commission for Agricultural Costs and Prices
CCLP	Chance constrained linear programming
$C_i$	Climatic Index
cm	Centimetre
o	Degree
°C	Degree centigrade
Divn.	Division
Drain.	Drainage
$e_s$	Saturation vapour pressure
$e_a$	Actual vapour pressure
$e_s - e_a$	Saturation vapour pressure deficit
E	Kinetic energy of rain
Econ.	Economics
Eq.	Equation
et al.	et alibi, and others
etc.	et cetra
$ET_o$	Reference crop evapotranspiration
ETc	Crop evapotranspiration
FAO	Food and Agricultural Organization
Fig.	Figure
FYM	Farm yard manure
g	Gram
G	Soil heat flux density
GoI	Government of India
Govt.	Government
h	hour

ha	Hectare
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
IFMOP	Interactive fuzzy multi objective programming
i.e.	That is
Irrig.	Irrigation
I <sub>30</sub>	Maximum 30 minute rainfall intensity
J.	Journal
K	Soil erodibility factor of USLE
K <sub>c</sub>	Crop coefficient
K <sub>c dev</sub>	K <sub>c</sub> at the development stage
K <sub>c end</sub>	K <sub>c</sub> at the late season stage
K <sub>c ini</sub>	K <sub>c</sub> during the initial period
K <sub>c mid</sub>	K <sub>c</sub> at the mid season stage
kg	Kilogram
kPa	Kilo Pascal
L	Slope length factor of USLE
l <sub>i</sub>	Rate of soil loss of i <sup>th</sup> crop sequence set
m	Metre
m <sub>i</sub>	Rate of investment of i <sup>th</sup> crop sequence set
MJ	Mega joule
mm	Millimeter
MoA	Ministry of Agriculture
MOLFP	Multi objective fuzzy linear programming
MSP	Minimum support price
N	Natural number
NIN	National Institute of Nutrition
OUAT	Orissa University of Agriculture and Technology
%	Per cent
Prosc.	Proceedings
Publ.	Publications
P	Supporting conservation practice factor of USLE
P <sub>e</sub>	Monthly effective rainfall

$p_{ar}$	Productivity of arhar
$p_{br}$	Productivity of black gram
$p_{gn}$	Productivity of groundnut
$p_{kl}$	Productivity of <i>kulthi</i>
$p_{kvg}$	Productivity of vegetable in <i>kharif</i>
$p_{mz}$	Productivity of maize
$p_{mg}$	Productivity of mung
$p_{ms}$	Productivity of mustard
$p_{ng}$	Productivity of niger
$p_{rg}$	Productivity of ragi
$p_{rc}$	Productivity of rice
$P_t$	The total monthly rainfall
$p_{rvg}$	Productivity of vegetable in <i>rabi</i>
$r_i$	Rate of net return of $i^{th}$ crop sequence set
$R_{ar}$	Requirement of arhar
$R_{br}$	Requirement of black gram
$R_{gn}$	Requirement of groundnut
$R_{kl}$	Requirement of <i>kulthi</i>
$R_{mg}$	Requirement of mung
$R_{ms}$	Requirement of mustard
$R_{mz}$	Requirement of maize
$R_n$	Net radiation at the crop surface
$R_{ng}$	Requirement of niger
$R_{rg}$	Requirement of ragi
$R_{rc}$	Requirement of rice
$R_{vg}$	Total requirement of vegetable in a year
$R$	Rainfall erosivity factor of USLE
$R^2$	Coefficient of determination
RDA	Recommended dietary allowance
Res.	Research
s	Second
S	Slope gradient factor of USLE
Sci.	Science

SCS	Soil Conservation Service
Soci.	Society
t	Tonne
T	Mean daily air temperature at 2 m height
$u_2$	Wind speed at 2 m height
USDA	United States Department of Agriculture
UNDP	United Nations Development Programme
USLE	Universal Soil Loss Equation
Veg.	Vegetable
Viz.	Namely
Vol.	Volume
$WR_1$	Crop water requirement of $i_6$ th crop sequence
$WR_2$	Crop water requirement of $i_7$ th crop sequence
$W_{kh}$	Total water available in <i>kharif</i>
$W_{rb}$	Total water available in <i>rabi</i>
WHO	World Health Organization
WinQSB	Windows Quantitative Systems for Business
yr	Year
$Z_1$	Total soil loss from the optimum crop sequence sets
$Z_2$	Total investment from the optimum crop sequence sets
$Z_3$	Total return from the optimum crop sequence sets
$\gamma$	Psychrometric constant
$\Delta$	Slope vapour pressure curve
₹	Rupees

# ABSTRACT

Koraput district located in the Eastern Ghat region of Odisha is selected for the study. Fragile topography, rainfed agriculture, low input use, declining productivity, subsistence farming, continuous land degradation, rising population, poverty and malnutrition are the major constraints of the district. To cater the need and deal with the prevalent problems, the present study is framed for planning optimal utilization of available land and water resources of the district for minimal soil loss and increased returns.

The climatic data for 27 years from 1986 to 2012 of the Koraput district was analysed to determine effective rainfall ( $P_e$ ), reference crop evapotranspiration ( $ET_o$ ), climatic index ( $C_i$ ) and initial crop coefficient ( $K_{c_{ini}}$ ). The values of 80% dependable  $C_i$  were correlated with monthly initial crop coefficient to suggest the starting of the cropping period at water balance and surplus stage. Using the values of  $K_{c_{dev}}$ ,  $K_{c_{mid}}$  and  $K_{c_{end}}$  of different crops and taking in to account the local cropping practices, the total cropping period was worked out. A crop calendar and a possible set of cropping sequences were prepared based on it. The extent of investment, net return and soil loss from agriculture were estimated as per the prevailing situation and suggested cropping sequences. As per the guidelines of recommended dietary allowance (RDA), the annual food requirement in terms of gross production requirement for the projected population during 2021 was estimated. Using SCS-Curve Number method, the water resource potential of the district was assessed.

For optimal allocation of area, mathematical models were formulated considering the local constraints to suggest the suitable cropping sequences/ best possible pattern of cropland utilization, which would minimize the soil loss, involve lowest investment and highest net return. It was solved using linear goal programming technique with the help of Windows Quick Statistical Business (WinQSB) Software. A total of 3 objectives and 75 variables were used in formulation of models.

It is found that the crops can be taken up suitably from 3<sup>rd</sup> week onwards of June and may be sown up to the end of 2<sup>nd</sup> week of September with sufficient  $K_{c_{ini}}$  values. Keeping in view the local cropping practices and existing climatic conditions, the total cropping period is determined as 255 days commencing from mid June to end of December. Crops with more water demand having higher  $K_{c_{dev}}$ ,  $K_{c_{mid}}$  and  $K_{c_{end}}$  values, are proposed from mid June onwards to till end of September, and crops with less water demand having lower  $K_{c_{dev}}$ ,  $K_{c_{mid}}$  and  $K_{c_{end}}$  values, are proposed from October onwards. No crop is proposed in the month of March, April and May due to lack of assured irrigation facility as most of the water sources becomes dry. As per the water balance, climatic suitability and local cropping practices, a

standard crop schedule is prepared and based on it as many as 75 possible cropping sequences including an option of a perennial grass cover in upland areas are proposed for the district.

Under the existing cropping practices, the average investment, gross return and net return per hectare from agriculture in the district are found to be ₹ 22569, ₹ 38473 and ₹ 15904, respectively. It reveals that the present benefit cost ratio (BCR) from agriculture in the district is 1.7 though it has enough potential and scope for further growth. It is observed that the existing cost and net return from agriculture is much lower in comparison to standard package of practices of cultivation which is not followed. As per the guidelines of recommended dietary allowance (RDA), the annual food requirement in terms of gross production requirement for the projected population during 2021 is estimated to be 443534, 98490, 75792 and 323660 tonnes of cereals, pulses, oilseeds and vegetables including tubers.

Under the prevailing agricultural scenario, soil loss to the extent of 13333.35 thousand tonnes is found annually at the rate of 43.86 t ha<sup>-1</sup> yr<sup>-1</sup> from the agricultural fields of the Koraput district. Single and double cropped agricultural fields contributed 68.8% and 20.7% of total soil loss at the rate of 44.23 and 38.92 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. Under suggested cropping pattern, the average soil loss from single cropped land and double cropped land is found to be 40.50 and 36.33 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. The total water availability of the district during *kharif* and *rabi* is estimated to be 160086.4 ha-m and 45007.2 ha-m, respectively.

Out of 75 decision variables considered in model formulations under the study, only 14 variables were found having optimal solution. As per the suggestions given by model, the food crops to be taken up in 299000 ha and perennial grass cover in 5000 ha, with a cropping intensity of 193% (100% in *Kharif*, 87% in pre *rabi* and 6% in *rabi*) resulting in net return of ₹ 148216.90 lakhs with the investment of ₹ 201053 lakhs and soil loss yield to the extent of 7978.24 thousand tonnes per year from the cultivable area of 304000 ha under different cropping sequences. The model suggested highest area of 118438 ha under cropping sequence ragi-horse gram-fallow and lowest area of 1132.8 ha under cropping sequence sweet potato-fallow-potato for the proposed cropping pattern. Under proposed sequence suggested by model, the rate of soil loss is decreased by 40% and the rate of net return is increased by 131%.

# INTRODUCTION

---

Agriculture is the backbone of Indian economy. It provides livelihood to about 70% of country's population and ensures food and nutritional security, employment opportunities and alleviation of poverty. Burgeoning population and rapid urbanisation resulted in increased food requirement and continuous decrease in land under agriculture. To feed the ever increasing population, sustainable agricultural development and food security are the major challenges of this 21<sup>st</sup> century for India. For agriculture and food production, land and water both are important finite natural resources, and their growing demand and scarcity due to high population pressure and urbanisation, has resulted into the emergence of various issues for their efficient use, management and sustainability.

India contributes 8% of world agricultural gross domestic product and supports almost 18% of the world's population and about 20% of world's livestock having only 2.3% of world's geographical area, 9% of world arable land and 4% of its water resources. The global food demand is expected to be doubled by 2050, and in India food grain production of about 345 million tonnes (MT) will be required in 2030 at the rate of 5.5 MT increment annually to feed its large population (ICAR, 2011). According to a study by Bhalla *et al.* (1999), baseline projection for total cereal demand in 2020 is 246 MT for direct human consumption. Under the assumption of 3.5% growth in per capita GDP (low income growth scenario), demand for food grains (including feed, seed, wastage and export) is projected in the year 2020 at the level of 256 MT comprising 112 MT of rice, 82 MT of wheat, 39 MT of coarse grains and 22 MT of pulses. To meet the projected demand in the year 2020, country must attain a per hectare yield of 2.7 tonnes for rice, 3.1 tonnes for wheat, 2.1 tonnes for maize, 1.3 tonnes for coarse cereals, 2.4 tonnes for cereal, 1.3 tonnes for pulses, 22.3 tonnes for potato, 25.7 tonnes for vegetables, and 24.1 tonnes for fruits (Govt. of India, 2004).

In India, the rainfed agriculture characterized by high climatic variability in the region occupies nearly 58% of the cultivated area, contributes 40% of country's food production, and supports 40% of the human and 60% of the livestock population (Venkateswarlu and Prasad, 2012). Poor management and continuous degradation of land and water is a major constraint towards augmentation of agricultural production.

Unsustainable land use and inappropriate agricultural practices are major concerns of land degradation occurring in India. Presently 146.82 million hectare area (about 45% of the land area) is under various forms of land degradation and it includes 120.72 million hectare under soil erosion only (Govt. of India, 2009). As a result of soil erosion, India is losing nearly 0.8 million tonnes of nitrogen, 1.8 million tonnes of phosphorus and 26.3 million tonnes of potassium annually causing deterioration in soil health and quality (ICAR, 2011). Panigrahi *et al.* (2009) stated that any forms of agriculture involve alteration of ecological system and cause large-scale land degradation. Agriculture can result in soil erosion when improper management is applied on arable land (Oldeman, 1997). Brandon *et al.* (1995) has estimated the total annual loss of productivity of major crops due to soil erosion in India as 7.2 million tonnes. Over exploitation of forest and grassland to meet the fuel and fodder demands, up and down cultivation in sloppy area and shifting cultivation have been the major causes of high runoff, soil loss and land degradation. It is estimated that India is losing forest cover at the rate of 3% per annum and it has created a kind of disaster for flora and fauna of the country affecting the production requirements for man's co-existence and development.

In National Land Use Policy -1988, it was suggested to meet the consumption needs of growing population by increasing the productivity of integrated land resources without further deterioration of land resources by adopting appropriate preventive measures and to restore the productivity of land by appropriate package and practices as well. Land use changes through change in cropping pattern have potential consequence on runoff and soil loss (Sahoo *et al.*, 2006). Erosion is one of the most important indicators that actually show the results of the actions and reactions of the effective factors in a watershed; therefore, erosion minimization can be a very important objective in watershed management planning.

As the water scarcity is increasing day by day, much attention is to be given towards water management in agriculture. A farmer at the start of each cropping season needs to have optimum cropping pattern with available water, which can maximize the economic return from agriculture. Under these circumstances, there is an urgent need for optimal utilization of the available land and water resources (Sethy *et al.*, 2002). Because of this, land use optimization is a useful tool in soil conservation that allows watershed managers and decision makers to choose the best land use practices. Optimal crop planning and judicious resource sharing has good

potential and may yield quick results in increasing agricultural production and net returns (Singh *et al.*, 2002). Nikkami *et al.* (2002) indicated that land use optimization is one of the appropriate strategies for soil conservation and maximization of farm production. Scientific planning of natural resources viz. land and water on watershed basis implies rational utilization of these resources for optimal and sustained production with minimum hazards to ecology (Thakur *et al.*, 2006).

So, optimum utilization of the natural resources is of paramount importance for the economic development of an area. In addition, the need of the hour is to have an integrated, systematic and scientific approach to augment the agricultural productivity by utilizing the available resources and to reduce soil erosion and restore the fertility of crop land simultaneously.

For optimal model development, linear programming (LP) is an effective tool (Shishiny, 1988; Verma, 1998; Lal *et al.*, 1999). In a study of hilly catchment in Uttar Pradesh, Sen and Painuli (1984) used multi objective programming approach to have optimal land use plan and it showed a sizeable reduction in the rate of soil erosion, increase in income and employment opportunities. Mohalle (1989) formulated a LP model to give a plan that can be implemented in context of resources, farmers and their needs with major objective of erosion control. Singh and Singh (1999) used linear programming model for integrated resource planning of Mahi command in Gujarat. Nikkami *et al.* (2002) used multi-objective linear programming to minimize soil erosion and maximize agricultural benefit for a watershed in Iran. Mohseni *et al.* (2003) used goal programming to determine optimal solution for different activities i.e. maximization of benefits, production, employment opportunities, and minimization of total investment and sediment yield in a watershed in Iran.

Optimal land use model provides an opportunity to adopt better cropping systems or putting additional land under cultivation with the same availability of water and land (Thakur *et al.*, 2006). In a watershed in Iran, Sadeghi *et al.* (2008) used a multi- objectives linear optimisation problem for minimizing soil erosion and maximizing farm production of each land use. From a study in rainfed hill plateaus of Odisha, Panigrahi *et al.* (2010) stated that optimal resource use planning using linear goal programming indicated possibility of reducing risk in agriculture, increase in net return and decrease in soil loss. Using linear programming model, Dogra *et al.* (2011) stated that optimal allocation of utilized land and water resources to agricultural production activities can improve production from the watershed as a whole.

Today, the entity of the management sciences appears in modelling methods and from above, it is clear that linear programming is one of the most important applied tools for optimal utilization of the rare resources in the management sciences. The agricultural and natural resources decision makers usually face multi-objective planning, unlike those in industries. 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 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.

A number of techniques have been developed for multiple objective decisions making but Goal programming (GP) is one of the most promising techniques for multiple objective decision analysis. It is a powerful tool which draws upon the highly developed and tested technique of linear programming and at the same time provides a solution to complex system of competing objectives (Aris *et al.*, 2006). GP is one of the oldest multi-criteria decision making techniques and the most frequently used one in agricultural planning (Latinopolous and Mylopoulos, 2005). It is a mathematical programming approach that incorporates various goals or objectives which cannot be reduced to a single dimension. It is an extension of linear or nonlinear programming involving an objective function with multiple objectives. While developing a GP model, the decision variables of the model are to be defined first. Then the managerial goals related to the problems are to be listed down and ranked in order of priority. Since it may be very difficult to rank these goals on a cardinal scale, an ordinal ranking is usually applied to each of the goals. It may not always be possible to fully achieve every goal specified by the decision-maker.

GP is also a good approach to solve multi-criteria decision making problems with conflicting objectives (Charnes and Cooper, 1961; Ignizio, 1976). The fundamental concept in GP is to incorporate all goals of the decision-maker in the model formulation. In reality, the decision-maker generally chooses the achievement of certain goals at the expense of others. Therefore, GP requires an ordinal ranking of the goals in order of importance by the decision-maker. The solution process then satisfies goals beginning with the goal with the highest priority. Lower order goals are

considered only after higher order goals have been satisfied. The solutions to the higher order goals then become constraints for the lower order goals. As such it may not be possible to satisfy all goals to the required extent. GP can then be used to find a satisfactory level of achievement of the goals. Accordingly it is necessary to specify aspiration levels for the goals. Therefore, the objective function deals with minimization of the positive and negative deviations from the goals following the preemptive priorities assigned to the deviations.

Keeping in view the above and considering the inherent problems, the present study has been conceptualised to have integrated planning for agricultural development in Koraput district in the Eastern Ghat region of Odisha. Eastern Ghats covering an area of 19.8 million hectares spread over of 4 states of India i.e. Tamil Nadu, Karnataka, Andhra Pradesh and Odisha and is severely affected by various forms of erosion (Sikka *et al.*, 2000). This region comprises of hillocks, sloping lands and low lands/fertile flat lands (widened and terraced gully beds serving as drains to sediment-rich runoff from upper topo-sequences). The elevation ranges from 150 to over 1600 m above mean sea level. The Eastern Ghat region of Odisha comprising area of 4.87 million hectares spread over 10 districts is endowed with potentially rich natural resources but subjected to inherent problems like undulating topography, fragile steep slopes, shifting cultivation, large scale deforestation, over grazing, poor soil fertility and productivity, high and intense rainfall, heavy runoff and severe soil erosion leading to continuous land degradation. Due to high and intense rainfall (about 1500 mm per annum) and no or very sparse vegetation, large amount of runoff is generated on hillocks, which severely erode the downside cultivated lands (silt production rates 2.7 to 8.96 ha m/100 sq km in Koraput region) and thus jeopardizing the sustainability of crop productivity and ecological balance (Sudhishri *et al.*, 2003).

Shifting cultivation on steep slopes locally called “*Poduchasa* ” is prevalent among the resource poor tribal farmers of the district and is a major concern for environmental degradation and ecology (Naik *et al.*, 2013). In this region the annual soil loss estimated is 45 t ha<sup>-1</sup> yr<sup>-1</sup> (Govt. of Odisha, 1988). The absence of any conservation measures and adoption of traditional unscientific land use practices are further aggravating the land degradation problems of this region. Due to the high population growth and limited scope of extension of agriculture in low lands (*Jhola*), there is a tremendous pressure on sloping upland (*Dangar*) in Eastern Ghat region of Odisha for food crop production. Since the sloping uplands are highly erosion prone,

cultivation in these areas are ecologically very sensitive. It may result lowering in crop yield periodically due to continuous loss of top fertile soil with heavy runoff leading to hazardous consequence. All these warrants for proper and effective management of available natural resources for the integrated development of the people in a sustainable, viable and replicable frame work.

Optimal land and water use planning in Eastern Ghat region of Odisha is highly essential to cater the need of people and tackle the problem of land degradation. Optimal allocation of land and water use is an activity to improve the efficiency of land use types by specifying the appropriate use of land and maximizing the water productivity by its economic utilization. There is an urgent need to devise best cropping pattern conducive for the agro-climatic and socio-economic conditions of the region for maximization of net return from agriculture with minimum investment and soil loss. This would also help the policy makers at the Government level to think of the alternatives and prioritize the activities to be taken up to ensure food security, economic growth and overall development of the area. Therefore, the present study is proposed with the following objectives.

### **Objectives**

1. To analyze the climatic data and assess the water resource potential of the area.
2. To find out the suitable cropping pattern and sequences based on water balance through assessment of soil loss, extent of agricultural investment and net return.
3. To develop an optimised model for effective crop land utilisation based on highest return and minimum soil loss.

# REVIEW OF LITERATURE

---

This chapter involves a brief review of the past research works carried out by various researchers relevant to the present study comprising land degradation due to agricultural practices, land and water management, food requirement for nutritional sufficiency, estimation of evapotranspiration, determination of effective & dependable rainfall, estimation of soil loss and mathematical modeling for resource allocation in agriculture.

## **2.1 Land degradation due to agricultural practices**

Land degradation refers to the temporary or permanent reduction in the productive capacity of land and is human-induced or natural process which negatively affects the land to function effectively within an ecosystem. All forms of agriculture involve alteration of ecological system. In the process of agricultural development, large scale land degradation has occurred in countries world over. This causes increasing decline in productivity over the years and finally lead to land abandonment. This in turn has limited the future gains from the land and water resources.

Intensive farming practices, particularly with wheat and rice in India, have virtually mined nutrients from the soil. Due to heavy use of fertilizers, excess nitrates have leached into groundwater and contamination of groundwater with nitrates has increased dramatically. As such, the cultivable lands have become sick by over-application of chemicals. Apart from over use of chemicals, equally important issue is imbalance in the application of fertilizers and pesticides. Intensive agriculture has also led to extension of area under irrigation. Improper use and maintenance of canal irrigation has contributed significantly to the soil degradation problem. Extension of canal irrigation to arid and semi arid areas has resulted in water-logging and salinity problem.

The theoretical studies highlight the fact that the soil erosion is a result of rational farm decision making (Mc Connell, 1983). A rational producer, maximizing the discounted net revenue from land over time would not respond to soil loss until the present value of marginal private returns obtained from additional soil loss goes

below the implicit marginal private cost of soil loss. The net value from land consists of two components; the present value of the revenue stream and the terminal value of the land. Soil erosion, not only affects future productivity but also affects the terminal value of the land (Miranowski, 1984). The presence of large external cost (off-site costs) is neglected in the private decision. The rationale for policy intervention arise in two contexts (i) where offsite costs are significant (ii) where the on-site land degradation effect is not transparent to the owner.

An estimate of soil erosion and sedimentation for India reveals that about 5300 million tonnes of top soil are eroded annually and 24% of this quantity is carried by rivers as sediments and deposited in the sea, and nearly 10% is deposited in reservoirs reducing their storage capacity by 2%. It has been estimated that total annual loss of productivity of major crops due to soil erosion in India is 7.2 million tonnes (Brandon *et al.* 1995).

According to an estimation by Eswaran, *et al.* (2001), the total annual cost of erosion from agriculture in the USA is about US\$ 44 billion per year, i.e. about US\$ 247 per ha of cropland and pasture. On a global scale the annual loss of 75 billion tonnes of soil costs the world about US\$ 400 billion per year, or approximately US\$ 70 per person per year.

As per National Remote Sensing Agency and Forest Survey of India, 60% of the country's total area under cultivation is substantially degraded and most of this damage is in the form of loss of topsoil. It has been reported that a major portion (98%) of total soil loss from a watershed is from the cultivated crop lands (Suresh *et al.*, 2002).

Nagdeve (2002) observed that direct impacts of agricultural development on the environment arise from farming activities accompanied by over exploitation of land and water resources and use of fertilizers and pesticides. He also cited that, in India out of the total geographical area of 328.7 million hectares, 175 million hectares are considered to be land-degraded area of which 141.3 million hectares relates to water and wind erosion.

Mythili (2003) has expressed that soil degradation in India presents the very real threat of limiting future gains in agricultural output and forest production as well as risks to human health. He also stated that the extent of land area dedicated to food

grain cropping has grown steadily from 97 m ha in 1951 to 120 m ha in 2001. Much of this increment of land over the last four decades has come from previously forested areas. He has suggested that a comprehensive approach be taken by the authorities responsible for policy in different areas such as food security, forest and soil conservation and water resources.

Earles (2005) studied the agriculture situation in the United States and stated that conventional 20th-Century agriculture took industrial production as its model, and vertically-integrated agri-business was the result. This, coupled with substantial government subsidies, made food abundant and cheap. Through its emphasis on high production, the industrial model has degraded soil and water, reduced the biodiversity that is a key element to food security, increased our dependence on heavy import and driven more and more acres into the hands of fewer and fewer “farmers,” crippling rural communities.

The UN millennium ecosystem assessment ranked land degradation among the world's greatest environmental challenges, claiming it risked destabilising societies, endangering food security and increasing poverty. Some 40% of the world's agricultural land is seriously degraded (Ian, 2007). Among the worst affected regions are Central America, where 75% of land is infertile, Africa, where a fifth of soil is degraded, and Asia, where 11% is unsuitable for farming.

## **2.2 Land and water management**

Land and water have been the basic elements of life support system on our planet since the dawn of civilization. All great civilizations flourished where these resources were available in plenty, and they declined or perished with the depletion of these resources. The respect for the importance of land resources is best depicted in the conventional concept of *Panchabhutas*– land, water, fire, sky and air that constitute a set of divine forces. There are innumerable examples of the traditional conservation practices and systems, which are still surviving and are effective. But with the advent of modern age and the advent of newer forces, this tradition is fast deteriorating mainly on account of consumerism, materialistic value systems, short-term profit-driven motives and greed of the users. As a result, land has degraded, soil fertility depleted, the rivers polluted and the forests destroyed ([http:// expertmindsias.in/resources/Resources.pdf](http://expertmindsias.in/resources/Resources.pdf)).

Conversion of agricultural land to urban uses is a particular concern worldwide, as rapid growth and escalating land values threaten farming on prime soils. Existing farmland conversion patterns often discourage farmers from adopting sustainable practices and a long-term perspective on the value of land. At the same time, the close proximity of newly developed residential areas to farms is increasing the public demand for environmentally safe farming practices. Comprehensive new policies to protect prime soils and regulate development are needed. By helping farmers to adopt practices that reduce chemical use and conserve scarce resources, sustainable agriculture research and education can play a key role in building public support for agricultural land preservation. Educating land use planners and decision-makers about sustainable agriculture is an important priority (<http://asi.ucdavis.edu/sarep/about-sarep/def>). In recent years, the land resource has been subjected to a variety of pressures. Still it is surviving and sustaining mankind. What is alarming in the way land is being used is the tendency towards over-exploitation on account of a number of reasons leading this pristine resource being robbed of its resilience.

Water is the principal resource that has helped agriculture and society to prosper, and it has been a major limiting factor when mismanaged. Water supports all forms of life on this mother earth. It plays a vital role in agricultural and industrial development and sustaining human life. Rainfall is the only source of water. The water is confined as i) soil moisture, ii) stored water in surface storage like reservoirs, tanks, ponds, temple tanks and in open wells etc., iii) groundwater in sub surface, iv) sea water and v) waste water like sewage and effluent. Depending upon the rainfall, its intensities and frequencies, an area becomes drought or flood affected. Management of watershed thus entails the rational utilization of land and water resources for optimum production but with minimum hazard to natural and human resources. The main objectives of watershed management are to protect the natural resources such as soil, water and vegetation from degradation. In the broader sense, it is an undertaking to maintain the equilibrium between elements of natural ecosystem of vegetation, land or water on the one hand and man's activities on the other hand (<http://pib.nic.in/feature/feyr2000/fsep2000/f120920001.html>). If water is managed more effectively in agriculture, the available land and water resources would be sufficient to satisfy global food demands during the next 50 years (De Fraiture and Wichelns, 2010). Water allocation and management have socioeconomic,

environmental and technical dimensions that have to be addressed simultaneously for sustainable development of available water resources (Dogra *et al.*, 2011).

### **2.3 Food requirement for nutritional sufficiency**

Nutrition is a basic human need and a prerequisite to a healthy life. Nutrients that we obtain through food have vital effects on physical growth and development, maintenance of normal body function, physical activity and health. Nutritious food is, thus needed to sustain life and activity (<http://ninindia.org/DietaryguidelinesforIndians-Finaldraft.pdf>).

Our diet must provide all essential nutrients in the required amounts. Requirements of essential nutrients vary with age, gender, physiological status and physical activity. A proper diet is essential from the very early stages of life for proper growth, development and to remain active. Food consumption, which largely depends on production and distribution, determines health and nutrition of the population. Health and nutrition are the most important contributory factors for human resource development in the country ([http://shodh.inflibnet.ac.in/bitstream/123456789/766/2/02\\_synopsis.pdf](http://shodh.inflibnet.ac.in/bitstream/123456789/766/2/02_synopsis.pdf)).

The major food issues of concern are insufficient/ imbalanced intake of foods/nutrients. Long-term malnutrition (under and over) leads to stunting and wasting, non-communicable chronic diet related disorders, increased morbidity and mortality and reduced physical work output. It is a great economic loss to the country and undermines development (<http://www.puraenetwork.com/vdc/currentdiet.html>).

Dietary guidelines are a translation of scientific knowledge on nutrients into specific dietary advice. They represent the recommended dietary allowances of nutrients in terms of diets that should be consumed by the population. The guidelines promote the concept of nutritionally adequate diets and healthy lifestyles from the time of conception to old age. The guidelines are consistent with the goals set in national policies on Agriculture, Health and Nutrition. A variety of foods, which are available and are within the reach of the common man, can be selected to formulate nutritionally adequate diets.

In the wake of reports by the Food and Agriculture Organization (FAO) on calorie and protein in 1950 and 1957 respectively, an attempt was made by the Indian Council of Medical Research (ICMR) in 1958 through its Nutrition Advisory

Committee (NAC) to revise protein and calorie requirements of Indians, based on data available at that time. In 1968, the requirements of all nutrients except energy were reviewed by an Expert Committee constituted by ICMR. In arriving at these new recommendations, the international data provided by the FAO/WHO Expert Group and those generated by then in India, were used. In 1978, the Recommended Dietary Allowances (RDA) for Indians was again reviewed by another Expert Group of the ICMR and RDAs of several nutrients were revised. In the recommendations made by the ICMR Expert Group in 1968 and 1978, a wide range of balanced diets for different age and sex groups were formulated which, if consumed, could ensure a daily intake of all nutrients at the recommended levels (ICMR, 1978).

The recommendations on human protein and energy requirements were again revised by a Joint Expert Group of FAO, WHO and United Nations University (UNU) in 1985 (WHO, 1985). In 1988, an Expert Group was again constituted by the ICMR to review the energy and protein requirements of Indians based on update data. This Expert Group included in its recommendations several additional nutrients not considered by the earlier ICMR Expert Committees and altered the reference body weights of normal healthy adult man, woman and children based on body weight data then obtained by National Institute of Nutrition (ICMR, 1990).

The working group on dietary allowances for Indians, constituted by the National Institute of Nutrition, studied extensively the nutrients available in common Indian food materials and suggested sample meal plans for adult men and women under sedentary, moderate and heavy working groups (NIN, 1998).

Shirgure (1998) used multi-objective linear programming approach to solve the multi resource utilization and land allocation problem in Bishnupur watershed in Bihar. For optimum land allocation to crops, he kept a objective of maximization of food production considering the nutritional constraints of protein and calorie to meet the nutritional sufficiency as per recommended dietary allowance (RDA). He calculated 40312 kg of protein and 1777372 kcal of energy is needed for meeting the nutritional sufficiency of total population of the watershed. He calculated total food production of 512.47 tonnes by optimised allocation of crops to take care of the nutritional constraints.

Gupta *et al.* (2000) had tried to deal with the real-world problem of irrigation water management of evolving suitable cropping pattern, which should be in harmony with optimal operation of the multi-reservoir system in the Narmada river basin. They used fuzzy linear programming to formulate the multi-objective fuzzy linear programming (MOLFP) area allocation model considering various conflicting objectives involved in irrigation planning of Narmada river basin. They had kept maximization of calorie intake as one of the objectives in formulating the model to get maximum calorie production to prevent calorie deficiency of the community. They calculated total need of  $190.92 \times 10^9$  kcal as per the RDA and it can be met from optimised cropping pattern consists of paddy (4655.15 ha), maize (4070.76 ha), wheat (6254.26 ha), groundnut (4552 ha), pigeon pea (1205.90 ha) and gram (2295.85 ha).

The Karnataka State Land Use Board has estimated availability and requirement of food grains in the state for the projected population during 2005, 2010, 2015, 2020 and 2025 considering the recommended dietary requirements of ICMR. They have calculated the food requirement of the population considering 86% of the total population as adult equivalent (KSLUB, 2001).

Paul *et al.* (2004) attempted for optimal utilization of land, water and human resources considering the basic objectives like food, fodder, fuel wood, net income generation, labour employment generation and runoff water augmentation. Under the study, they calculated the total food requirement for the people of Barapita nallah mini watershed (Odisha) considering the nutritional sufficiency as per recommended dietary allowance (RDA). They reported that 55000 kg of protein and energy of 2410000 kcal was needed for meeting the nutritional sufficiency of total population of study area. They calculated total food production of 1012 tonnes by optimised allocation of crops considering the nutritional constraints.

Govindaraj *et al.* (2008) calculated the energy and protein consumption by the tribal households of Koraput district in Odisha to ascertain the nutritional intake status of tribal population. They used the standard nutritional content of commodities published by the National Institute of Nutrition, Hyderabad (Gopalan *et al.*, 1996), to assess the energy consumption from the food habit of tribal people. They reported that the energy and protein consumption by tribals is 1781 kcal and 45.3 g per capita per day and is much below the minimal requirement of 2400 kcal and 55 g per capita per day.

Panigrahi *et al.* (2010) calculated the edible component of the four major food groups namely, cereals, pulses, oilseeds and vegetables including tubers required for a projected population of Kandhamal district of Odisha using the recommended dietary allowance (RDA) for reference Indian male and female as suggested by the National Institute of Nutrition considering 88% of the total population as adult equivalent. The physical/manual workers were treated as heavy and others were treated as moderate diet consuming humans. As reported by them, the total food requirement estimated for nutritional sufficiency was found to be 234399, 43373, 42598 and 61764 tonnes of cereals, pulses, oilseeds and vegetables, respectively.

#### **2.4 Estimation of evapotranspiration**

There are several methods for estimating evapotranspiration but most commonly used are i.e. aerodynamic, energy balance method, combination method and empirical method (Thornthwaite method, modified Blaney-Criddle method and pan evaporation method).

Penman (1948) treated evaporation as a dynamic process by combining the energy balance and the aerodynamic methods. The resulting relationship is referred to as the combination equation. Penman has modified the original equation in 1963. By combining these equations Penman obtained an expression for potential evaporation that eliminated the surface temperature dependence of the sensible heat in earlier equations. His original equation was based on evaporation from the tank of water. The definition of potential ET that emerged from his early work implied a maximum value of ET. Formally, potential ET has been defined as the evaporation from an extended surface of short green crop which fully shades the ground, exerts little or negligible resistance to the flow of water, and is always supplied with water. Potential evapotranspiration cannot exceed free water evaporation under the same weather conditions (Rosenberg, 1974).

Doorenbos and Pruitt (1977) have recommended a procedure for calculating evapotranspiration and crop water requirements which is termed the ' $K_c$   $ET_o$ ' approach, whereby the effect of the climate on crop water requirements is given by the reference evapotranspiration  $ET_o$  and the effect of the crop by the crop coefficient  $K_c$ . The modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop.

Doorenbos and Pruitt (1977) used an 8 to 15 cm grass cover as the reference crop to estimate ET, whereas Jensen (1974) used 30 to 50 cm tall crop of alfalfa. This dichotomy in the definition of a reference crop has led to the use of the term "reference crop evapotranspiration". The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as  $ET_0$ . The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions.

The reference crop evapotranspiration ( $ET_0$ ), which is the evapotranspiration from a reference grass surface, is used as a standard to evaluate evapotranspiration. It was formerly called potential evapotranspiration. The Penman–Monteith equation for computation of  $ET_0$  has been extensively evaluated worldwide and is considered the most widely accepted (Jensen *et al.*, 1990).

Malek and Bingham (1993) reported that evapotranspiration measured by water balance method and Bowen ratio energy balance method over a homogeneous field showed a very close relationship between the two measurements (correlation coefficient of 0.987). This implies that Bowen ratio system can be used for long term measurement of micrometeorological elements and provide an accurate estimation of evapotranspiration in any agricultural and non agricultural ecosystems.

In May 1990, FAO organized a consultation of experts and researchers in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advise on the revision and update of procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculating the various parameters. The FAO Penman-Monteith method was developed by defining the reference crop as a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of  $70 \text{ s m}^{-1}$  and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered. The method overcomes the shortcomings of the previous FAO Penman method and provides values that are more consistent with actual crop water use data worldwide. The modified form of the Penman–Monteith equation as given in the publication paper no. 56 of Food and

Agriculture Organization of the United Nations (FAO-56) was adopted as a benchmark equation to estimate  $ET_0$  for all climate conditions (Allen *et al.*, 1998).

Prenger *et al.* (2002) used the data from a lysimeter study to compare the evapotranspiration rate of a red maple tree in a controlled environment green house. The measured ET was compared with two empirical climatic factors (solar radiation and vapour pressure deficit) and with calculated ET of four models (Penman, Penman-Monteith, Stanghellini and Fynn). It was observed that vapour pressure deficit alone yielded a good linear correlation to measured ET and Stanghellini method gives the nearest calculated ET as the measured ET. In a similar study, Jharjharia *et al.* (2004) had compared the Christiansen model and the Penman-Monteith FAO 56 model to estimate  $ET_0$  of different stations of Assam and found out that the Christiansen model overestimated the  $ET_0$  values at all locations.

Irmak (2005) have evaluated the hourly  $ET_0$  values using Penman-Monteith model and have compared the sum of the hourly values of the  $ET_0$  with the daily  $ET_0$  in different climates. The result indicated significant difference between the two sets of  $ET_0$  values. The difference however reduced when considered on weekly, monthly and annual basis. They attributed the difference partly to the uncertainties in using constant ratios of  $G$  to  $R_n$  in the hourly computation time steps and possibly to the inability of 24 h time step computation procedure to account for the abnormal diurnal changes in wind speed, air temperature and vapour pressure deficit.

For estimating evapotranspiration, empirically based methods are established grounded on observations and statistical analysis, and usually are appropriate for a specific region or climatic condition (Gavilán *et al.*, 2006; Ahmadi & Fooladmand, 2008; Fooladmand & Ahmadi, 2009). On the other hand, physically based models aim to simulate fundamental principles such as energy balance and mass transfer. Although some disadvantages and problems were reported, physically based models have proven to perform well in a great variety of climatic conditions (Cancela *et al.*, 2006; Villa *et al.*, 2007; Liu & Luo, 2010). Eduardo *et al.* (2011) reported that the Hargreaves, the Thornthwaite and the Blaney-Criddle are the three tested methods and these are the most recommended approaches for determining evapotranspiration when only air temperature data are available.

Maina *et al.* (2012) stated that the FAO Penman-Monteith method is generally considered to be the best approach for estimating  $ET_o$  and determination of crop coefficient because of its good approximation to accurate lysimeter observations. They calculated  $ET_o$  values from the weather parameters recorded by automatic weather station system with the help of FAO CROPWAT 8.0 for Windows software. The weather parameters used were minimum and maximum temperature, relative humidity, sunshine hours, wind speed at 2 m height, solar radiation, vapor pressure, and rainfall.

## **2.5 Determination of effective and dependable rainfall**

Hershfield (1964) defined effective rainfall as that part of the total rainfall during the growing season, which is available to meet the consumptive water requirements of a crop. Miller and Thompson (1970) defined effective precipitation as the ratio of precipitation to evaporation at a given place. Dastane (1978) pointed out that instead of annual rainfall, effective seasonal or effective growing season rainfall should have been considered for effective water balance studies.

Dependable rainfall is the amount of rainfall which can be depended upon in 1 out of 4 or 5 years corresponding to a 75% or 80% probability of exceedance or representing a dry year. The dependable rainfall (80%) is used for design of the irrigation system capacity (Smith, 1992).

As rainfall varies from year to year, Doorenbos and Pruitt (1977) suggested that for irrigation planning purposes, the use of a dependable level of rainfall should be selected (saying the depth of rainfall that can be expected 3 out of 4 years or 4 out of 5 years) rather than using mean rainfall data (saying roughly one year is drier, the next is wetter). A higher level of dependable rainfall (say 9 out of 10 years) may need to be selected during the period that crops are germinating or are most sensitive to water stress and yields are severely affected.

Ganng (1986) has analyzed the relationship of mean monthly rainfall and the 70% monthly (10 days) dependable rainfall of three climatological stations. He recommended that the use of two separate regression lines give a better approximation of the 70% monthly dependable rainfall, especially when the rainfall is low and bimodal.

Smith (1992) used 70% of the rainfall at 80% probability of exceedance as the planned effective rainfall for irrigation scheduling. He included 4 widely used methods to predict the amount of rainfall that is utilizable by plants and set the USDA Soil Conservation Service method as the default option for estimation of effective rainfall in software package FAO CROPWAT.

Borton and Nicholds (1994) has opined that because of the importance of timeliness, particularly in semi-arid areas where soil moisture retention capacity is low, rainfall must be described and analyzed in appropriately short time periods so that prolonged dry periods are not “hidden” within aggregate figures which may indicate that rainfall has been around or even above the average.

Savva and Frenken (2002) has suggested that for planning purposes the use of mean values of rainfall should be avoided if more than 10 years of annual rainfall data are available and probability analysis be carried out so that a dependable level of rainfall is selected with a certain statistical probability, determined from a range of historical rainfall records as rainfall contribution may be substantial in some years and may be limited in other years.

Zhang and Garbrecht (2002) has probabilistically quantified the impact of precipitation variations on precipitation retention in five watersheds with similar silt loam soil and found that the precipitation retention distribution resembles the precipitation distribution. They observed that the available soil water storage, which was largely controlled by ET played an important role in retaining precipitation indicating that that the cropping systems should be adjusted to the precipitation patterns, if predictable, for better soil water use.

Haque (2005) determined the dependable rainfall from monthly mean rainfall using monthly rainfall graph and from yearly mean rainfall using yearly rainfall graph. The comparison of frequency analysis and computed values of dependable rainfall using yearly and monthly rainfall graphs showed good correspondence. He reported that based on dependable rainfall, net irrigation requirement can be obtained of each crop cultivated.

Sharma *et al.* (2010) have used the USDA Soil Conservation Service method to calculate monthly effective rainfall with help of “FAO CropWat4Windows” software for calculation of effective rainfall for rainfed districts of India.

Panigrahi *et al.* (2010) have also used the same procedure to calculate monthly effective rainfall for the Eastern Ghat Hill plateaus of Odisha and stated that this method is being widely used in India to calculate monthly effective rainfall.

## **2.6 Estimation of soil loss**

Soil erosion is a naturally occurring process that affects all land forms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage. Erosion, whether it is by water, wind or tillage, involves three distinct actions i.e. soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes. It is a complex phenomenon governed by a so many of factors and its actual measurement in the field is not feasible except in very small runoff plots. Work on development of empirical models to predict soil erosion by water started about half a century ago. The development of erosion prediction technology began with the analysis, such as those by Cook (1936) to identify the overriding variables that affect soil erosion by water. Cook listed three major factors, which affect soil erosion. These are: susceptibility of soil to erosion, potential erosivity of rainfall and runoff and soil protection afforded by plant cover.

Zingg (1940) is often credited with the development of the first erosion-prediction equation used to evaluate erosion problems and select conservation practices to reduce excessive erosion. Zingg's equation was a simple expression that related soil erosion to slope steepness and slope length.

Browning *et al.* (1947) added soil conductivity and management factors to the equation of Smith (1941), and prepared more extensive tables of relative factor values for different soils, crop rotations and slope lengths. This approach emphasized on the evaluation of slope length limits for different cropping systems on specific soils and slope steepness with and without contouring, terracing or strip cropping.

Smith and Whitt (1947) added terms to Zingg's equation to reflect the influence of cover and management on soil erosion. Relative differences among conservation practices do not consider important differences among locations caused by differences

in rainfall erosivity or soil. Thus, rainfall-erosivity and soil-erodibility terms were added to the Zingg and the Smith and Whitt equations (Musgrave, 1947; Wischmeier and Smith, 1958).

In the 1960s much of the field-erosion research shifted from natural runoff plots to rainfall simulator plots. Concurrent with the development of these erosion-prediction equations was the development of a soil loss tolerance concept (Stanley and Smith, 1964; Schmidt *et al.*, 1982). These terms along with the soil loss tolerance concept allowed users to consider differences among site characteristics and to consider the severity of erosion relative to a measure of how much erosion a soil could "tolerate" before experiencing excessive damage. By the early 1950s a set of regional equations had been developed that used soil-erodibility terms reflective of major soils in each region. Even though these equations proved to be quite useful, the United States Department of Agriculture (USDA), Soil Conservation Service (SCS), needed a more "universal" soil loss equation than these regionally based equations. Beginning in the mid-1950s W. H. Wischmeier, D. D. Smith, and their associates began to assemble and analyze an extensive quantity of available plot data. The result was the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), which became the most widely used equation for estimating inter rill and rill erosion.

The basis of a soil-erodibility nomograph and the cover-management factor values in the 1978 USLE version were derived from rainfall simulators. Another important USLE concept introduced in 1970 was the subfactor method for estimating cover-management factor values (Wischmeier, 1975).

Development of the USLE continued after 1965, resulting in a major revision of the equation in 1978 (Wischmeier and Smith, 1978). Many of the modifications between 1965 and 1978 used data collected from rainfall simulators (Meyer, 1960). This method was originally introduced for computing factor values for range, woodland, and similar land uses where plot data were not available, but where agencies needed to apply the USLE. This method has since been extended to all land uses (Laflen, Foster, and Onstad, 1985).

### **2.6.1 Universal Soil Loss Equation**

Wischmeier and Smith (1958) reported that a joint conference of key researchers and users were held at Purdue University in 1956 to fasten the

development of a national equation of soil loss estimation for the United States of America. The equation that resulted had seven factors consisting of crop rotation, management, slope steepness, slope length, conservation practice, soil conductivity and previous erosion. Subsequent studies also showed that the equation's crop rotation and management factors could be combined into one factor. Using the data assembled at the Data Centre along with conclusions from deliberations at the 1956 conferences and subsequent analysis, Wischmeier, Smith and others developed the Universal Soil Loss Equation (USLE), which quantified soil erosion as the product of six factors representing rain fall erosiveness, soil erodibility, slope length, slope steepness, cover management practices and support conservation practices (Wischmeier and Smith, 1965).

Wischmeier (1972) commented that the USLE overcomes many of the deficiencies of its predecessors. The form of USLE is similar to that of previous equations, but the concepts, relationships and procedures underlying the definitions and evaluation of the erosion factors are distinctly different.

Wischmeier and Smith (1978) noted that the acceptance of the USLE progressed slowly during this period. Techniques for the evaluation of its factors, such as, soil erodibility nomograph for farm land and construction areas, topographic factors for irregular slopes, cover factors for range and wood land, effects of tillage practices on cover and management, prediction of erosion in construction areas, estimated erosion index values for the western states and Hawaii and evaluation of erosion - control support practices, were developed.

Singh *et al.* (1992) prepared an iso-erosion rate map of India and reported that the annual erosion rates in Western Ghats coastal regions varied from 20 to 30 Mg/ha (9 to 13 tons/acre). Erosion rates in the black soil region (vertisols) of the country, occupying a 64-million-ha (158-million-acre) area in Karnataka, Andhra Pradesh, Madhya Pradesh, and Maharashtra states, generally were 20 Mg/ha/yr. Red soils of Chhotanagpur plateau also recorded a soil loss value of 10 to 15 Mg/ha/yr (4.5 to 7 tons/acre/year). The north western hills of Jammu and Kashmir, Himachal Pradesh, and Uttar Pradesh and the north eastern hills of Bengal and the north eastern states contribute more than 20 Mg/ha/yr. Foothills of the Himalayas and the Doon Valley produced 20 Mg/ha/yr of soil loss. Erosion rates on alluvial Indo-Gangetic Plains of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are moderate (5-10

Mg/ha/yr). The salt-affected saline and sodic soils of these plains were within limits of 5 Mg/ha/yr.

Folly (1997) had used Universal Soil Loss Equation (USLE) for the assessment of erosivity with an investigation of the spatial variability of erodibility in Ghana. He determined the topographic characteristics using digital terrain models. He assessed the land cover by using LANDSAT-TM satellite image and derived crop management factor of USLE.

Mughogho (1998) carried out soil loss research on three experimental plots at Kamundi catchment area in the Southern Region of Malawi using both RUSLE and SLEMSA models and found out that both models RUSLE and SLEMSA have proved to be suitable for estimating soil loss using seasonal rainfall i.e. estimate long term soil loss rather than individual storm and monthly rainfall.

Kitahara *et al.* (2000) applied the Universal Soil Loss Equation (USLE) for a mountainous forest terrain in Japan and concluded that the USLE can be used successfully to estimate surface erosion on long, steep mountainous forest slopes. The cover and management factors of many kinds of natural and artificial forest stands, cutting types, and disturbance regimes were calculated from the literature. The support practice factors of many types of soil and water conservation practices were also calculated from published information. Based on these results, they showed that the USLE can be applied to estimations of soil erosion from wide areas including many kinds of agricultural and forest lands.

For predicting soil erosion, Universal Soil Loss Equation, popularly known as USLE model is most widely used throughout the world for estimating annual soil loss from agricultural basins though a number of parametric models have been developed to forecast soil erosion, and it is often used in different climatic and topographical conditions (Ahmad *et al.*, 2000).

Suresh *et al.* (2000) estimated soil loss from different orchards in Naurar watershed in Uttar Pradesh and reported that mango fruit trees yielded lowest rate of soil loss ( $2.4 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) in comparison to apple, pear, plum and apricot based plantations ( $3.15 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). Among all plantations, banana resulted highest soil loss of  $8.35 \text{ t ha}^{-1} \text{ yr}^{-1}$ .

Suresh *et al.* (2001) reported from a study in Naurar watershed in Uttar Pradesh that among various food grain crops grown under single cropping system, *mandua* generated lowest soil loss at the rate 0.010 & 0.014 t ha<sup>-1</sup> yr<sup>-1</sup> and 0.334 & 0.620 t ha<sup>-1</sup> yr<sup>-1</sup> on improved and traditionally terraced lands under irrigation and rainfed conditions, respectively. Among cash crops, capsicum and chillies found to generate lowest rate of soil loss i.e. 0.024 & 0.033 t ha<sup>-1</sup> yr<sup>-1</sup> on improved and traditionally terraced lands under irrigation, and 0.767 & 1.420 t ha<sup>-1</sup> yr<sup>-1</sup> on improved and traditionally terraced lands under rainfed condition, respectively. Under mixed cropping system, the combination of paddy + *jhungra* resulted lowest soil loss and *mandua* + *gauhat* generated highest soil loss.

Suresh *et al.* (2002) had estimated soil loss under various land use systems in Naurar watershed in Uttar Pradesh using Revised Universal Soil Loss Equation (RUSLE). They reported soil loss to the tune of 246911.14 tonnes from the entire watershed at the rate of 39.97 t ha<sup>-1</sup> yr<sup>-1</sup>. Among different land uses, the cultivated crop land was found to be the major contributor to total soil loss (97.94%) followed by forest lands (0.94%), grass lands (0.68%), orchard lands (0.38%) and waste lands (0.60%). They observed highest rate of soil loss from crop lands (79.66 t ha<sup>-1</sup> yr<sup>-1</sup>) followed by grass land (8.66 t ha<sup>-1</sup> yr<sup>-1</sup>), orchard land (3.78 t ha<sup>-1</sup> yr<sup>-1</sup>), waste land (1.98 t ha<sup>-1</sup> yr<sup>-1</sup>) and forest land (0.98 t ha<sup>-1</sup> yr<sup>-1</sup>), respectively. The rate of soil loss was found to increase with increase in land slope.

Potdar *et al.* (2003) assessed the erosional soil loss in Nanda-Khairi watershed of Nagpur district in Maharashtra. The data related to soil, slope length and steepness, crop management and conservation measures were derived by them from satellite data, toposheet and ground truth survey and used as inputs in USLE Model for assessment of erosional soil loss. They prepared soil erosion map by the integration of USLE factors and it revealed five soil erosion classes. Nearly 62 per cent area of the watershed was under slight erosion with soil loss of <5 t ha<sup>-1</sup> yr<sup>-1</sup>. The moderately slight erosion (5-10 t ha<sup>-1</sup> yr<sup>-1</sup>) and moderate erosion (10-15 t ha<sup>-1</sup> yr<sup>-1</sup>) covered 28.1 and 0.4 per cent area of the watershed, respectively. The area under moderately severe (15-20 t ha<sup>-1</sup> yr<sup>-1</sup>) and very severely erosion (>40 t ha<sup>-1</sup> yr<sup>-1</sup>) classes covered 6.5 and 1.0 per cent area, respectively.

In Taiwan, Lin and Lin (2004) used the USLE to evaluate the rates of soil erosion in rice-planted paddy fields and abandoned paddy fields, assuming that the

topsoil had no plant cover. They found that the rates of erosion increased from 4.8 ton ha<sup>-1</sup> yr<sup>-1</sup> for lowland rice-planted paddies (with mild slope approximate to 1.5°) to 192.5 ton ha<sup>-1</sup> yr<sup>-1</sup> for abandoned paddies on plains and from 8.3 ton ha<sup>-1</sup> yr<sup>-1</sup> for terraced rice-planted paddies to 2049.8 ton ha<sup>-1</sup> yr<sup>-1</sup> for abandoned paddies in mountainous areas (with steep slope approximate to 25°).

Gupta (2010) stated that USLE can be of great benefit to the Indian farmers not only to assess soil loss from their fields but take appropriate control measures to bring soil loss to reasonable limits.

Panigrahi *et al.* (2010) used USLE and calculated the soil loss to the extent 12626.95 thousand tons at the rate of 94.23 tons/ha from the crop fields of Kandhamal district in Odisha. They reported that a major percentage of soil loss (22.66%) occurred from the fallow fields. The soil loss from the fallow fields was found to be very high at the rate of 143.21, 217.01 and 378.67 t ha<sup>-1</sup> yr<sup>-1</sup> from the slope ranges of 0–2%, 2–8% and 8–15%, respectively. The average soil loss in single cropped, double cropped and three cropped lands were 48%, 47% and 40% of the soil loss estimated from the fallow fields in all the slope ranges. The crop cover in single cropped, double cropped and three-cropped lands, therefore, resists the soil loss to the extent of 52%, 53% and 60%, respectively.

Shinde *et al.* (2011) had done quantitative assessment of average annual soil loss and prioritization of micro-watersheds of Upper Damodar Valley Catchment (UDVC) of India using most widely used USLE along with GIS and remote sensing. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the USLE parameters. Annual average soil loss for the entire basin was found to be 22.04 t ha<sup>-1</sup> yr<sup>-1</sup> and areas covered by high, medium and low erosion potential zones were 47.88%, 22.42% and 29.68%, respectively. The micro-watershed prioritization indicated that 345 micro watersheds out of 705 micro-watersheds were falling high priority class which required immediate attention for soil conservation treatment.

Prasannakumar *et al.* (2011) used Revised Universal Soil Loss Equation (RUSLE) in combination with remote sensing and GIS techniques to assess the spatial pattern and annual rate of soil erosion in the Munnar Forest Division in Western Ghats, Kerala, India. The RUSLE takes into account several factors such as rainfall,

soil erodibility, slope length and steepness, land cover and erosion control practice for soil erosion prediction. They observed maximum soil loss of  $109.31 \text{ t ha}^{-1} \text{ yr}^{-1}$  and the areas with extreme erosion (erosion is higher than  $50 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) are confined to 11.46% of the total area, while the area occupied by severe erosion (erosion rate between 25 and  $50 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) is 27.53%.

Chen *et al.* (2012) reported, though numerous models have been developed to quantify and predict soil erosion, the Universal Soil Loss Equation (USLE) is a frequently used model to determine areas at risk from erosion, and informs decision making for the reduction of erosion as a part of the long-term management of agricultural land.

Ahmad and Verma (2013) estimated soil loss to the tune of 490615 tonnes/year by applying Universal Soil Loss Equation (USLE) model and GIS, for the Tandula reservoir catchment area in Durg district of Chhattisgarh State, India. The result obtained from USLE model had been compared with existing model, Nayak and Khosla's method and revealed that USLE with GIS gave better result as compared to other two methods. They stated that the USLE model has been accepted and used most widely all over the world to predict the soil erosion from a watershed.

## **2.6.2 Factors of Universal Soil Loss Equation**

### **Erosivity index (R)**

Erosivity is a measure of the potential ability of soil, regolith, or other weathered material to be eroded by rain, wind, or surface runoff. Generally the striking power of raindrop is considered for calculating the erosivity index.

Wischmeier and Smith (1958) used the data of Laws and Parsons (1943) to develop a regression equation between the kinetic energy of rainfall and the rainfall intensity, and developed the following relationship:

$$E = 1.213 + 0.890 \log I \quad (2.1)$$

Where, E is the kinetic energy ( $\text{kg m/m}^2 \cdot \text{mm}$ ) and I is the rainfall intensity ( $\text{mm/hr}$ ).

Wischmeier (1959) observed that soil erosion from bare fallow plots is highly correlated with the cross product of total kinetic energy and the maximum 30 minute rainfall intensity and coined the  $EI_{30}$ . The R factor was expressed as:

$$R = \sum_{i=1}^j (EI_{30} / 100) \quad (2.2)$$

Where,  $j$  is the number of rainstorms per year.

Wischmeier (1962) related  $EI_{30}$  with other rainfall parameters, such as annual precipitation ( $P$ ), 1 h rainfall with a return period of 2 years and 24 h rainfall with a return period of 2 years. Babu *et al.* (1969) developed daily, monthly, seasonal and annual rainfall erosivity index relationships based on rainfall amounts (mm) for Dehradun. The relationships are as follows:

$$Y = 3.1 + 0.533 X \quad (\text{daily}) \quad (2.3)$$

$$Y = 1.9 + 0.64 X \quad (\text{monthly}) \quad (2.4)$$

$$Y = 50 + 0.389 X \quad (\text{seasonal}) \quad (2.5)$$

$$Y = 79 + 0.363 X \quad (\text{annual}) \quad (2.6)$$

Where,  $Y$  = rainfall energy (m tons / ha) x 30 minutes rainfall intensity (cm/h) and

$X$  = the daily, monthly, seasonal and annual rainfall (mm), respectively.

Hudson (1971) found that the accumulative kinetic energy of storms with intensity greater than 2.5 cm/h correlated better with soil loss than the  $EI_{30}$  index. Utomo and Mahmud (1984) reported that a significant correlation exists between  $R$  and weekly ( $W$ ), monthly ( $M$ ), and annual ( $P$ ) rainfall in cm for east Java. The relationships were given as:

$$(i) \text{ Annual index, } R = 237.4 + 2.61 P \quad (2.7)$$

$$(ii) \text{ Monthly Index, } R = 2.8 + 4.15 M \quad (2.8)$$

$$(iii) \text{ Weekly index, } R = 25.48 + 8.11 \sum (W^2/M) \quad (2.9)$$

Selker *et al.* (1990) presented a general procedure for the calibration of a model for rainfall erosivity based on the daily rainfall. The approach was based on probability distribution of wet day precipitation amount and monthly erosivities, which were inferred from published data summaries.

Thomas *et al.* (1990) formulated a model for computing monthly erosion index of the USLE from daily rainfall records. The prediction is based on the month of a year, maximum one-day rainfall during the month, and the extended rainfall is

expressed as a difference between the total rainfall of month and the maximum one-day rainfall.

One of the most important factors in soil erosion by water is the erosive potential of raindrop impact. The rainfall erosivity factor (R) in the Universal Soil Loss Equation (USLE) is generally recognized as one of the best parameters for the prediction of the erosive potential of raindrop impact (Loureiro and Coutinho 2001).

Sudhisri and Pattanaik (2004) have studied the annual and seasonal rainfall of Eastern Ghat High Land (EGHL) Zone from 1970-2001 and found that erosion index during the month from May to September accounts for about 83.7% of annual value. Highest erosion index was recorded during the year 1995 and lowest in 1997. The average annual and seasonal erosion index varies from 618.78 to 1061.66 and 388.03 to 945.39, respectively. It was also observed that the amount of erosive rainfall from the month of October to April is negligible. Linear regression equations were developed between the annual, seasonal, monthly erosion index ( $EI_{30}$ ) and total rainfall (P) as:

$$\text{Annual,} \quad EI_{30} = -419.485 + 0.803 P \quad (2.10)$$

$$\text{Seasonal,} \quad EI_{30} = -530.641 + 0.947 P \quad (2.11)$$

$$\text{Monthly,} \quad EI_{30} = 6.02 + 0.464 P \quad (2.12)$$

Zheng *et al.* (2005) pointed out that lower rainfall amounts and intensity (rainfall amount  $< 15$  mm or  $I_{30} < 10$  mm h<sup>-1</sup>) generated lower runoff discharge as well as corresponding transport capacity, resulting in lower sediment yields and erosion rates.

Duan *et al.* (2006), based on correlations between rainfall factors and runoff and sediment amounts, stated that the  $P \times I_{30}$ ,  $P \times I_{60}$ , and  $P \times I_{10}$  indices are the main factors influencing soil erosion when rainfall amount and intensity are lower.

Kinnel (2007) reported that the major advantage of an erosivity factor that includes runoff terms is the reduction of large overestimates of soil loss when the runoff is negligible and rainfall amounts and rates are great. Conceptually, the  $EI_{30}$  index accounts for the effect of runoff on erosion best when the soil surface is impervious.

Sharifan (2008) studied the relations between annual R and other rainfall parameters. He developed the following equation to measure the annual R.

$$R_{yr} = 1.22 \times 10^{-3} \times \frac{P_y^{2.116}}{T^{0.122}} \quad (2.13)$$

Where,  $R_{yr}$  is the annual rainfall erosivity,  $P_y$  is the annual rainfall amount, and T is the return period.

On an annual basis, the R value (rainfall erosivity index) was taken to be the summation of values over the storms in an individual year as a Brown and Foster equation (Martinez et al. 2009):

$$R = \frac{1}{n} \sum_{j=1}^n \sum_{k=1}^{m_j} (r)_k \quad (2.14)$$

Where r is rainfall erosivity for any individual event, j is the index for the number of years used to compute the average, k is the index of the number of storms in each year, n is the number of years to obtain the average R, and  $m_j$  is the number of storms in each year.

Khorsandi *et al.* (2010) also measured the long-term average of the mean  $EI_{30}$  at some synoptic stations in the northern part of Iran and investigated the relations between  $EI_{30}$  and some indices based on rainfall amount. They found that following equation can be used to predict the  $EI_{30}$  at climatology stations without rainfall intensity data. In this equation,  $FI_{mod}$  is the modified Fournier index.

$$EI_{30} = -223.30 + 214.548 FI_{mod} \quad (2.15)$$

### **Soil erodibility factor (K)**

The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (i.e. infiltration rate, permeability, total water capacity,

dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting K, but structure, organic matter, and permeability also contribute.

Bouyoucos (1935) reported that soil erodibility depends on the mechanical composition of soil, such as, sand, silt and clay, and expressed erodibility as the ratio of (% sand + % silt) and (% clay). The clay ratio was considered as being a measure of the binding ability of clay fraction to form soil aggregates. He found that higher clay ratio indicates lower binding influence due to clay and therefore greater susceptibility to erosion and concluded that the value of this ratio correlates with the erosiveness of soils.

Chorley (1959) analyzed physical properties of soil in the Oxford region, England, and showed striking differences with which variations in local relief features are considered to be related. He derived indexes of resistance and erodibility for determining the relative resistance of each soil type to sheet erosion, and developed a relationship for erodibility index, based on mean shearing resistance and soil permeability and described it as the product of inverse of mean shearing resistance and inverse of permeability.

Pasak (1967) derived a relationship between soil erodibility, contents of non - erodible particles, moisture content and wind velocity at soil surface. The relationship was given as:

$$E = 22.02 - 0.72 P - 1.69 V + 2.64 R \quad (2.16)$$

Where, E is the soil erodibility, P is the content of non-erodible particles in the soil, V is the relative moisture content and R is the wind velocity at the soil surface.

Bryan (1968) reported that the aggregate stability is an efficient index to show the effects on soil erodibility. He used the proportion of water-stable non-primary aggregates larger than 0.5 mm in diameter as an indicator of soil erodibility. A greater proportion of it in the soil produced more resistance to soil erosion.

Wischmeier and Mannering (1969) used the binding influence of clay as reflected by inverse of clay ratio for soil loss in field plots. He suggested a more common index of K for the prediction of soil loss and stated it as soil loss per unit of EI<sub>30</sub>, and reported that soil properties that contributed significantly to soil loss variance included percentages of sand, silt, clay and organic matter; pH, structure and bulk density of plow layer and subsoil; steepness and concavity or convexity of slope; pore

space filled by air; residual effects of sod crops; aggregation; parent material; and various interactions of these variables.

The most widely used and frequently cited relationship is the soil erodibility nomograph developed by Wischmeier *et al.* (1971). The nomograph comprises five soil profile parameters: percent modified silt (0.002-0.1 mm), percent modified sand (0.1-2.0 mm), percent organic matter (OM), and classes for structure (S) and permeability (P).

Yamamoto and Anderson (1973) used the soil loss data generated from a rainfall simulator to test the indices of soil erodibility, based on soil aggregate size and Middleton's suspension percent. The gross soil loss was related to soil erodibility index, bulk density and infiltration and saturation moisture content. The maximum splash erosion (soil loss) variation was also related to organic matter content, erodibility index and bulk density of the soil.

Tejwani *et al.* (1975) reported the value of K as equal to 0.04 for deep lateritic soil at Ootacamund (India) at 25 percent slope of the runoff plot. Dangler *et al.* (1976), Dangler and EL - Swaify (1976) and EL - Swaify (1977) determined the values of K for some tropical soils of Hawaii on a rainfall simulator and found that the erodibility factor (K) determined by them ranged from 0 to 0.60 m.ton/ha/yr.

Wischmeier and Smith (1978) derived the following algebraic approximation of the nomograph for those cases where the silt fraction does not exceed 70%.

$$K = [2.1 \times 10^{-4} (12 - OM) M^{1.14} + 3.25 (S - 2) + 2.5 (P - 3)] / 100 \quad (2.17)$$

Where, M is the product of primary particle size fractions: (% modified silt of the 0.002-0.1 mm size fraction) & (% silt + % sand).

Nema *et al.* (1978) and Narain *et al.* (1980) evaluated the value of K in USLE as 0.059 and 0.04 for the sandy loam alluvial soils of Vasad (Gujarat) at 2 percent slope of runoff plot and for clay loam (black soil) of Kota (Rajasthan), respectively.

Singh *et al.* (1981) determined the value of K factor at different locations throughout India and reported that at Agra the average value of K was 0.07 for loamy sand and alluvial soils with a slope percent of runoff plot as 2. At Hyderabad it was 0.08 for red chalka sandy loam soil on 8 percent slope of the runoff plot. Similarly

0.13, 0.04 and 0.17 was the value of K factor for Dhulkot silt loam soils, loam and alluvial soils respectively at Dehradun, Kharagpur and Rahman Khera.

Singh and Prakash (1985) evaluated the characteristics and erodibility of some types of Siwalik range soils in Almora district of Uttar Pradesh under varying types of land use, slope and bench terrace conditions. They determined the average value of clay ratio, silt/clay ratio, clay/moisture equivalent ratio, dispersion ratio, erosion ratio and erosion index of soils as 11.1, 1.5, 0.5, 31.6, 63.1 and 64.0, respectively.

Vanslande *et al.* (1985) measured the K factor for some types of the Nigerian soils and observed that it ranged from 0 to 0.535. They also compared the measured value of K with that estimated by the nomograph. The measured erodibility value was found to be generally greater than the value estimated by the nomograph.

Mtakwa *et al.* (1987) compared the measured soil erodibility for alfisols in the Western Nigeria with that estimated from the nomograph of Wischmeier *et al.* (1971). Their results showed that the nomograph underestimated the erodibility of soils.

The soil erodibility factor (K) is commonly predicted using the USLE nomograph on the basis of five soil and soil profile parameters that include soil particles (% sand, % silt, % very fine sand and silt, and % clay), % organic matter, soil structure code and soil permeability class (Schwab *et al.*, 1993).

This factor is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and sequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter, soil chemistry and water transmission characteristics (Lal, 1994).

Soil erodibility is defined as ‘the inherent susceptibility of soil particles or aggregates to become detached or transported by erosive agents such as rainfall, runoff, through flow, wind or frost’. Soil erodibility expresses the resistance of soil particles to both detachment and transport by raindrop impact and runoff (Renard *et al.*, 1997).

Panda and Andrianasolo (2000) determined soil properties of different soils at Kuniguda watershed, a part of Balimela-Sileru catchment in Northern Orissa and calculated the K factor using nomograph application as 0.344 for loamy sand, 0.244 for sandy loam, 0.377 for loam and 0.277 for sandy clay loam soils.

Potdar *et al.* (2003) carried out a study to map the erosional soil loss in Nanda-Khairi watershed of Nagpur district in Maharashtra. They used physiography-soil map to generate information on soil erodibility factor (K) and preparation of soil erodibility map. The soil erodibility factor was determined by them for each soil units i.e. 0.181 (*khairi-1*), 0.219 (*khairi-2*), 0.205 (*khairi-3*), 0.156 (*khairi-4*), 0.206 (*panjri*), 0.206 (*kirmati*) and 0.230 (*shivmarka*), respectively.

As many erosion mechanism act at the same instant time, there is less likelihood for a relatively few soil characteristics to accurately describe the K values for each type of soil. However, many attempts have been made to relate the measured K values with the soil properties. For the USLE, the concept of soil erodibility was introduced as the K factor, which is defined as the average rate of soil loss per unit of rainfall erosivity index from a unit plot (Zhang *et al.*, 2004).

Pradhan *et al.* (2012) attempted to assess, prognosis and observe dynamism of soil erosion by universal soil loss equation (USLE) method at Penang Island, Malaysia. Multi-source (map, space and ground-based) datasets were used to obtain both static and dynamic factors of USLE, and an integrated analysis was carried out in raster format of GIS. They determined K values for different soil series types i.e. 0.1144 (*serong*), 0.07 (*selangor*), 0.09 (*rengam*), 0.1125 (*kuala-kedah*), 0.11 (*steep land*), 0.1159 (*rengam*), 0.1137 (*local alluvium*) and 0.1102 (*urban land*), respectively.

Manyiwa and Dikinya (2013) assessed the soil erosion in Botswana using USLE and determined the K factor values. The results have shown that erodibility factor K significantly correlates with slope length, organic matter and %clay fractions as well as with structural properties including plastic limit, plastic index, bulk density and soil porosity. Generally the erodibility K-factor values were found high in eroded than non-eroded areas. The average K- factor value in eroded area was 0.031 with a range of 0.013 to 0.055. Similarly the average K-value in non-eroded area was 0.018 with a range of 0.012 to 0.026.

Ahmad and Verma (2013) estimated soil loss by applying USLE model and GIS, for the Tandula reservoir catchment area in Durg district of Chhattisgarh State, India. They determined ‘ K ’ factor for different types of soil class i.e. 0.25, 0.28, 0.35, 0.24, 0.27, 0.14, 0.35, 0.38 and 0, for silty clay, clay loam, fine sandy loam, loamy

fine sand, sandy loam, sandy clay, sandy clay loam, loam and water body, respectively.

### **Topographic factor (LS)**

The topographic factors L and S are used to adjust the erosion rate based upon the length and steepness of the slope. The erosivity of runoff increases with the velocity of the runoff water. Steep slopes produce high runoff velocities. Soil loss increases with increasing slope due to the greater volume of runoff accumulating on the longer slope lengths. The slope length is the distance from the point of origin of the runoff to the point where the slope steepness decreases sufficiently to cause deposition or to the point where runoff enters a well defined channel. Often the L and S factors are combined into a single topographic factor as LS.

LS is the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the “standard” slope steepness of 9%, slope length of 22.13 m (72.6 ft) and when all other conditions are the same. The values of factor LS are not absolute, but are referenced to a value of 1 at a 22.13 m slope length and 9 % slope steepness. Many empirical relationships have been developed which, relate slope steepness to the erosion potential.

Zingg (1940) proposed a simple equation relating soil loss to slope characteristics, using simulated rainfall under field conditions. He observed that by doubling the degree of slope, the soil loss increased from 2.61 to 2.80 times. He also observed that an exponential relationship exists between soil loss and LS factor and stated it as:

$$A = a s^m L^{n-1} \quad (2.18)$$

Where, A is the average soil loss per unit area from a land slope of unit width, a is a constant, s is the degree of land slope, L is the horizontal length of land slope and m and n are empirical constants with values of 1.49 and 1.60, respectively.

Musgrave (1947) proposed a similar equation but he proposed the values for m and n as equal to 1.35 and 1.37, respectively. On comparison, Van Doren and Bartelli (1956) observed that the average value of exponent for slope steepness was 1.5. Kirkby (1969) reported the values of m and n to be nearly equal to 1.35 and 1.72, respectively. The other reported values for the slope exponent are: 1.4 at Papua in New Guinea (Humphreys, 1984) and 2.02 in Zimbabwe (Hudson and Jackson, 1959).

Smith and Wischmeier (1962) established a polynomial relationship between slope steepness and soil erosion, which is of the following form:

$$A = 0.43 + 0.30 s + 0.43 s^2 \quad (2.19)$$

Where, A is the soil loss in tons per acre and s is the slope in percent. The effects of slope length on soil erosion have been described by a linear power of polynomial functions.

Smith and Wischmeier (1962) proposed a relationship for the topographic factor (LS) in form of a polynomial equation, and stated it as:

$$LS = [ L^{0.5} (0.76 + 0.53S + 0.076S^2) ] / 100 \quad (2.20)$$

Where, L is slope length in feet and S is the slope steepness in percent.

Wischmeier and Smith (1978) derived the following relationship for the slope length factor (L) based on plot data.

$$L = (\lambda / 72.6)^m \quad (2.21)$$

Where, 72.6 is the length of unit plot (feet) and m is a slope-length exponent and  $\lambda$  is the horizontal projection of the field length (not the distance parallel to the soil surface).

Mc Issac *et al.* (1987) examined the effect of slope steepness on soil loss from disturbed lands and found that there was a close agreement between observed slope steepness effect on soil loss from disturbed lands and that predicted by the USLE slope steepness factor. They evaluated the effects for two slope lengths, viz. for slopes lengths less than 4 m and for slopes length greater than 4 m and steepness less than 9 percent. For slope lengths greater than 4 m and slope between 9 and 33 per cent, the USLE tended to overestimate the observed slope steepness effect. For this category of slope specification, they developed a relationship of the following form:

$$S = (12 \pm 7) \sin\theta + \beta \quad (2.22)$$

Where, S is the slope steepness factor,  $\theta$  is the slope inclination from the horizontal and  $\beta$  is an intercept chosen, such that S = 1.0 at 9 % slope.

Mc Cool *et al.* (1993) evaluated the topographic effect on erosion from croplands in the North Western Wheat Pacific region of the USA and developed relationships for the topographic factor (LS) of the USLE as:

$$LS = (\lambda / 22.13)^{0.5} \times (10.8 \sin\theta + 0.03) \quad \text{for } s < 9\% \quad (2.23)$$

$$LS = (\lambda / 22.13)^{0.5} \times (10.8 \sin\theta / \sin 5.143) \quad \text{for } s > 9\% \quad (2.24)$$

Where,  $\lambda$  is the horizontal slope length (m) and  $\theta$  is the slope angle (degree).

Kinnell and Cummings (1993) found that the rate of interrill erosion increased with slope gradient at a decreasing rate when the soil contained large stable aggregates.

Liu *et al.* (1994) studied the effect of slope gradient on soil loss from steep slopes in China on natural runoff plots of 5 m x 20 m size with slopes ranging from 9 to 55 per cent. The results obtained indicated that soil loss was linearly related to the sine of the slope angle.

Desmet and Gobers (1996) had used the GIS technique for automatically calculating the USLE LS factor on topographically complex landscape units. When compared to a manual method, both methods yielded broadly similar results in terms of relative erosion risk mapping. However, there were important differences in absolute values. Although both methods gave similar slope values, the use of the manual method led to an underestimation of the erosion risk because the effect of flow convergence was not accounted for. The computer procedure had the advantage in that it could easily be linked to geographical information systems (GIS) software.

Vincini (1999) had used a GIS procedure to determine the LS factor on abandoned agricultural land in the Perino Valley (Italy). He found out from simulation models that the abandonment of agricultural practices increased the LS factor values. They had also found that erosion susceptibility of soil and had an impact on the succession of vegetation.

Panda and Andrianasolo (2000) used the formula as given in equation 2.25, suggested by SCS Engineering Division, USDA, to calculate the 'LS' factor for each slope gradient percentage (1-45%) factor for Sileru-Machhkund catchment in North Odisha with help of remote sensing imagery and GIS technique. They have suggested LS factor for slope ranges of 1-5%, 6-15%, 16-30%, 31-45% and > 45% as 1.82, 4.11, 7.58, 11.79 and 13.71 respectively.

$$LS = (\lambda / 100 (0.136 + 0.097s + 0.0139s^2))^{1/2} \quad (2.25)$$

Where,  $\lambda$  = measured slope length in the field and  $s$  = slope gradient in percentage.

Lin *et al.* (2002) calculated combined LS factor using the equation:

$$LS = (\lambda / 22.13)^m (65.4 \sin^2 \beta + 4.56 \sin \beta + 0.0654) \quad (2.26)$$

Where, m takes the values 0.5, 0.4, 0.3, and 0.2 for  $\tan \beta > 0.05$ ,  $0.03 < \tan \beta \leq 0.05$ ,  $0.01 < \tan \beta \leq 0.03$  and  $\tan \beta \leq 0.01$ , respectively ( $\lambda$  is the slope length in m;  $\beta$  the slope angle in degrees).

Brath *et al.* (2002) mentioned that m value is 0.2 for gradients of less than 1% and increases to a value 0.5 for gradients greater than 5%. The S and L grids have been combined through multiplication operator to obtain the topographical factor LS layer. The range values vary from 0.65 to 9.8 for the flat areas to higher ones respectively.

Suresh *et al.* (2002) used Revised Universal Soil Loss Equation (RUSLE) for estimation of soil loss in Naurar watershed in Uttar Pradesh. They evaluated slope steepness factor (LS) using the formula suggested by Wischmeier and Smith (1978) and Mc Cool *et al.* (1989) for various land use conditions. The factor LS derived by them for cultivated crop lands are 0.1142 (improved terraced land under irrigation), 0.5008 (improved terraced land under rainfed condition), 0.1142 (traditionally terraced land under irrigation), 0.3287 (traditionally terraced land under rainfed condition) in single cropped terraced land, 0.5008 (improved terraced land under rainfed condition), 0.4203 (traditionally terraced land under rainfed condition) in mixed crop land, 4.7393 (strongly sloping land), 10.9141 (moderately sloping land), 25.0601 (steep sloping land), 40.6548 (very steep sloping land) in unterraced land under rainfed condition, 5.0030 (strongly sloping land), 11.9210 (moderately sloping land), 23.6510 (steep sloping land), 26.2682 (very steep sloping land) and 39.7475 (scarp land) in unterraced rainfed land with trees.

Potdar *et al.* (2003) mapped the erosional soil loss in Nanda-Khairi watershed of Nagpur district in Maharashtra. The LS factor for each physiographic units were determined by them based on degree and length of slope using nomograph developed by Wischmeier *et al.* (1971). The LS factor determined by them are 0.40, 6.60, 0.9, 0.4, 0.20 and 0.11 for plateau (slope 3-5%), escarpment (slope 15-35%), upper foot slope (5-10%), lower foot slope (3-5%), upper alluvial plain (slope 1-3%) and lower alluvial plain (slope 0-1 %), respectively.

Cohen *et al.* (2005) and Schiettecatte *et al.* (2008) used Digital elevation model (DEM) method for calculating LS factor for erosion risk assessment in a tropical watershed in western Kenya and in a watershed in Cuba respectively.

Panigrahi *et al.* (2010) computed the value of slope length and slope gradient factor (LS) for the Eastern Ghat region of Odisha from the data suggested by Panda and Andrianasolo (2000) by interpolating the slope ranges suggested by them.

Jebari *et al.* (2012) calculated L factor using equation given by Renard and Freidmund (1994) and S factor from digital elevation model (DEM).

$$L = (\lambda/22.1)^m \quad (2.27)$$

Where,  $\lambda$  is the horizontal distance of the slope length m.

### **Crop management practice factor (C)**

The C factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The C factor indicates how the conservation plan will affect the average annual soil loss and how that soil loss potential will be distributed in time during construction activities, crop rotations or other management schemes.

The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. The C factor can be determined by selecting the crop type and tillage method that corresponds to the field and then multiplying these factors together. C represents the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion.

Lal (1976) determined the values of C factor for mulch farming and no-till systems in the Western Nigeria. He found that the C factor approaches a value of zero for maize-maize and maize-cowpea rotations under mulch and no-till farming system, laid on a slope up to 15%. In case of mulch systems, the value of C factor varied with the slope and the mulch rate. He obtained a value of 0.001 for C at a mulch rate of 6 t/ha on a 10% land slope.

Ghosh and Babu (1977) while working on the runoff plots at 11% slope under the cover of three types of fruit species, namely, strawberry, pineapple and pomegranate at Dehradun, found that the values of C were 0.27 for strawberry with

weeds, 0.10 for pineapple with trees, 0.34 for pineapple clean, 0.08 for pomegranate with weeds, 0.56 for pomegranate clean, 0.13 for grass (*Cymbopogon citratus*) and 1.0 for cultivated fallow.

Rose (1977 a, b) determined the cover and management factor-C for a range of crops and management systems in West Africa. He found that the lowest C value was 0.01 for some of the conservation effective systems, viz. surface residue mulch, and a quick growing cover crop.

Nema *et al.* (1978) also predicted the C factor for some common crops of Vasad (Gujarat, India) as 0.47 for moong, 0.38 for groundnut, 0.32 for cowpea and 0.28 for paddy crop.

Wischmeier and Smith (1978) compiled a list of factor C for the crops and management practices followed in the United States. The USDA tabulated the C values for construction areas, mulch factors, pastures, rangelands, woodlands and idle lands. The lowest value of factor C is zero, signifying no soil loss from the land surface due to its complete vegetative coverage.

Narain *et al.* (1980) reported for Kota (Rajasthan, India) that the value of C of some common crops in that area ranged from 0.01 for grass cover to 0.62 for jowar. The C values for other crops like black gram, groundnut, soybean, cowpea, maize, moong etc. were 0.54, 0.41, 0.42, 0.39, 0.50 and 0.39, respectively.

Shri Niwas *et al.* (1980) at Hyderabad, on a watershed area of 0.02 ha having an average land slope of 3 percent, found the value of C for castor crop as 0.79, 0.64 for jowar, 0.40 for bajra, 0.38 for jowar + red gram and 0.12 for grass covers. They also found that C value was 1.0 for cultivated fallow.

Rao (1981) for natural rainfall conditions of Kharagpur (West Bengal, India) found the highest C values of 0.38 for red gram, 0.35 for maize, 0.17 for cowpea and 0.04 for *dub* grass.

For Doon valley region, Singh *et al.* (1981) determined the factor C for different crops, ranging from 0.1 for pineapple (weed) to 0.538 as highest for black gram. The C values of the other crops like paddy, maize, cowpea, soybean and green gram were found to be 0.280, 0.502, 0.386, 0.421 and 0.392, respectively.

The percentage of land area covered by residue can be estimated from residue weight by use of the relationship developed by Gregory (1982), as follows:

$$S_p = [1 - \exp(-\alpha \cdot B_s)] \cdot 100 \quad (2.28)$$

Where,  $S_p$  is percent residue cover,  $\alpha$  is the ratio of the area covered by a piece of residue to the mass of that residue (acre. lb<sup>-1</sup>), and  $B_s$  is the dry weight of crop residue on the surface (lb. acre<sup>-1</sup>).

Surface cover affects erosion by reducing the transport capacity of runoff water by causing deposition in ponded areas (Laflen 1983), and by decreasing the surface area susceptible to raindrop impact. It is perhaps the single most important factor in determining SLR values. Surface cover includes crop residue, rocks, cryptogams, and other non-erodible material that is in direct contact with the soil surface. The effect of surface cover on soil erosion is given by:

$$SC = \exp[-b \cdot S_p \cdot (0.24 / R_u)^{0.08}] \quad (2.29)$$

Where  $SC$  is the surface-cover sub factor,  $b$  is an empirical coefficient,  $S_p$  is percentage of land area covered by surface cover, and  $R_u$  is surface roughness. The  $b$  value indicates the effectiveness of surface cover in reducing soil erosion.

Sulaiman *et al.* (1983) determined the lowest  $C$  value as 0.01 for the cropping systems of fallow + maize residue and mulch and fallow + groundnut residue and the highest value as 0.39 for maize and sugarcane crops. For other crops like chilli, cowpea, groundnut and mung, it was 0.33, 0.27, 0.28 and 0.04 respectively.

Srikhajon *et al.* (1984) reported that the value of  $C$  factor for tropical rain forest and perennial covers is usually low in Thailand and it ranged from 0.0003 to 0.017. For human created forests, it ranged from 0.019 to 0.09 and for disturbed forest it was 0.40.

Based on new descriptions of cropping and management practices and their influence on soil loss (Laflen *et al.* 1985), soil loss ratios are computed as:

$$SLR = PLU - CC * SC * SR - SM \quad (2.30)$$

Where  $SLR$  is the soil loss ratio for the given conditions,  $PLU$  is the prior-land-use sub factor,  $CC$  is the canopy cover subfactor,  $SC$  is the surface cover subfactor,  $SR$  is the surface roughness subfactor, and  $SM$  is the soil moisture sub factor.

Weltz *et al.* (1987) developed data for estimating root biomass on rangelands. The effective below-ground root biomass ( $B_b$ ) is given as

$$B_b = B_a * n_i \quad (2.31)$$

Where  $B_b$  is total average annual site production potential ( $\text{lb} \cdot \text{acre}^{-1}$ ), and  $n_i$  is the ratio of effective root mass to annual site production potential.

Based on work by Stott *et al.* (1990) and Barrett (1991), a first-order rate equation is derived and is calculated as:

$$M_e = M_b \exp(-a D) \quad (2.32)$$

Where  $M_e$  is residue mass at end of a time period,  $M_b$  is mass at beginning of the period,  $D$  is period length in days, and

$$a = p - [\text{minimum of } (W, F)] \quad (2.33)$$

Where  $p$  is a coefficient depending on residue characteristics (taken from the CROP database), and  $W$  and  $F$  are precipitation and temperature factors defined subsequently.

Narain *et al.* (1994) estimated the crop management factor ( $C$ ) for native hill crops like cowpea, *mandua* and *jhingora* for Doon Valley (India) as 0.31, 0.17 and 0.18, respectively.

Suresh *et al.* (1999) attempted to evaluate the crop management factor ( $C$ ) in USLE, of some common vegetations occurring in different land uses in Naurar watershed (Uttar Pradesh). They found that the forest trees noticed lowest values of factor- $C$  i.e. 0.0007, 0.0017, 0.0018, 0.001 and 0.0039 for Deodar, Sal, Cypruss, Oak and Chirpine, respectively while grasses showed highest range of factor  $C$ . Among various grass species, *dub* grass revealed the lowest factor  $C$  equal to 0.0213, 0.0287 and 0.0361 for poor grazed, medium grazed and over grazed grass lands, respectively. While comparison they found that the weighted value of factor  $C$  of forest lands was lowest i.e. 0.0024, followed by orchard lands 0.0026, waste lands 0.0299 and grasslands 0.0231, 0.0316 and 0.0421 for poor grazed, medium grazed and over grazed grass lands, respectively.

For south-eastern Rajasthan, Ali *et al.* (2001) determined cover and management factor ( $C$ ) for row crops, legumes, and intercropping of row crops with legumes and found it ranged from 0.5236 to 0.6165, 0.3511 to 0.5115 and 0.3084 to

0.3718, respectively. For grasses it ranged from 0.0072 to 0.1349, whereas natural cover comprising *Dichanthium annulatum* and *Cynodon dactylon* recorded value of 0.1512.

Kurothe *et al.* (2001) evaluated C factor of 0.01 for good forest area and 0.1 for degraded forest/grass land areas for Maharashtra (India). Sikka *et al.* (2003) used documented values of 'C' for agricultural crops as suggested by CSWCRTI (1982), Singh *et al.* (1981) and Narayana and Babu (1983). The tabulated values given by Wischmeier *et al.* (1971) and research findings (CSWCRTI, 1982) were used by them as a guide to assign the values ranging from 0.003 to 0.01 to the forest area of Tamilnadu depending on their condition.

Potdar *et al.* (2003) mapped the erosional soil loss in Nanda-Khairi watershed of Nagpur district in Maharashtra. The 'C' values adopted by them for different land utilization type in the watershed are 0.01, 0.1, 0.2, 0.35, 0.38, 1.0, 0.20, 0.30 and 0 for moderately dense forest, thin forest, degraded forest, single crop, double crop, fallow land, wasteland with scrub, wasteland without scrub and habitation, respectively.

Pradhan *et al.* (2012) attempted to assess soil erosion by universal soil loss equation (USLE) method at Penang Island, Malaysia. They adopted C factor for different land uses as 0, 0.003, 0.004, 0, 1 and 0.40 for water body, settlement, forest, urban, bare land and agriculture, respectively.

Kelvin *et al.* (2013) employed Buffer Zone Calculator as a tool to determine the sediment removal efficiency for different C and P factors in a study at Santubong River, Malaysia and found that the outfall total suspended solid (TSS) was increasing with the increase of C values. They investigated various land uses to determine the most effective and efficient land use for reducing TSS and evaluated the 'C' values as 0.30, 0.20, 0.20, 0.15 and 0.01 for beans, tea, coffee, wet rice and cultivated grass, respectively.

Ahmad and Verma (2013) estimated soil loss by applying USLE model and GIS, for the Tandula reservoir catchment area in Durg district of Chhattisgarh State, India. They determined C factor for different types of land uses i.e. 0.28, 0.75, 0.05, 1.0, 0.15, 0.25 and 0, for agriculture, barren land, forest, mining activity, shrub land, settlement and water body, respectively.

### **Supporting conservation practice factor (P)**

The support practice factor (P) reflects the effects of practices that will reduce the amount and rate of runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross-slope cultivation, contour farming, ridge furrow system and contour strip cropping.

Tejwani *et al.* (1975) determined the value of 'P' for up and down slope cultivation equal to 1.0 and 0.74 for contour cultivation and bare cultivated fallow treated with shallow furrow at 4% slope with maize crop. They also reported the P values for bench terraced plots (0.5% longitudinal gradient, 2.5% inward gradient) as 0.027 for Ootacamund, having a 25% land slope.

Bhatia and Chaudhary (1977) computed P values as 1.0 for the treatment of up and down slope cultivation and 0.39 for contour cultivated fallow land treated with shallow furrows taking large field plot of 25 m x 4.65 m with 2.2% slope under jowar crop at Kanpur.

Singh *et al.* (1981) found P values as 1.0 for up and down cultivation, 0.68 for contour cultivation, 0.38 for channel terrace with contour farming, 0.51 for strip cropping (3 maize: 1 cowpea) and 0.36 for channel terraces with graded furrows at Dehradun on large size field plots (100 m x 20 m and 100 m x 15 m) with 4% slope.

Kurothe *et al.* (2001) derived P values for field bunding, contour bunding and terracing using data of Singh *et al.* (1990) and took P value as 1.0 for the forest areas for Maharashtra. Ali *et al.* (2001) determined 'P' factor for contouring, dead furrows at 5.5 m and 7.3 m horizontal interval and compartmental bunding at 5.5 m and 3 m horizontal interval as 0.77, 0.21 and 0.29, and 0.02, and 0.03, respectively for south-eastern Rajasthan.

Potdar *et al.* (2003) mapped the erosional soil loss in Nanda-Khairi watershed of Nagpur district in Maharashtra. The 'P' values adopted by them for different land utilization types in the watershed are 1, 1, 1, 0.5, 0.3, 0.5, 1, 1 and 0 for moderately dense forest, thin forest, degraded forest, single crop, double crop, fallow land, wasteland with scrub, wasteland without scrub and habitation, respectively.

Panigrahi *et al.* (2010) calculated the soil loss from crop fields of the rainfed hill plateaus of Odisha using Universal Soil Loss Equation (USLE). They adopted 'P' factors as 0.39 for the USLE equation.

Kelvin *et al.* (2013) employed Buffer Zone Calculator as a tool to determine the sediment removal efficiency for different C and P factors in a study at Santubong River, Malaysia and found that the % reduction of TSS is increasing with the decrease of P factor. The most effective support practice to reduce the outfall TSS is found to be terracing, followed by contour-strip cropping, contouring and lastly not implementing any soil conservation practice. They evaluated the P values as 0.6, 0.35, 0.15 and 1 for contouring, contour-strip cropping, terracing and without any support practice, respectively.

## **2.7 Mathematical modeling for resource allocation in agriculture**

Problems of resources allocation arise in all cases when it is essential to implement a variety of activities under the restrictions associated either with resources availability or with the possibility of their utilization. In these situations the problem of optimal resources allocation between the forms of activities is important. Many such problems can be solved by mathematical programming or other related methods.

As the consumptions of natural resources are saturating day by day due to inappropriate and uncontrolled use, their sustainable and optimal use can only result their effective utilization and distribution without damaging the environment. Optimum utilization of the natural resources is of paramount importance for the agricultural and economic development of any country.

### **2.7.1 Linear programming**

Linear programming is a mathematical technique used in computer modeling to find the best possible solution in allocating limited resources to achieve maximum profit or minimum cost. It involves the planning of activities to obtain an optimal result among all feasible alternatives.

The linear programming technique is a strong tool for solving managerial decision making problems. But it is impossible in linear programming to have multiple goals, unless they can be measured in the same units. Such problems can be solved by the technique of goal programming, developed by Charnes and Cooper (1961), which uses simplex method for finding the optimum solution.

The theoretical development and practical application of linear programming has been remarkable after Dantzing formulated the general linear programming problems and devised the simplex method of solution in 1947 (Hadley, 1962). Historically, development in linear programming is driven by its applications in economics and management.

### **2.7.2 Goal programming**

Goal Programming (GP) is extended from linear programming and is the most widely used approach in the field of multiple criteria decision making that enables the decision maker to incorporate numerous variations of constraints and goals. It is one of the popular and powerful methods for multiple objective decision analysis (Lee and Shim, 1986).

### **2.7.3 Application of linear / goal programming in agriculture**

Hinderson (1959) did a theoretical analysis within the institutional frame work of agriculture as practiced in the United States and confirmed linear programming a predictive tool for determining actual economic behavior and suggested two basic principles for the land allocative behaviour of a farmer i.e. the allocation of farmer's given stock of land so as to maximize the total expected net return and the allocation decisions of land for a given crop year as a deviation from the pattern of the preceding year. Especially the farmer's planting areas for each crop were assumed to be constrained by the maximum and the minimum limits, which indicated his desire for diversity and reluctance to depart from an established pattern. The national and state land allocation pattern was also predicted by it.

At University of New England, Flinn and Musgrave (1967) used one-state variable dynamic programming model to maximize the net economic benefit. They divided crop production process into a number of stages in which each stage had its own revenue function that resulted from allocating a quantity of water to the  $i^{\text{th}}$  stage. The decision variable was to select the amount of water that would maximize the total return to all the stages. Their study revealed that the optimal allocation of water to any stage will be function of the total quantity of water available and the marginal product of water in each stage of the production process.

Rogers and Smith (1970) used a static and deterministic linear programming model for allocation of land among the various crops in an irrigation project area in

USA. They suggested that the future investment in agriculture would consider allocations of water, land and other scarce resources within the frame work of the systems analysis that would be capable of capturing complex physical and economic inter-relationships as well as the economic efficiency costs of achieving social goals.

In Illinois (USA), Windsor and Chow (1971) developed a mathematical model for 'n' crops and 'j' soils for irrigation system. They used the approach of decomposition to break the complex problem down into two subsystems. In the first subsystem, dynamic programming is used as a function of the amount of water subject to the particular constraints involved in that area. In the second subsystem, linear programming is used to determine the optimal combination of crops to be grown, the level of irrigation and type of irrigation system. The linear programming starts when the first optimization of each crop has been completed by dynamic programming. The practical use of this problem is to make use of the water, which is available and try to use all of it to irrigate the land, which is benefited.

Guglani and Sirohi (1972) used linear programming technique and found that farm returns in the union territory of Delhi could be increased considerably on various groups of farm, viz. small, medium and large, through optimal allocation of crops and dairy enterprises. They noticed that the net farm income can be increased by 251.98% in a normal year on medium size farms and by 384.47% in wet year and 130.02% in normal year on large farms.

Heady *et al.* (1973) attempted to obtain optimal water and land allocation, and agricultural water needs for the United States in 2000 A.D employing linear programming models. He used objective functions to minimize the cost of producing and transporting the crop and livestock commodities among producing regions. The variables and equations for 223 agricultural producing regions and water resources for 51 water supply regions for 25 crops and livestock commodities. The model was tested to estimate whether there was enough water to allow the nation's future food needs by the year 2000.

Agrawal *et al.* (1974) examined the potentiality of farm income on the dry lands of Aligarh district in Uttar Pradesh. They used the linear programming technique for obtaining optimum plans for crop activities and concluded that there was a considerable scope for increasing the farm income from dry lands through a suitable

reshuffle of cropping patterns. The percentage increase in net profits was 61.08, 14.42 and 23.25 on small, medium and large farms respectively.

Sinha and Charyulu (1980) formulated a linear programming model considering the existing irrigation system of Gomti Kalyani Doab in Uttar Pradesh and the optimal cropping pattern was determined by allocating the cultivated areas to various alternative crops with a view to maximizing the net benefits. Ground water was planned to be used conjunctively with surface water. The optimal solution gave crop intensities of 184.2% and 173.2% depending on the assessed ground water potential of 65000 ha-m and the present ground water balance of 43494 ha-m respectively. The objective function includes returns from the irrigated area, operation costs for canal and tube-wells and capital costs for additional installation of pumps.

Wang and Fluck (1979) formulated a linear programming model to examine the impact of resource alternatives on vegetable cropping pattern in Florida (USA). The model objective was to maximize the total net returns of vegetable crop. They concluded that crops, which required large amounts of energy, were sensitive to reductions in energy. When subjected to water reduction only, it gives a relatively balanced cropping pattern. The crop area generally declined, when both energy and water levels were reduced. Crops with medium resource requirements were not as adversely affected by reduced inputs; crops with low resource inputs showed marked increases in acreage when resources were limited.

Panda *et al.* (1983) used deterministic linear programming and chance constrained linear programming (CCLP) for conjunctive use of surface and groundwater to canal command area of Punjab by adopting an optimal cropping to maximize net return, and resolved the complex problem of irrigation management within a large heterogeneous basin. They found 14.1% increase in net return in case of deterministic linear programming and 5% increase in net return in case of chance constrained linear programming.

Hernandiz (1990) developed a static linear programming model to determine the optimal allocation of resources for crop production in the Ocoa watershed in the Dominican Republic with resource constraints of land, labour, capital, soil loss tolerance and average minimum family labour wages. They considered two separate models, viz. on income maximization model and a soil loss minimization model.

Existing crop rotation and potential agro forestry activities were considered in both the models. Under the soil loss minimization model the value of optimal solution was 60% lower than its current situation, but the soil loss reduced was only 0.002% of the current soil loss.

Singh (1996) described studies on crop optimization with a view to maximize net benefits in Bijnor district in Uttar Pradesh. The available and anticipated water resources have been worked out and then a practical cropping pattern arrived which would increase the net benefit by more than 80%. He used the linear programming model to obtain optimum crop combination for maximum net benefit with the available land and water resources.

Shirgure (1998) applied multi-objective linear programming approach with STEP method for optimal utilization of land, water and human resources in the Bishunpur watershed in Gumla district of Bihar. For optimization, he took various objective functions i.e. maximization of food production, fodder production, fuel wood production, labour employment generation, net income generation from field crops and runoff water augmentation, considering a set of resource constraints like land, water, labour and nutrients etc. It revealed from the study that there was an increase in net income generation of ₹ 1021917 from field crops and increase in cropping intensity by 184% over the existing practices by optimal land allocation.

Singh and Singh (1999) used linear programming model for integrated resource planning of Mahi command in Gujarat. They found that optimum crop planning and judicious resource use has good potential and may yield quick results in increasing agricultural production and net returns from the waterlogged areas. The planning shows a clear increase of 2582 MT in paddy, 425.3 MT in pulses, 184.2 MT in oilseeds and 3483 MT in vegetable production potential.

Raju and Kumar (1999) attempted for selection of the best compromise irrigation plan of Sri Ram Sagar Project, Andhra Pradesh, India in the multi objective context. The study deals with three conflicting objectives: net benefits, agricultural production and labour employment. Three-stage procedure is adopted combining multi objective optimisation, cluster analysis and multi criterion decision-making (MCDM) methods. It is found that net benefits, agricultural production and labour employment per hectare on average for the culturable command area are ₹ 8980, 3.73

tonnes and 242 man-days, respectively, in the best compromise plan.

Singh *et al.* (2001) used linear programming model to suggest optimal cropping pattern giving the maximum net return at different water availability levels in the Shahi Distributory command area in Bareilly district of Uttar Pradesh. The objective function of the model was subject to the following constraints: total available water and land during different seasons, the minimum area under wheat and rice for local food requirements, farmers' socio- economic conditions, and preference to grow a particular crop in a specific area. This mode gave the optimal cropping pattern for a command area of 11818 ha at water availability levels of 100, 70 and 50% and net returns of ₹ 185, ₹ 146 and ₹ 114 million, respectively. It was found that the water available in the command area may support optimally 4981, 3560, 1817, 632, 355, 87 and 3653 ha of wheat, sugarcane, mustard, lentil, potato, chick pea and rice, respectively, to get maximum net return of ₹ 185 million at 100% water availability level. Wheat appears to provide most consistent profit in the command area.

Nikkami *et al.* (2002) indicated that land use optimization is one of the appropriate strategies for soil conservation. They used the optimization model to decrease environmental and economic effects of soil erosion caused by mismanagement of land use activities in one of the sub-basins of Damavand watershed in Iran. Multi-objective linear programming simplex method was used in the study. They found that due to land use optimization, the annual soil erosion from the watershed was reduced by 5% and the annual net firm income was increased by 134%.

Singh *et al.* (2002) reported that optimal crop planning and judicious resource sharing at community level has good potential and may yield quick results in increasing agricultural production and net returns from the water logged areas. Multiple objective models of linear programming were tried in six waterlogged areas of Barak Valley of Assam to maximize the net returns and crop production. The study showed that in order to get maximum benefit, 55 percent area must be allocated to pulses, oilseeds and vegetables. The optimum crop planning shows an increase in profit to the tune of ₹ 92.4 lakh from these areas. The planning shows a clear increase of 2582 MT in paddy, 425.3 MT in pulses, 184.2 MT in oilseeds and 3483 MT in vegetable production potential.

Paul *et al.* (2004) carried out a study using multi objective programming approach (STEP method), in Barapita nallah mini watershed (Odisha) for optimal utilization of land, water and human resources considering the basic objectives like food, fodder, fuel wood, net income generation, labour employment generation and runoff water augmentation. Their study revealed that, optimisation could fetch the benefit cost ratio to the extent of 1.3:1 with increased cropping intensity of 142% from proposed planning over the existing practices. The net benefit obtained from proposed planning was 177% higher than the existing practices.

Hassan (2005) used a linear programming model to determine the optimal cropping pattern as a prerequisite to the efficient utilization of the available resources of land, water, and capital for Pakistan's agriculture. His results showed that cotton farming should be increased in acreage by about 10%, at the expense of all other crops. Doing so would, compared to the existing conditions, decrease the overall optimal crop acreage by 1.64%, while still increasing the agricultural income by 2.91%.

Sethy *et al.* (2006) applied deterministic linear programming (DLP) and chance-constrained linear programming (CCLP) models to allocate available land and water resources optimally on seasonal basis so as to maximize the net annual return from coastal groundwater basin in Balasore district (Odisha), considering net irrigation water requirement of crops as stochastic variable. These models were solved using the quantitative systems for business (QSB) software package. Sensitivity analysis of the models has been carried out by varying three ranges of cropping scenarios (20, 40 and 50% deviation from the existing cropping pattern) and combinations of surface water and groundwater at various risk levels (10, 20, 30 and 40%). The total groundwater available and withdrawal in the region are  $655.87 \times 10^3$  and  $255.03 \times 10^3$  km<sup>3</sup>, respectively. The study reveals that 40% deviation of the existing cropping pattern is the optimal that satisfies the minimum food requirement and maintain geo-hydrological balance of the basin. The sensitivity analysis of conjunctive use of surface water and groundwater shows that 20% surface water and 30% groundwater availability as the optimum water allocation level. The proposed cropping and water resources allocation policies of the developed models were found to be socioeconomically acceptable that maintained the balance of the entire system, considering all the constraints and restrictions imposed.

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.

Sahoo *et al.* (2006) developed linear programming and fuzzy optimization models for planning and management of available land-water-crop system of Mahanadi-Kathajodi delta in eastern India. The models are used to optimize the economic return, production and labour utilization, and to search the related cropping patterns and intensities with specified land, water, fertilizer and labour availability, and water use pattern constraints. They found that these non-structural models facilitate the conjunctive use of available surface water and groundwater resources. Their study shows that the linear programming based management models have the capability for optimal land-water-crop system planning in case of single criteria decision systems, while the fuzzy rule based management models can still be used to deal with multiple criteria management decision systems.

Wang *et al.* (2006) conducted a study to find out a preferable solution for the local agencies in a watershed in china comprising components like 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.

Jha and Singh (2008) used multi-objective model/weighted goal programming technique for the optimal allocation of resources like land, crop and water of Kosi irrigation system in Nepal and they found that, the net return and cropping intensity was increased to ₹ 224.5 million and 270% respectively.

Sadeghi *et al.* (2008) used a multi-objectives linear optimization for minimizing soil erosion and maximizing farm production of each land use in a watershed in Iran. It revealed from their study that the amount of soil erosion and benefit could respectively reduce and increase to the tune of 7.9% and 18.6%, in case of implementing optimal allocation of the study land uses.

In Kharestan watershed (Iran), Nikkami *et al.* (2009) applied multi-objective linear programming (LP) model for land use optimization in three different land use scenarios including existing land uses plus land management (scenario 1), existing land uses with some degrees of land management (scenario 2), and proper land uses plus land management (scenario 3). They solved the problem using the simplex method with the help of LINGO software package and determined the optimal solution. The results showed that in the optimized condition, the soil erosion decreased by 3.7% and net income increased by 163% under scenario 1, soil erosion decreased by 37% and net income increased by 206% under scenario 2, and soil erosion decreased by 53% and net income increased by 208% under scenario 3.

Vivekanandan (2009) attempted a Goal programming approach to maximize the net return from Upper Indravati Irrigation Project in Odisha. He took three different cropping patterns with goal programming approach for optimizing cropping pattern with available land and water resources. The model gave a higher net return of ₹ 229.6 crores with increased cropping intensities of 170, 180 and 199%, respectively for three different cropping patterns.

From a study in rainfed hill plateaus of Odisha, Panigrahi *et al.* (2010) revealed that optimal resource use planning indicates possibility of reducing risk in agriculture, increase in net return and decrease in soil loss. They found that, as suggested by linear goal programming, taking up food crops in area of 130777 ha and perennial grass cover in 3223 ha with a cropping intensity of 1.61, which would provide higher net return of ₹ 8862.34 and lesser soil loss of 23.41 tonnes/ha than the corresponding present values.

Kaura *et al.* (2010) formulated a linear programming model to suggest the optimal cropping pattern for maximizing the net return and ensuring significant saving of groundwater at different levels of groundwater availability for sustainable use of groundwater resources in Punjab. At the existing level of water availability,

the optimal crop plan has not revealed any significant changes in the production pattern. Restricting the availability of groundwater has resulted into a major shift in the cropping pattern. Such changes could ensure groundwater savings of almost 25 per cent, without any adverse impact on the net returns from crop production. Introduction of new crops in the production plan, such as Bt cotton, has further enhanced the returns from crop production by about 4 per cent along with groundwater savings of 26.55 per cent. It has been found that the area under paddy has reduced from 70.65 per cent of cultivated area at 100 per cent water availability level to 57.34 per cent at 64 per cent water availability level. Introduction of pulses and oilseeds in the cropping pattern does not seem feasible under the present regime of prices and productivity.

In a mid Himalayan watershed, applying Linear programming model, Dogra *et al.* (2011) stated that optimal allocation of utilized land and water resources to agricultural production activities can improve production from the watershed as a whole. They found that optimal allocation can improve agricultural production by 23 % without availing any extra utilizable water and / or land resources in the water shed.

Tzimopolous, *et al.* (2011) had used Linear programming model to determine the best agricultural production planning in the territory of Agios Athanasios irrigation network, which is located in the northern region of Greece. Their results showed that proposed linear programming model gives the optimum cropping pattern for the region providing the highest profit both for the cultivator and the water resources.

Liu *et al.* (2012) used mixed-integer linear programming algorithm to calculate the optimal scenario (location and capacities of desalination plants and wastewater treatment and water reclamation plants, as well as the desalinated water, reclaimed water and wastewater conveyance infrastructure needed) by minimising the annualised total cost including capital and operating costs. They found that the annualised total cost of all alternative scenarios is higher to the one calculated for the optimal scenario. If the current situation is used to satisfy all water needs and wastewater treatment obligations, the annualised capital cost is calculated 14.5% higher than the optimal solution.

Honghai and Altinakar (2013) worked on multi-objective optimization of agricultural land-use management problems in Northern Mississippi and revealed that it is useful for the development of a complex system of estimating the responses between management goals and miscellaneous environmental factors under uncertainty.

Majeke *et al.* (2013) stated that linear programming is a very flexible tool for modeling agricultural kind of complexities. They used linear programming model to determine the optimal crop combination for a rural farmer in Bindura, Zimbabwe and revealed that the model produced an optimal crop combination that gives higher income than that obtained from the farmer's plan. The income difference was 72.79 percent.

Igwe and Onyenweaku (2013) applied linear programming technique to farm data obtained from thirty arable crop farmers of the Aba Agricultural Zone of Abia State, Nigeria, to maximize gross margin from various combination of arable crop and selected livestock enterprises. They found that optimization and reallocation of available resources brought significant changes in the existing plan. It is recommended that crop mixtures be undertaken by farmers in combination with poultry and fish enterprises for improved gross margin.

Sunandar *et al.* (2014) applied linear programming for land use optimization in Asahan Watershed located in North Sumatera Province, and their result indicated that to minimize erosion, there is a large change in forested land area, increased plantation and rice field areas, reduced dry farm land areas, and barren land soil and shrubs converted into other vegetated areas.

Dawoud (2014) attempted to optimize the water allocation to crops by formulating a linear programming model to ensure the efficient allocation of scarce water resources among the competing crops in Egypt. This model was constrained by land, water, labour, production costs, and organization constraints, determining the optimal plan for two possible future scenarios. The results of the two scenarios are as follows: under the maximization of the net return per unit of land, there is an increase in total net returns by 3.56% more than the actual net returns. The optimized cropping pattern has been coupled with about 3.24% water saving and about 3.13% reduction in production costs compared to actual cropping pattern. However, under the

minimization of irrigation water requirements, the total net returns decreased by 10.20% indicating losses below the actual situation. It has resulted in about 11.05% water saving and 11.24% reduction in the costs of production compared to the existing situation.

# MATERIALS AND METHODS

---

This chapter deals with methodologies used for the present study to develop an optimized model for effective cropland utilization with available water, which will minimize the soil loss from crop lands, minimize the agricultural investment and maximize the net return from agriculture and acceptable socially and economically to the farmers of study area. This chapter involves description of study area, data collection, its analysis, calculation of various parameters required for the study, formulation of models and determination of their coefficients.

## 3.1 Description of the study Area

Under the present study, Koraput district located in the Eastern Ghat region of Odisha is selected and its various features have been discussed here.

### 3.1.1 General features

Description of the study area can help in identifying the relevant problems and for preparing a comprehensive action plan for the area. Koraput district is located in the extreme southern part of Odisha in the eastern plateau and hill region (Agro-Climatic Zone VII) in Eastern Ghats. It lies between Latitudes of 18° 15' 00" to 19° 12' 30" North and Longitude of 82° 08' 04" to 83° 24' 46" East with altitude varies from 500 to 1600 m above mean sea level. It is bounded by Rayagada (Odisha) and Srikakulam (Andhra Pradesh) districts in the east, Malkangiri (Odisha) and Bastar (Chhatisgarh) districts in the west, Nabarangapur and Rayagada districts in the north and Vizianagaram and Vizag (Andhra Pradesh) districts in the south. The district having 881 thousand ha of geographical area occupies 3<sup>rd</sup> rank in the state. The location map of Koraput district is given in Fig.3.1.

### 3.1.2 Climate

The climate of Koraput district is warm and humid with mean maximum and minimum temperatures of 38° C and 12° C respectively. The normal annual rainfall in the district amounts to 1567 mm occurring in 83.9 rainy days. June to September is the usual wet period, where 79% rainfall is recorded in 62.4 rainy days due to south west monsoon. Relative humidity varies from 67 to 96% during monsoon and 48 to

95% during off season. Bright sunshine hours vary from 1.8 to 6.4 in monsoon period and from 6.8 to 9.4 in post monsoon season. The mean wind velocity varies from 2.1 to 9.9 km/hr in monsoon period and from 2.1 to 13.7 km hr<sup>-1</sup> in post monsoon period.

### 3.1.3 Soil

The soils of Koraput district are mainly developed from the rock types Charnockite and Khondalites, the underlying parent rock is mostly granite and gneiss. Based on the USDA soil taxonomy, the soils have been identified as Alfisols (Suborder Ustalfs; Typic Rhodustalfs, Typic Haplustalfs, Ultic Haplustalfs) and Inceptisols (Vertic Haplaquepts, Typic Ustochrepts). The major soil types found in the district are red, alluvial, mixed red and yellow having sandy loam to sandy clay loam texture. The water holding capacity is generally very poor since the soil structure is mostly single grained or of a weak granular type. Soils are acidic with pH ranging from 4.5 to 6.2 having very low salt content (EC varying 0.184 to 0.321 dS /m). The area covered under major soil groups is given in Table 3.1. Patnaik *et al.*, (2004) reported that soils of Koraput district are low in N, P and organic matter content and having low nutrient value index i.e. 1.63, 1.2, 1.1 and 2.77 for organic C, N and P, respectively. Soil depth, drainage and soil texture vary with the topography and become less favourable for cultivation with increasing slope steepness.

**Table 3.1 Area covered under major soils in Koraput district.**

Major Soils	Area ('000 ha)
Red soils	437.9
Alluvial soils	200.0
Mixed Red and Yellow soils	140.0
Red and black soils	60.0
Total	837.9

Source: <http://agricoop.nic.in/Agriculture%20Contingency%20Plan/Odisha/Odisha%2022-%20Koraput%2031.05.2011.pdf>

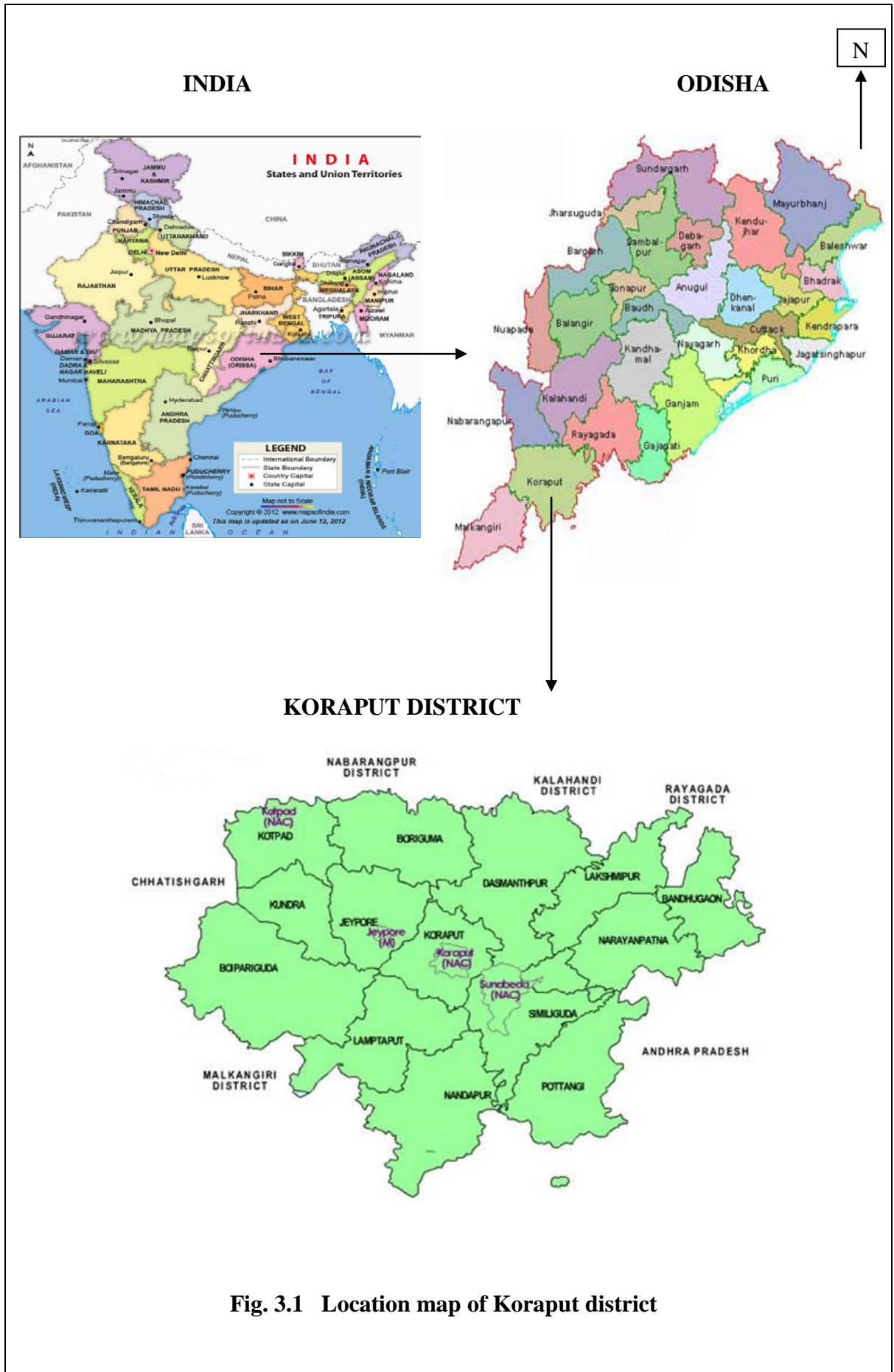


Fig. 3.1 Location map of Koraput district

### **3.1.4 Topography**

The district is located in a section of Eastern Ghats, which consists of a series of mountains and high hills. The district is also covered by scattered and high slope hills having thin forest covers. Physiographically the district is contiguous to the main land of Eastern Ghat. The general topography of the area is of broken mountains intercepted by large riverbeds and water courses. The altitude varies from 500 m near western side to 1600 m on the eastern side with mountain peaks and ridges. Deomali (1672 m) is the highest mountain peak of Odisha found in this district.

As per the district planning map by Survey of India, the entire district is divided into three average slope ranges i.e., > 1, 1 to 2, and 2 to 8% and three elevation ranges i.e., 450-750, 750-1200, and 1200-1800 m above mean sea level, respectively. As per calculation, 12, 18 and 70% of total area are under slope ranges > 1, 1 to 2, and 2 to 8%, and 40, 47 and 13% of total area are under elevation ranges 450-750, 750-1200, and 1200- 1800 m above mean sea level.

### **3.1.5 Drainage**

The district has a widespread drainage system and is controlled by Indravati, Sabari (Kolab), Sileru, Vegavati, Subarnamukhi, Jaryhavati and their tributaries. The river Indravati and Kolab drains the major parts of Koraput district. Most of the tributaries of Kolab river and Indravati river are perennial in nature. East west flowing Indravati and north-south flowing Sabari river pass through the northern and western border of Koraput district. South east - north west flowing Kolab river traverses through the central part of the district. The rivers in general exhibit dendritic drainage pattern and are effluent in nature. These rivers drain most part of this plateau westward to the Godavari basin in Andhra Pradesh.

### **3.1.6 Forest**

Forest occupies 21.3% of the total geographical area of the district. The principal species commonly found in the forest are timber, fire wood, bamboo and minor forest produces like tamarind, hill brooms and different types of fibres, oil seeds, *mahua* flower, *siali* leaves, medicinal plants, kendu leaves etc. The tribals mostly depend on forest for their livelihood and it is an integral part of their life and culture. Tribals collect minor forest produces and sell in local market to earn their

bread. The economy of Koraput district is primarily based upon agriculture and forestry ([http://www.ordistricts.nic.in/district\\_profile/aboutus.php](http://www.ordistricts.nic.in/district_profile/aboutus.php)).

Koraput district is mostly having the forest growth with climax species 'Sal'. There is also intermixture of bamboo forest mainly because of the biotic interference. Large-scale mining and over exploitation of forest, rampant clearing of forest by tribals for timber & fire-wood have resulted in loss of flora and fauna, and severe land degradation of the region's natural base.

### **3.1.7 Shifting cultivation**

The tribals of Koraput district still practice shifting cultivation on steep slopes and hill tops, which is an unscientific way of cultivation and mostly responsible for severe erosion and land degradation in the region. Presently, shifting cultivation is practiced in 43.03 km<sup>2</sup> (0.5%) area of Koraput district (Naik *et al.*, 2013). In this practice, trees and bushes are cut during November-January, allowed to dry and burnt by fire. Before the onset of monsoon, seeds are sown or dibbled on the cleaned area. The crops normally grown are millets, cereals, pulses and oilseeds. In one patch, this process continues for 2-3 years till the fertility goes down. Then, the patch is abandoned and a new site is selected for the purpose. The abandoned patch regenerates, become fertile but the original forest flora, fauna and ecology are never restored.

### **3.1.8 Land use**

The land use details of the Koraput district is given in Table 3.2. The total cultivable area of the district is 304 thousand ha. The area under forest and barren and unculturable land is 21% and 24%, respectively.

The total cultivated area is divided in to three land types i.e., upland (*Dangar*), medium land (*Saria*) and low land (*Jhola*). Area under upland, medium land and low land is 187000 ha (62%), 79000 ha (26%) and 38000 ha (12%), respectively. Major crops grown in the district are paddy, ragi, maize, niger, horse gram, black gram, field pea and arhar. In *kharif*, rice, ragi, maize, arhar, mung, black gram, groundnut, niger, turmeric, ginger and off season vegetables are generally grown and in *rabi*, crops like *kulthi*, mustard, vegetables etc. are taken. During *kharif*, paddy covers the highest area of 114.28 thousand ha followed by ragi (73.02 thousand ha), niger (38.14 thousand ha), maize (18.85 thousand ha) and arhar (5.45 thousand ha). The district is famous

for ginger cultivation due to the climatic suitability for it and has potential for its production and export for the high quality. The prevailing cropping pattern and productivity scenario of Koraput district is given in Table 3.3.

**Table 3.2 Land use pattern of the Koraput district (Area in ‘000 ha)**

Sl no	Land use	Area
1	Forest area	188
2	Land under misc. tree crops and groves	17
3	Permanent pastures	45
4	Culturable waste	44
5	Land put to non- agricultural use	54
6	Barren and unculturable land	210
7	Current fallows	36
8	Other fallows	19
9	Net sown area	268
10	Total geographical area	881

Source: Odisha Agricultural Statistics 2010-11 (Govt. of Odisha, 2012).

### 3.1.9 Irrigation potential

Agriculture is mostly rainfed in Koraput district. Out of total cultivated area of 304 thousand ha, 225.8 thousand ha area is rainfed and 78.20 thousand ha area is irrigated in the district. The major sources of irrigation are canals, tanks and ponds, and bore wells. Canals contribute about 60% of irrigated area. There is much scope for bringing more area under irrigation through construction of minor irrigation projects, dug wells, shallow tube wells and water harvesting structures. Total irrigation potential created up to 2010-11 is 167.46 thousand ha which includes 100.82 thousand ha in *kharif* and 66.64 thousand ha in *rabi*.

### 3.1.10 Socio-economic feature

Koraput is a backward and tribal dominant district. As per the 2011 census, the total population of the state is 13.8 lakh with population density 157 per sq.km. There has been change of 16.86% in the population compared to population as per 2001. The Scheduled Castes and Scheduled Tribes population constitute 13.04% and 49.62% of the district population. The rural and urban population constitutes 83.61% and 16.39% of total district population. The sex ratio is 1032 females per 1000 males. The literacy rate in the district is 49.21%. The economy of the district is mainly dependent upon cultivation.

**Table 3.3 Prevailing cropping pattern (*Kharif and Rabi*) and productivity scenario in Koraput district.**

Sl .No.	Crops	Total area ( "000 ha)	% of total cultivable area	Yield (q/ha)
1	Rice( <i>Kharif</i> )	114.28	37.6	23
2	Rice ( <i>Rabi</i> )	20.07	6.6	26
3	Maize( <i>Kharif</i> )	18.85	6.2	25
4	Maize( <i>Rabi</i> )	1.99	0.7	31
5	Ragi( <i>Kharif</i> )	73.02	24.0	10
6	Ragi( <i>Rabi</i> )	0.08	0.0	9
7	Jowar( <i>Kharif</i> )	1.48	0.5	8
8	Bajra( <i>Kharif</i> )	0.32	0.1	7
9	Small millets( <i>Kharif</i> )	4.54	1.5	4
10	Mung( <i>Kharif</i> )	2.21	0.7	3.9
11	Black gram( <i>Kharif</i> )	3.39	1.1	3.9
12	Black gram( <i>Rabi</i> )	2.40	0.8	3.9
13	Horse gram( <i>Rabi</i> )	10.07	3.3	6.5
14	Arhar( <i>Kharif</i> )	5.45	1.8	10
15	Field pea ( <i>Rabi</i> )	6.94	2.3	8
16	Other pulses( <i>Kharif</i> )	6.42	2.1	6
17	Groundnut( <i>Kharif</i> )	1.36	0.4	12
18	Niger( <i>Kharif</i> )	38.14	12.5	5
19	Mustard( <i>Rabi</i> )	3.94	1.3	4
20	Other oil seeds	2.39	0.8	4
21	Vegetables( <i>Kharif</i> )	14.49	4.8	140
22	Vegetables( <i>Rabi</i> )	14.04	4.6	160
23	Ginger( <i>Kharif</i> )	3.04	1.0	105
24	Turmeric( <i>Kharif</i> )	2.79	0.9	34.5
25	Sweet potato( <i>Kharif</i> )	3.2	1.1	102.5
26	Fibre crops( <i>Kharif</i> )	0.47	0.2	14.36

Source: Odisha Agricultural Statistics 2010-11 (Govt. of Odisha, 2012).

The predominant tribal population of this region is characterized by low literacy, lack of awareness, high level of backwardness and they believe in subsistence agriculture. There is a preponderance of marginal and landless farmers, higher fragmentation of land holdings and more reliance on common pool resources. The crop productivity is low and alternate livelihood options are not explored. Low agricultural productivity due to traditional cropping practices, lack of irrigation facility, poor connectivity/transportation and absence of proper marketing facility/

regulated markets are the main reasons leading to low income from agriculture in the district. Land degradation, subsistence farming with poor crop harvest, low input uses and lack of employment opportunities have resulted in to poverty in Eastern Ghats of Odisha (Dass *et al.*, 2009). In addition, the rising population, limited land for agriculture and more food demand in the region have led to the extension of cultivation on steep slopes vulnerable to erosion.

As per the existing land holding pattern of Koraput district, out of total farmers (1,62,880), 75,768 (46.5%) comes under marginal (< 1 ha) category, 52,675 (32.3%), 25,908 (15.9%), 7,713 (4.7%), 816 (0.5%) under small (1-2 ha), semi-medium (2-4 ha), medium (4-10 ha) and large (>10 ha) category, respectively with average land holding of 1.53 ha. Continuous decrease in size of land holding in district may be attributed to population rise and rapid fragmentation of land holding. As far as workers population is concerned, the district is having total workers of 5,70,435 which include main workers of 3,53,367 (62%) and marginal workers of 2,17,068 (38%).

### **3.2 Data collection**

Basic relevant information on Koraput district and primary data related to agriculture i.e. existing area under food crops (cereals, pulses, oilseeds) and vegetable crops, their productivity and production, the level of application of inputs like seeds, manures, fertilizers and labour, etc. were collected from published reports i.e. “District Statistical Hand Book, Koraput” by Directorate of Economics and Statistics, Govt. of Odisha, “Odisha Agricultural Statistics” by Directorate of Agriculture and Food Production, Govt. of Odisha, as well as from personal interview with line department officials and farmers. Climatic data i.e. rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours, wind velocity, etc. were collected from existing meteorological stations in the district and Department of Agriculture and Bureau of Statistics, Govt. of Odisha. The data on soil type, texture etc. were collected from the Directorate of Soil Conservation and Divisional Soil Conservation Office (Survey) of Government of Odisha. The data on land uses and cropping pattern, extent of slope and elevation were correlated and found from the district planning map of Koraput obtained from the office of the Survey of India at Bhubaneswar.

### 3.3 Climatic data analysis

#### 3.3.1 Effective rainfall

According to the Soil Conservation Service of USDA (1967), effective rainfall is that which is received during the growing period of a crop and is available to meet consumptive water requirements. It does not include surface runoff or deep percolation losses. The USDA Soil Conservation Service method as given in Eq. 3.1 and Eq. 3.2 was used to determine the effective rainfall with the help of “FAO CROPWAT 8.0 for Windows” software being inbuilt default option with it.

$$P_e = (P_t / 125) \times (125 - 0.2 \times P_t) \quad (\text{When } P_t < 250 \text{ mm}) \quad (3.1)$$

$$P_e = 125 + 0.1 \times P_t, \quad (\text{When } P_t > 250 \text{ mm}) \quad (3.2)$$

Where,

$P_e$  = Monthly effective rainfall (mm) and  $P_t$  = Total monthly rainfall (mm).

#### 3.3.2 Water resource potential

To determine the total water availability during *kharif* season, monthly rainfall data for the period from 1986 to 2012 was analyzed using the different probability distribution functions and the best fit probability distributions were determined and applying it, expected month wise rainfall at different probabilities were estimated. Rainfall at 80% probability and its resulting effective rainfall for the period from June to October was considered. The water availability was obtained by multiplying the estimated effective rainfall with total cultivable area.

For *rabi* season, monthly runoff yield from individual rainfall events (from 1986 to 2012) was determined using SCS-Curve Number method. Applying the different probability distribution functions, month wise runoff for the period from 1986 to 2012 was analyzed and the best fit probability distributions were determined and using it, expected month wise runoff at different probabilities were estimated. Runoff at 80% probability for the period from June to February was considered and it was multiplied with total cultivable area for determining the water resource potential of the region. It was assessed based on storage capacity, which was predicted by knowing the wetness status i.e., antecedent moisture condition (AMC) and physical characteristics of the area. The US Soil Conservation Service (SCS-CN) Curve

Number method as given in Eq. 3.3 and 3.4 below was used for assessing the runoff yield.

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (3.3)$$

Where,

Q= Surface runoff in mm, P= Rainfall in mm, S= Storage capacity in mm,

$$S = (25400 / CN) - 254 \quad (3.4)$$

CN = Value of curve number (CN) depending on land use conditions and hydrologic soil groups.

### 3.3.3 Reference crop evapotranspiration

Using FAO Penman-Monteith method (Allen *et al.*, 1998) as given in Eq. 3.5 below and with help of the FAO CROPWAT 8.0 Windows software, the reference crop evapotranspiration ( $ET_o$ ) was calculated from climatic data such as daily mean maximum and minimum temperature, humidity, wind speed and daily sunshine hours. As the software having provision to calculate  $ET_o$  using only data on daily mean maximum and minimum temperature in case of non-availability of data on relative humidity, wind speed, and daily sunshine hours, it was used directly for finding the  $ET_o$  for the said data missing period under the present study.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3.5)$$

Where,

- $ET_o$  = Reference evapotranspiration [ $\text{mm day}^{-1}$ ],
- $R_n$  = Net radiation at the crop surface [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],
- $G$  = Soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],
- $T$  = Mean daily air temperature at 2 m height [ $^{\circ}\text{C}$ ],
- $u_2$  = Wind speed at 2 m height [ $\text{m s}^{-1}$ ],
- $e_s$  = Saturation vapour pressure [kPa],
- $e_a$  = Actual vapour pressure [kPa],
- $e_s - e_a$  = Saturation vapour pressure deficit [kPa],

$\Delta$  = Slope vapour pressure curve [kPa °C<sup>-1</sup>],

$\gamma$  = Psychrometric constant [kPa °C<sup>-1</sup>].

A correction factor of 0.91 was multiplied to wind speed as it is measured at 10 feet above the ground surface against the requirement of standard height of 2 m above ground surface as per Table 2.9 of FAO Irrigation and drainage paper 56 (Allen *et al.*, 1998).

### 3.3.4 Crop coefficient ( $K_c$ )

The crop coefficient during the initial growth period ( $K_{c\ ini}$ ) is a function of wetting interval, evaporating power of the atmosphere and magnitude of the wetting event. It was estimated from Fig. 3.2, Fig. 3.3 and Eq. 3.6 as suggested by Allen *et al* (1998) in FAO Irrigation and Drainage paper 56, assuming one wetting event per one rainy day. The average infiltration depth per wetting event, daily  $ET_o$  and interval between significant rains were required to get the value of  $K_{c\ ini}$ . The average infiltration depth per wetting event was calculated by dividing the number of normal rainy days to the total monthly rainfall and the mean wetting interval was calculated by dividing the number of normal rainy days by 30 considering one event per normal rainy day.

$$K_{c\ ini} = K_{c\ ini\ (Fig\ 3.2)} + \frac{(I-10)}{(40-10)} [K_{c\ ini\ (Fig\ 3.3)} - K_{c\ ini\ (Fig\ 3.2)}] \quad (3.6)$$

Where,

$K_{c\ ini\ (Fig.3.2)}$  = Value for  $K_{c\ ini}$  from Figure 3.2,

$K_{c\ ini\ (Fig.3.3)}$  = Value for  $K_{c\ ini}$  from Figure 3.3,

I = Average infiltration depth [mm].

### 3.3.5 Climatic index ( $C_i$ )

Climatic index is the ratio of effective rainfall and  $ET_o$ . The values of  $C_i$  for each month was calculated using equation 3.7. Monthly values of  $C_i$  were grouped using 0.1 groupings (0–0.1, 0.1–0.2, 0.2–0.3,.....and 0.9–1.0) and 80% dependable values of  $C_i$  for each month was calculated, by dividing the number of times the monthly value of  $C_i$  falls within a group by the number of monthly records (Savva and Frenken, 2002).

$$\text{Mathematically, } C_i = (P_e / ET_o) \quad (3.7)$$

### 3.3.6 Selection of cropping period

The cropping period was selected taking in to consideration of the water availability and water utilized in the crop field. The amount of effective rain should be at least equal to the water loss through crop evapotranspiration ( $ET_c$ ) from a crop field in a particular period for successful crop growth. For climatic suitability, the value of crop coefficient ( $K_c$ ) should, therefore, be less than climatic index at each stage of crop growth, and for state of water balance,  $K_c$  value should be equal to climatic index (Panigrahi *et al.* 2010). The calculated values of 80% dependable  $C_i$  were correlated with the  $K_{c\text{ ini}}$  values to suggest starting of the cropping period. Using the values of  $K_c$  at the development stage ( $K_{c\text{ dev}}$ ), mid season stage ( $K_{c\text{ mid}}$ ) and late season stage ( $K_{c\text{ end}}$ ) of different crops as suggested by Doorenbos and Pruitt (1977) and Allen *et al.* (1998) and considering the local cropping practices, the total cropping period was worked out.

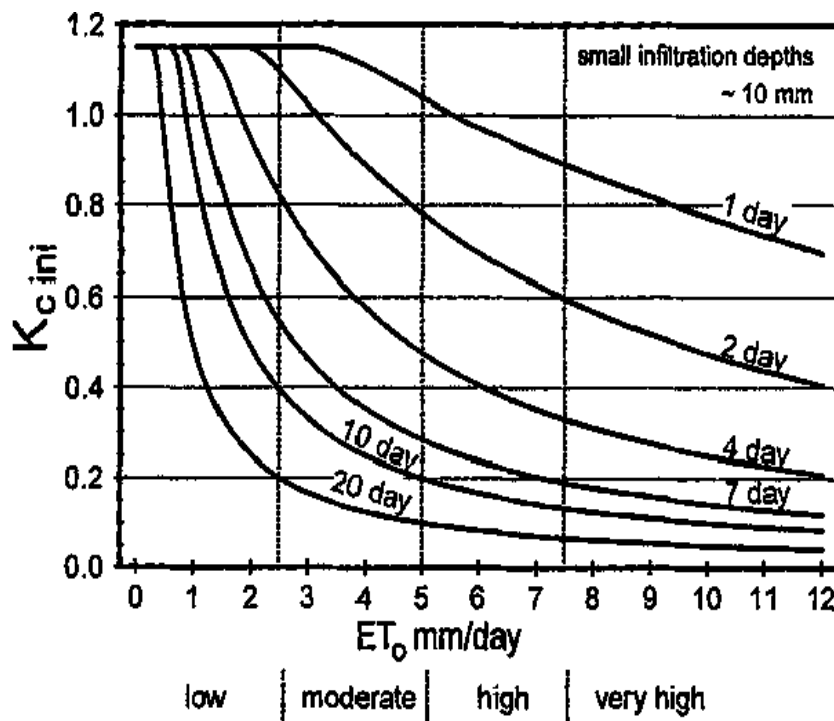
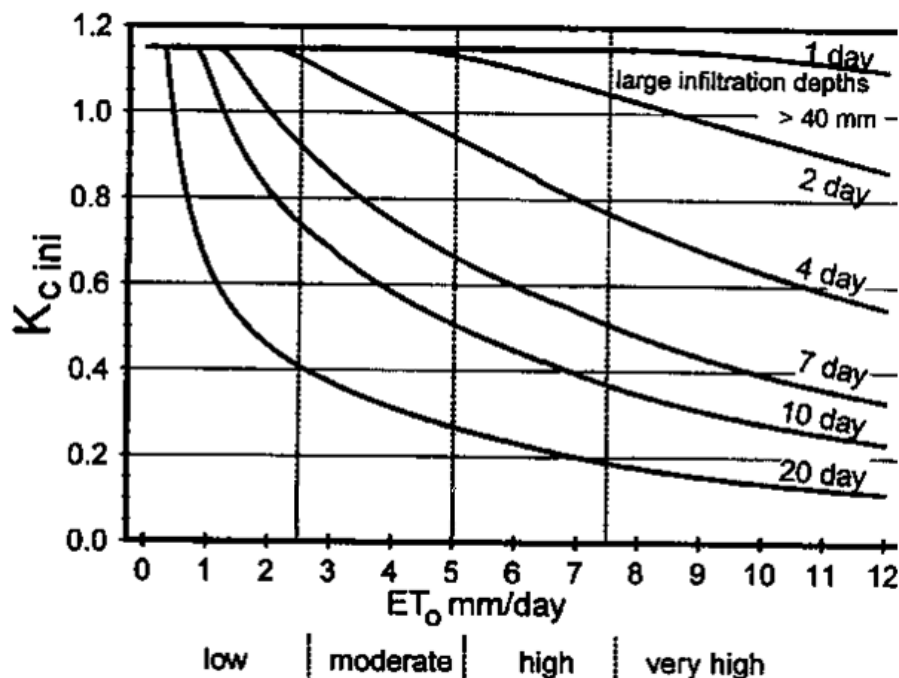


Fig 3.2 Average  $K_{c\text{ ini}}$  as related to the level of  $ET_o$  and the mean wetting interval during the initial growth stage for small infiltration depths (Figure 29 of Allen *et al.*, 1998)



**Fig 3.3 Average  $K_{c\ ini}$  as related to the level of  $ET_0$  and the mean wetting interval during the initial growth stage for large infiltration depths (Figure 30 of Allen *et al.*, 1998).**

Crops that are traditionally grown in the area were planned as per the local affinity and scheduled in the selected cropping period by comparing the values of 80% dependable  $C_i$  with the values of  $K_{c\ dev}$ ,  $K_{c\ mid}$  and  $K_{c\ end}$  (Allen *et al.*, 1998) and as per the land type. A crop calendar and a possible set of crop sequences were prepared to be used in the model for optimal allocation of areas with respect to the objectives taken. The provision of growing perennial grass cover was suggested on upland to reduce soil loss from cultivated croplands.

### 3.4 Return from agriculture

The net return for different cultivated food crops and crop sequence sets were computed by deducting the variable cost incurred in raising of crops from the gross return obtained from them. The costs towards seeds, manure, green manure, fertilizer, plant protection, land preparation and labour charges were considered while calculating the cost of cultivation of the crops. The standard rates of production of different crops as suggested by the Directorate of Agriculture & Food Production and Directorate of Horticulture, Govt. of Odisha, Bhubaneswar were considered for calculation of gross return from each crop. The net return of each crop was then calculated by deducting the cost of cultivation from the gross return.

### 3.5 Food requirement

The projected population of the district for 2021 was estimated from the population of 2011 as per the decadal growth rate of 16.86% during 2001 to 2011. The edible component of the four major food groups namely, cereals, pulses, oilseeds and vegetables including tubers required for a projected population in 2021 was calculated by using the recommended dietary allowance (RDA) for adult Indian male and female suggested by the National Institute of Nutrition as per Table 3.4 (<http://ninindia.org/DietaryguidelinesforIndians-Finaldraft.pdf>), considering 88% of the total population as the adult equivalent (Panigrahi *et al.*, 2010). Out of total population, 48.31% are workers, they were treated as heavy and others were treated as moderate diet consuming humans.

The requirement of edible portion of the individual food crops grown were estimated according to the local affinity as per the present level of production. The net production requirement and the gross production requirement were calculated considering the edible portion in the food grains and the requirements for seeds, feed and wastage, respectively as given in Table 3.5.

**Table 3.4 Recommended dietary allowance (RDA) for Indian adult male and Female**

Sl. No.	Food groups	RDA (grams per day)			
		Moderate		Heavy	
		Man	Woman	Man	Woman
1	Cereals and millets	450	330	600	480
2	Pulses	90	75	120	90
3	Fats and oils	30	25	40	30
4	Vegetables and tubers/roots	500	500	500	500

**Source:** <http://ninindia.org/DietaryguidelinesforIndians-Finaldraft.pdf>

**Table 3.5 Edible portion, local affinity and requirement towards seed, feed & losses of food items**

Sl. No.	Food items	Edible portion (% of whole grain)	Local affinity (% of food group)	Requirement towards seed, feed and wastage (% of gross production)
	<b>Cereals</b>			
1	Rice	66	71	22
2	Maize	78	12	22
3	Ragi	78	17	22
	<b>Pulses</b>			
4	Mung	70	6	30
5	Black gram	70	15	30
6	Horse gram	70	43	30
7	Arhar	70	36	30
	<b>Oilseeds</b>			
8	Groundnut	28	7	25
9	Niger	28	86	25
10	mustard	33	7	25

### 3.6 Soil loss from agricultural land

The soil erosion rate from crop lands of Koraput district was estimated using Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) as given in Eq. 3.8.

$$A = R K L S C P \quad (3.8)$$

Where,

A = Average soil loss, t ha<sup>-1</sup> yr<sup>-1</sup>

R = Rainfall erosivity index

K = Soil erodibility factor

L = Slope length factor

S = Slope gradient factor

C = Crop management factor

P = Supporting conservation practice factor

Using the rainfall data for the period from 1986 to 2012, rainfall erosivity factor (R) was estimated using Eq. 3.9 developed by Sudhishri and Patnaik (2004) for the Koraput region. As per the prevailing cropping practice, total crop growing seasons (*Khariif + Pre-rabi + Rabi*) was taken as 9 months (June to February) and R value was computed accordingly. R value for individual crop was determined considering its cropping period. When the land was fallow, R value for that particular fallow period was taken for soil loss calculation. The value of soil erodibility factor (K) was determined as 0.12 from the revised USLE nomograph referring the technical report published by Sahoo *et al.* (2005). It was worked out from planning map of Koraput district that 12, 18 and 70% of total area is under slope ranges 0-1, 1-2 and 2-8%, respectively. The value of slope length and slope gradient factor (LS) for the prevailing slope ranges of 0-1, 1-2 and 2-8% was interpolated from the values suggested by Panda and Andrianasolo (2000). They had used the formula 3.10 as suggested by SCS Engineering Division, USDA to calculate the 'LS' factor for each slope gradient percentage for the nearby Machhkund-Sileru catchment in the same region with the help of remote sensing imagery and GIS technique.

As adopted and suggested by Panigrahi (2007) referring different published journals and reports, the same values of crop management factor (C) of common crops were used in this study (Table 3.6). The value of C factor was considered as 1 during the period when the field was left fallow (Ghosh and Babu, 1977 and Shri Niwas *et al.*, 1980). The value of supporting conservation practice factor (P) was determined as 0.73 for the Koraput district referring the report published by Sahoo *et al.* (2005).

$$\text{Monthly R} = 6.02 + 0.464 P \quad (3.9)$$

Where, P is the monthly rainfall in mm and R is the rainfall erosivity factor in MJ mm ha<sup>-1</sup> hr<sup>-1</sup>

$$LS = \sqrt{(\lambda / (100(0.136 + 0.097 s + 0.0139 s^2)))} \quad (3.10)$$

Where  $\lambda$  is measured slope length in the field and s is slope gradient in percentage.

**Table 3.6 Values of crop management factor ‘C’**

Sl. No	Crop	Value of C factor
1	Early rice	0.28
2	Rice	0.28
3	Ragi	0.17
4	Maize	0.45
5	Mung	0.41
6	Black gram	0.49
7	Arhar	0.38
8	<i>Kulthi</i>	0.45
9	Groundnut	0.36
10	Niger	0.49
11	Mustard	0.30
12	Ginger	0.30
13	Turmeric	0.35
14	Sweet Potato	0.33
15	Vegetable	0.33
16	Perennial Grass	0.03
17	Fallow field	1.00

Source: Panigrahi (2007)

After determining all the USLE parameters as above, the crop sequence wise annual soil loss was calculated using Eq. 3.8 considering the corresponding values of R and C factors for different crop sequences.

### 3.7 Formulation of mathematical models

For the present study, three objective functions, one for minimization of soil loss, one for minimization of investment and the other for maximization of net return from agriculture were formulated with a set of constraints, as described below, to reach at the best possible solution in the given circumstance.

$$\text{Minimize } Z_1 = \sum_{i=1}^n (a_i l_i) \quad (i=1,2,\dots,n) \quad (3.11)$$

$$\text{Minimize } Z_2 = \sum_{i=1}^n (a_i m_i) \quad (i=1,2,\dots,n) \quad (3.12)$$

$$\text{Maximize } Z_3 = \sum_{i=1}^n (a_i r_i) \quad (i=1,2,\dots,n) \quad (3.13)$$

Where,

$Z_1$  = Total soil loss from the optimum crop sequence sets (tonnes)

$Z_2$  = Total investment from the optimum crop sequence sets (₹)

$Z_3$  = Total return from the optimum crop sequence sets (₹)

$a_i$  = Area of  $i^{\text{th}}$  crop sequence set (ha)

$l_i$  = Rate of soil loss of  $i^{\text{th}}$  crop sequence set (tonnes/ha)

$m_i$  = Rate of investment of  $i^{\text{th}}$  crop sequence set (₹/ha)

$r_i$  = Rate of net return of  $i^{\text{th}}$  crop sequence set (₹/ha)

### Assumptions

A few assumptions as under have been taken for development of the model

- i) All the relationships within the model are linear.
- ii) Soil of the project area is homogenous.
- iii) Each unit of land under consideration receives same management practices for a particular activity.
- iv) Timing and period of cropping are constant and do not vary over years.

#### 3.7.1 Constraint structures

##### i) Area constraint

The summation of areas allocated to crop sequence sets should be less than equal to the total cultivable area. Mathematically,

$$\sum_{i=1}^n a_i \leq A_t \quad (i = 1, 2, \dots, n \text{ and } n \in \mathbb{N}) \quad (3.14)$$

Where,

$A_t$  = Total cultivable area in ha

**ii) Land type constraint**

A particular crop is suitable in a particular land in a particular season only due to change in property of soil. The cultivable land of Koraput district is divided into three types i.e. upland, medium land and low land. The restriction of crops and crop sequences in a particular land type is therefore to be defined as a constraint as given below (from 3.15 to 3.22).

$$\sum_{i_1=1}^{n_1} a_{i_1} \leq A_u \quad (i_1 = 1, 2, \dots, n_1 \text{ and } n_1 \in \mathbb{N}) \quad (3.15)$$

Where,

$a_{i_1}$  = Area of  $i_1^{\text{th}}$  crop sequence in upland areas (ha)

$A_u$  = Total cultivable area in upland (ha)

$$\sum_{i_2=1}^{n_2} a_{i_2} \leq A_m \quad (i_2 = 1, 2, \dots, n_2 \text{ and } n_2 \in \mathbb{N}) \quad (3.16)$$

Where,

$a_{i_2}$  = Area of  $i_2^{\text{th}}$  crop sequence in medium land areas (ha)

$A_m$  = Total cultivable area in medium land (ha)

$$\sum_{i_3=1}^{n_3} a_{i_3} \leq A_{um} \quad (i_3 = 1, 2, \dots, n_3 \text{ and } n_3 \in \mathbb{N}) \quad (3.17)$$

Where,

$a_{i_3}$  = Area of  $i_3^{\text{th}}$  crop sequence in up and medium land areas (ha)

$A_{\text{um}}$  = Total cultivable area in up and medium land (ha)

$n_4$

$$\sum a_{i_4} \leq A_{\text{ml}} \quad (i_4 = 1, 2, \dots, n_4 \text{ and } n_4 \in \mathbb{N}) \quad (3.18)$$

$i_4 = 1$

Where,

$a_{i_4}$  = Area of  $i_4^{\text{th}}$  crop sequence in medium and low land areas (ha)

$A_{\text{ml}}$  = Total cultivable area in medium and low land areas (ha)

### iii) Irrigated area constraint

Suitable crop sequence sets are to be taken up in the limited areas, where some assured irrigation is available. The constraint structure is defined as below (3.19).

$n_5$

$$\sum a_{i_5} \leq A_i \quad (i_5 = 1, 2, \dots, n_5 \text{ and } n_5 \in \mathbb{N}) \quad (3.19)$$

$i_5 = 1$

Where,

$a_{i_5}$  = Area of  $i_5^{\text{th}}$  crop sequence in assured irrigated areas (ha)

$A_i$  = Total cultivable area in assured irrigated areas (ha)

### iv) Water constraints

As per the water availability in the area, suitable crops to be taken and total crop water requirement by crops should be less than or equal to total water availability. During *kharif*, crop water requirement is met from rainfall and during *rabi*, it is met from runoff yield from rainfall which is to be harvested. Effective rainfall and runoff yield at desired probability level (80%) is determined for this. For *kharif*, effective rainfall from June to October is taken, and for *rabi*, runoff yield from June to February is taken in to account. Crop water requirement of different crops is taken

from published reports and available literatures. The constraint structure is defined as below.

**For *kharif* season**

$$\sum_{i_6=1}^{n_6} WR_1 a_{i_6} \leq W_{kh} \quad (i_6 = 1, 2, \dots, n_6 \text{ and } n_6 \in \mathbb{N}) \quad (3.20)$$

Where,

$WR_1$  = Crop water requirement of  $i_6^{\text{th}}$  crop sequence (m)

$a_{i_6}$  = Area of  $i_6^{\text{th}}$  crop sequence (ha)

$W_{kh}$  = Total water available in *kharif*

**For *rabi* season**

$$\sum_{i_7=1}^{n_7} WR_2 a_{i_7} \leq W_{rb} \quad (i_7 = 1, 2, \dots, n_7 \text{ and } n_7 \in \mathbb{N}) \quad (3.21)$$

Where,

$WR_2$  = Crop water requirement of  $i_7^{\text{th}}$  crop sequence (m)

$a_{i_7}$  = Area of  $i_7^{\text{th}}$  crop sequence (ha)

$W_{rb}$  = Total water available in *rabi*

**iv) Grass cover constraint**

For erosion control, there should be provision of having minimum grass cover in sloppy areas/upland areas. Under the study, perennial hybrid napier grass is considered for its multiple uses (erosion control, fodder and livelihood) and its plantation is limited to 5000 ha in upland area. The constraint structure is defined as below (3.22).

$$a_g \leq 5000 \text{ ha} \quad (3.22)$$

Where,

$a_g$  = Area of crop sequence with perennial grass cover (ha)

**v) Nutritional and affinity Constraint**

Crop production should meet the nutrients requirement of the population as per the recommended dietary allowance prescribed by the National Institute of Nutrition/Indian Council of Medical Research. For this, a minimum production of individual food crops must be ensured keeping in view the affinity and dietary habit of the local people. The constraint structures are defined as below (3.23 to 3.35).

$$\sum_{i_g=1}^{n_g} a_{i_g} p_{rc} \geq R_{rc} \quad (i_g = 1, 2, \dots, n_g \text{ and } n_g \in \mathbb{N}) \quad (3.23)$$

$$i_g = 1$$

Where,

$a_{i_g}$  =Area of  $i_g^{\text{th}}$  crop sequence set, where rice is taken (ha)

$p_{rc}$  = Productivity of rice (tonnes/ha)

$R_{rc}$  = Requirement of rice (tonnes)

$$\sum_{i_g=1}^{n_g} a_{i_g} p_{rg} \geq R_{rg} \quad (i_g = 1, 2, \dots, n_g \text{ and } n_g \in \mathbb{N}) \quad (3.24)$$

$$i_g = 1$$

Where,

$a_{i_g}$  =Area of  $i_g^{\text{th}}$  crop sequence set, where ragi is taken (ha)

$p_{rg}$  = Productivity of ragi (tonnes/ha)

$R_{rg}$  = Requirement of ragi (tonnes)

$$\sum_{i_{10}=1}^{n_{10}} a_{i_{10}} p_{mz} \geq R_{mz} \quad (i_{10} = 1, 2, \dots, n_{10} \text{ and } n_{10} \in \mathbb{N}) \quad (3.25)$$

$$i_{10} = 1$$

Where,

$a_{i_{10}}$  = Area of  $i_{10}$ <sup>th</sup> crop sequence set, where maize is taken (ha)

$p_{mz}$  = Productivity of maize (tonnes/ha)

$R_{mz}$  = Requirement of maize (tonnes)

$n_{11}$

$$\sum a_{i_{11}} p_{mg} \geq R_{mg} \quad (i_{11} = 1, 2, \dots, n_{11} \text{ and } n_{11} \in \mathbb{N}) \quad (3.26)$$

$i_{11} = 1$

Where,

$a_{i_{11}}$  = Area of  $i_{11}$ <sup>th</sup> crop sequence set, where mung is taken (ha)

$p_{mg}$  = Productivity of mung (tonnes/ha)

$R_{mg}$  = Requirement of mung (tonnes)

$n_{12}$

$$\sum a_{i_{12}} p_{bg} \geq R_{bg} \quad (i_{12} = 1, 2, \dots, n_{12} \text{ and } n_{12} \in \mathbb{N}) \quad (3.27)$$

$i_{12} = 1$

Where,

$a_{i_{12}}$  = Area of  $i_{12}$ <sup>th</sup> crop sequence set, where black gram is taken (ha)

$p_{br}$  = Productivity of black gram (tonnes/ha)

$R_{br}$  = Requirement of black gram (tonnes)

$n_{13}$

$$\sum a_{i_{13}} p_{ar} \geq R_{ar} \quad (i_{13} = 1, 2, \dots, n_{13} \text{ and } n_{13} \in \mathbb{N}) \quad (3.28)$$

$i_{13} = 1$

Where,

$a_{i_{13}}$  = Area of  $i_{13}$ <sup>th</sup> crop sequence, where arhar is taken (ha)

$p_{ar}$  = Productivity of arhar (tonnes/ha)

$R_{ar}$  = Requirement of arhar (tonnes)

$$n_{14}$$

$$\sum a_{i_{14}} p_{kl} \geq R_{kl} \quad (i_{14} = 1, 2, \dots, n_{14} \text{ and } n_{14} \in \mathbb{N}) \quad (3.29)$$

$$i_{14} = 1$$

Where,

$a_{i_{14}}$  = Area of  $i_{14}^{\text{th}}$  crop sequence, where *kulthi* is taken (ha)

$p_{kl}$  = Productivity of *kulthi* (tonnes/ha)

$R_{kl}$  = Requirement of *kulthi* (tonnes)

$$n_{15}$$

$$\sum a_{i_{15}} p_{gn} \geq R_{gn} \quad (i_{15} = 1, 2, \dots, n_{15} \text{ and } n_{15} \in \mathbb{N}) \quad (3.30)$$

$$i_{15} = 1$$

Where,

$a_{i_{15}}$  = Area of  $i_{15}^{\text{th}}$  crop sequence, where groundnut is taken (ha)

$p_{gn}$  = Productivity of groundnut (tonnes/ha)

$R_{gn}$  = Requirement of groundnut (tonnes)

$$n_{16}$$

$$\sum a_{i_{16}} p_{ng} \geq R_{ng} \quad (i_{16} = 1, 2, \dots, n_{16} \text{ and } n_{16} \in \mathbb{N}) \quad (3.31)$$

$$i_{16} = 1$$

Where,

$a_{i_{16}}$  = Area of  $i_{16}^{\text{th}}$  crop sequence set, where niger is taken (ha)

$p_{ng}$  = Productivity of niger (tonnes/ha)

$R_{ng}$  = Requirement of niger (tonnes)

$$n_{17}$$

$$\sum a_{i_{17}} p_{ms} \geq R_{ms} \quad (i_{17} = 1, 2, \dots, n_{17} \text{ and } n_{17} \in \mathbb{N}) \quad (3.32)$$

$$i_{17} = 1$$

Where,

$a_{i_{17}}$  = Area of  $i_{17}^{\text{th}}$  crop sequence, where mustard is taken (ha)

$p_{\text{ms}}$  = Productivity of mustard (tonnes/ha)

$R_{\text{ms}}$  = Requirement of mustard (tonnes)

$$\sum_{i_{18}=1}^{n_{18}} (a_{i_{18}} p_{\text{kvg}}) + \sum_{i_{19}=1}^{n_{19}} (a_{i_{19}} p_{\text{rvg}}) \geq R_{\text{vg}} \quad (3.33)$$

$$i_{18} = 1 \quad i_{19} = 1$$

$$(i_{18} = 1, 2, \dots, n_{18} \text{ and } n_{18} \in \mathbb{N}, i_{19} = 1, 2, \dots, n_{19} \text{ and } n_{19} \in \mathbb{N})$$

Where,

$a_{i_{18}}$  = Area of  $i_{18}^{\text{th}}$  crop sequence, where vegetables is taken in *kharif* (ha)

$a_{i_{19}}$  = Area of  $i_{19}^{\text{th}}$  crop sequence, where vegetable is taken in *rabi* (ha)

$p_{\text{kvg}}$  = Productivity of vegetable in *kharif* (tonnes/ha)

$p_{\text{rvg}}$  = Productivity of vegetable in *rabi* (tonnes/ha)

$R_{\text{vg}}$  = Total requirement of vegetable in a year (tonnes)

**v) Local suitability constraint**

Due to prevailing local conditions and basing on the production potential of the area, a minimum area is to be set for cultivation of some drought tolerant crops that are traditionally being cultivated since ages, like, a minimum of 5,000 ha for turmeric and 10,000 ha for ginger.

$$a_{\text{tr}} > 5,000 \quad (3.34)$$

$$a_{\text{gn}} > 10,000 \quad (3.35)$$

Where,

$a_{\text{tr}}$  = Area of crop sequence, where turmeric is taken (ha)

$a_{\text{gn}}$  = Area of crop sequence, where ginger is taken (ha)

### **3.7.2 Solution of linear programming models**

The land and water use optimization models have been formulated as explained previously to suggest the best possible pattern of cropland utilization, which would minimize soil loss, involve lowest investment and highest net return. A total of 3 objectives and 75 variables (crop sequence wise) are used for formulation of models.  $Z_1$ ,  $Z_2$  and  $Z_3$  are the objectives denoting i.e. minimization of soil loss, minimization of investment & maximization of net return, and  $a_1, a_2, a_3, \dots, a_{75}$  are the variables according to the serial number of cropping sequence suggested. The equations formed for objective functions and constraints are given in Appendix Q.

Using the crop sequence wise values of equations, the model was solved using linear goal programming technique with the help of Windows Quantitative Systems for Business (WinQSB) software (Chang, 1998) to suggest the best possible pattern of cropland utilization.

# RESULTS AND DISCUSSION

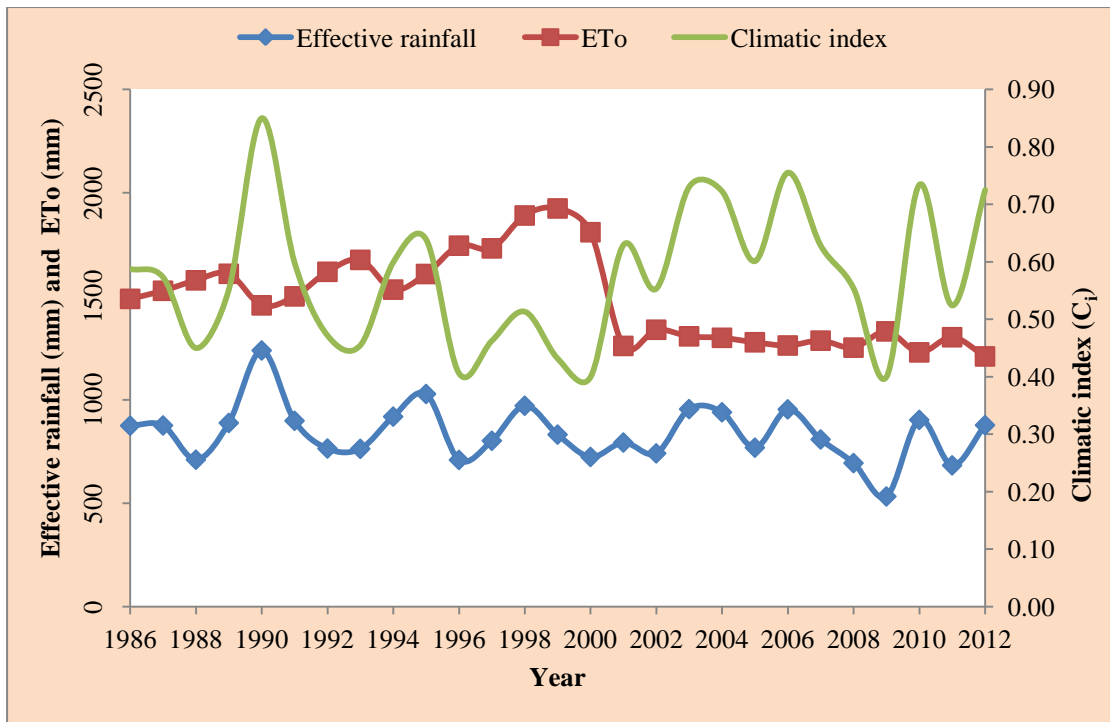
---

This chapter includes presentation and discussion of the results obtained from analysis of climatic data for selection of cropping period and sequences/patterns, assessment of water resource potential, estimation of cost of cultivation and net return from agriculture, and food requirement to meet the nutritional need of population, prediction of soil loss from the crop lands, and optimisation using the multiple objective mathematical model (Goal programming) to have an effective crop land utilization which can minimize soil loss and investment and maximize the net return from agriculture considering various constraints.

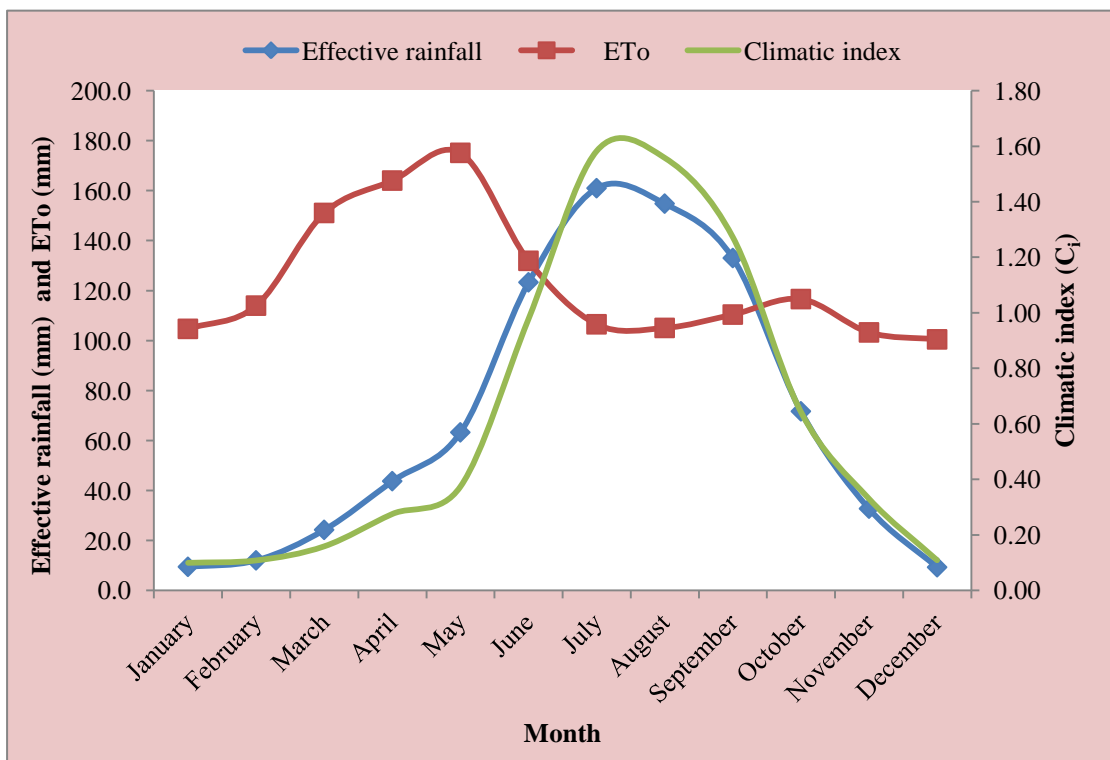
## 4.1 Effective rainfall, evapotranspiration and climatic index

From the observed climatic data (Appendix A to C), monthly effective rainfall ( $P_e$ ), reference crop evapotranspiration ( $ET_o$ ) and climatic index ( $C_i$ ) of Koraput district for 27 years from 1986 to 2012 were calculated and presented in Appendix D, E and F, respectively. The trend of their annual values is shown in Fig. 4.1. The annual value of effective rainfall was found lowest (532.2 mm) during 2009 and highest (1238.1 mm) during 1990, where as the annual value of  $ET_o$  was found lowest (1209.3 mm) during 2012 and highest (1924.7 mm) during 1999. The annual value of climatic index ( $C_i$ ) was found lowest (0.40) during 2000 and 2009, and highest (0.85) during 1990. The average values of annual effective rainfall ( $P_e$ ), reference crop evapotranspiration ( $ET_o$ ) and climatic index ( $C_i$ ) over the said period of 26 years were found to be 838.4 mm, 1483.1 mm and 0.58, respectively.

The trend of monthly effective rainfall, reference crop evapotranspiration and climatic index are shown in Fig. 4.2. The monthly value of effective rainfall was found lowest (9.3 mm) in the month of December and highest (161 mm) in the month of July, where as the monthly value of  $ET_o$  was found lowest (100.5 mm) in the month of December and highest (175.1 mm) in the month of May. The monthly value of climatic index ( $C_i$ ) was found lowest (0.10) in the month of January and highest (1.58) in the month of July. The trend of monthly value of  $C_i$  was observed similar to that of effective rainfall during the whole year. The value of climatic index was found in its peak stage between 15<sup>th</sup> July to 15<sup>th</sup> August.



**Fig. 4.1** Trend of annual effective rainfall, reference crop evapotranspiration (ET<sub>o</sub>) and climatic index (C<sub>i</sub>) of Koraput district.



**Fig. 4.2** Trend of monthly effective rainfall, reference crop evapotranspiration (ET<sub>o</sub>) and climatic index (C<sub>i</sub>) of Koraput district.

## 4.2 Initial crop coefficient, dependable climatic index and water balance

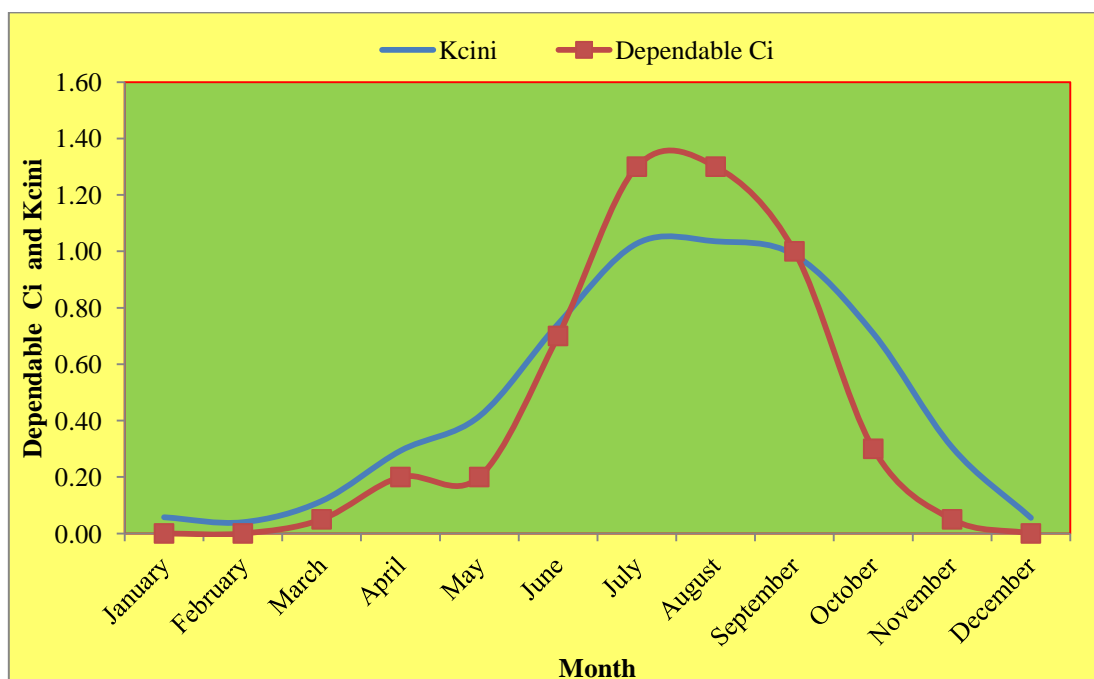
The month wise calculated values of crop coefficient at initial stage ( $K_{cini}$ ) and values of 80% dependable  $C_i$  (as suggested by Savva and Frenken, 2002; Panigrahi *et al.*, 2010) are given in Table 4.1 and the same is shown in Fig. 4.3.

**Table 4.1 Month wise values of initial crop coefficient ( $K_{cini}$ )**

Month	Normal Rainfall (mm)	Normal rainy days	Average infiltration depth (mm)	Mean wetting interval, days	Daily $ET_o$ (mm)	$K_{cini}$ value $i=10$ mm	$K_{cini}$ value $i=40$ mm	Calculated $K_{cini}$	80% dependable $C_i$
Jan.	5.7	0.4	14.25	30	3.38	0.05	0.10	0.06	0
Feb.	8.6	0.9	9.56	30	4.07	0.04	0.08	0.04	0
Mar.	18.3	1.5	12.20	20	4.87	0.10	0.30	0.11	0.05
Apr.	55.2	3.9	14.15	8	5.47	0.25	0.56	0.29	0.2
May	81.9	5.5	14.89	5	5.65	0.35	0.75	0.42	0.2
Jun.	206.8	10.6	19.51	3	4.40	0.60	1.05	0.74	0.7
Jul.	375.6	18.6	20.19	2	3.44	0.96	1.16	1.03	1.3
Aug.	393.6	19.3	20.39	2	3.39	0.97	1.16	1.04	1.3
Sept.	256.3	13.9	18.44	2	3.68	0.92	1.16	0.99	1
Oct.	126.1	6.7	18.82	4	3.76	0.58	1.02	0.71	0.3
Nov.	32.6	2.1	15.52	14	3.44	0.25	0.55	0.31	0.05
Dec.	6.5	0.5	13.00	30	3.24	0.05	0.10	0.06	0

The value of  $K_{cini}$  was found minimum (0.04) in the month of February, and maximum (1.04) in the month of August followed by July (1.03). The value of 80% dependable  $C_i$  was found minimum (0) in the month of December, January and February, and maximum (1.3) in the month of July and August. The value of  $C_i$  was found nearly equal to the corresponding value of  $K_{cini}$  during the month of June and more in the month of July, August and September. Since, for climatic suitability and water surplus stage, the value of crop coefficient should be less than climatic index, and at water balance stage, the climatic index should be equal to  $K_{cini}$ , it is clear from

Table 4.1 that June, July, August and September are the suitable period for crop growth but June in particular is the onset of water surplus period as dependable climatic index ( $C_i$ ) is greater than initial crop coefficient ( $K_{cini}$ ). From Fig. 4.3, the exact date of onset of water surplus is after 2<sup>nd</sup> week of June, as from this onwards the value of  $C_i$  is more than  $K_{cini}$  value till 2<sup>nd</sup> week of September.



**Fig. 4.3 Month wise trend of dependable climatic index ( $C_i$ ) and initial crop Coefficient ( $K_{cini}$ ) of Koraput district**

#### 4.3 Selection of cropping period

From Table 4.1 and Fig. 4.3, it is observed that the monthly values of 80% dependable climatic index ( $C_i$ ) become equal to the value of  $K_{cini}$  just after 2<sup>nd</sup> week of June and there after it exceeds  $K_{cini}$  till 2<sup>nd</sup> week of September. It indicates that crops can be taken up suitably from 3<sup>rd</sup> week / 16<sup>th</sup> June onwards and may be sown up to the end of 2<sup>nd</sup> week of September with sufficient  $K_{cini}$  values.

Keeping in view the local cropping practices and existing climatic conditions, the total cropping period was determined as 255 days commencing from mid June to end of December. Crops with more water demand having higher  $K_{cdev}$ ,  $K_{cmid}$  and  $K_{cend}$  values, were proposed from mid June onwards to till end of September, and crops with less water demand having lower  $K_{cdev}$ ,  $K_{cmid}$  and  $K_{cend}$  values, were proposed from October onwards. No crops were proposed in the month of March, April and

May due to lack of assured irrigation facility as most of the water sources becomes dry.

Basing on all the factors and with respect to water balance and climatic suitability, a standard crop schedule (Fig.4.4) was prepared and centring it as many as 75 possible cropping sequences including an option of a perennial grass cover (Table 4.2) were proposed for the district with following considerations:

- Crop coverage is limited to total cultivable area.
- Crops like niger, ginger and turmeric are to be taken in uplands.
- Crops like early rice, maize, arhar, green gram (mung), horse gram, black gram, ragi, sweet potato and groundnut are to be taken in uplands as well as medium lands.
- Mustard is to be taken up in uplands and medium lands as well as in areas with some assured irrigation.
- Vegetables are to be taken up in *kharif* in uplands and medium lands and a second vegetable is to be taken up in *rabi* in areas with some assured irrigation.
- The option of having a perennial grass cover is limited to the upland areas.

**Table 4.2 Proposed cropping sequences for Koraput district**

Sl. No.	Kharif	Pre Rabi	Rabi	Limitations
1	Early Rice	Fallow	Fallow	Up and medium land
2	Early rice	Wheat	Fallow	Medium and irrigated land
3	Early rice	Black gram	Fallow	Up and medium land
4	Early rice	Horse gram	Fallow	Up and medium land
5	Early rice	Fallow	Groundnut	Medium and irrigated land
6	Early Rice	Niger	fallow	Upland
7	Early rice	Mustard	Fallow	Up and medium land
8	Early rice	Fallow	Mustard	Medium and irrigated land
9	Early rice	Fallow	Potato	Medium and irrigated land
10	Early rice	Fallow	Vegetables	Medium and irrigated land
11	Rice	Fallow	Fallow	Medium and low land
12	Rice	Fallow	Groundnut	Medium and irrigated land
13	Rice	Fallow	Mustard	Medium and irrigated land
14	Rice	Fallow	Potato	Medium and irrigated land
15	Rice	Fallow	Vegetables	Medium and irrigated land
16	Ragi	Fallow	Fallow	Upland

17	Ragi	Wheat	Fallow	Medium and irrigated land
18	Ragi	Black gram	Fallow	Up and medium land
19	Ragi	Horse gram	Fallow	Up and medium land
20	Ragi	Fallow	Groundnut	Medium and irrigated land
21	Ragi	Fallow	Mustard	Medium and irrigated land
22	Ragi	Fallow	Potato	Medium and irrigated land
23	Ragi	Fallow	vegetables	Medium and irrigated land
24	Maize	Fallow	fallow	Up and medium land
25	Maize	Wheat	Fallow	Medium and irrigated land
26	Maize	Black gram	Fallow	Up and medium land
27	Maize	Horse gram	Fallow	Up and medium land
28	Maize	Fallow	Groundnut	Medium and irrigated land
29	Maize	Fallow	Mustard	Medium and irrigated land
30	Maize	Fallow	Potato	Medium and irrigated land
31	Maize	Fallow	Vegetables	Medium and irrigated land
32	Green gram	Fallow	Fallow	Up and medium land
33	Green gram	Wheat	fallow	Medium and irrigated land
34	Green gram	Fallow	Groundnut	Medium and irrigated land
35	Green gram	Niger	Fallow	Upland
36	Green gram	Mustard	Fallow	Up and medium land
37	Green gram	Fallow	Mustard	Medium and irrigated land
38	Green gram	Fallow	Potato	Medium and irrigated land
39	Green gram	Fallow	Vegetables	Medium and irrigated land
40	Black gram	Fallow	Fallow	Up and medium land
41	Black gram	Wheat	Fallow	Medium and irrigated land
42	Black gram	Niger	Fallow	Upland
43	Black gram	Mustard	Fallow	Up and medium land
44	Black gram	Fallow	Mustard	Medium and irrigated land
45	Black gram	Fallow	Potato	Medium and irrigated land
46	Black gram	Fallow	Vegetables	Medium and irrigated land
47	Arhar	Fallow	Fallow	Up and medium land
48	Arhar	Fallow	Groundnut	Medium and irrigated land
49	Arhar	Fallow	Mustard	Medium and irrigated land
50	Arhar	Fallow	Potato	Medium and irrigated land
51	Arhar	Fallow	Vegetables	Medium and irrigated land
52	Groundnut	Fallow	Fallow	Up and medium land
53	Groundnut	Fallow	Mustard	Medium and irrigated land
54	Groundnut	Fallow	Potato	Medium and irrigated land
55	Groundnut	Fallow	Vegetables	Medium and irrigated land
56	Ginger			Upland
57	Turmeric			Upland
58	Sweet potato	Fallow	Fallow	Upland
59	Sweet potato	Fallow	Groundnut	Medium and irrigated land

60	Sweet potato	Fallow	Mustard	Medium and irrigated land
61	Sweet potato	Fallow	Potato	Medium and irrigated land
62	Sweet potato	Fallow	Vegetables	Medium and irrigated land
63	Potato	Fallow	Fallow	Medium land
64	Potato	Fallow	Groundnut	Medium and irrigated land
65	Potato	Fallow	Mustard	Medium and irrigated land
66	Potato	Fallow	Vegetables	Medium and irrigated land
67	Vegetables	Fallow	Fallow	Up and medium land
68	Vegetable	Wheat	Fallow	Medium and irrigated land
69	Vegetable	Black gram	Fallow	Medium land
70	Vegetable	Horse gram	Fallow	Medium land
71	Vegetables	Fallow	Groundnut	Medium and irrigated land
72	Vegetables	Fallow	Mustard	Medium and irrigated land
73	Vegetables	Fallow	Potato	Medium and irrigated land
74	Vegetables	Fallow	Vegetables	Medium and irrigated land
75	Grass cover (Perennial hybrid napier)			Upland

#### 4.4 Investment and return from agriculture

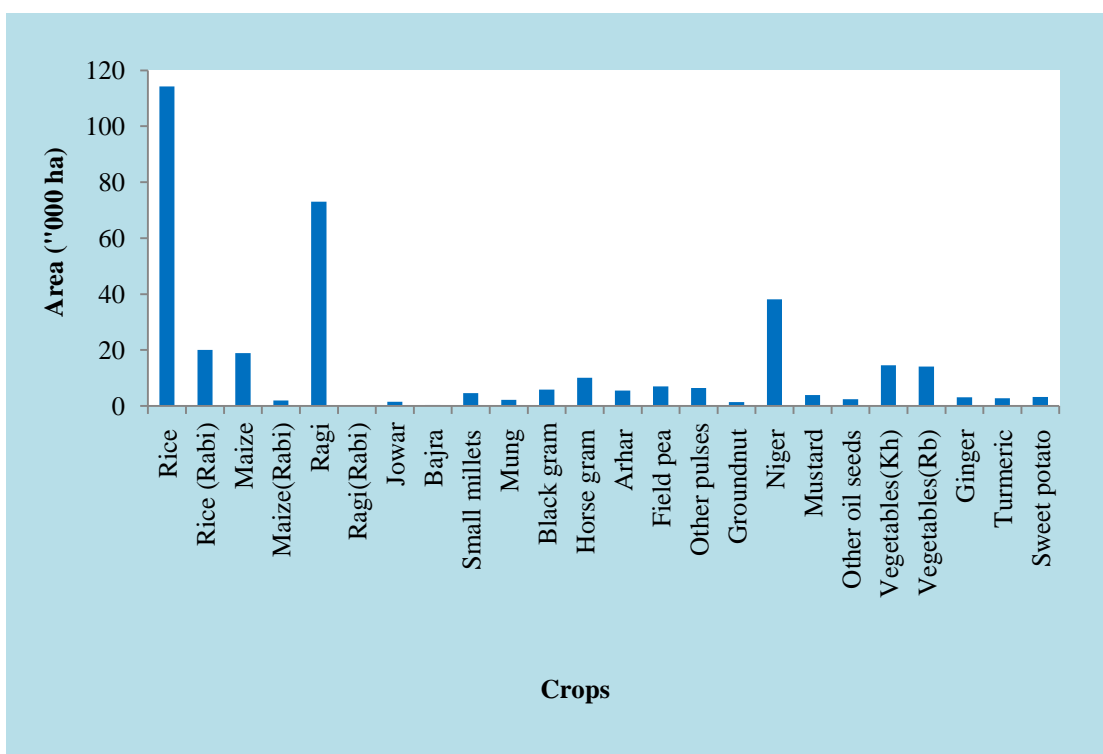
##### 4.4.1 Present status of agriculture

The present status of investment (cost involved towards seeds, farm yard manure (FYM), fertilizer, pesticide/ plant protection and wages) as well as return (gross and net return) from agriculture in Koraput district is given in Appendix G. It is observed that against an investment of ₹ 80205.22 lakhs (including cost towards wages of ₹ 38074.6 lakhs), the gross and net returns are ₹ 136722.98 lakhs and ₹ 56517.76 lakhs, respectively. The average investment, gross return and net return per hectare from agriculture in the district are ₹ 22569, ₹ 38473 and ₹ 15904, respectively. It reveals that the benefit cost ratio (BCR) from agriculture in the district is 1.7 though it has enough potential and scope for further growth. The present cropping patterns, and crop wise investment and net return are given in Figs. 4.5 and 4.6.

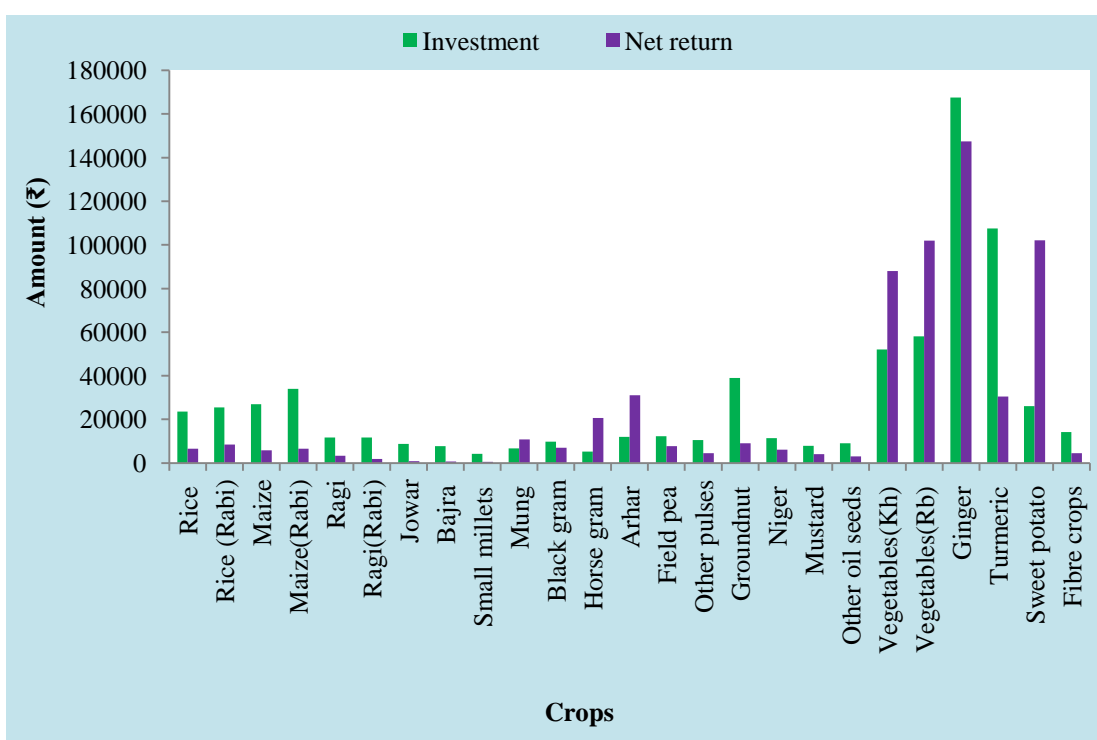
Sl. No.	Name of the crop	Crop duration									
		June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	
1	Early rice ( <i>Kharif</i> )		90 days								
2	Rice ( <i>Kharif</i> )		120 days								
3	Ragi ( <i>Kharif</i> )		100 days								
4	Maize ( <i>Kharif</i> )		100 days								
5	Wheat ( <i>Pre rabi</i> )					120 days					
6	Green gram ( <i>Kharif</i> )		70 days								
7	Black gram ( <i>Kharif</i> )		80 days								
8	Black gram ( <i>Pre rabi</i> )					90 days					
9	Horse gram ( <i>Pre rabi</i> )					90days					
10	Arhar ( <i>Kharif</i> )		135 days								
11	Ground nut ( <i>Kharif</i> )		110 days								
12	Groundnut ( <i>Rabi</i> )					110 days					
13	Niger ( <i>Pre rabi</i> )					110 days					
14	Mustard ( <i>Pre rabi</i> )					80days					
15	Mustard ( <i>Rabi</i> )						80 days				
16	Ginger ( <i>Kharif</i> )		210 days								
17	Turmeric ( <i>Kharif</i> )		210 days								
18	Sweet potato ( <i>Kharif</i> )		120 days								
19	Potato ( <i>Kharif</i> )		135 days								
20	Potato ( <i>Rabi</i> )					120 days					
21	Vegetables ( <i>Kharif</i> )		90 days								
22	Vegetables ( <i>Rabi</i> )					90 days					

Vegetables (*Kharif*): Cabbage, Cauliflower and Knol khol , Vegetables (*Rabi*): Brinjal, Tomato, Capsicum and Chilli

**Fig. 4.4 Suggested crop schedule for Koraput district**



**Fig. 4.5 Present cropping pattern in Koraput district**

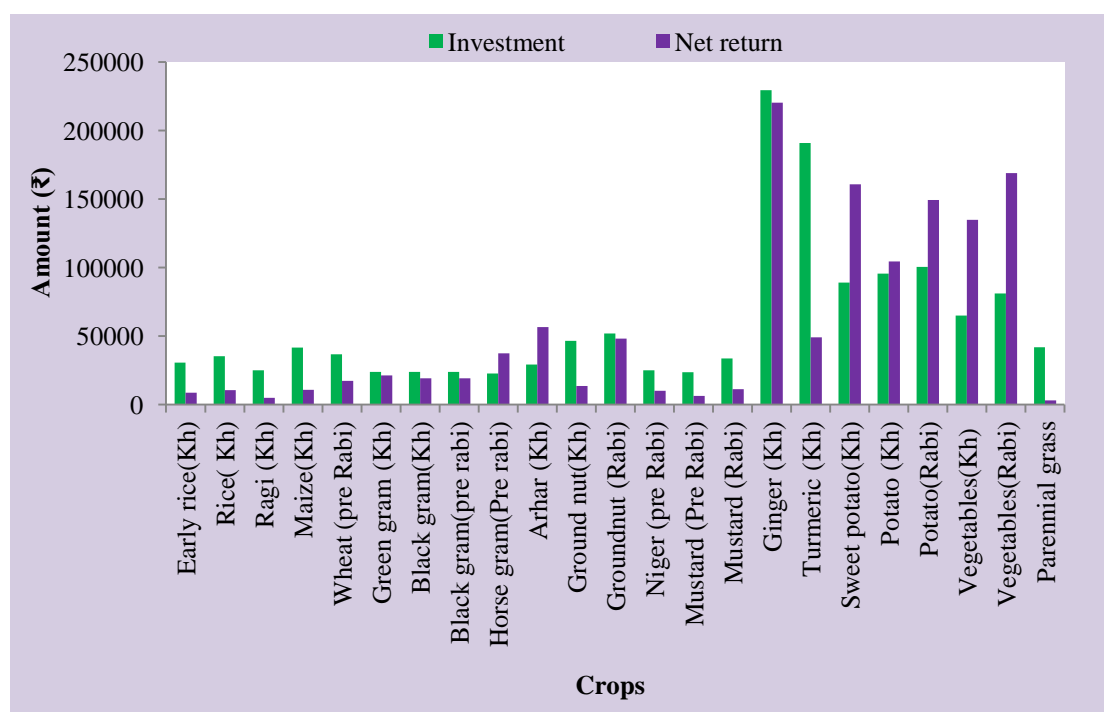


**Fig. 4.6 Present investment and net returns from crops**

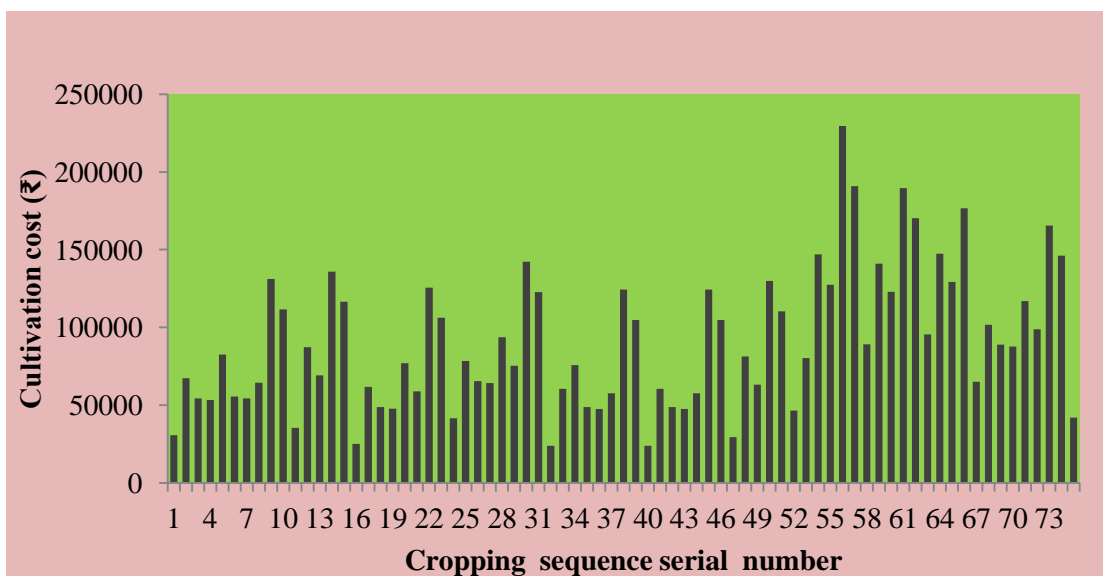
#### 4.4.2 Based on standard package of practices and suggested cropping patterns

The cost of cultivation and net return from agriculture in details for different crops as per standard package of practices is given in Appendix H and shown in Fig. 4.7. It is observed that cultivation of ginger involves highest investment of ₹ 229500 per ha (including ₹ 132000 in terms of inputs other than wages), where as horse gram requires lowest investment of ₹ 22590 ( including ₹ 12840 in terms of inputs other than wages) per ha. The net return is highest (₹ 220500) in case of ginger and lowest (₹ 3100) in case of hybrid napier.

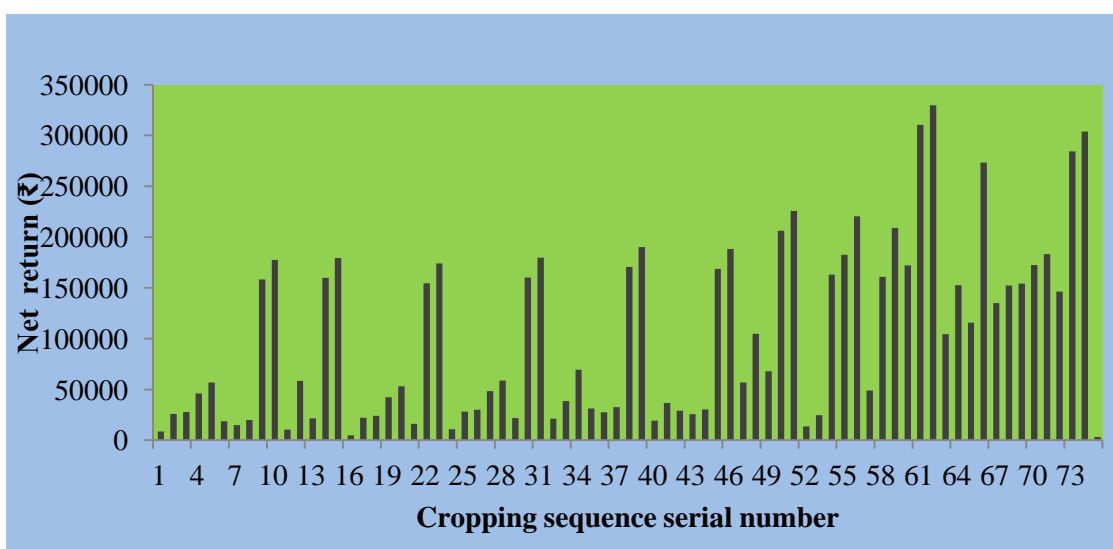
Basing on standard package of practices, the investments and net returns from suggested cropping patterns are given in Appendix I. The cost of cultivation is highest (₹ 229500) in case of cropping pattern ginger–fallow and lowest (₹ 23790) in case of both black gram-fallow-fallow and green gram-fallow. The net return is highest (₹ 329800) in case of cropping pattern sweet potato-fallow-vegetables and lowest (₹ 3100) in case of perennial grass cover. The cropping pattern wise cost of cultivation and net return is shown in Fig 4.8 and 4.9.



**Fig. 4.7 Investment and net returns from crops as per standard package of practices**



**Fig. 4.8 Cost of cultivation of suggested cropping patterns**



**Fig. 4.9 Net returns of suggested cropping patterns**

#### 4.5 Projected population

As per 2011 census, the total population of the district is 1379647 consisting of 678809 males and 700838 females. The people of the district are resource poor and economically backward, and 48.31% of them are workers. As calculated, the projected population of the district in 2021 at the present decadal growth rate of 16.86% is 1612255 comprising 793256 males and 818999 females.

#### 4.6 Food requirement

The annual net food requirement of the district for the said projected population is calculated as per guidelines of recommended dietary allowance (RDA) for Indians

prescribed by National Institute of Nutrition, Hyderabad and is given in Appendix J. The net production requirement of the individual food crop is estimated basing on the edible portion of the food items, and the gross production requirements are estimated considering the requirements of seeds, feed and wastage. The estimated net food requirement, net production requirement and gross production requirement as per recommended dietary allowance is given in Table 4.3.

**Table 4.3 Food requirement as per RDA for the projected population of Koraput district during 2021**

Sl. No.	Food groups	Net food requirement (Tonnes)	Net production requirement (Tonnes)	Gross production requirement (Tonnes)
1	Rice	169686	257100	329615
2	Maize	28679	36768	47139
3	Ragi	40629	52088	66780
	<b>Cereals</b>	<b>238994</b>	<b>345956</b>	<b>443534</b>
4	Mung	2896	4137	5909
5	Black gram	7239	10341	14773
6	Horse gram	20752	29645	42351
7	Arhar	17374	24819	35456
	<b>Pulses</b>	<b>48260</b>	<b>68943</b>	<b>98490</b>
8	Groundnut	1126	4022	5362
9	Niger	13835	49410	65880
10	mustard	1126	3412	4550
	<b>Oilseeds</b>	<b>16087</b>	<b>56844</b>	<b>75792</b>
11	Vegetables	240803	240803	301004
12	Sweet potato	18125	18125	22656
	<b>Vegetables and tubers</b>	<b>258928</b>	<b>258928</b>	<b>323660</b>
	<b>Total</b>	<b>562269</b>	<b>730671</b>	<b>941476</b>

## **4.7 Soil loss from agricultural land**

### **4.7.1 Existing cropping pattern**

The monthly determined values of the rainfall erosivity factor 'R' for 26 years from 1986 to 2012 are given in Appendix K. Applying USLE, crop pattern wise annual soil loss from the agricultural field was calculated and given in Appendix L. Soil loss to the extent of 13333.35 thousand tonnes was found annually at the rate of 43.86 t ha<sup>-1</sup> yr<sup>-1</sup> from the agricultural fields of the Koraput district (Table 4.4). Single and double cropped agricultural fields contributed 68.8% and 20.7% of total soil loss at the rate of 44.23 and 38.92 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. Maximum rate of soil loss (98.38 t ha<sup>-1</sup> yr<sup>-1</sup>) was found in case of fallow land sharing 10.5% total soil loss. Under single cropped lands, maximum (68.53 t ha<sup>-1</sup> yr<sup>-1</sup>) and minimum (26.85 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of mung-fallow-fallow and jowar-fallow-fallow. Under double cropped lands, maximum (53.71 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of both maize-fallow-*kulthi* and maize-fallow-maize, and minimum (24.76 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of small millets-fallow-other pulses. From double cropped lands, 70% less soil loss was observed when compared to single cropped lands of the district. Higher soil loss under single cropped lands may be due to upland situations and longer fallow period. Lower soil loss under double cropped lands may be attributed to mild slopping conditions, thick crop canopy due to better soil moisture and shorter fallow period.

### **4.7.2 Suggested cropping pattern**

The soil loss estimated from the suggested cropping pattern for the district is given in Appendix M. Highest soil loss of 90.82 t ha<sup>-1</sup> yr<sup>-1</sup> was found in case of fallow land and lowest soil loss of 4.27 t ha<sup>-1</sup> yr<sup>-1</sup> was found in case of perennial grass cover (hybrid napier). Among single cropped area, maximum (59.24 t ha<sup>-1</sup> yr<sup>-1</sup>) and minimum (28.05 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was observed in case of black gram-fallow-fallow and potato-fallow-fallow. Among double cropped area, maximum (55.90 t ha<sup>-1</sup> yr<sup>-1</sup>) and minimum (17.98 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was observed in case of black gram-fallow-mustard and ragi-wheat-fallow. The average soil loss from single cropped land and double cropped land was found to be 40.50 t ha<sup>-1</sup> yr<sup>-1</sup> and 36.33 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. The crop pattern wise soil loss in details under single and double cropped land is given in Table 4.5 and 4.6. The soil loss from single cropped, double

cropped and fallow land, under existing and suggested cropping pattern is given in Fig 4.10

**Table 4.4 Estimated soil losses from crop lands under existing cropping pattern of Koraput district**

Sl. No.	Cropping pattern	Area ('000ha)	Rate of Soil loss ( $t\ ha^{-1}\ yr^{-1}$ )	Total annual soil loss ('000 tonnes)
1	Rice-Fallow-Fallow	69.64	38.16	2657.69
2	Ragi- Fallow-Fallow	71.03	38.36	2724.93
3	Maize- Fallow-Fallow	8.78	58.61	514.58
4	Jowar- Fallow-Fallow	1.48	26.85	39.74
5	Bajra- Fallow-Fallow	0.32	28.96	9.27
6	Small millets- Fallow-Fallow	1.15	28.96	33.31
7	Mung- Fallow-Fallow	0.53	68.53	36.32
8	Black gram- Fallow-Fallow	3.39	68.48	232.15
9	Arhar- Fallow-Fallow	5.45	44.95	244.98
10	Other pulses- Fallow-Fallow	2.38	49.03	116.70
11	Sweet potato- Fallow-Fallow	3.01	42.34	127.46
12	Vegetable- Fallow-Fallow	3.11	49.93	155.29
13	Groundnut- Fallow-Fallow	0.57	48.48	27.63
14	Niger- Fallow-Fallow	38.14	50.64	1931.45
15	Other oilseeds- Fallow-Fallow	1.35	44.85	60.55
16	Fibres- Fallow-Fallow	0.47	44.85	21.08
17	Chilly- Fallow-Fallow	1.25	42.34	52.93
18	Ginger	3.04	30.57	92.93
19	Turmeric	2.79	35.41	98.80
	<b>Total single cropped area</b>	<b>217.88</b>	<b>44.23</b>	<b>9177.79</b>
20	Early rice-Fallow- Mustard	3.94	45.41	178.91
21	Early rice-Fallow-Ragi	0.08	44.48	3.56
22	Rice-Fallow-Field pea	6.94	33.75	234.21

23	Rice-Fallow-Cowpea	1.83	33.75	61.76
24	Rice-Fallow-Gram	2.26	33.75	76.27
25	Rice-Fallow-Wheat	0.34	32.82	11.16
26	Rice-Fallow-Vegetables	7.5	33.39	250.44
27	Rice-Fallow-Mung	1.68	33.96	57.06
28	Rice-Fallow-Rice	20.07	33.04	663.03
29	Ragi-Fallow-Kulthi	1.99	34.45	68.55
30	Maize-Fallow-Kulthi	8.08	53.71	433.94
31	Maize-Fallow-Maize	1.99	53.71	106.87
32	Small millets-Fallow-Black gram	2.4	25.33	60.80
33	Small millets-Fallow-Other pulses	0.99	24.76	24.51
34	Other pulses-Fallow-Chilly	1.76	44.26	77.90
35	Other pulses-Fallow-Coriander	1.29	44.26	57.10
36	Vegetable-Fallow-Vegetable	6.54	45.16	295.35
37	Vegetable-Fallow-Groundnut	0.79	45.37	35.85
38	Vegetable-Fallow-Other oilseeds	1.04	45.37	47.19
39	Chilly-Fallow-Garlic	0.43	37.57	16.16
	<b>Total double cropped area</b>	71.94	38.92	2760.61
40	Fallow-Fallow-Fallow	14.18	98.38	1394.96
	<b>Total cultivable land</b>	304	43.86	13333.35

**Table 4.5 Soil loss from single cropped land under suggested cropping pattern**

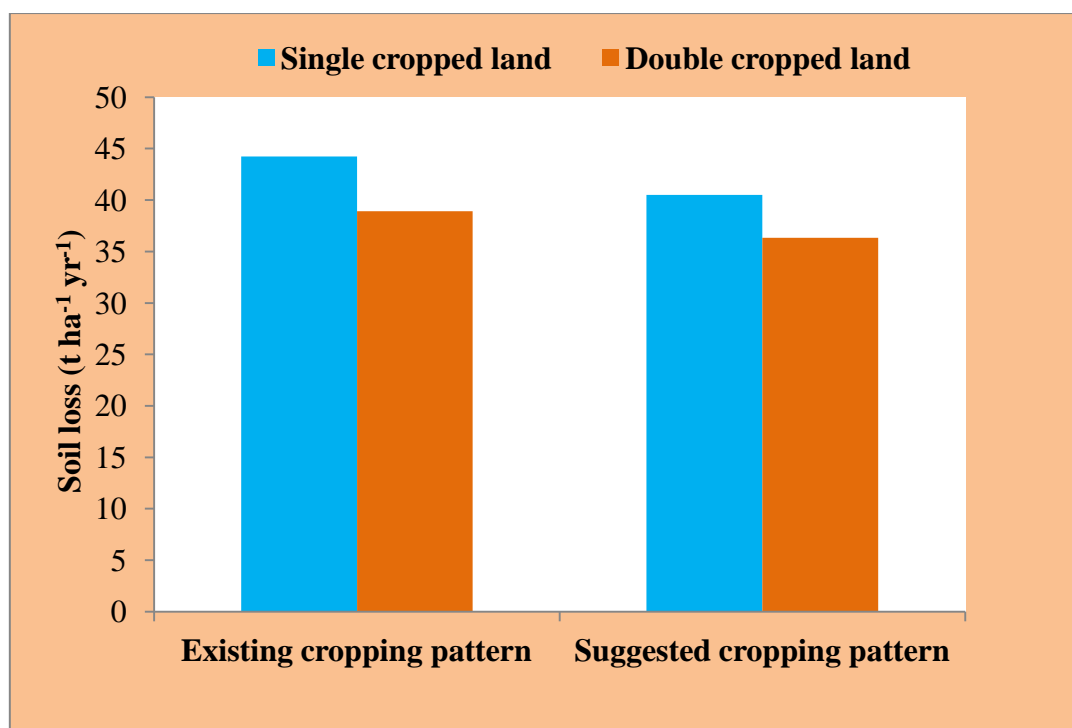
Sl. No.	Cropping pattern			Total soil loss(t ha <sup>-1</sup> yr <sup>-1</sup> )
1	Early Rice	Fallow	Fallow	42.16
2	Rice	Fallow	Fallow	33.30
3	Ragi	Fallow	Fallow	30.03
4	Maize	Fallow	Fallow	50.54
5	Green gram	Fallow	Fallow	58.33
6	Black gram	Fallow	Fallow	59.24

7	Arhar	Fallow	Fallow	38.93
8	Groundnut	Fallow	Fallow	41.32
9	Ginger	-	Fallow	28.67
10	Turmeric	-	Fallow	33.11
11	Sweet potato	Fallow	Fallow	37.30
12	Potato	Fallow	Fallow	28.05
13	Vegetables	Fallow	Fallow	45.54

**Table 4.6 Soil loss from double cropped land under suggested cropping pattern**

Sl. No.	Cropping pattern			Soil loss (t ha <sup>-1</sup> yr <sup>-1</sup> )
1	Early rice	Wheat	Fallow	25.87
2	Early rice	Black gram	Fallow	31.61
3	Early rice	Horse gram	Fallow	30.78
4	Early rice	Fallow	Groundnut	37.61
5	Early Rice	Niger	Fallow	31.52
6	Early rice	Mustard	Fallow	30.15
7	Early rice	Fallow	Mustard	38.82
8	Early rice	Fallow	Potato	36.82
9	Early rice	Fallow	Vegetables	37.39
10	Rice	Fallow	Groundnut	28.75
11	Rice	Fallow	Mustard	29.96
12	Rice	Fallow	Potato	27.96
13	Rice	Fallow	Vegetables	28.53
14	Ragi	Wheat	Fallow	17.98
15	Ragi	Black gram	Fallow	22.36
16	Ragi	Horse gram	Fallow	21.76
17	Ragi	Fallow	Groundnut	25.47
18	Ragi	Fallow	Mustard	26.69
19	Ragi	Fallow	Potato	24.69
20	Ragi	Fallow	vegetables	25.26
21	Maize	Wheat	Fallow	38.49
22	Maize	Black gram	Fallow	42.87
23	Maize	Horse gram	Fallow	42.27
24	Maize	Fallow	Groundnut	45.98
25	Maize	Fallow	Mustard	47.19
26	Maize	Fallow	Potato	45.20

27	Maize	Fallow	Vegetables	45.77
28	Green gram	Wheat	Fallow	32.65
29	Green gram	Fallow	Groundnut	53.77
30	Green gram	Niger	Fallow	41.31
31	Green gram	Mustard	Fallow	35.58
32	Green gram	Fallow	Mustard	54.98
33	Green gram	Fallow	Potato	52.99
34	Green gram	Fallow	Vegetables	53.56
35	Black gram	Wheat	Fallow	38.70
36	Black gram	Niger	Fallow	45.71
37	Black gram	Mustard	Fallow	41.29
38	Black gram	Fallow	Mustard	55.90
39	Black gram	Fallow	Potato	53.90
40	Black gram	Fallow	Vegetables	54.47
41	Arhar	Fallow	Groundnut	34.37
42	Arhar	Fallow	Mustard	35.58
43	Arhar	Fallow	Potato	33.59
44	Arhar	Fallow	Vegetables	34.16
45	Groundnut	Fallow	Mustard	37.98
46	Groundnut	Fallow	Potato	35.98
47	Groundnut	Fallow	Vegetables	36.55
48	Sweet potato	Fallow	Groundnut	32.74
49	Sweet potato	Fallow	Mustard	33.95
50	Sweet potato	Fallow	Potato	31.96
51	Sweet potato	Fallow	Vegetables	32.53
52	Potato	Fallow	Groundnut	23.49
53	Potato	Fallow	Mustard	24.70
54	Potato	Fallow	Vegetables	23.28
55	Vegetable	Wheat	Fallow	29.25
56	Vegetable	Black gram	Fallow	34.99
57	Vegetable	Horse gram	Fallow	34.16
58	Vegetables	Fallow	Groundnut	40.99
59	Vegetables	Fallow	Mustard	42.20
60	Vegetables	Fallow	Potato	40.20
61	Vegetables	Fallow	Vegetables	40.77



**Fig 4.10 Comparison of soil loss from single and double cropped lands under existing cropping pattern and suggested cropping pattern**

#### 4.8 Water resource potential

##### 4.8.1 Water availability during *kharif*

Using the different probability distribution functions, monthly rainfall data for the period from 1986-2012 was analysed and the best fit probability distributions were determined (Table 4.7) and applying it, expected month wise rainfall at different probabilities were estimated (Table 4.8).

**Table 4.7 Month wise best fit probability distributions of rainfall**

Month	Best fit distribution (Chi-square value is minimum)
January	Extreme value type -III
February	Log normal
March	Log normal
April	Log pearson
May	Log pearson
June	Log pearson
July	Weibull
August	Log normal 3 parameter
September	Extreme value type III
October	Log normal 3 parameter
November	Log pearson
December	Log pearson

**Table 4.8 Expected month wise rainfall (mm) at different probability levels**

Month	Probability level (%)								
	90	80	70	60	50	40	30	20	10
Jan.	0	0	0	0	0	0	6.1	21.71	39.79
Feb.	0	0	0	1.22	2.98	5.52	9.62	17.25	36.52
Mar.	0	1.36	4.75	8.21	12.52	18.36	27	41.63	74.45
Apr.	0	20.17	29.46	37.66	45.83	54.58	64.64	77.3	96.23
May	16.81	25.42	34.38	44.61	57.02	73.02	95.42	130.95	204.26
June	92.93	113.28	131.73	150.69	171.65	196.43	228.16	273.82	357.22
July	206.53	263.78	307.36	345.55	381.71	418.08	457	502.37	564.59
Aug.	184.57	225.41	258.03	288.2	318.48	350.9	388.15	435.37	507.99
Sept.	101.86	138.33	168.29	195.92	223.21	251.7	283.27	321.41	375.92
Oct.	16.58	32.26	46.35	60.66	76.24	94.33	116.9	148.32	202.83
Nov.	0	2.32	5.37	9.53	15.36	23.87	37.24	60.95	115.93
Dec.	0	0	0	0	0	0.3	4.73	13.35	34.32

The total rainfall and resulting effective rainfall during *kharif* (June to October) at 80% and 60% probability levels was determined using USDA Soil Conservation Service method and using it, total water available during *kharif* was estimated to be 160086.4 ha- m (at 80 % probability level) and 187598.4 ha-m (at 60 % probability level) (Appendix N )

#### **4.8.2 Water availability during *rabi***

Using SCS-Curve Number method, the month wise surface runoff due to rainfall was estimated (Appendix O). Applying the different probability distribution functions, month wise runoff for the period from 1986- 2012 was analysed and the best fit probability distributions were determined (Table 4.9). Applying it, expected month wise runoff at different probabilities were estimated (Table 4.10) and using it, the total surface runoff from June to February was estimated to be 45007.2 ha-m (at 80 % probability level) and 65578.88 ha-m (at 60% probability level) ( Appendix P ).

**Table 4.9 Month wise best fit probability distributions of runoff**

Month	Best fit distribution (Chi-square value is minimum)
January	Log normal 3 parameter
February	Gumbel-maximum (MOM)
March	Exponential
April	Extreme value type III
May	Exponential
June	Log pearson
July	Log pearson
August	Log normal 3 parameter
September	Log pearson
October	Generalized extreme value
November	logpearson
December	Log pearson

**Table 4.10 Expected month wise runoff (mm) at different probability levels**

Month	Probability level (%)								
	90	80	70	60	50	40	30	20	10
Jan	0	0	0	0	0	1.80	2.97	6.85	12.64
Feb	0	0	0	1.49	2.36	3.06	3.79	4.67	6.02
Mar	0	0.13	1.11	2.24	3.57	5.21	7.32	10.23	15.37
Apr	0	3.24	6.04	8.29	10.37	12.45	14.69	17.34	21.04
May	2.46	5.23	8.36	11.97	16.24	21.47	28.22	37.72	53.97
Jun	10.74	15.92	20.81	26.18	32.55	40.65	51.92	69.79	107.10
July	41.71	52.62	62.22	71.80	82.07	93.81	108.27	128.06	161.67
Aug	32.27	39.40	46.14	53.24	61.26	70.89	83.32	101.32	134.18
Sept	23.94	29.94	35.54	41.44	48.12	56.20	66.82	82.58	112.60
Oct	3.53	8.38	12.47	16.47	20.7	25.5	31.4	39.53	53.62
Nov	0	1.79	3.36	5.10	7.17	9.76	13.22	18.35	27.73
Dec	0	0	0	0	0	0.24	2.12	5.01	11.20

#### 4.9 Mathematical models for land and water use optimization

Using linear goal programming technique with the help of Windows Quick Statistical Business (WinQSB) Software, the mathematical models formulated under the present study consisting three objective functions with seventy five variables and

twenty three constraints were solved and feasible solutions were found. From the feasible solution, the optimal solution for each objective function was obtained. While solving the models, Goal I (minimisation of soil loss), Goal II (minimization of investment) and Goal III (maximization of net return from agriculture) were given 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> priorities for optimal solution. The allocation of area to different cropping patterns obtained from the optimal solution is given in Table 4.11.

#### 4.9.1 Solution of models

Out of 75 decision variables considered in model formulations under the study, only 14 variables are found having optimal solution and others are having zero value at boundary. As per the suggestions given by model, the food crops to be taken up in 299000 ha and perennial grass cover in 5000 ha with a cropping intensity of 193% (100% in *kharif*, 87% in pre *rabi* and 6% in *rabi*). It was also suggested by the model that a net return of ₹ 148216.90 lakhs can be obtained from agriculture with the investment of ₹ 201053 lakhs. Soil loss to the extent of 7978.24 thousand tonnes was estimated by the model to occur from the cultivable area of 304000 ha under different cropping patterns.

Maximum and minimum soil loss of 2577211 and 21350 tonnes was observed in case of cropping patterns ragi-horse gram-fallow, and perennial grass cover (hybrid napier) at the rate of 21.76 and 4.27 t ha<sup>-1</sup> yr<sup>-1</sup>. Highest and lowest investment of ₹ 564.60 crores and ₹ 14.60 crores was found in case of cropping pattern ragi-horse gram-fallow and ragi-black gram-fallow at the rate of ₹ 47670 and ₹ 48870, respectively. Highest (₹ 501.35 crores) net return was obtained in case of cropping pattern ragi-horse gram-fallow at the rate of ₹ 42330 per ha and lowest net return (₹ 1.55 crores) was obtained in case of cropping pattern perennial grass cover at the rate of ₹ 3100 per ha. All the constraints are satisfied with the values within the desired limit (Table 4.12). The model suggested highest area of 118438 ha under cropping pattern ragi- horse gram-fallow and lowest area of 1132.8 ha under cropping pattern sweet potato-fallow-potato for the proposed cropping pattern.

**Table 4.11 Allocation of area for different cropping patterns as suggested by Goal programming**

Sl . No.	Cropping pattern			Area (ha)	Goal I (Minimization of soil loss)		Goal II (Minimization of investment)		Goal III (Maximization of net return)	
					Unit cost (t/ha/yr)	Total (t/yr)	Unit cost (₹/ha)	Total (₹)	Unit cost (₹/ha)	Total (₹)
1	Early rice	Wheat	Fallow	43991.67	25.87	1138065	67340	2962399058	25960	1142023753
2	Early Rice	Niger	fallow	65880	31.52	2076538	55610	3663586800	18690	1231297200
3	Ragi	Wheat	Fallow	16147.53	17.98	290333	61790	997755879	22210	358636641
4	Ragi	Black gram	Fallow	2988.25	22.36	66817	48870	146035778	24130	72106473
5	Ragi	Horse gram	Fallow	118438	21.76	2577211	47670	5645939460	42330	5013480540
6	Maize	Black gram	Fallow	11784.75	42.87	505212	65450	771311888	29950	352953263
7	Green gram	Mustard	Fallow	5909	35.58	210242	47500	280677500	27500	162497500
8	Arhar	Fallow	Groundnut	2144.8	34.37	73717	81280	174329344	104720	224603456
9	Arhar	Fallow	Potato	3543.04	33.59	119011	129880	460170035	206120	730291405
10	Arhar	Fallow	Vegetables	12040.16	34.16	411292	110390	1329113262	225610	2716380498
11	Ginger	-	-	10000	28.67	286700	229500	2295000000	220500	2205000000
12	Turmeric	-	-	5000	33.11	165550	190920	954600000	49080	245400000
13	Sweet potato	Fallow	Potato	1132.8	31.96	36204	189690	214880832	310310	351519168
14	Grass cover	-	-	5000	4.27	21350	41900	209500000	3100	15500000
	<b>Total</b>			<b>304000</b>		<b>7978241</b>		<b>20105299835</b>		<b>14821689896</b>

#### 4.9.2 Comparison of the model solution with present status of agriculture

When the suggested values by the model for the proposed cropping pattern were compared with existing cropping status in terms of soil loss, investment and net return, it was found that total investment and net return were on much higher side and total soil loss was on much lower side for the proposed cropping pattern than the existing status (Table 4.13). Under proposed pattern, the rate of soil loss was decreased by 40% and the rate of net return was increased by 131%. The rate of investment was less in existing cropping pattern but at the same time, the rate of net return was also much less compared to proposed cropping patterns. The investment and net return, and soil loss under present cropping pattern and suggested cropping pattern by model is given in Fig 4.11 and 4.12.

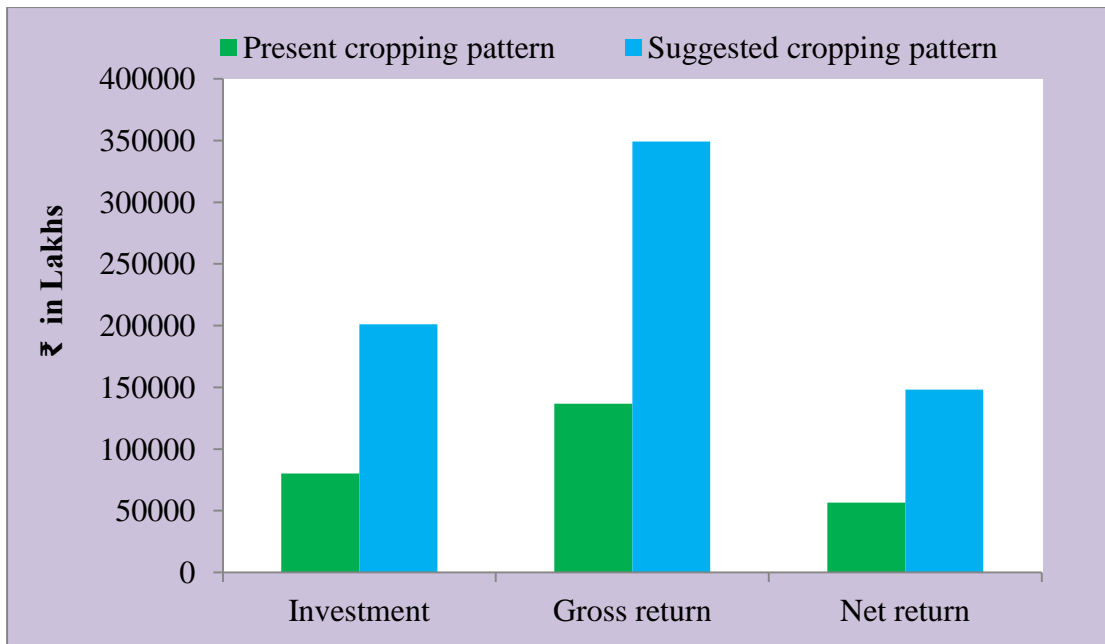
**Table 4.12 Summary of constraints of Goal programming**

Sl. No.	Constraints	Calculated value	Direction	Desired value
1	Cultivable area (ha)	3,04,000.00	=	3,04,000.00
2	Upland area (ha)	85,880.00	<=	1,87,000.00
3	Medium land area (ha)	79,000.00	<=	79,000.00
4	Upland and medium land area (ha)	1,39,120.00	<=	2,66,000.00
5	Medium land and low land area (ha)	Rejected	<=	1,17,000.00
6	Net irrigated area (ha)	79,000.00	>=	78,200.00
7	Area under grass cover (ha)	5,000.00	<=	5,000.00
8	Water availability during <i>kharif</i> (ha.m)	2,23,550.34	>=	1,60,086.41
9	Water availability during <i>rabi</i> (ha.m)	41,169.95	<=	45,007.20
10	Rice production (tonnes)	3,29,615.00	>=	3,29,615.00
11	Ragi production (tonnes)	2,75,147.56	>=	66,780.00
12	Maize production (tonnes)	47,139.00	>=	47,139.00
13	Mung production (tonnes)	5,909.00	>=	5,909.00

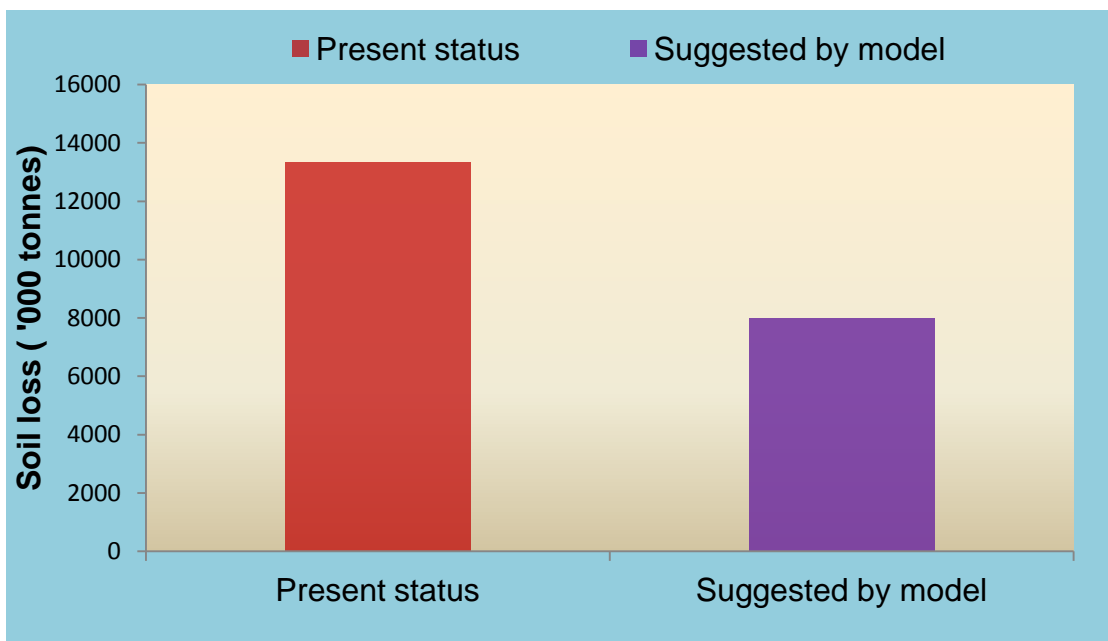
14	Black gram production (tonnes)	14,773.00	>=	14,773.00
15	Horse gram production (tonnes)	1,77,657.00	>=	42,351.00
16	Arhar production (tonnes)	35,456.00	>=	35,456.00
17	Ground nut production (tonnes)	5,362.00	>=	5,362.00
18	Niger production (tonnes)	65,880.00	>=	65,880.00
19	Mustard production (tonnes)	5,909.00	>=	4,550.00
20	Vegetables production (tonnes)	3,01,004.00	>=	3,01,004.00
21	Sweet potato production (tonnes)	22,656.00	>=	22,656.00
22	Area under ginger (ha)	10,000.00	>=	10,000.00
23	Area under turmeric (ha)	5,000.00	>=	5,000.00

#### 4.13 Comparison of the model results with the existing agricultural situation

Sl. No.	Item	Unit	Present status	Suggested by model	Increase /decrease(-)
1	Total investment towards agriculture	₹ Lakhs	80205.22	201053	120847.8
2	Net return from agriculture	₹ Lakhs	56517.76	148216.90	91699.14
3	Soil loss from farming land	'000 tonnes	13333.35	7978.24	-5355.11
4	Net sown area	Hectare	268000	304000	36000
5	Investment per ha (as per net sown area)	₹ /ha	29927	66136	36209
6	Rate of net return (as per net sown area)	₹ /ha	21089	48756	27667
7	Rate of soil loss (as per cultivable area)	t/ha	43.86	26.24	-17.62



**Fig 4.11 Investment, gross return and net return from present cropping pattern and suggested cropping pattern**



**Fig 4.12 Soil loss from present cropping pattern and suggested cropping pattern**

# SUMMARY AND CONCLUSIONS

---

Agriculture has played in the past and will continue to play a dominant role for the future growth of Indian economy. Indian agriculture has progressed a long way from an era of frequent droughts and vulnerability to food shortages to becoming a significant exporter of agricultural commodities. This has been possible due to persistent efforts at harnessing the potential of land and water resources for agricultural purposes. The pressure of rising population and rapid urbanisation has resulted in to growing demand and scarcity of available land and water resources. Their poor management and continuous degradation is a major constraint towards augmentation of agricultural production. So the challenging goals of enhanced food production and agricultural growth will have to be met from declining availability of land and water with their proper scientific planning, efficient use and judicious management. Optimal land and water use planning is the appropriate strategy to deal with land degradation problem due to soil erosion, and maximization of agricultural production in sustainable manner.

The present study was undertaken for optimal use of land and water resources of Koraput district located in the Eastern Ghat region of Odisha with the following objectives:

1. To analyze the climatic data and assess the water resource potential of the area.
2. To find out the suitable cropping pattern and sequences based on water balance through assessment of soil loss, extent of agricultural investment and net return.
3. To develop an optimised model for effective cropland utilisation based on highest return and minimum soil loss.

Under the study, the climatic data for 27 years from 1986 to 2012 of the selected Koraput district was analysed to find out the monthly climatic index from the calculated values of effective rainfall and evapotranspiration. The 80% dependable monthly climatic index values were correlated with monthly initial crop co-efficient to suggest the starting of the cropping period at water balance and surplus stage. Using the values of  $K_{c\ dev}$ ,  $K_{c\ mid}$  and  $K_{c\ end}$  of different crops and taking in to account

the local cropping practices, the total cropping period was worked out. A crop calendar and a possible set of crop sequences were prepared based on it. The extent of investment, net return and soil loss from agriculture were estimated as per the prevailing situation and for the suggested cropping patterns. From rainfall data, using SCS-Curve Number method, the water resource potential (water availability during *kharif* and *rabi*) of the district was assessed. Mathematical models were formulated for optimal allocation of area to suggested cropping patterns with three different objectives viz. minimisation of soil loss (Goal I), minimization of investment (Goal II) and maximization of net return from agriculture (Goal III) and was solved using linear goal programming technique with the help of Windows Quick Statistical Business (WinQSB) Software.

The following conclusions are drawn from the present study.

1. The annual value of effective rainfall was found varying between 532.2 mm and 1238.1 mm, where as the annual value of  $ET_o$  was found varying between 1209.3 mm and 1924.7 mm. The annual value of climatic index ( $C_i$ ) was found varying between 0.40 and 0.85. The average values of annual effective rainfall ( $P_e$ ), reference crop evapotranspiration ( $ET_o$ ) and climatic index ( $C_i$ ) over the period of 26 years were found to be 838.4 mm, 1483.1 mm and 0.58, respectively.
2. The monthly value of effective rainfall was found lowest (9.3 mm) in the month of December and highest (161 mm) in the month of July; whereas the monthly value of  $ET_o$  was found lowest (100.5 mm) in the month of December and highest (175.1 mm) in the month of May. The monthly value of climatic index ( $C_i$ ) was found lowest (0.10) in the month of January and highest (1.58) in the month of July. The trend of monthly value of  $C_i$  was observed similar to that of effective rainfall during the whole year. The value of climatic index was found in its peak stage between 15<sup>th</sup> July to 15<sup>th</sup> August.
3. The value of  $K_{cini}$  was found minimum (0.04) in the month of February, and maximum (1.04) in the month of August followed by July (1.03). The value of 80% dependable  $C_i$  was found minimum (0) in the month of December, January and February, and maximum (1.3) in the month of July and August.

The value of  $C_i$  was found nearly equal to the corresponding value of  $K_{cini}$  during the month of June and more in the month of July, August and September. It indicates that crops can be taken up suitably from 3<sup>rd</sup> week / 16<sup>th</sup> June onwards and may be sown up to the end of 2<sup>nd</sup> week of September with sufficient  $K_{cini}$  values.

4. Keeping in view the local cropping practices and existing climatic conditions, the total cropping period was determined as 255 days commencing from mid June to end of December. Crops with more water demand having higher  $K_{cdev}$ ,  $K_{cmid}$  and  $K_{cend}$  values, were proposed from mid June onwards to till end of September, and crops with less water demand having lower  $K_{cdev}$ ,  $K_{cmid}$  and  $K_{cend}$  values, were proposed from October onwards. No crop was proposed in the month of March, April and May due to lack of assured irrigation facility as most of the water sources becomes dry.
5. As per the water balance, climatic suitability and local cropping practices, a standard crop schedule was prepared and based on it as many as 75 possible cropping sequences including an option of a perennial grass cover in upland areas were proposed for the district.
6. The present status of investment (cost involved towards seeds, farm yard manure (FYM), fertilizer, pesticide/ plant protection and wages) was estimated to be ₹ 80205.22 lakhs (including cost towards wages of ₹ 38074.6 lakhs). The gross and net return from agriculture in Koraput district was found to be ₹ 136722.98 lakhs and ₹ 56517.76 lakhs.
7. Under the existing cropping practice, the average investment, gross return and net return per hectare from agriculture in the district was found to be ₹ 22569, ₹ 38473 and ₹ 15904, respectively. It reveals that the benefit cost ratio (BCR) from agriculture in the district is 1.7 though it has enough potential and scope for further growth.
8. It is observed that the existing cost and net return from agriculture is much lower in comparison to standard package of practices of cultivation which is

not followed. It was observed that cultivation of ginger involved highest investment of ₹ 229500 per ha (including ₹ 132000 in terms of inputs other than wages), where as horse gram needed lowest investment of ₹ 22590 (including ₹ 12840 in terms of inputs other than wages) per ha. The net return was highest (₹ 220500) in case of ginger and lowest (₹ 3100) in case of perennial grass cover (hybrid napier).

9. Basing on standard package of practices, the cost of cultivation was found highest (₹ 229500) in case of cropping sequence ginger–fallow and lowest (₹ 23790) in case of both black gram-fallow-fallow and green gram-fallow. The net return is highest (₹ 329800) in case of cropping sequence sweet potato-fallow-vegetables and lowest (₹ 3100) in case of perennial grass cover.
10. As per the guidelines of recommended dietary allowance (RDA), the annual food requirement in terms of gross production requirement for the projected population of 1612255 in 2021 was estimated to be 443534, 98490, 75792 and 323660 (including sweet potato of 22656) tonnes of cereals, pulses, oilseeds and vegetables & tubers.
11. Under the prevailing agricultural scenario, soil loss to the extent of 13333.35 thousand tonnes was found annually at the rate of 43.86 t ha<sup>-1</sup> yr<sup>-1</sup> from the agricultural fields of the Koraput district. Single and double cropped agricultural fields contributed 68.8% and 20.7% of total soil loss at the rate of 44.23 and 38.92 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively. Maximum rate of soil loss (98.38 t ha<sup>-1</sup> yr<sup>-1</sup>) was found in case of fallow land sharing 10.5% total soil loss. Under single cropped lands, maximum (68.53 t ha<sup>-1</sup> yr<sup>-1</sup>) and minimum (26.85 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of mung-fallow-fallow and jowar-fallow-fallow. Under double cropped lands, maximum (53.71 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of both maize-fallow-*kulthi* and maize-fallow-maize, and minimum (24.76 t ha<sup>-1</sup> yr<sup>-1</sup>) soil loss was obtained in case of small millets-fallow-other pulses. From double cropped lands, 70% less soil loss was observed when compared to single cropped lands of the district.

12. Under suggested cropping pattern, among single cropped area, maximum ( $59.24 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) and minimum ( $28.05 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) soil loss was observed in case of black gram-fallow-fallow and potato-fallow-fallow. Among double cropped area, maximum ( $55.90 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) and minimum ( $17.98 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) soil loss was observed in case of black gram-fallow-mustard and ragi-wheat - fallow. The average soil loss from single cropped land and double cropped land was found to be  $40.50$  and  $36.33 \text{ t ha}^{-1} \text{ yr}^{-1}$ , respectively. Lowest soil loss of  $4.27 \text{ t ha}^{-1} \text{ yr}^{-1}$  was found in case of perennial grass cover (hybrid napier).
13. Water resource potential in terms of water availability in *kharif* and *rabi* season was determined. The total water available during *kharif* was estimated to be  $160086.4 \text{ ha-m}$  (at 80% probability level) and  $187598.4 \text{ ha-m}$  (at 60% probability level). For the *rabi* season, it was estimated to be  $45007.2 \text{ ha-m}$  (at 80% probability level) and  $65578.88 \text{ ha-m}$  (at 60% probability level).
14. As per the suggestions given by the model, the food crops to be taken up in  $299000 \text{ ha}$  and perennial grass cover in  $5000 \text{ ha}$ , with a cropping intensity of 193% (100% in *kharif*, 87% in pre *rabi* and 6% in *rabi*). It was also suggested by the model that a net return of ₹ 148216.90 lakhs can be obtained from agriculture with the investment of ₹ 201053 lakhs. Soil loss to the extent of 7978.24 thousand tonnes was estimated by the model to occur from the cultivable area of  $304000 \text{ ha}$  under different cropping sequences. The model suggested highest area of  $118438 \text{ ha}$  under cropping sequence ragi-horse gram-fallow and lowest area of  $1132.8 \text{ ha}$  under cropping sequence sweet potato-fallow-potato for the proposed cropping pattern.
15. Under proposed sequence suggested by model, the rate of soil loss was decreased by 40% and the rate of net return was increased by 131%.
16. The optimal solution suggested by the models will be much more helpful for efficient and judicious use of land and water resources of Koraput district, which can not only reduce level of land degradation by minimizing soil loss, but also minimize the investment and maximize the net return.

# SUGGESTIONS FOR FUTURE WORK

---

Optimal resource use planning is essential to reduce risk in agriculture. It can increase production, economic return, minimize input and labour use, and decrease soil loss considering the existing constraints by effective and economic utilization of resources. Under the present study, optimisation of land and water use has been done using linear goal programming model and there is a wide scope for further research in the relevant field. Some suggestions for future work are as below:

1. In the present study, only limited goals and constraints are considered for optimisation. There is ample scope for considering more goals and constraints to get the suitable solution.
2. Planning may be tried by keeping more water availability through more water resource creation.
3. Optimisation may be attempted by randomly changing the priority orders of goals to get the best solution.
4. The present findings may be validated in field situation by its implementation in a small scale watershed taking the proportionate allocation of area to different crop sequences.
5. A comparison study on optimisation can be done using other available optimising techniques/ models.
6. In the present study, USLE is used for soil loss estimation. Other available soil loss estimation models may be tried for better comparison.
7. Modern tools like geographical information system (GIS) and remote sensing (RS) may be used in combination with optimizing models to have precision in planning.

## REFERENCES

---

- Agrawal, R.C., Rao, D. and Singh, M. 1974. Potential for farm increase on dry lands. *Eastern Economist*, **62**(1): 6-9.
- Ahmad, I. and Verma, M. K. 2013. Application of USLE Model & GIS in Estimation of Soil Erosion for Tandula Reservoir. *International Journal of Emerging Technology and Advanced Engineering*, **3**(4): 570-576.
- Ahmad, M., Suripin, M. N. A. and Marutani, T. 2000. Application of geographic information system (GIS-IDRISI) for assessing land use risks on sediment yields. *Journal of the Faculty of Agriculture, Kyushu University*, **44**(3-4): 463-471.
- Ahmadi, S. H. and Fooladmand, H. R. 2008. Spatially distributed monthly reference evapotranspiration derived from the calibration of Thornthwaite equation: a case study, South of Iran. *Irrigation Science*, **26**: 303–312.
- Ali, S., Prasad, S. N., Singh, K. D. and Samra, J. S. 2001. Evaluation of some parameters of USLE for various cropping management practices in south-eastern Rajasthan. *Indian Journal of Soil Conservation*, **29**(3): 235-240.
- Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements-FAO Irrigation and Drainage Paper 56.
- Aris, B., Ahmad, M. H., Shiong, K. B., Ali, M. B., Harun, J. & Tasir, Z. 2006. Learning “Goal Programming” Using an Interactive Multimedia Courseware: Design Factors and Students’ Preferences. *Malaysian Online Journal of Instructional Technology (MOJIT)*, **3**(1): 85-95.
- Babu, R., Gupta, S. K., Tezwani, K. G. and Rawat, N. S. 1969. Correlation of daily, monthly and annual rainfall with energy product (Presented at the 7th annual meeting, Indian Society of Agricultural Engineering, Pantnagar (UP).
- Barrett, S. 1991. Optimal soil conservation and the reform of agricultural pricing policies, *Journal of Development Economics*, **36**: 167-187.

- Bhalla, G. S., Peter, H. and John, K. 1999. ‘Prospects for India’s cereal supply and demand to 2020. In IFPRI 2020 vision brief no. 63.
- Bhatia, K. S. and Chaudhary, H. P. 1977. Runoff and erosion losses and crop yields from slopy and eroded alluvial soils of Uttar Pradesh in relation to contour farming and fertilization. *Soil Conservation Digest*, **5**(2): 16-22.
- Borton, J. and Nicholds, N. 1994. Drought and Famine (2nd Edition). Disaster Management Training Programme. UNDP-DHA. pp.17.
- Bouyoucos, G. J. 1935. The clay ratio as a criterion of susceptibility of soils to erosion. *Journal of American Society of Agronomy*, **100**: 293–307.
- Brandon, C., Hommann, K. and Kishore, N. M. 1995. The cost of inaction: Valuing the economy wide cost of environmental degradation in India. In Proceedings of the UNU Conference on the sustainable future of the global system, Tokyo, 16-18 Oct, 1995.
- Brath, A., Castellarin, A. and Montanari, A. 2002. Assessing the effects of land-use changes on annual average soil losses. *Hydrology and Earth Systems Sciences*, **6**: 255–65.
- Browning, G. M., Parish, C. L. and Glass, J. A. 1947. A method for determining the use and limitation of rotation and conservation practices in control of soil erosion in Iowa. Proceedings of Soil Science Society of America, **23**: 249-264.
- Bryan, R. B. 1968. The development, use and efficiency of indices of soil erodibility. *Geoderma* - Elsevier Publishing Company, Amsterdam (Netherland), **2**: 5-26.
- Cancela, J. J., Cuesta, T. S., Neira, X. X. and Pereira, L. S. 2006. Modelling for improved irrigation water management in a temperate region of Northern Spain. *Bio systems Engineering*, **94**(1): 151-163.
- Chang, Y. L. 1998. WinQSB: Decision support software for MS/OM, Ed. John Wiley & Sons, Inc., New York.
- Charnes, A. and Cooper, W. W. 1961. Management models and industrial applications of Linear Programming. Vol. I and II. John Wiley and sons, New York.

- Chen, S. K., Liu, C. W. and Chen, Y. R. 2012. Assessing soil erosion in a terraced paddy field using experimental measurements and universal soil loss equation. *Catena*, **95**: 131–141.
- Chorley, R. J. 1959. The geomorphic significance of some Oxford soils. *American Journal of Science*, **257**: 503-15.
- Cohen, M. J., Shepherd, K. D. & Walsh, M. G. 2005. Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed. *Geoderma*, **124**: 235–252.
- Cook, H. L. 1936. The nature and controlling variables of the water erosion process. *Soil Science Society of America, Proceedings*, **1**: 60-64.
- CSWCRTI 1982. Twenty five years research on soil and water conservation in southern hill high rainfall regions. Central Soil and Water Conservation Research and Training Institute, Research Centre, Udhagamandalam.
- Dangler, E. W. and El Swaify, S. A. 1976. Erosion of selected Hawaii soils by simulated rainfall. *Soil Science Society of America*, **40**(5): 769-773.
- Dangler, E. W., EL Swaify, S. A., Ahuja, L. R. and Barnett, A. P. 1976. Erodibility of Selected Hawaiian Soils by Rainfall Simulation. ARS - W, USDA, Publication 35.
- Dass, A., Sudhishri, S., Patnaik, U. S. and Lenka, N. K. 2009. Effect of agronomic management on watershed productivity, impact indices, crop diversification and soil fertility in Eastern Ghats of Orissa. *Journal of Soil and Water Conservation, India*, **8**(3): 34-42.
- Dastane, N. G. 1978. Effective rainfall in irrigated agriculture. FAO publication No.25, Rome, Italy.
- Dawoud, S. D. Z. 2014. Economic optimal allocation of irrigation water in Egypt. *Journal of Development and Agricultural Economics*, **6**(12): 472-480.
- De Fraiture, C. and Wichelns, D. 2010. Satisfying future water demands for agriculture. *Agricultural Water Management*, **97**(4): 502-511.

- Desmet, P. J. J. and Gobers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of Soil and Water Conservation*, **51**(5): 427-433.
- District Statistical Hand Book 2009 Koraput. Directorate of Economics and Statistics, Odisha, Bhubaneswar.
- Dogra, P., Sharda, V. N., Ojasvi, P. R., Prasher, S. O. and Patel, R. M. 2011. Optimal allocation of water for enhanced food production in a mid Himalayan watershed. *Indian Journal of Soil Conservation*, **39**(3): 251-262.
- Doorenbos, J. and Pruitt, W. O. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24.
- Duan, Q., Zi, S. and Wu, B. 2006. The grey correlation changes between rainfall factors and runoff and soil erosion from a watershed in the Central Yunnan Province after conservation implementation. *Journal of Yunnan Agricultural University*, **21**: 336-340.
- Earles, R. 2005. Sustainable agriculture: An introduction. National Center for Appropriate Technology (on the Web at: [www.attra.ncat.org/attra-pub/sustagintro.html](http://www.attra.ncat.org/attra-pub/sustagintro.html)). IP043. pp.8.
- Eduardo, E. M., David, A. W. and Petri, K. E. P. 2011. Estimating reference evapotranspiration using remote sensing and empirical models in a region with limited ground data availability in Kenya. *Applied Geography*, **31**: 251-258.
- El Swaify, S. A. 1977. Susceptibility of certain tropical soils to erosion by water in relation to structural and hydrological parameters. In: Soil Erosion: Prediction and Control, *Soil Conservation Society of America*, Anakeny, Iowa. pp. 105–114.
- Eswaran, H., Lal, R. and Reich, P. F. 2001. Land degradation: an overview. In: Bridges, E. M., I. D. Hannam, L. R. Oldeman, F. W. T. Pening de Vries, S. J. Scherr, and S. Sompatpanit (eds.). Responses to Land Degradation. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

- Flinn, J. C. and Musgave, W. F. 1967. Development and analysis of input-output relation for irrigation water. *Australian Journal Agricultural Economics*, **11**: 1-19.
- Folly, A. 1997. Land use planning to minimize soil erosion – a case study in upper east region in Ghana. Institute of Geography, University of Copenhagen, Copenhagen, Denmark.
- Fooladmand, H. R. and Ahmadi, S. H. 2009. Monthly spatial calibration of Blaney–Criddle equation for calculating monthly ETo in south of Iran. *Irrigation Drainage*, **58**: 234–245.
- Ganng, A. W. 1986. Statistical analysis of climatological data for irrigation scheduling. M.Sc. Thesis, Catholic University Leuven, Belgium.
- Gavilan, P., Lorite I. J., Tornero, S. and Berengena, J. 2006. Regional calibration of Hargreaves equation for estimation of reference ET in a semiarid environment. *Agricultural Water Management*, **81**: 257–281.
- Ghosh, S. P. and Babu, R. 1977. Effect of dominant fruit crops and their management on runoff and soil loss on sloping land. *Soil Conservation Digest*, **5(I)**: 15 - 18.
- Gopalan, C., Ramasastri, B. V. and Balasubramanian, S. C. 1996. Nutritive Value of Indian Foods, National Institute of Nutrition, Indian Council of Medical Research, Hyderabad.
- Govindaraj, G, Basu, M. S. and Barik, N. C. 2008. Impact of Grain Legume (Groundnut) on Energy and Nutritional Levels of Tribal Farm Households in Koraput (Orissa). *Agricultural Economics Research Review*, **21**: 54-59.
- Government of India. 2004. India :Vision 2020 : The Report Plus Background Papers. Planning Commission, New Delhi.
- Government of India. 2009. State of Environment Report. India-2009. Environmental Information System (ENVIS), Ministry of Environment & Forests, New Delhi.
- Government of Odisha. 1988. History of Upper Kolab Project, Irrigation and Power Department, Bhubaneswar.
- Government of Odisha. 2012. Odisha Agricultural Statistics 2010-11, Agriculture Department, Bhubaneswar.

- Gregory, J. M. 1982. Soil covers prediction with various amount and types of crop residue. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **25**: 1333--1337.
- Guglani, P. L. and Sirohi, A. S. 1972. Production pattern in Union Territory of Delhi - A case study. *Indian Journal of Agricultural Economics*, **27**(4): 147-157.
- Gupta, A. P., Harboe, R. and Tabucanon, M. T. 2000. Fuzzy multiple-criteria decision making for crop area planning in Narmada river basin. *Agricultural Systems*, **63**: 1-18.
- Gupta, R. N. 2010. Suggested modification in the USLE-K variables for estimating soil loss in the Gangetic basin of India. *Indian Journal Soil Conservation*, **38** (1): 10-15.
- Hadley, G. 1962. *Linear Programming*. Oxford and IBH publishing Co., New Delhi, India.
- Haque, A. M. 2005. Estimating monthly and yearly dependable rainfall for different climatic zones of the world. Songklanakarin. *Journal of Science Technology*, **27**(3): 667-673.
- Hassan, I., Muhammad, A. R., Khan, A. I. and Ilahi, R. 2005. Use of linear programming model to determine the optimum cropping pattern, production and income level: a case study from Dera ghazi khan division. *Journal of Agricultural and Social Science*, **V1**(1): 32-34.
- Heady, E. G., Madsen, H. C., Nicol, K. J. and Hargrove, S. H. 1973. Agricultural water allocation, land use and policy. *Journal of Hydraulics Division, American Society of Civil Engineers (ASCE)*, **99**(10): 1795-1812.
- Hernandez, B. 1990. Optimal resource allocation for development planning and policy formation in the Ocoa watershed, Dominican Republic. *Dissertation abstracts, International*, **50**(12): 4036.
- Hershfield, D. M. 1964. Effective rainfall and irrigation water requirements. *Journal of Irrigation and Drainage Division, American Society of Civil Engineers (ASCE)*, **90**(IR 2): 3920: 33-47.
- Hinderson, J. M. 1959. The utilization of agricultural land: A theoretical and empirical inquiry. *Review of Economics and Statistics*, **XLI** (3): 242 - 260.

- Honghai, Qi. and Altinakar, M. S. 2013. Integrated watershed management with multi-objective land use optimizations under uncertainty, *Journal of Irrigation and Drainage Engineering, American Society of Civil Engineers (ASCE)*, **139** (3): 239-245.
- Hudson, N. W. 1971. Soil Conservation. Cornell Univ. Press Ithaca, New York.
- Hudson, N. W. and Jackson, D. C. 1959. Result achieved in the measurement of erosion and runoff in south Rhodesia. Third Inter - African Soils Conference Dalaba, **2**: 575-595.
- Humphreys, G. S. 1984. The environment and soils of Chimbu Province, Papua, New Guinea, with particular reference to soil erosion. Deptt of Primary Industries, Research Bull. **2**: 575-584.
- Ian Sample 2007. "Global food crisis looms as climate change and population growth strip fertile land". The Guardian. Retrieved 2008-07-23.
- ICAR 2011. Vision 2030. Indian Council of Agricultural Research (ICAR), New Delhi, India.
- ICMR 1978. Recommended dietary intakes for Indians. Indian Council of Medical Research, New Delhi.
- ICMR 1990. Report of expert group on nutrient requirements and recommended dietary allowances for Indians, Indian Council of Medical Research, New Delhi.
- Ignizio, J. P. 1976. Goal programming and extensions. Lexington Books, D. C. Heath and Company, Massachusetts, Canada, pp 1-114.
- Igwe, K. C., Onyenweaku, C. E. 2013. A Linear Programming Approach to Food Crops and Livestock Enterprises Planning in Aba Agricultural Zone of Abia State, Nigeria. *American Journal of Experimental Agriculture*. **3**(2):412-431.
- Irmak, S., Howel, T. A., Allen, R. G., Payero, J. O. and Martin, D. L. 2005. Standardized ASCE Penman-monteith: Impact of sum of hourly vs. 24 hour time step computation at reference weather station sites.
- Jebari, S., Berndtsson, R., Olsson, J. and Bahri, A. 2012. Soil erosion estimation based on rainfall disaggregation. *Journal of Hydrology*, 436–437: 102–110.

- Jensen, M. E., Burman, R. D., and Allen, R. G. 1990. Evapotranspiration and irrigation water requirements: a manual, *American Society of Civil Engineers (ASCE)*, New York.
- Jha, M. M. and Singh, R. 2008. Crop and irrigation planning of Kosi irrigation system, *Journal of Indian Water Resources Society*, **28**(3): 30-38.
- Jharjharia, D., Barma, S. D. and Agrawal, G. 2004. Comparison of pan evaporation based reference evaporation model with Penman-Monteith FAO 56 model. *Journal of Agricultural Engineering*, **41**(3): 46-52.
- Kaura, B., Sidhub, R. S. and Vattaa, K. 2010. Optimal Crop Plans for Sustainable Water Use in Punjab. *Agricultural Economics Research Review*, **23**: 273-284.
- Kelvin, K. K. K., Darrien, Y. S. M. and Chiu, P. C. 2013. Evaluation of C and P Factors in Universal Soil Loss Equation on Trapping Sediment: Case Study of Santubong River. *Journal of Water Resource and Protection*, **5**: 1149-1154.
- Khorsandi, N., Mahdian, M. H., Pazira, E., Nikkami, D. 2010. Comparison of rainfall erosivity indices in runoff -sediment plots in northern Iran. *World Applied Sciences Journal*, **10**: 975-979.
- Kinnell, P. I. A. and Cummings, D. 1993. Soil / slope gradient interactions in erosion by raindrop-impacted flow. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **36** (2): 381-387.
- Kinnell, P. I. A. 2007. Runoff dependent erosivity and slope length factors suitable for modeling annual erosion using the Universal Soil Loss Equation. *Hydrological Sciences*, **21**: 2681-2689.
- Kirkby, M. J. 1969. Infiltration through flow and overland flow. In *Water, Earth and Man* (R. J. Chorley, ed), Mothuen, UK. pp 215 – 228.
- Kitahara, H., Okura, Y., Sammor, T. and Kawanami, A. 2000. Application of Universal Soil Loss Equation (USLE) to Mountainous Forests in Japan. *Journal of Forest Research*, **5**: 231-236.
- KSLUB 2001. Perspective Land Use Plan for Karnataka 2025. Karnataka State Land Use Board, Bangalore.

- Kurothe, R. S., Challa, O., Samra, J. S. and Velayutham, M. 2001. Assessment of soil erosion in Maharashtra. *Indian Journal of Soil Conservation*, **29**(2): 133-137.
- Laflen, J. M. 1983. Tillage and residue effect on erosion from cropland. In: D. A. De Coursey, ed. Natural Resources Modeling Symposium. USDA-Agricultural Research Service, Pingree Park, CO. pp. 438-441.
- Laflen, J. M., Foster, G. R., and Onstad, C. A. 1985. Simulation of individual-storm soil loss for modeling impact of erosion on crop productivity. In: Soil erosion and conservation, Proc. International Conference on Soil Erosion and Conservation, Honolulu, HI. Jan. 16-22, 1983. Soil Conservation Society of America, Ankeny, IA. pp. 285-295.
- Lal, G., Malakar, A. R., Faroda, A. S., Joshi, N. I., Kathju, S. and Amal, K. 1999. Land use planning for sustainable development of arid ecosystem using remote sensing. Proceedings of symposium held in India, March, 1999, pp 35-44.
- Lal, R. 1976. Soil erosion on alfisols in Western Nigeria. Effects of rainfall characteristics. *Geoderma*, **16**(5): 389 – 40.
- Lal, R. 1994. Soil Erosion Research Methods. Soil and Water Conservation Society (Ankeny), 3rd ed. St. Lucie Press, Delray Beach.
- Latinopoulos, D. and Mylopoulos, Y. 2005. Optimal allocation of land and water resources in irrigated agriculture by means of goal programming application: application in Loudias river basin. *Global NEST Journal*, **7**(3): 264-273.
- Laws, J. O. and Parsons, D. A. 1943. The relationship of raindrop size to intensity. *Transactions of the American Geophysics Union*, **24**: 452-460.
- Lee, S. M. and Shim, J. 1986. Micro Management Science: Microcomputer Applications of Management Science. Dubuque, Iowa Wm. C. Brown Publishers. pp. 169-185.
- Lin, C. C. and Lin, W. Y. 2004. Investigation the magnitudes of erosion reduction for paddy field. Determining Paddy Irrigation Multifunctionality Workshop, Taipei, (In Chinese). pp. 37–48.
- Lin, C. Y., Lin, W. T. and Chou, W. C. 2002. Soil erosion prediction and sediment yield estimation: the Taiwan experience. *Soil and Tillage Research*, **68** (2): 143-152.

- Liu, B. Y., Nearing, M. A. and Risse, L. M. 1994. Slope gradient effects on soil loss for steep slopes. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **37**(6): 1835-1840.
- Liu, S., Lazaros, G. P., and Gikas, P. 2012. Integrated Management of Non-conventional Water Resources in Anhydrous Islands. *Water Resource Management*, **26**: 359–375.
- Liu, Y. and Luo, Y. 2010. A consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain. *Agricultural Water Management*, **97**(1): 31-40.
- Loureiro, N. and Coutinho, M. 2001. A new procedure to estimate the RUSLE EI<sub>30</sub> index based on monthly rainfall data and applied to the Algarve region, Portugal. *Journal of Hydrology*, **250**: 12-18.
- Maina, M. M., Amin, M. S. M., Aimrun, W. and Asha, T. S. 2012. Evaluation of different ETo calculation methods: A Case study in Kano state, Nigeria. *Philippine Agricultural Scientist*. **95**(4): 378–382.
- Majeke, F., Mubvuma, M. T., Makaza, K. and Mutambara, J. 2013. Optimum Combination of Crop Farm Activities: Application of a Linear Programming Model to a Rural Farmer in Zimbabwe. *Greener Journal of Economics and Accountancy*, **2**(2): 58-61.
- Malek, E. and Bingham, G. E. 1993. Comparison of the Bowen ratio-energy balance and the water balance methods for the measurement of evapotranspiration. *Journal of Hydrology*, **146**: 209-220.
- Manyiwa, T. and Dikinya, O. 2013. Using universal soil loss equation and soil erodibility factor to assess soil erosion in Tshesebe village, north east Botswana. *African Journal of Agricultural Research*, **8**(30): 4170-4178.
- Martinez, M. A., Vicente, M. L., Serrano, S. M. V. and Begueria, S. 2009. Mapping rainfall erosivity at a regional scale: a comparison of interpolation methods in the Ebro Basin (NE Spain). *Hydrology and Earth System Sciences Discussions*, **6**: 417-453.

- Massimo, B. and Maurizio, B. 2006. A combined goal programming AHP approach to maintenance selection problem. *Reliability Engineering and System Safety*, **91**(7): 839-848.
- Mc Connell, K. E. 1983. An econometric model of soil conservation. *American Journal of Agricultural Economics*, **65**: 83-89.
- Mc Cool, D. K., Foster, G. R., Mutchler, C. K. and Meyer, L. D. 1989. Revised slope length factor for the Universal Soil Loss Equation. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **32**(5): 1571-1576.
- Mc Cool, D. K., George, G. O., Freckleton, M., Douglas Jr., C. L. and Papendick, R. I. 1993. Topographic effect on erosion from cropland in the Northwestern Wheat region, *Transactions of the American Society of Agricultural Engineers (ASAE)*, **36**(93): 771-775.
- Mc Issac, G. F., Mitchell, J. K. and Hirschi, M. C. 1987. Slope steepness effects on soil loss from distributed lands. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **34**(4): 1005-1013.
- Meyer, L. D. 1960. Use of the rainulator for runoff plot research. *Soil Science Society of America, Proceedings*, **24**: 319-327.
- Meyer, L. D., Johnson, C. B., and Foster, G. R. 1972. Stone and woodchip mulches for erosion control on construction sites. *Journal of Soil and Water Conservation*, **27**(6): 264-269.
- Miller, A. and Thompson, J. C. 1970. Elements of meteorology. Ohio, Merrill Pub. Co.
- Miranowski, J. A. 1984. Impacts of productivity loss on crop production and management in a dynamic economic model. *American Journal of Agricultural Economics*, **66**(1): 61-71.
- Mohalle, J. P. 1989. Optimal land use for soil conservation in Maharashtra State, India. M.S.Thesis, Silsoi College, Bedford, U.K.
- Mohseni, S. M., Farzanegan, M., Koopae, M. and Kholghi, M. 2003. Optimum utilization pattern of watershed resources using goal programming, *Iranian Journal of Natural Resources*, **56**(1-2): 3-15.

- Mtakwa, P. W., Lal, R. and Sharma, R. B. 1987. An evaluation of the Universal Soil Loss Equation and field techniques for assessing soil erosion on a tropical alfisol in Western Nigeria. *Hydrology Processes*, **1**(2): 199-209.
- Mughogho. M. M. 1998. Evaluation of the RUSLE and the SLEMSA under Malawai conditions: A case study of Kamundi catchment near Mangochi, University of Malawi. On the web at <http://ag.arizona.edu/OALS/malawi/Malawi.html>.
- Musgrave, G. W. 1947. The quantitative evaluation of factors in water erosion. A first approximation. *Journal of Soil and Water Conservation*, **2**: 133-138.
- Mythili, G. 2003. Land degradation due to agriculture. In Envisage – the newsletter of EMCBTAP-ENVIS Environmental economics node, Madras school of economics, Volume 3, July 2003.
- Nagdeve, D. A. 2002. Environment and health in India. Paper presented at the IUSSP Regional Population Conference on Southeast Asia's Population in a Changing Asian Context at Bangkok, Thailand, 10-13 June 2002.
- Naik, B. S., Jakhar, P. and Madhu, M. 2013. Status of tribal agriculture in Odisha perspective. *Journal of soil and water conservation, India*, **12**(4): 355-361.
- Narain, P., Verma, B. and Rao, D. H. 1980. Prediction of rainfall erosion potential and some parameters of USLE at Kota, Rajsthan (Presented at the National Symposium on soil Conservation and Water management at Dehradun during March, 1980).
- Narain, P., Khybri, M. L., Tomar, H. P. S. and Sindhwal, N. S. 1994. Estimation off runoff, soil loss and USLE parameters for Doon Valley. *Indian Journal of Soil Conservation*, **22**(3): 1-9.
- National Land Use Policy 1988. Ministry of Agriculture, Government of India, New Delhi.
- Narayan D. V. V. and Babu, R. 1983. Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering, American Society of Agricultural Engineers (ASAE)*, **109**: 419–431.
- Nema, J. P., Verma, B. and Patel, A .P. 1978. Predicting Universal Soil Loss equation parameters. *Indian Journal of Soil Conservation*, **6**(2): 75-79.

- NIN 1998. Report of working group on dietary guidelines for Indians, National Institute of Nutrition, Hyderabad.
- Nikkami, D., Elektorowicz, M. and Mehuys, G. R. 2002. Optimizing the management of soil erosion. *Water Quality Research Journal of Canada*, **37**: 577-586.
- Nikkami, D., Shabani, M. and Ahmadi, M. 2009. Land use scenarios and optimization in a watershed. *Journal of Applied Sciences*, **9**(2): 287-295.
- Oldeman, L. R. 1997. Soil degradation: A threat to food security? Paper presented at the International conference on time ecology. Time for soil culture - temporal perspectives on sustainable use of soil. 6 - 9 April, Turtzing, Germany.
- Panda, S. N, Kushal, M. P. and Khepar, S. D. 1983. Irrigation deterministic linear programming. *Journal of Agricultural Engineering, Indian Society of Agricultural Engineers (ISAE)*, **21**(3): 37-47.
- Panda, S. S. and Andrianasolo, H. 2000. Watershed soil erodibility (K) factor and slope length and gradient (LS) factor determination using satellite images, topographic map, and GIS Technique. paper presented at the North Central Intersectional Meeting of ASAE. September 29-30, 2000. (Paper No RRV00202 ASAE).
- Panigrahi, D. 2007. Water and land use optimisation in hill plateaus of Orissa. Unpublished Ph.D. Thesis. Utkal University, Bhubaneswar.
- Panigrahi, D., Acharya, M., and Senapati, P. C. (2009). Estimation of soil loss from croplands of Kandhamal Plateau in Odisha. *Indian Journal of Dryland Agricultural Research and Development*, **24**(1): 52-56.
- Panigrahi, D., Mohanty, P. K., Acharya, M. and Senapati, P. C. 2010. Optimal utilization of natural resources for agricultural sustainability in rainfed hill plateaus of Odisha. *Agricultural Water Management*, **97**(7): 1006-1016.
- Pasak, V. 1967. Factors underlying the wind erosion of soil. Vedecke Prace VUM (Czeck).
- Patnaik, U. S., Choudhury, P. R., Sudhishri, S., Dass, A. and Paikaraya, N. K. 2004. Participatory watershed management for sustainable development in Kokriguda watershed, Koraput, Odisha, CSWCRTI, Research Centre, Sunabeda, Koraput, Odisha. 123p.

- Paul, J. C., Mishra, S. B. and Dhal, G. C. 2004. Multi objective programming approach for watershed planning – A case study. *Journal of Soil and Water Conservation, India*, **3**(1&2): 73-79.
- Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London, Series A **193**: 120-146.
- Potdar, S. S., Srivastava, R., Nagaraju, M. S. S., Prasad, J., and Saxena, R. K. 2003. Mapping of erosional soil loss in Nanda-Khairi watershed of Nagpur district of Maharashtra using remotely sensed data and GIS techniques. *Agropedology*, **13**(2): 10-18.
- Pradhan, B., Chaudhari, A., Adinarayana, J. and Buchroithner, M. F. 2012. Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: a case study at Penang Island, Malaysia. *Environmental Monitoring and Assessment*, **184**: 715–727.
- Prasannakumar, V., Vijith, H., Geetha, N. and Shiny, R. 2011. Regional scale erosion assessment of a sub-tropical highland segment in the Western Ghats of Kerala, south India. *Water Resource Management*, **25**: 3715–3727.
- Prenger, J. J., Fynn, R. P. and Hansen, R. C. 2002. A comparison of four evapotranspiration models in a green house environment. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **45**(6): 1779-1788.
- Raju, K. S. and Kumar, D. N. 1999. Multicriterion decision making in irrigation planning. *Agricultural Systems*, **62**: 117-129.
- Rao, Y. P. 1981. Evaluation of cropping management factor in universal soil Loss equation under natural rainfall condition of Kharagpur, India. Proceedings of Southeast Asian regional symposium on problems of soil erosion and sedimentation, Asian Institute of Technology, Bangkok, **5**: 241-254.
- Renard, K. G., Foster, G. R., Weesies, G. A., Mc Cool, D. K. and Yoder, D. C. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U. S. Department of Agriculture, Agriculture Handbook No. 703, pp. 404.

- Rogers, P. and Smith, D. V. 1970. The integrated use of ground and surface water in irrigation project planning. *American Journal of Agricultural Economics*, **52**: 13-24.
- Rose, E. J. 1977a. Application of the universal soil loss equation in West Africa. In: Conservation and Soil Management in the Humid Tropics (DJ. Greenland and R. Lal, eds), Wiley, UK, pp. 177-187.
- Rose, E. J. 1977b. Use of the universal soil loss equation to predict erosion in West Africa. In: Soil erosion - prediction and control (G.R. Foster, ed). SCSA Special Publication, 21, Iowa, pp. 60-74.
- Rosenberg, N. J. 1974. Microclimate-The Biological Environment. Wiley. (Interscience), New York.
- Sadeghi, S. H. R., Jalili, K. and Nikkami, D. 2008. Land use optimization in watershed scale. *Land Use Policy*, **26**(2): 186-193.
- Sahoo, A. K., Sarkar, D., Sah, K. D., Maji, A. K, and Dhyani, B. L., 2005. Soil erosion of Odisha. NBSS Publ. No.126, pp. 48.
- Sahoo, B., Lohani, A. K. and Sahu, R. 2006. Fuzzy multi-objective and linear programming based management models for optimal land-water-crop system planning. *Water Resources Management*, **20**: 931–948.
- Sahoo, D. C., Sharda, V. N., Jayakumar, M., Tripathi, K. P., Padmanabhan, M. V., Raghunath, B., Mohanraj, R. and Chandran, B. 2006. Hydrology of small watersheds in high hills of Nilgiris. *Indian Journal of Soil Conservation*, **34**(2): 97-101.
- Savva, A. P. and Frenken, K. 2002. Crop water requirements and irrigation scheduling. In: Irrigation Manual, Module 4. FAO Sub-Regional Office for East and Southern Africa, Harare, p. 57.
- Schiettecatte, W., Gabriels, D., Cornelis, W. M. and Hofman, G. 2008. Enrichment of organic carbon in sediment transport by interrill and rill erosion processes. *Soil Science Society of America Journal*, **72**: 50–55.
- Schmidt, B. L., Allmaras, R. R., Mannering, J. V. and Papendick, R. I. 1982. Determinants of Soil Loss Tolerance. ASA Special Publication No. 45, American Society of Agronomy, Madison, Wisconsin, pp. 153.

- Schwab, G. O., Fangmeier, D. D., Elliot, W. J. and Frevert, R. K. 1993. Soil and water conservation engineering, John Wiley, New York.
- Selker, J. S., Haith, D. A. and Reynolds, J. E. 1990. Calibration and Testing of a daily rainfall erosivity model. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **33**(5): 1612-1618.
- Sen, C. and Painuli, D. K. 1984. An integrated land use planning for minimizing soil erosion in the hills of Uttar Pradesh. *Indian Journal of Soil Conservation*, **12**(1): 1-4.
- Sethy, L. N., Nagesh, K. D., Panda, S. N. and Mal, B. C. 2002. Optimal crop planning and conjunctive use of water resources in a coastal river basin. *Water Resources Management*, **16**: 145–169.
- Sethy, L. N., Panda, S. N. and Nayak, M. K. 2006. Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India. *Agricultural Water Management*, **83**: 209 – 220.
- Sharifan, H. 2008. Evaluation of equations erosivity index and parameters of rainfall in Gorgan. *Journal of Agricultural Science and Natural Resources*, **14**: 207-215.
- Sharma, B. R., Rao, K. V., Vittal, K. P. R., Ramakrishna, Y. S., Amarasinghe, U. 2010. Estimating the potential of rainfed agriculture in India: prospects for water productivity improvements. *Agricultural Water Management*, **97**(1): 23–30.
- Shinde, V., Sharma, A., Tiwari, K. N. and Singh, M. 2011. Quantitative Determination of Soil Erosion and Prioritization of Micro-Watersheds Using Remote Sensing and GIS. *Journal of Indian Society Remote Sensing*, **39**(2): 181 – 192.
- Shirgure, P. S. 1998: An interactive multi-objective linear programming approach to watershed planning: a case study of the Bishunpur watershed. *Indian Journal of Soil Conservation*, **26**(3): 258-263.
- Shishiny, H. E. 1988. A goal programming for planning the development of newly reclaimed lands. *Agriculture Systems*, **26**: 245-261.
- Shri Niwas, Gupta, P. D. and Das, S. K. 1980. Runoff and soil loss studies on red charka soils at Hyderabad (Paper presented at National Symposium on Soil

Conservation and Water Management in 1980's at Dehradun, March 12 -13, 1980).

- Sikka, A. K. Selvi V., Singh, D. V., Madhu, M., Mohanraj, R., Krishanan, P., Srinivas, S., Ramesh, M. and Nair, M. 2003. Soil erosion map of Kerala State. *Indian Journal of Soil Conservation*, **31**(2): 127-130.
- Sikka, A. K., Singh, D. V., Gadekar, H., Madhu, M. 2000. Diagnostic Survey and Zonation of Eastern Ghats for Natural Resource Conservation and Management. CSWCRTI, Research Centre, Ootacamund, India, p.82.
- Singh, A. K and Singh, J. 1999. Production and benefit maximization through optimal crop planning-A case study of Mahi command. *Indian Journal of Soil Conservation*, **27**(2): 152-157.
- Singh, A. K., Sharma, A. K. and Debnath, A. C. 2002. Optimal crop planning and income maximisation in waterlogged areas of Barak valley of Assam. *Indian Journal of Soil Conservation*, **31**(3): 253-258.
- Singh, D. K, Jaiswal, C. S., Reddy, K. S., Singh, R. M., Bhandarkar, D. M. 2001. Optimum cropping pattern in a canal command area. *Agricultural Water Management*, **50**: 1-8.
- Singh, G., Babu, R. and Chandra, S. 1981. Research work done on K factor in soil loss research in India. ICAR Bull. T 12/ D - 9, Dehradun, India.
- Singh, G., Babu, R., Narain, P., Bhushan, L. S. and Abrol, I. P. 1992. Soil erosion rates in India. *Journal of Soil and Water Conservation*, **47** (1): 97-99.
- Singh, G. R. and Praksh, O. 1985. Characteristics and erodibility of some hills soils in Uttar Pradesh under varying landuse, slope and Terracing conditions. *Journal of Indian Society of Soil Science*, **33**(4): 858 - 864.
- Singh, G. S., Shastri, G. and Bhardwaj, S. P. 1990. Watershed response to conservation measures under different agro-climatic regions of India. *Indian Journal of Soil Conservation*, **18**(3): 16-22.
- Singh, N. 1996. Optimization study of agricultural benefits in Bijnor district, U.P. *Journal of Indian Water Resources Society*, **2**(4): 25-34.

- Sinha, C. P. and Charyulu, P. G. 1980. Optimal crop planning for Gomti Kalyani Doab. Proceedings of International symposium on water resource system, Roorkee.
- Smith, D. D. 1941. Interpretation of soil conservation data for field use. *Agricultural Engineering*, **22**: 173 - 175.
- Smith, D. D. and Whitt, D. M. 1947. Estimating soil losses from field areas of claypan soil. *Soil Science Society of America, Proceedings*, **12**: 485 - 490.
- Smith, D. D. and Wischmeier, W. H. 1962. Rainfall erosion. *Advances in Agronomy*, **14**: 109- 148.
- Smith, M. 1992. CROPWAT: A Computer Programme for Irrigation Planning and Management. FAO Irrigation and Drainage Paper 46.
- Srihajan, M, Somrang, A., Pramojane, P., Pradabwit, S. and Anecksamphent, C. 1984. Application of Universal Soil Loss Equation for Thailand. In: Proc. 5th ASEAN Soil Conference, OLD Bangkok, Thailand, pp. E 8.1 - 8.15
- Stanley, W. L, and Smith, R. M. 1964. A conservation definition of erosion tolerance. *Soil Science*, **97**: 183-186.
- Stott, D. E., Stroo, H. F., Elliott, L. F., Papendick, R. I. and Unger, P. W. 1990. Wheat residue loss from fields under no-till management. *Soil Science Society of America Journal*. **54**: 92-98.
- Sudhishri, S., Patnaik, U. S. and Mahapatra, N. 2003. Rainfall-runoff modelling for Upper Kolab catchment of Odisha. *Journal of Applied Hydrology*, **XVI** (3): 5-9.
- Sudhishri, S. and Patnaik U. S. 2004. Erosion index analysis for Eastern Ghat high zone of Odisha. *Indian Journal of Dry land Agricultural Research & Development*, **19**(1): 42-47.
- Sulaiman, W. H. W., Mok, C. K., Maeschalck and Jamal, T. 1983. Advances in soil and water conservation research in Malaysia. *Pertanika*, **6**: 115-132.
- Sunandar, A. D., Suhendang, E., Hendrayanto, Jayad, I. N. S. I and Marimin 2014. Land use optimization in Asahan watershed with linear programming and SWAT model. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, **18**(1): 63-78.

- Suresh, R., Das, G. and Singh, J. K. 1999. Evaluation of factor-C in Universal Soil Loss Equation of some common vegetations of Kumaon hills. *Journal of Indian Water Resources Society*, **19**(4): 22-31.
- Suresh, R., Das, G. and Singh, J. K. 2000. Soil loss potential of various orchard's activities in a watershed of Kumaon hills (UP). *Journal of Indian Water Resources Society*, **20**(2): 84-91.
- Suresh, R., Das, G. and Singh, J. K. 2001. Estimation of soil loss of various cultivated crops in Naurar watershed of Kumaon hills (U.P). *Journal of Indian Water Resources Society*, **21**(1): 24-33.
- Suresh, R., Das, G. and Singh, J. K. 2002. Estimation of soil loss generating potential of various land use activities in Naurar watershed of Ramganga catchment, UP (India). *Journal of Indian Water Resources Society*, **22**(3): 107-116.
- Tezwani, K. G., Gupta, S. K. and Mathur, H. N. 1975. Soil and Water Conservation Research. 1956 - 71. ICAR, New Delhi.
- Thakur, A. K., Singh, J. K. and Kumar, A. 2006. Optimal land use model to minimize soil loss in a Himalayan watershed. *Indian Journal of Soil Conservation*, **34**(2): 114-117.
- Thomas, A. W., Snyder, W. M. and Dillard, A. L. 1990. Prediction of monthly erosion index from daily rainfall records. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **33**(1): 118-126.
- Tzimopoulos, C., Mpalioti, B., Evangelides, C. and Yannopolous, S. T. 2011. Irrigation network planning using linear programming. Geophysical Research Abstracts. Vol. 12, EGU2010-15121, 2010 EGU General Assembly 2010.
- USDA 1967. Irrigation water requirements. Technical Release 21. The United States Department of Agriculture (USDA), Soil Conservation Service, Washington DC.
- Utomo, W. H. and Mahmud, N. 1984. The possibility of using the Universal Soil Loss Equation in mountainous areas of east Java with humus - rich andosols. In: Proc. 5th ASEAN Soil Conference, DLD, Bangkok, Thailand. E 5.1 - E 5.13.

- Van Dooren, C. A. and Bartelli, L. J. 1956. A method of forecasting soil losses. *Agricultural Engineering*, **37**: 335 - 341.
- Vandslande, A., Lal, R. and Gabriels, D. 1985. Erodibility of some Nigerian soils. Proc. Int. Symp. on Erosion, Debris Flow and Disaster Prevention, Tsukuba, Japan. Erosion Control Engg. Soci. pp. 51 - 56.
- Venkateswarlu, B. and Prasad, J. V. N. S. 2012. Carrying capacity of Indian agriculture: issues related to rainfed agriculture. *Current Science*, **102**(6): 882-888.
- Verma, R. S. 1998. Optimal land use planning in Naurar watershed of Ramganga catchment, UP (India). PhD Thesis, Department of Soil and Water Conservation Engineering, G.B.Pant University of Agriculture and Technology, Pantnagar.
- Villa Nova, N. A., Pereira, A. B. and Shock, C. C. 2007. Estimation of reference evapotranspiration by an energy balance approach. *Biosystems Engineering*, **96**(4): 605-615.
- Vincini, M. 1999. The effect of abandoning agricultural activity on the LS factors of the erosion models in the Perino Valley: simulation using GIS technique. *Genio Rurale*, **62**(1): 58-64.
- Vivekanandan, N. 2009. Maximization of net returns for upper Indrawati project using goal programming Approach. *Journal of Water Management*, **17**(2): 149-155.
- Wang, F. C. and Fluck, R. C. 1979. Vegetable crops acreage comparison under resource alternatives. *Transactions of the American Society of Agricultural Engineers (ASAE)*, **22**(1): 87-92.
- Wang, L., Meng, W., Guo, H., Zhang, Z., Liu, Y. and Fan, Y. 2006. An interval fuzzy multi objective watershed management model for the lake Qionghai watershed, China, *Water Resource Management*, **20**: 701-721.
- Weltz, M. A., Renard, K. G., and Simanton, J. R. 1987. "Revised Universal Soil Loss Equation for Western Range- lands." Strategies for Classification and Management of Native Vegetation and Food Production in Arid Zones. USDA Forest Service Rocky Mtn. Forest and Range Exp. Sta. Rep. RM-150, pp. 104-111.

- Windsor, J. S. and Chow, V. T. 1971. Model for farm irrigation in humid areas, *American Society of Civil Engineers, Journal of Irrigation and Drainage Division*, **97**(IR3): 369-385.
- WHO 1985. Energy and protein requirements. (WHO Tech. Rep. Series No. 724). World Health Organization.
- Wischmeier, W. H. and Smith, D. D. 1958. Rainfall energy and its relationship to soil loss. *Transaction of American Geophysics Union*, **39**: 285-291.
- Wischmeier, W. H. 1959. A rainfall erosion index for a Universal Soil Loss Equation. *Soil Science Society America, Prosc.* **23**: 246-249.
- Wischmeier, W. H. 1962. Rainfall erosion potential. *Agricultural Engineering*, **43**: 212 - 214, 225.
- Wischmeier, W. H. and Mannering, J. V. 1969. Relation of soil properties to its erodibility. *Proceedings of Soil Science Society of America.* **33**(1): 131- 137.
- Wischmeier, W. H., Johson, C. B. and Cross, B. V. 1971. A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, **26**: 189 - 193.
- Wischmeier, W. H. 1972. Upslope erosion analysis. In *Environmental Impact on Rivers*. Water Resources Publication, Ft. Collins, Colorado. pp 15-1 to 15-26.
- Wischmeier, W. H. 1975. Estimating the soil loss equations cover and a management factor for undisturbed lands. In *Present and Prospective Technology for Predicting Sediment Yields and Sources*, ARS-S-40, Agricultural Research Service, U.S. Dept. of Agriculture, Washington, DC, pp. 118-125.
- Wischmeier, W. H. and Smith, D. D. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. *Agriculture Handbook No. 282*, U.S. Department of Agriculture, Washington, DC.
- Wischmeier, W. H. and Smith, D. D. 1978. Predicting rainfall erosion losses: A guide to conservation planning. *USDA, Agriculture Handbook No. 537*.
- Yamamoto, T. and Anderson, H. W. 1973. Splash erosion related to soil erodibility indexes and other Forest Soil Properties in Hawaii. *Water Resources Research*, **9**(2): 336 - 345.

- Zhang, J and Garbrecht, J. D. 2002. Precipitation retention and soil erosion under varying climate, land use, tillage and cropping systems. *Journal of American Water Resources Association*. **38**(5): 1241-1253.
- Zhang, K., Li, S., Peng, W. and Yu, B. 2004. Erodibility of agricultural soils on the loess plateau of China. *Soil and Tillage Research*, **76**: 157-165.
- Zheng, F., He, X., Gao, X., Zhang, C. E. and Tang, K. 2005. Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. *Agriculture Ecosystem and Environment*, **108**: 85-97.
- Zingg, A. W. 1940. Degree and length of land slope as it affects soil loss in runoff. *Agricultural Engineering*, **21**: 59-64.

# APPENDICES

## Appendix A

### Monthly rainfall of Koraput district from 1982 to 1999

(Rainfall in mm)

Month	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
January	31.6	36.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	33.0	0.0	21.4	0.0	0.0
February	57.7	2.8	3.4	0.0	46.6	0.0	3.0	11.2	0.0	1.2	0.0	0.0	9.8	4.0
March	14.8	34.9	11.8	109.3	79.3	36.7	0.0	14.0	7.1	73.6	9.0	51.6	155.4	0.0
April	31.5	43.1	82.7	9.4	26.6	39.2	71.4	26.8	105.3	63.4	58.0	41.0	44.2	0.0
May	81.1	110.6	59.4	74.8	440.5	46.4	24.6	69.4	121.4	366.4	63.8	12.4	79.8	268.8
June	199.9	103.7	82.9	281.7	184.5	263.9	120.8	155.6	187.8	111.0	120.4	190.6	186.2	472.8
July	263.8	313.2	227.6	475.3	432.7	708.5	498.3	359.9	484.0	648.8	453.8	214.8	502.4	270.4
August	461.9	197.8	197.4	275.6	499.7	413.5	374.3	309.5	363.0	385.8	380.4	248.8	94.6	244.8
September	136.0	139.7	186.2	165.6	283.9	157.7	283.8	316.5	488.0	286.0	163.8	133.8	99.8	196.2
October	70.4	97.0	56.2	162.7	407.1	114.6	23.8	54.0	68.6	98.2	35.4	108.8	177.8	66.6
November	44.8	134.3	1.0	0.0	138.5	62.4	66.9	11.0	26.0	32.2	5.2	33.4	201.2	8.2
December	8.2	0.7	37.2	2.0	32.8	2.5	0.0	0.0	0.0	0.0	0.0	35.2	0.0	0.0
Total	1401.7	1213.8	945.8	1556.4	2572.2	1845.4	1470.3	1327.9	1851.2	2099.6	1289.8	1091.8	1551.2	1531.8

Contd.

**Monthly rainfall of Koraput district from 2000 TO 2012**

**(Rainfall in mm)**

<b>Month</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>AVG</b>
January	0.0	2.3	74.1	0.0	51.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0	18.3	10.2
February	103.2	0.0	0.0	54.0	0.4	2.8	0.0	3.4	23.8	0.0	8.6	12.0	8.6	13.2
March	0.0	8.0	4.8	23.6	23.6	2.6	16.3	12.3	53.6	2.8	2.0	0.0	0.0	27.7
April	0.0	122.5	36.5	67.6	77.8	78.8	100.8	38.2	19.0	0.0	16.4	47.7	83.7	49.3
May	45.8	32.1	33.6	19.1	65.4	6.8	170.5	76.4	21.8	54.8	93.0	28.6	22.3	92.2
June	142.5	286.9	154.4	59.1	409.4	257.1	193.6	638.8	178.4	98.2	127.0	143.7	199.3	205.6
July	328.9	443.7	372.3	406.8	333.4	252.8	548.6	106.3	196.0	422.0	430.0	328.8	358.8	384.5
August	317.7	304.8	363.1	509.3	346.0	158.1	719.2	299.2	359.0	248.0	226.0	247.7	511.9	335.4
September	224.6	140.5	108.1	241.4	215.2	388.6	343.7	315.9	232.0	42.1	417.0	317.9	262.7	232.8
October	12.5	29.8	87.3	277.3	152.6	110.8	51.6	124.2	10.2	37.9	112.7	17.7	63.6	97.4
November	3.0	40.8	0.0	30.5	1.6	11.3	12.1	1.4	3.4	5.0	100.0	0.0	87.9	39.3
December	11.1	0.0	0.0	92.4	0.0	0.0	0.0	0.0	0.0	0.0	43.2	7.5	0.0	10.1
<b>Total</b>	<b>1189.3</b>	<b>1411.4</b>	<b>1234.2</b>	<b>1781.1</b>	<b>1677.3</b>	<b>1271.8</b>	<b>2156.4</b>	<b>1616.1</b>	<b>1097.2</b>	<b>910.8</b>	<b>1575.9</b>	<b>1151.6</b>	<b>1617.1</b>	<b>1497.7</b>

**Contd...**

**Appendix B**

**Monthly average maximum and minimum temperature (<sup>0</sup>C) of Koraput district from 1986 - 2000 (January to June)**

Year	January		February		March		April		May		June	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1986	24.9	8.8	27.4	12.3	31.4	15.5	34.5	18.8	34.8	21.4	29.1	22.6
1987	26.0	10.0	27.3	11.0	30.6	14.6	34.5	18.9	33.0	19.7	31.8	21.7
1988	26.3	9.5	29.2	12.2	32.7	16.5	34.2	18.8	35.9	21.8	32.1	21.6
1989	26.2	8.8	30.0	9.0	31.1	14.4	34.6	17.3	35.3	20.9	29.0	20.0
1990	27.5	7.6	28.2	12.3	30.6	15.8	34.3	18.4	29.9	19.6	27.9	19.8
1991	26.5	11.3	29.8	12.2	32.3	16.6	33.8	19.1	35.3	20.8	28.6	20.1
1992	25.3	6.5	27.5	10.7	33.4	13.6	34.6	17.3	34.9	19.7	30.4	19.7
1993	26.9	7.4	28.9	10.3	31.4	13.7	34.7	17.9	34.9	19.9	30.0	19.7
1994	26.3	8.3	28.3	12.8	33.5	15.6	33.6	19.4	35.0	21.0	29.6	20.7
1995	26.1	8.0	29.6	13.0	31.8	15.0	34.1	19.7	31.9	20.0	31.6	21.0
1996	30.0	9.0	31.7	11.0	33.6	14.6	35.3	19.8	36.3	20.8	31.2	20.8
1997	27.9	5.5	32.8	12.2	33.7	13.0	33.2	16.2	36.1	19.5	32.0	19.8
1998	28.8	6.5	29.9	8.4	33.4	14.7	36.5	17.0	36.8	18.3	32.9	17.8
1999	30.5	5.0	33.6	10.9	34.4	15.8	37.4	17.9	33.0	17.7	33.1	17.4
2000	30.4	7.3	28.7	7.5	32.7	19.2	32.2	20.2	34.6	20.1	31.4	18.3

**Monthly average maximum and minimum temperature (<sup>0</sup>C) of Koraput district from 1986-2000 (July to December)**

Year	July		August		September		October		November		December	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1986	25.6	20.1	25.7	19.6	27.3	19.5	28.3	16.6	26.2	12.7	26.3	11.0
1987	25.9	20.8	27.7	20.3	28.5	19.9	28.1	16.8	26.1	14.3	25.8	10.1
1988	27.2	20.4	27.0	20.3	27.5	20.1	27.1	15.3	26.4	9.9	25.7	9.0
1989	27.3	19.4	26.5	19.4	27.7	18.8	28.0	15.2	27.8	8.5	25.2	8.0
1990	24.7	19.0	26.6	19.7	26.6	19.1	25.9	16.6	26.6	13.6	25.0	9.9
1991	25.4	19.7	24.8	19.2	27.2	18.4	26.6	16.0	24.7	11.9	24.1	7.8
1992	26.6	19.0	25.1	13.4	26.9	17.3	27.4	14.6	25.5	14.4	25.2	5.6
1993	26.4	8.5	24.8	13.0	26.5	17.0	27.3	14.1	25.3	6.3	25.1	4.9
1994	25.8	20.3	26.1	18.9	26.1	18.5	27.8	16.2	26.0	11.6	24.0	4.7
1995	26.5	20.4	27.9	18.8	29.0	18.9	29.4	16.7	29.0	12.7	27.4	6.0
1996	28.1	21.0	27.3	18.7	30.9	18.4	29.5	16.0	30.5	13.0	29.3	6.6
1997	26.9	19.7	25.9	18.7	28.9	18.2	30.2	14.2	30.4	13.2	28.6	9.9
1998	28.0	18.3	29.9	19	33.3	15.6	31.4	14.3	29.5	11.7	30.0	3.9
1999	28.3	13.3	28.8	13.1	31.0	15.9	30.4	15.1	29.5	6.6	30.1	4.4
2000	27.8	15.2	27.9	16.3	30.2	16.3	32.1	12.7	31.5	8.7	32.6	2.9

**Contd...**

**Monthly average maximum and minimum temperature (<sup>0</sup>C) and relative humidity (%) of Koraput district from 2001-2012  
(January to June)**

Year	January			February			March			April			May			June		
	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH
2001	29.9	6.8	58.0	30.5	22.0	49.3	32.4	17.5	54.4	32.1	19.0	72.2	35.3	21.5	56.7	27.7	20.4	82.2
2002	26.5	9.1	66.2	29.0	12.7	56.1	32.7	17.2	52.6	35.2	19.8	48.7	36.3	22.2	50.4	28.7	21.0	77.3
2003	26.5	8.8	57.8	29.7	14.5	59.7	31.6	16.2	59.9	35.2	19.2	59.1	37.1	21.7	46.6	33.9	22.1	63.9
2004	25.4	9.7	65.2	27.0	10.6	59.8	33.1	15.4	51.5	33.5	19.3	57.9	32.9	20.5	61.5	28.8	19.7	76.2
2005	26.9	9.9	64.9	30.4	11.0	56.5	33.2	14.7	51.8	33.9	19.0	59.2	35.3	21.1	53.4	32.4	22.1	67.7
2006	27.9	8.4	59.1	31.1	10.6	53.3	31.5	15.9	59.1	34.0	18.7	61.0	32.7	20.6	70.2	29.9	21.3	77.4
2007	27.3	8.8	63.8	28.5	11.1	56.7	32.8	16.1	56.1	34.3	18.5	53.7	34.9	20.8	55.6	29.2	20.8	79.3
2008	27.5	8.0	60.7	27.9	12.7	69.0	31.2	15.1	55.4	33.9	18.0	58.0	36.1	20.5	54.3	27.8	25.2	80.3
2009	28.8	9.0	59.2	31.2	12.0	55.2	33.2	13.8	50.1	36.3	18.4	49.8	44.6	20.1	57.1	33.1	20.7	65.1
2010	25.6	8.8	64.7	29.6	10.6	57.3	33.7	15.4	55.5	36.3	18.7	54.8	34.3	19.7	63.8	31.5	19.7	77.0
2011	26.6	5.6	65.7	28.3	8.9	62.7	32.2	12.9	56.2	32.2	15.4	65.0	34.6	19.0	62.4	29.3	18.8	79.6
2012	26.4	6.9	66.0	30.5	8.3	54.0	33.7	11.5	47.3	34.3	15.4	55.7	35.7	17.6	53.0	31.4	17.7	69.6

**Contd...**

**Monthly average maximum and minimum temperature (<sup>0</sup>C) and relative humidity (%) of Koraput district from 2001-2012  
(July-December)**

year	July			August			September			October			November			December		
	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH	Max	Min	RH
2001	25.6	19.8	88.6	25.6	20.0	86.4	28.9	17.4	82.7	28.4	14.5	77.6	26.8	9.8	73.7	26.4	5.1	61.0
2002	28.0	20.3	81.3	25.0	19.6	89.2	27.4	18.6	78.2	28.2	16.3	72.5	26.8	10.7	62.2	26.6	8.8	59.4
2003	25.7	20.7	89.4	26.7	20.5	87.2	27.5	20.1	86.8	27.4	18.2	81.8	27.1	11.0	66.8	25.0	9.3	68.6
2004	27.1	19.9	85.0	25.3	19.4	87.2	28.6	19.0	81.7	27.3	16.4	78.4	27.0	10.1	64.2	26.3	5.9	62.6
2005	26.6	21.0	84.1	25.9	20.1	87.1	27.0	20.0	86.7	27.1	19.0	85.6	26.7	10.7	66.3	26.0	9.3	64.1
2006	25.4	20.6	88.2	25.7	19.8	90.3	27.4	19.6	84.5	28.3	16.7	73.4	26.5	13.9	75.1	26.8	9.4	71.0
2007	27.0	20.3	82.3	26.6	19.6	86.2	26.6	19.7	88.1	27.5	16.8	77.3	26.8	9.9	68.3	26.7	10.3	64.1
2008	26.5	19.9	86.5	26.0	19.2	89.0	27.3	18.8	86.2	29.0	15.3	71.5	28.1	12.3	69.3	26.8	7.6	60.5
2009	25.5	19.2	88.1	27.4	19.1	86.8	28.9	18.6	81.6	28.5	13.9	69.7	28.5	13.1	72.1	26.4	7.9	64.4
2010	26.3	18.7	88.9	27.2	18.4	87.3	27.5	17.9	89.6	27.6	16.2	83.5	26.8	14.1	80.1	24.8	7.5	71.7
2011	27.5	17.9	84.8	26.5	17.8	88.0	25.7	17.3	87.6	29.1	13.4	71.0	28.2	8.8	65.9	35.2	5.6	64.5
2012	25.5	15.9	89.0	25.1	15.4	90.1	26.6	15.7	86.5	27.7	12.5	75.3	26.0	8.4	74.2	27.2	5.0	63.7

Appendix C

Wind speed (WS) and sunshine hour (SH) of Koraput district from 2001 to 2012 (WS in km/hr & SH in hrs)

Year	January		February		March		April		May		June	
	WS	SH	WS	SH	WS	SH	WS	SH	WS	SH	WS	SH
2001	2.3	8.0	2.7	9.0	2.6	9.0	3.0	8.3	4.3	9.0	7.0	1.7
2002	2.2	8.1	2.9	9.1	2.7	9.1	3.2	9.4	6.3	8.6	5.1	4.3
2003	2.5	8.0	3.2	8.8	3.2	8.1	3.1	11.5	4.4	8.9	7.3	4.2
2004	2.2	8.4	2.6	9.6	2.9	10.6	4.7	9.7	3.8	7.8	6.5	3.7
2005	2.7	8.3	3.1	9.8	3.1	9.2	2.9	7.6	4.0	8.8	5.9	3.9
2006	1.9	9.7	2.3	9.6	3.0	8.5	3.2	8.8	3.4	7.3	4.1	2.7
2007	2.1	9.3	3.1	9.0	3.4	9.4	4.1	8.9	4.5	7.9	5.8	3.0
2008	2.4	9.1	3.0	8.0	2.4	7.8	2.6	8.9	4.6	8.5	7.0	1.9
2009	2.1	9.5	2.7	9.4	2.8	8.0	3.5	9.4	4.0	8.1	5.1	3.5
2010	2.0	7.4	2.3	9.4	2.2	7.7	3.7	9.4	3.5	7.4	4.0	5.2
2011	1.7	9.0	2.0	8.9	2.3	18.1	2.4	8.1	3.5	8.7	5.9	3.5
2012	1.8	7.8	2.0	9.0	2.9	9.3	3.1	8.5	3.1	8.3	5.4	3.5

Year	July		August		September		October		November		December	
	WS	SH	WS	SH	WS	SH	WS	SH	WS	SH	WS	SH
2001	6.0	1.1	8.7	1.3	3.3	5.5	2.1	6.3	1.9	5.5	2.2	8.7
2002	6.8	3.4	8.6	1.8	4.7	3.9	2.4	6.5	2.2	6.8	2.1	8.9
2003	6.1	0.7	6.2	1.9	5.2	3.3	2.8	5.3	1.3	9.2	1.8	7.4
2004	5.2	2.2	8.7	2.2	3.0	5.6	2.2	6.3	1.9	8.0	2.0	9.4
2005	7.3	1.8	7.3	2.3	4.2	3.5	1.7	4.0	1.7	8.1	1.7	7.8
2006	8.1	1.1	8.5	1.4	3.7	4.4	2.0	7.1	1.7	7.0	1.9	9.0
2007	7.0	2.9	6.1	2.7	4.1	2.3	1.6	5.4	1.8	9.0	2.0	8.0
2008	5.8	1.8	5.3	1.8	3.4	3.8	1.5	7.8	1.6	7.5	1.9	9.2
2009	9.1	1.1	3.8	2.8	3.1	5.2	2.0	7.4	1.8	7.0	1.9	6.4
2010	4.5	1.6	3.0	3.1	2.7	3.8	1.6	5.2	1.1	6.1	1.4	5.7
2011	4.1	2.9	4.0	2.2	4.0	3.8	1.3	8.0	1.3	8.7	1.3	6.5
2012	6.6	1.4	5.6	1.2	3.2	2.6	1.3	6.4	1.1	6.5	1.2	9.0

**Appendix D**

**Monthly actual and effective rainfall of Koraput district from 1986 to 1994**

**(Rainfall in mm)**

Month	1986		1987		1988		1989		1990		1991		1992		1993		1994	
	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.	Act.	Eff.
Jan.	31.6	30.0	36.0	33.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	3.4	0.0	0.0	0.0	0.0
Feb.	57.7	52.4	2.8	2.8	3.4	3.4	0.0	0.0	46.6	43.1	0.0	0.0	3.0	3.0	11.2	11.0	0.0	0.0
Mar.	14.8	14.4	34.9	33.0	11.8	11.6	109.3	90.2	79.3	69.2	36.7	34.5	0.0	0.0	14.0	13.7	7.1	7.0
Apr.	31.5	29.9	43.1	40.1	82.7	71.8	9.4	9.3	26.6	25.5	39.2	36.7	71.4	63.2	26.8	25.7	105.3	87.6
May	81.1	70.6	110.6	91.0	59.4	53.8	74.8	65.8	440.5	169.1	46.4	43.0	24.6	23.6	69.4	61.7	121.4	97.8
Jun.	199.9	136.0	103.7	86.5	82.9	71.9	281.7	153.2	184.5	130.0	263.9	151.4	120.8	97.5	155.6	116.9	187.8	131.4
July	263.8	151.4	313.2	156.3	227.6	144.7	475.3	172.5	432.7	168.3	708.5	195.8	498.3	174.8	359.9	161.0	484.0	173.4
Aug.	461.9	171.2	197.8	135.2	197.4	135.1	275.6	152.6	499.7	175.0	413.5	166.3	374.3	162.4	309.5	155.9	363.0	161.3
Sept.	136.0	106.4	139.7	108.5	186.2	130.7	165.6	121.7	283.9	153.4	157.7	117.9	283.8	153.4	316.5	156.7	488.0	173.8
Oct.	70.4	62.5	97.0	81.9	56.2	51.1	162.7	120.3	407.1	165.7	114.6	93.6	23.8	22.9	54.0	49.3	68.6	61.1
Nov.	44.8	41.6	134.3	105.4	1.0	1.0	0.0	0.0	138.5	107.8	62.4	56.2	66.9	59.7	11.0	10.8	26.0	24.9
Dec.	8.2	8.1	0.7	0.7	37.2	35.0	2.0	2.0	32.8	31.1	2.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0
Tot.	1401.7	874.4	1213.8	875.4	945.8	710.0	1556.4	887.6	2572.2	1238.1	1845.4	898.0	1470.3	764.0	1327.9	762.6	1851.2	918.3

**Contd...**

**Monthly actual and effective rainfall of Koraput district from 1995 to 2003**

**(Rainfall in mm)**

Month	1995		1996		1997		1998		1999		2000		2001		2002		2003	
	Act .	Eff.	Act .	Eff.	Act.	Eff.	Act .	Eff.	Act .	Eff.	Act .	Eff.	Act .	Eff.	Act .	Eff.	Act .	Eff.
Jan.	33.0	31.3	0.0	0.0	21.4	20.7	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.3	74.1	65.3	0.0	0.0
Feb.	1.2	1.2	0.0	0.0	0.0	0.0	9.8	9.6	4.0	4.0	103.2	86.2	0.0	0.0	0.0	0.0	54.0	49.3
Mar.	73.6	64.9	9.0	8.9	51.6	47.3	155.4	116.8	0.0	0.0	0.0	0.0	8.0	7.9	4.8	4.8	23.6	22.7
Apr.	63.4	57.0	58.0	52.6	41.0	38.3	44.2	41.1	0.0	0.0	0.0	0.0	122.5	98.5	36.5	34.4	67.6	60.3
May	366.4	161.6	63.8	57.3	12.4	12.2	79.8	69.6	268.8	151.9	45.8	42.4	32.1	30.5	33.6	31.8	19.1	18.5
Jun.	111.0	91.3	120.4	97.2	190.6	132.5	186.2	130.7	472.8	172.3	142.5	110.0	286.9	153.7	154.4	116.3	59.1	53.5
July	648.8	189.9	453.8	170.4	214.8	141.0	502.4	175.2	270.4	152.0	328.9	157.9	443.7	169.4	372.3	162.2	406.8	165.7
Aug.	385.8	163.6	380.4	163.0	248.8	149.8	94.6	80.3	244.8	148.9	317.7	156.8	304.8	155.5	363.1	161.3	509.3	175.9
Sept.	286.0	153.6	163.8	120.9	133.8	105.2	99.8	83.9	196.2	134.6	224.6	143.9	140.5	108.9	108.1	89.4	241.4	148.2
Oct.	98.2	82.8	35.4	33.4	108.8	89.9	177.8	127.2	66.6	59.5	12.5	12.3	29.8	28.4	87.3	75.1	277.3	152.7
Nov.	32.2	30.5	5.2	5.2	33.4	31.6	201.2	136.4	8.2	8.1	3.0	3.0	40.8	38.1	0.0	0.0	30.5	29.0
Dec.	0.0	0.0	0.0	0.0	35.2	33.2	0.0	0.0	0.0	0.0	11.1	10.9	0.0	0.0	0.0	0.0	92.4	78.7
Tot.	2099.6	1027.7	1289.8	708.8	1091.8	801.5	1551.2	970.9	1531.8	831.3	1189.3	723.3	1411.4	793.1	1234.2	740.5	1781.1	954.6

**Contd...**

**Monthly actual and effective rainfall of Koraput district from 2004 to 2012**

**(Rainfall in mm)**

Month	2004		2005		2006		2007		2008		2009		2010		2011		2012		Average	
	Act.	Eff.	Act .	Eff.	Act.	Eff.	Act .	Eff.	Act.	Eff.	Act.	Eff.	Act .	Eff.	Act .	Eff.	Act.	Eff.	Act.	Eff.
Jan.	51.9	47.6	2.1	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	17.8	10.2	9.4
Feb.	0.4	0.4	2.8	2.8	0.0	0.0	3.4	3.4	23.8	22.9	0.0	0.0	8.6	8.5	12.0	11.8	8.6	8.5	13.2	12.0
Mar.	23.6	22.7	2.6	2.6	16.3	15.9	12.3	12.1	53.6	49.0	2.8	2.8	2.0	2.0	0.0	0.0	0.0	0.0	27.7	24.2
Apr.	77.8	68.1	78.8	68.9	100.8	84.5	38.2	35.9	19.0	18.4	0.0	0.0	16.4	16.0	47.7	44.1	83.7	72.5	49.3	43.7
May	65.4	58.6	6.8	6.7	170.5	124.0	76.4	67.1	21.8	21.0	54.8	50.0	93.0	79.2	28.6	27.3	22.3	21.5	92.2	63.2
Jun.	409.4	165.9	257.1	150.7	193.6	133.6	638.8	188.9	178.4	127.5	98.2	82.8	127.0	101.2	143.7	110.7	199.3	135.7	205.6	123.3
July	333.4	158.3	252.8	150.3	548.6	179.9	106.3	88.2	196.0	134.5	422.0	167.2	430.0	168.0	328.8	157.9	358.8	160.9	384.5	161.0
Aug.	346.0	159.6	158.1	118.1	719.2	196.9	299.2	154.9	359.0	160.9	248.0	149.6	226.0	144.3	247.7	149.5	511.9	176.2	335.4	154.8
Sept.	215.2	141.1	388.6	163.9	343.7	159.4	315.9	156.6	232.0	145.9	42.1	39.3	417.0	166.7	317.9	156.8	262.7	151.3	232.8	133.0
Oct.	152.6	115.3	110.8	91.2	51.6	47.3	124.2	99.5	10.2	10.0	37.9	35.6	112.7	92.4	17.7	17.2	63.6	57.1	97.4	71.7
Nov.	1.6	1.6	11.3	11.1	12.1	11.9	1.4	1.4	3.4	3.4	5.0	5.0	100.0	84.0	0.0	0.0	87.9	75.5	39.3	32.7
Dec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.2	40.2	7.5	7.4	0.0	0.0	10.1	9.3
Tot.	1677.3	939.3	1271.8	768.3	2156.4	953.4	1616.1	807.9	1097.2	693.6	910.8	532.2	1575.9	902.4	1151.6	682.6	1617.1	877.0	1497.7	838.4

**Appendix E**

**Monthly and annual reference crop evapotranspiration (ET<sub>o</sub>) of Koraput district from 1986 to 1999**

**(ET<sub>o</sub> in mm)**

<b>Month</b>	<b>1986</b>	<b>1987</b>	<b>1988</b>	<b>1989</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>
January	106.0	109.4	111.0	112.2	121.8	107.0	111.9	117.8	112.2	112.5	132.1	127.4	130.8	141.4
February	109.8	113.4	119.8	132.2	114.5	123.8	113.7	123.5	113.1	120.4	137.8	140.3	132.4	147.3
March	153.8	150.7	160.3	155.6	147.3	157.2	174.2	159.7	169.3	159.0	173.0	180.7	170.5	175.5
April	173.7	173.7	171.3	179.7	175.2	167.4	180.6	178.5	164.4	167.7	176.1	173.4	196.8	202.5
May	178.9	170.5	186.3	186.3	145.1	187.2	187.9	187.2	182.9	159.7	195.6	197.8	210.2	181.0
June	116.4	147.3	151.8	132.6	122.7	128.7	146.4	146.1	133.8	149.1	147.3	159.9	176.4	180.0
July	101.7	98.9	115.9	122.8	99.8	102.3	120.9	165.5	102.0	108.5	120.6	118.1	135.5	162.8
August	102.6	116.9	110.7	111.9	110.4	96.7	132.4	129.3	111.9	128.3	123.7	111.0	144.5	160.6
September	108.6	117.3	108.0	116.4	105.9	114.0	116.1	114.3	104.4	126.0	143.4	128.4	173.1	153.0
October	124.0	121.8	121.5	127.7	106.0	114.4	124.0	127.1	121.8	130.8	134.2	144.2	153.1	144.8
November	105.9	101.1	114.0	125.1	105.6	100.5	97.8	116.4	109.5	123.0	130.2	128.1	128.1	138.3
December	106.3	105.7	106.6	106.3	102.0	100.4	112.5	110.7	107.0	122.8	130.8	122.5	139.2	137.6
Total	1487.6	1526.7	1577.3	1608.8	1456.3	1499.6	1618.4	1676.1	1532.3	1607.8	1744.7	1731.7	1890.6	1924.7

**Contd...**

**Monthly and annual reference crop evapotranspiration (ET<sub>o</sub>) of Koraput district from 2000 to 2012**

**(ET<sub>o</sub> in mm)**

<b>Month</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>Avg.</b>
January	139.2	85.6	84.3	84.3	83.7	88.0	90.8	90.5	90.2	91.8	78.1	86.5	79.7	104.7
February	127.4	108.9	98.0	101.4	94.9	105.3	123.5	98.0	92.1	104.2	96.9	90.7	94.4	114.0
March	148.5	136.4	136.1	128.7	144.2	138.0	129.6	140.4	120.9	127.1	122.8	183.5	136.4	151.1
April	150.6	137.4	164.4	167.7	160.8	135.9	147.0	153.9	142.2	155.1	160.2	130.8	142.2	164.0
May	183.8	177.6	187.9	176.7	152.2	167.1	143.5	163.4	170.2	185.4	149.7	158.4	156.2	175.1
June	162.6	93.0	113.1	142.2	110.7	126.3	100.8	104.1	98.4	126.3	121.5	106.8	117.6	131.9
July	150.0	78.1	106.3	77.2	90.8	91.8	80.3	99.8	87.7	80.9	82.5	94.6	80.6	106.5
August	140.7	79.4	80.6	84.6	85.3	87.1	76.9	91.1	80.9	89.6	91.1	84.6	73.5	105.0
September	146.4	107.4	95.7	88.5	105.0	87.9	95.1	78.9	89.7	103.8	88.2	86.4	78.9	110.4
October	162.1	102.3	103.2	95.8	100.1	85.6	105.4	93.9	107.6	105.4	90.5	105.1	95.8	116.6
November	144.9	75.6	84.3	91.2	88.2	87.3	84.0	90.3	87.3	86.4	79.5	89.7	75.6	103.3
December	153.5	78.4	84.3	68.2	83.4	77.5	85.3	81.2	84.6	74.4	67.9	84.9	78.4	100.5
<b>Total</b>	<b>1809.8</b>	<b>1260.1</b>	<b>1338.3</b>	<b>1306.4</b>	<b>1299.3</b>	<b>1277.7</b>	<b>1262.1</b>	<b>1285.6</b>	<b>1251.9</b>	<b>1330.3</b>	<b>1228.9</b>	<b>1302.1</b>	<b>1209.3</b>	<b>1483.1</b>

**Appendix F**

**Climatic index of Koraput district from 1986-1999**

<b>Month</b>	<b>1986</b>	<b>1987</b>	<b>1988</b>	<b>1989</b>	<b>1990</b>	<b>1991</b>	<b>1992</b>	<b>1993</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>	<b>1998</b>	<b>1999</b>
January	0.28	0.31	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.28	0.00	0.16	0.00	0.00
February	0.48	0.02	0.03	0.00	0.38	0.00	0.03	0.09	0.00	0.01	0.00	0.00	0.07	0.03
March	0.09	0.22	0.07	0.58	0.47	0.22	0.00	0.09	0.04	0.41	0.05	0.26	0.69	0.00
April	0.17	0.23	0.42	0.05	0.15	0.22	0.35	0.14	0.53	0.34	0.30	0.22	0.21	0.00
May	0.39	0.53	0.29	0.35	1.17	0.23	0.13	0.33	0.53	1.01	0.29	0.06	0.33	0.84
June	1.17	0.59	0.47	1.16	1.06	1.18	0.67	0.80	0.98	0.61	0.66	0.83	0.74	0.96
July	1.49	1.58	1.25	1.41	1.69	1.91	1.45	0.97	1.70	1.75	1.41	1.19	1.29	0.93
August	1.67	1.16	1.22	1.36	1.59	1.72	1.23	1.21	1.44	1.27	1.32	1.35	0.56	0.93
September	0.98	0.92	1.21	1.05	1.45	1.03	1.32	1.37	1.66	1.22	0.84	0.82	0.48	0.88
October	0.50	0.67	0.42	0.94	1.56	0.82	0.18	0.39	0.50	0.63	0.25	0.62	0.83	0.41
November	0.39	1.04	0.01	0.00	1.02	0.56	0.61	0.09	0.23	0.25	0.04	0.25	1.06	0.06
December	0.08	0.01	0.33	0.02	0.30	0.02	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00
Annual	0.59	0.57	0.45	0.55	0.85	0.60	0.47	0.45	0.60	0.64	0.41	0.46	0.51	0.43

**Contd...**

**Climatic index of Koraput district from 2000-2012**

<b>Month</b>	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>Average</b>
January	0.00	0.03	0.77	0.00	0.57	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.10
February	0.68	0.00	0.00	0.49	0.00	0.03	0.00	0.03	0.25	0.00	0.09	0.13	0.09	0.11
March	0.00	0.06	0.04	0.18	0.16	0.02	0.12	0.09	0.41	0.02	0.02	0.00	0.00	0.16
April	0.00	0.72	0.21	0.36	0.42	0.51	0.57	0.23	0.13	0.00	0.10	0.34	0.51	0.28
May	0.23	0.17	0.17	0.10	0.38	0.04	0.86	0.41	0.12	0.27	0.53	0.17	0.14	0.37
June	0.68	1.65	1.03	0.38	1.50	1.19	1.33	1.81	1.30	0.66	0.83	1.04	1.15	0.98
July	1.05	2.17	1.53	2.15	1.74	1.64	2.24	0.88	1.53	2.07	2.04	1.67	2.00	1.58
August	1.11	1.96	2.00	2.08	1.87	1.36	2.56	1.70	1.99	1.67	1.58	1.77	2.40	1.56
September	0.98	1.01	0.93	1.67	1.34	1.86	1.68	1.98	1.63	0.38	1.89	1.81	1.92	1.27
October	0.08	0.28	0.73	1.59	1.15	1.07	0.45	1.06	0.09	0.34	1.02	0.16	0.60	0.64
November	0.02	0.50	0.00	0.32	0.02	0.13	0.14	0.02	0.04	0.06	1.06	0.00	1.00	0.33
December	0.07	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.09	0.00	0.11
Annual	0.40	0.63	0.55	0.73	0.72	0.60	0.76	0.63	0.55	0.40	0.73	0.52	0.73	0.58

## Appendix G

### Present status of investments and returns from crops in Koraput district

Crops	Area ("000 ha)	Seed cost per ha (₹)	*Cost of FYM per ha (₹)	*Cost of FPPP per ha (₹)	*Cost of wages per ha (₹)	Investment per ha (₹)	Total investment (₹ in lakhs)	Yield (q/ha)	Rate of produce per quintal (₹)	Gross return (₹ in lakhs)	Net return (₹ in lakhs)	Net return per ha (₹)
Rice	114.28	1050	3000	7000	12500	23550	26912.94	23	1310	34432.56	7519.62	6580
Rice ( <i>Rabi</i> )	20.07	1050	1500	8000	15000	25550	5127.89	26	1310	6835.84	1707.96	8510
Maize	18.85	3000	5000	9000	10000	27000	5089.50	25	1310	6173.38	1083.88	5750
Maize( <i>Rabi</i> )	1.99	3000	5000	11000	15000	34000	676.60	31	1310	808.14	131.54	6610
Ragi	73.02	200	2000	1500	8000	11700	8543.34	10	1500	10953.00	2409.66	3300
Ragi( <i>Rabi</i> )	0.08	200	2000	1500	8000	11700	9.36	9	1500	10.80	1.44	1800
Jowar	1.48	200	2000	1000	5500	8700	128.76	8	1200	142.08	13.32	900
Bajra	0.32	200	1500	500	5500	7700	24.64	7	1200	26.88	2.24	700
Small millets	4.54	200	0	0	4000	4200	190.68	4	1200	217.92	27.24	600
Mung	2.21	1250	0	3500	2000	6750	149.18	3.9	4500	387.86	238.68	10800
Black gram	5.79	1250	3000	3500	2000	9750	564.53	3.9	4300	970.98	406.46	7020
Horse gram	10.07	300	0	3000	2000	5300	533.71	6.5	4000	2618.20	2084.49	20700
Arhar	5.45	1000	3000	4000	4000	12000	654.00	10	4300	2343.50	1689.50	31000
Field pea	6.94	1800	3000	4000	3500	12300	853.62	8	2500	1388.00	534.38	7700
Other pulses	6.42	1000	3000	3000	3500	10500	674.10	6	2500	963.00	288.90	4500
Groundnut	1.36	9000	5000	8000	17000	39000	530.40	12	4000	652.80	122.40	9000
Niger	38.14	400	4000	3000	4000	11400	4347.96	5	3500	6674.50	2326.54	6100
mustard	3.94	400	2000	1500	4000	7900	311.26	4	3000	472.80	161.54	4100
Other oil seeds	2.39	500	2000	1500	5000	9000	215.10	4	3000	286.80	71.70	3000
Vegetables( <i>Kh</i> )	14.49	3000	10000	15000	24000	52000	7534.80	140	1000	20286.00	12751.20	88000
Vegetables( <i>Rb</i> )	14.04	3000	10000	15000	30000	58000	8143.20	160	1000	22464.00	14320.80	102000
Ginger	3.04	120000	10000	12500	25000	167500	5092.00	105	3000	9576.00	4484.00	147500
Turmeric	2.79	60000	10000	12500	25000	107500	2999.25	34.5	4000	3850.20	850.95	30500
Sweet potato	3.2	15000	5000	0	6000	26000	832.00	102.5	1250	4100.00	3268.00	102125
Fibre crops	0.47	130	4000	0	10000	14130	66.41	14.36	1300	87.74	21.33	4538
<b>Total</b>	<b>355.37</b>						<b>80205.22</b>			<b>136722.98</b>	<b>56517.76</b>	

FYM: Farm yard manure, FPPP: Fertilizer, pesticide and plant protection, \*Cost in lump sum (LS), Rate of produce as per MSP 2013-14 (CACP, MoA,GoI).

## Appendix H

### Cost of cultivation and return (per ha) from crops as per the standard package of practices

Sl No.	Crop	Season	Seed		*Manure (₹)	Fertilizer				*Plant protection (₹)	*Land preparation (₹)	Human Labour		Farming cost (₹)	Yield (Qntl)	Rate of Produce (₹/Qntl)	Gross Return (₹)	Net Return (₹)
			Kg	₹		N(Kg)	P(Kg)	K(Kg)	(₹)			Day	₹					
1	Early rice	<i>Kharif</i>	75	1050	5000	40	20	20	2080	2000	5500	100	15000	30630	30	1310	39300	8670
2	Rice	<i>Kharif</i>	75	1050	5000	60	30	30	3120	2000	5500	125	18750	35420	35	1310	45850	10430
3	Ragi	<i>Kharif</i>	10	200	5000	40	20	20	2080	1000	4500	82	12300	25080	20	1500	30000	4920
4	Maize	<i>Kharif</i>	20	500	5000	80	40	40	4160	2000	4500	170	25500	41660	40		52400	10740
5	Wheat	<i>Pre Rabi</i>	125	3750	5000	80	50	40	4660	2000	4500	112	16800	36710	40	1350	54000	17290
6	Green gram	<i>Kharif</i>	25	1250	5000	20	40	20	2840	2000	2500	68	10200	23790	10	4500	45000	21210
7	Black gram	<i>Kharif</i>	25	1250	5000	20	40	20	2840	2000	2500	68	10200	23790	10	4300	43000	19210
8	Black gram	<i>Pre Rabi</i>	25	1250	5000	20	40	20	2840	2000	2500	68	10200	23790	10	4300	43000	19210
9	Horse gram	<i>Pre Rabi</i>	50	1500	5000	20	40	20	2840	1000	2500	65	9750	22590	15	4000	60000	37410
10	Arhar	<i>Kharif</i>	20	1000	5000	20	40	20	2840	3000	2500	100	15000	29340	20	4300	86000	56660
11	Ground nut	<i>Kharif</i>	175	10500	5000	20	40	40	3440	2000	4500	140	21000	46440	15	4000	60000	13560
12	Groundnut	<i>Rabi</i>	175	10500	5000	20	40	40	3440	3000	4500	170	25500	51940	25	4000	100000	48060
13	Niger	<i>Pre Rabi</i>	10	400	5000	40	20	20	2080	1000	3000	90	13500	24980	10	3500	35000	10020
14	Mustard	<i>Pre Rabi</i>	10	400	5000	30	15	15	1560	1000	3000	85	12750	23710	10	3000	30000	6290
15	Mustard	<i>Rabi</i>	10	400	10000	60	30	30	3120	2000	4000	95	14250	33770	15	3000	45000	11230
16	Ginger	<i>Kharif</i>	1500	90000	15000	125	100	100	9500	10000	7500	650	97500	229500	150	3000	450000	220500
17	Turmeric	<i>Kharif</i>	2000	60000	15000	60	30	90	4920	6000	7500	650	97500	190920	60	4000	240000	49080
18	Sweet potato	<i>Kharif</i>	80K	32000	6000	75	50	75	5650	3000	5000	250	37500	89150	200	1250	250000	160850
19	Potato	<i>Kharif</i>	1500	30000	5000	120	60	120	8040	8000	7000	250	37500	95540	200	1000	200000	104460
20	Potato	<i>Rabi</i>	1500	30000	10000	120	60	120	8040	8000	7000	250	37500	100540	250	1000	250000	149460
21	Vegetables	<i>Kharif</i>	0.5	6000	15000	150	75	75	7800	5000	5000	175	26250	65050	200	1000	200000	134950
22	Vegetables	<i>Rabi</i>	0.5	7000	15000	150	75	75	7800	5000	5000	275	41250	81050	250	1000	250000	168950
23	Hybrid Napier	Parrenial	16000	2400	5000	150	40	40	5000	2000	5000	200	22500	41900	300	150	45000	3100

Vegetables(*Kharif*): Cabbage,Cauliflower,Knol khol

Vegetables(*Rabi*) : Brinjal, Tomato, Capsicum, Chill

\*Cost in lump sum (LS), labour rate @ ₹ 150/day, and Rate of produce as per MSP

80K : 80000 vine cuttings, MSP is for the for year 2013-14 as fixed by CACP, MoA, GoI.

## Appendix I

### Suggested cropping pattern wise investments and net returns from crops

Sl No.	Cropping sequence set			Cost of inputs excluding wages (₹)				Cost of wages (₹)				Total farming cost (₹)	Net return (₹)			
				<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total		<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total
1	Early rice	Fallow	Fallow	15630			15630	15000			15000	30630	8670			8670
2	Early rice	Wheat	Fallow	15630	19910		35540	15000	16800		31800	67340	8670	17290		25960
3	Early rice	Black gram	Fallow	15630	13590		29220	15000	10200		25200	54420	8670	19210		27880
4	Early rice	Horse gram	Fallow	15630	12840		28470	15000	9750		24750	53220	8670	37410		46080
5	Early rice	Fallow	Groundnut	15630		26440	42070	15000		25500	40500	82570	8670		48060	56730
6	Early rice	Niger	Fallow	15630	11480		27110	15000	13500		28500	55610	8670	10020		18690
7	Early rice	Mustard	Fallow	15630	10960		26590	15000	12750		27750	54340	8670	6290		14960
8	Early rice	Fallow	Mustard	15630		19520	35150	15000		14250	29250	64400	8670		11230	19900
9	Early rice	Fallow	Potato	15630		63040	78670	15000		37500	52500	131170	8670		149460	158130
10	Early rice	Fallow	Vegetables	15630		39800	55430	15000		41250	56250	111680	8670		168950	177620
11	Rice	Fallow	Fallow	16670			16670	18750			18750	35420	10430			10430
12	Rice	Fallow	Groundnut	16670		26440	43110	18750		25500	44250	87360	10430		48060	58490
13	Rice	Fallow	Mustard	16670		19520	36190	18750		14250	33000	69190	10430		11230	21660
14	Rice	Fallow	Potato	16670		63040	79710	18750		37500	56250	135960	10430		149460	159890
15	Rice	Fallow	Vegetables	16670		39800	56470	18750		41250	60000	116470	10430		168950	179380
16	Ragi	Fallow	Fallow	12780			12780	12300			12300	25080	4920			4920
17	Ragi	Wheat	Fallow	12780	19910		32690	12300	16800		29100	61790	4920	17290		22210
18	Ragi	Black gram	Fallow	12780	13590		26370	12300	10200		22500	48870	4920	19210		24130
19	Ragi	Horse gram	Fallow	12780	12840		25620	12300	9750		22050	47670	4920	37410		42330
20	Ragi	Fallow	Groundnut	12780		26440	39220	12300		25500	37800	77020	4920		48060	52980
21	Ragi	Fallow	Mustard	12780		19520	32300	12300		14250	26550	58850	4920		11230	16150
22	Ragi	Fallow	Potato	12780		63040	75820	12300		37500	49800	125620	4920		149460	154380
23	Ragi	Fallow	vegetables	12780		39800	52580	12300		41250	53550	106130	4920		168950	173870
24	Maize	Fallow	Fallow	16160			16160	25500			25500	41660	10740			10740
25	Maize	Wheat	Fallow	16160	19910		36070	25500	16800		42300	78370	10740	17290		28030

Contd...

Sl No	Crop sequence set			Cost of inputs excluding wages (₹)				Cost of wages (₹)				Total farming cost (₹)	Net return (₹)			
	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total		<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total
26	Maize	Black gram	Fallow	16160	13590		29750	25500	10200		35700	65450	10740	19210		29950
27	Maize	Horse gram	Fallow	16160	12840		29000	25500	9750		35250	64250	10740	37410		48150
28	Maize	Fallow	Groundnut	16160		26440	42600	25500		25500	51000	93600	10740		48060	58800
29	Maize	Fallow	Mustard	16160		19520	35680	25500		14250	39750	75430	10740		11230	21970
30	Maize	Fallow	Potato	16160		63040	79200	25500		37500	63000	142200	10740		149460	160200
31	Maize	Fallow	Vegetables	16160		39800	55960	25500		41250	66750	122710	10740		168950	179690
32	Green gram	Fallow	Fallow	13590			13590	10200			10200	23790	21210			21210
33	Green gram	Wheat	Fallow	13590	19910		33500	10200	16800		27000	60500	21210	17290		38500
34	Green gram	Fallow	Groundnut	13590		26440	40030	10200		25500	35700	75730	21210		48060	69270
35	Green gram	Niger	Fallow	13590	11480		25070	10200	13500		23700	48770	21210	10020		31230
36	Green gram	Mustard	Fallow	13590	10960		24550	10200	12750		22950	47500	21210	6290		27500
37	Green gram	Fallow	Mustard	13590		19520	33110	10200		14250	24450	57560	21210		11230	32440
38	Green gram	Fallow	Potato	13590		63040	76630	10200		37500	47700	124330	21210		149460	170670
39	Green gram	Fallow	Vegetables	13590		39800	53390	10200		41250	51450	104840	21210		168950	190160
40	Black gram	Fallow	Fallow	13590			13590	10200			10200	23790	19210			19210
41	Black gram	Wheat	Fallow	13590	19910		33500	10200	16800		27000	60500	19210	17290		36500
42	Black gram	Niger	Fallow	13590	11480		25070	10200	13500		23700	48770	19210	10020		29230
43	Black gram	Mustard	Fallow	13590	10960		24550	10200	12750		22950	47500	19210	6290		25500
44	Black gram	Fallow	Mustard	13590		19520	33110	10200		14250	24450	57560	19210		11230	30440
45	Black gram	Fallow	Potato	13590		63040	76630	10200		37500	47700	124330	19210		149460	168670
46	Black gram	Fallow	Vegetables	13590		39800	53390	10200		41250	51450	104840	19210		168950	188160
47	Arhar	Fallow	Fallow	14340			14340	15000			15000	29340	56660			56660
48	Arhar	Fallow	Groundnut	14340		26440	40780	15000		25500	40500	81280	56660		48060	104720
49	Arhar	Fallow	Mustard	14340		19520	33860	15000		14250	29250	63110	56660		11230	67890
50	Arhar	Fallow	Potato	14340		63040	77380	15000		37500	52500	129880	56660		149460	206120

Contd...

Sl No	Crop sequence set			Cost of inputs excluding wages (₹)				Cost of wages (₹)				Total farming cost (₹)	Net return (₹)			
	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total	<i>Kharif</i>	<i>Pre rabi</i>	<i>rabi</i>	Total		<i>Kharif</i>	<i>Pre rabi</i>	<i>Rabi</i>	Total
51	Arhar	Fallow	Vegetables	14340		39800	54140	15000		41250	56250	110390	56660		168950	225610
52	Groundnut	Fallow	Fallow	25440			25440	21000			21000	46440	13560			13560
53	Groundnut	Fallow	Mustard	25440		19520	44960	21000		14250	35250	80210	13560		11230	24790
54	Groundnut	Fallow	Potato	25440		63040	88480	21000		37500	58500	146980	13560		149460	163020
55	Groundnut	Fallow	Vegetables	25440		39800	65240	21000		41250	62250	127490	13560		168950	182510
56	Ginger		Fallow	132000			132000	97500			97500	229500	220500			220500
57	Turmeric		Fallow	93420			93420	97500			97500	190920	49080			49080
58	Sweet potato	Fallow	Fallow	51650			51650	37500			37500	89150	160850			160850
59	Sweet potato	Fallow	Groundnut	51650		26440	78090	37500		25500	63000	141090	160850		48060	208910
60	Sweet potato	Fallow	Mustard	51650		19520	71170	37500		14250	51750	122920	160850		11230	172080
61	Sweet potato	Fallow	Potato	51650		63040	114690	37500		37500	75000	189690	160850		149460	310310
62	Sweet potato	Fallow	Vegetables	51650		39800	91450	37500		41250	78750	170200	160850		168950	329800
63	Potato	Fallow	Fallow	58040			58040	37500			37500	95540	104460			104460
64	Potato	Fallow	Groundnut	58040		26440	84480	37500		25500	63000	147480	104460		48060	152520
65	Potato	Fallow	Mustard	58040		19520	77560	37500		14250	51750	129310	104460		11230	115690
66	Potato	Fallow	Vegetables	58040		39800	97840	37500		41250	78750	176590	104460		168950	273410
67	Vegetables	Fallow	Fallow	38800			38800	26250			26250	65050	134950			134950
68	Vegetable	Wheat	Fallow	38800	19910		58710	26250	16800		43050	101760	134950	17290		152240
69	Vegetable	Black gram	Fallow	38800	13590		52390	26250	10200		36450	88840	134950	19210		154160
70	Vegetable	Horse gram	Fallow	38800	12840		51640	26250	9750		36000	87640	134950	37410		172360
71	Vegetables	Fallow	Groundnut	38800		26440	65240	26250		25500	51750	116990	134950		48060	183010
72	Vegetables	Fallow	Mustard	38800		19520	58320	26250		14250	40500	98820	134950		11230	146180
73	Vegetables	Fallow	Potato	38800		63040	101840	26250		37500	63750	165590	134950		149460	284410
74	Vegetables	Fallow	Vegetables	38800		39800	78600	26250		41250	67500	146100	134950		168950	303900
75	Hybrid Napier			19400			19400	22500			22500	41900	3100			3100

**Appendix J**

**Requirement of food materials as per recommended dietary allowance for the projected population of Koraput district during 2021**

Sl No.	Category	Population as per 2011 census	Projected population in 2021	Adult equivalent (88%)	Workers	Others	Annual net food requirement in MT				Remarks
							Cereals and millets	Pulses	Fats and oils	Vegetables and tubers/roots	
1	Male	678809	793256	698065	337235	360830	133121	26624	8875	127397	Workers taken as heavy and others taken as moderate for calculation of food requirement
2	Female	700838	818999	720719	348179	372540	105873	21636	7212	131531	
Total		1379647	1612255	1418784	685414	733370	238994	48260	16087	258928	

**Appendix K**

**Monthly rainall and erosion index (R) of Koraput district from 1986 to 1994**

Month	1986		1987		1988		1989		1990		1991		1992		1993		1994	
	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R
Jan.	31.60	20.68	36.00	22.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.40	7.60	0.00	0.00	0.00	0.00
Feb.	57.70	32.79	2.80	7.32	3.40	7.60	0.00	0.00	46.60	27.64	0.00	0.00	3.00	7.41	11.20	11.22	0.00	0.00
Mar.	14.80	12.89	34.90	22.21	11.80	11.50	109.30	56.74	79.30	42.82	36.70	23.05	0.00	0.00	14.00	12.52	7.10	9.31
April	31.50	20.64	43.10	26.02	82.70	44.39	9.40	10.38	26.60	18.36	39.20	24.21	71.40	39.15	26.80	18.46	105.30	54.88
May	81.10	43.65	110.60	57.34	59.40	33.58	74.80	40.73	440.50	210.41	46.40	27.55	24.60	17.43	69.40	38.22	121.40	62.35
June	199.90	98.77	103.70	54.14	82.90	44.49	281.70	136.73	184.50	91.63	263.90	128.47	120.80	62.07	155.60	78.22	187.80	93.16
July	263.80	128.42	313.20	151.34	227.60	111.63	475.30	226.56	432.70	206.79	708.50	334.76	498.30	237.23	359.90	173.01	484.00	230.60
Aug.	461.90	220.34	197.80	97.80	197.40	97.61	275.60	133.90	499.70	237.88	413.50	197.88	374.30	179.70	309.50	149.63	363.00	174.45
Sept.	136.00	69.12	139.70	70.84	186.20	92.42	165.60	82.86	283.90	137.75	157.70	79.19	283.80	137.70	316.50	152.88	488.00	232.45
Oct.	70.40	38.69	97.00	51.03	56.20	32.10	162.70	81.51	407.10	194.91	114.60	59.19	23.80	17.06	54.00	31.08	68.60	37.85
Nov.	44.80	26.81	134.30	68.34	1.00	6.48	0.00	0.00	138.50	70.28	62.40	34.97	66.90	37.06	11.00	11.12	26.00	18.08
Dec.	8.20	9.82	0.70	6.34	37.20	23.28	2.00	6.95	32.80	21.24	2.50	7.18	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total</b>	<b>1401.70</b>	<b>722.63</b>	<b>1213.80</b>	<b>635.44</b>	<b>945.80</b>	<b>505.07</b>	<b>1556.40</b>	<b>776.35</b>	<b>2572.20</b>	<b>1259.72</b>	<b>1845.40</b>	<b>916.47</b>	<b>1470.30</b>	<b>742.42</b>	<b>1327.90</b>	<b>676.35</b>	<b>1851.20</b>	<b>913.14</b>

**Contd...**

Month	1995		1996		1997		1998		1999		2000		2001		2002		2003	
	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R
Jan.	33.00	21.33	0.00	0.00	21.40	15.95	0.00	0.00	0.00	0.00	0.00	0.00	2.30	7.09	74.10	40.40	0.00	0.00
Feb.	1.20	6.58	0.00	0.00	0.00	0.00	9.80	10.57	4.00	7.88	103.20	53.90	0.00	0.00	0.00	0.00	54.00	31.08
Mar.	73.60	40.17	9.00	10.20	51.60	29.96	155.40	78.13	0.00	0.00	0.00	0.00	8.00	9.73	4.80	8.25	23.60	16.97
April	63.40	35.44	58.00	32.93	41.00	25.04	44.20	26.53	0.00	0.00	0.00	0.00	122.50	62.86	36.50	22.96	67.60	37.39
May	366.40	176.03	63.80	35.62	12.40	11.77	79.80	43.05	268.80	130.74	45.80	27.27	32.10	20.91	33.60	21.61	19.10	14.88
June	111.00	57.52	120.40	61.89	190.60	94.46	186.20	92.42	472.80	225.40	142.50	72.14	286.90	139.14	154.40	77.66	59.10	33.44
July	648.80	307.06	453.80	216.58	214.80	105.69	502.40	239.13	270.40	131.49	328.90	158.63	443.70	211.90	372.30	178.77	406.80	194.78
Aug.	385.80	185.03	380.40	182.53	248.80	121.46	94.60	49.91	244.81	119.61	317.70	153.43	304.80	147.45	363.10	174.50	509.30	242.34
Sept.	286.00	138.72	163.80	82.02	133.80	68.10	99.80	52.33	196.20	97.06	224.60	110.23	140.50	71.21	108.10	56.18	241.40	118.03
Oct.	98.20	51.58	35.40	22.45	108.80	56.50	177.80	88.52	66.60	36.92	12.50	11.82	29.80	19.85	87.30	46.53	277.30	134.69
Nov.	32.20	20.96	5.20	8.43	33.40	21.52	201.20	99.38	8.20	9.82	3.00	7.41	40.80	24.95	0.00	0.00	30.50	20.17
Dec.	0.00	0.00	0.00	0.00	35.20	22.35	0.00	0.00	0.00	0.00	11.10	11.17	0.00	0.00	0.00	0.00	92.40	48.89
<b>Total</b>	<b>2099.60</b>	<b>1040.43</b>	<b>1289.80</b>	<b>652.65</b>	<b>1091.80</b>	<b>572.82</b>	<b>1551.20</b>	<b>779.96</b>	<b>1531.81</b>	<b>758.92</b>	<b>1189.30</b>	<b>606.02</b>	<b>1411.40</b>	<b>715.09</b>	<b>1234.20</b>	<b>626.85</b>	<b>1781.10</b>	<b>892.65</b>

Contd...

Month	2004		2005		2006		2007		2008		2009		2010		2011		2012		Average	
	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R	Rainfall	R
Jan.	51.90	30.10	2.10	6.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.30	14.51	10.15	6.94
Feb.	0.40	6.21	2.80	7.32	0.00	0.00	3.40	7.60	23.80	17.06	0.00	0.00	8.60	10.01	12.00	11.59	8.60	10.01	13.20	10.14
Mar.	23.60	16.97	2.60	7.23	16.30	13.58	12.30	11.73	53.60	30.89	2.80	7.32	2.00	6.95	0.00	0.00	0.00	0.00	27.67	17.74
April	77.80	42.12	78.80	42.58	100.80	52.79	38.20	23.74	19.00	14.84	0.00	0.00	16.40	13.63	47.70	28.15	83.70	44.86	49.32	28.23
May	65.40	36.37	6.80	9.18	170.50	85.13	76.40	41.47	21.80	16.14	54.80	31.45	93.00	49.17	28.60	19.29	22.30	16.37	92.21	48.80
June	409.40	195.98	257.10	125.31	193.60	95.85	638.80	302.42	178.40	88.80	98.20	51.58	127.00	64.95	143.70	72.70	199.30	98.50	205.56	101.40
July	333.40	160.72	252.80	123.32	548.60	260.57	106.30	55.34	196.00	96.96	422.00	201.83	430.00	205.54	328.80	158.58	358.80	172.50	384.51	184.43
Aug.	346.00	166.56	158.10	79.38	719.20	339.73	299.20	144.85	359.00	172.60	248.00	121.09	226.00	110.88	247.70	120.95	511.90	243.54	335.45	161.67
Sept.	215.20	105.87	388.60	186.33	343.70	165.50	315.90	152.60	232.00	113.67	42.10	25.55	417.00	199.51	317.90	153.53	262.70	127.91	232.84	114.06
Oct.	152.60	76.83	110.80	57.43	51.60	29.96	124.20	63.65	10.20	10.75	37.90	23.61	112.70	58.31	17.70	14.23	63.60	35.53	97.39	51.21
Nov.	1.60	6.76	11.30	11.26	12.10	11.63	1.40	6.67	3.40	7.60	5.00	8.34	100.00	52.42	0.00	0.00	87.90	46.81	39.34	23.60
Dec.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.20	26.06	7.50	9.50	0.00	0.00	10.10	7.14
<b>Total</b>	<b>1677.30</b>	<b>844.49</b>	<b>1271.80</b>	<b>656.34</b>	<b>2156.40</b>	<b>1054.75</b>	<b>1616.10</b>	<b>810.07</b>	<b>1097.20</b>	<b>569.30</b>	<b>910.80</b>	<b>470.77</b>	<b>1575.90</b>	<b>797.44</b>	<b>1151.60</b>	<b>588.52</b>	<b>1617.10</b>	<b>810.53</b>	<b>1497.74</b>	<b>755.38</b>

Appendix L

Estimated soil loss from existing cropping pattern

Sl. No.	Kharif	Pre rabi	Rabi	Kharif						Pre rabi						Rabi						Total soil loss (t/ha/yr)
				R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	
1	Early rice	Fallow	Mustard	447.5	0.12	1.7	0.28	0.73	18.66	165.27	0.12	1.7	1	0.7	24.61	47.82	0.12	1.7	0.3	0.73	2.14	45.41
2	Early rice	Fallow	Ragi	447.5	0.12	1.7	0.28	0.73	18.66	165.27	0.12	1.7	1	0.7	24.61	47.82	0.12	1.7	0.17	0.73	1.21	44.48
3	Rice	Fallow	Fallow	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	38.16
4	Rice	Fallow	Field pea	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.38	0.73	2.71	33.75
5	Rice	Fallow	Cowpea	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.38	0.73	2.71	33.75
6	Rice	Fallow	Gram	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.38	0.73	2.71	33.75
7	Rice	Fallow	Wheat	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.25	0.73	1.78	32.82
8	Rice	Fallow	Vegetables	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.33	0.73	2.35	33.39
9	Rice	Fallow	Mung	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.41	0.73	2.92	33.96
10	Rice	Fallow	Rice	561.6	0.12	1.7	0.28	0.73	23.42	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.28	0.73	1.99	33.04
11	Ragi	Fallow	Fallow	485.5	0.12	1.7	0.17	0.73	12.29	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	1	0.73	7.12	38.36
12	Ragi	Fallow	Kulthi	485.5	0.12	1.7	0.17	0.73	12.29	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	0.45	0.73	3.20	34.45
13	Maize	Fallow	Fallow	485.5	0.12	1.7	0.45	0.73	32.54	115.21	0.12	1.7	1	0.7	17.16	59.86	0.12	1.7	1	0.73	8.91	58.61
14	Maize	Fallow	Kulthi	485.5	0.12	1.7	0.45	0.73	32.54	115.21	0.12	1.7	1	0.7	17.16	59.86	0.12	1.7	0.45	0.73	4.01	53.71
15	Maize	Fallow	Maize	485.5	0.12	1.7	0.45	0.73	32.54	115.21	0.12	1.7	1	0.7	17.16	59.86	0.12	1.7	0.45	0.73	4.01	53.71
16	Jowar	Fallow	Fallow	578.6	0.12	1.7	0.17	0.73	14.65	34.14	0.12	1.7	1	0.7	5.08	47.82	0.12	1.7	1	0.73	7.12	26.85
17	Bajra	Fallow	Fallow	561.6	0.12	1.7	0.17	0.73	14.22	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	28.96
18	Small millets	Fallow	Fallow	561.6	0.12	1.7	0.17	0.73	14.22	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	28.96
19	Small millets	Fallow	Black gram	561.6	0.12	1.7	0.17	0.73	14.22	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.49	0.73	3.49	25.33
20	Small millets	Fallow	Other pulses	561.6	0.12	1.7	0.17	0.73	14.22	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.41	0.73	2.92	24.76

Sl. No.	Kharif	Pre rabi	Rabi	Kharif						Pre rabi						Rabi						Total soil loss (t/ha/yr)
				R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	
21	Mung	Fallow	Fallow	339.7	0.12	1.7	0.41	0.73	20.74	273.05	0.12	1.7	1	0.7	40.66	47.82	0.12	1.7	1	0.73	7.12	68.53
22	Black gram	Fallow	Fallow	393.6	0.12	1.7	0.49	0.73	28.72	219.16	0.12	1.7	1	0.7	32.64	47.82	0.12	1.7	1	0.73	7.12	68.48
23	Arhar	Fallow	Fallow	578.6	0.12	1.7	0.38	0.73	32.74	0	0.12	1.7	1	0.7	0.00	81.96	0.12	1.7	1	0.73	12.21	44.95
24	Other pulses	Fallow	Fallow	561.6	0.12	1.7	0.41	0.73	34.29	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	49.03
25	Other pulses	Fallow	Chilly	561.6	0.12	1.7	0.41	0.73	34.29	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.33	0.73	2.35	44.26
26	Other pulses	Fallow	Coriander	561.6	0.12	1.7	0.41	0.73	34.29	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.33	0.73	2.35	44.26
27	Sweet potato	Fallow	Fallow	561.6	0.12	1.7	0.33	0.73	27.60	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	42.34
28	Vegetable	Fallow	Fallow	485.5	0.12	1.7	0.33	0.73	23.86	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	1	0.73	7.12	49.93
29	Vegetable	Fallow	vegetable	485.5	0.12	1.7	0.33	0.73	23.86	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	0.33	0.73	2.35	45.16
30	Vegetable	Fallow	Groundnut	485.5	0.12	1.7	0.33	0.73	23.86	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	0.36	0.73	2.56	45.37
31	vegetable	Fallow	Other oilseeds	485.5	0.12	1.7	0.33	0.73	23.86	127.25	0.12	1.7	1	0.7	18.95	47.82	0.12	1.7	0.36	0.73	2.56	45.37
32	Groundnut	Fallow	Fallow	523.5	0.12	1.7	0.36	0.73	28.07	89.23	0.12	1.7	1	0.7	13.29	47.82	0.12	1.7	1	0.73	7.12	48.48
33	Niger	Fallow	Fallow	628.5	0.12	1.7	0.49	0.73	45.86	0	0.12	1.7	1	0.7	0.00	32.09	0.12	1.7	1	0.73	4.78	50.64
34	Other oilseeds	Fallow	Fallow	561.6	0.12	1.7	0.36	0.73	30.11	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	44.85
35	Fibres	Fallow	Fallow	561.6	0.12	1.7	0.36	0.73	30.11	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	44.85
36	Chilly	Fallow	Fallow	561.6	0.12	1.7	0.33	0.73	27.60	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	1	0.73	7.12	42.34
37	Chilly	Fallow	Garlic	561.6	0.12	1.7	0.33	0.73	27.60	51.21	0.12	1.7	1	0.7	7.63	47.82	0.12	1.7	0.33	0.73	2.35	37.57
38	Ginger	Fallow	Fallow	650.5	0.12	1.7	0.3	0.73	29.06	0	0.12	1.7	1	0.7	0.00	10.14	0.12	1.7	1	0.73	1.51	30.57
39	Turmeric	Fallow	Fallow	650.5	0.12	1.7	0.35	0.73	33.90	0	0.12	1.7	1	0.7	0.00	10.14	0.12	1.7	1	0.73	1.51	35.41
40	Fallow	Fallow	Fallow	447.5	0.12	1.7	1	0.73	66.64	188.87	0.12	1.7	1	0.7	28.13	24.22	0.12	1.7	1	0.73	3.61	98.38

## Appendix M

### Estimated soil loss from suggested cropping pattern

Sl.No.	Cropping sequence	Kharif	Pre Rabi	Rabi	Kharif						Pre Rabi						Rabi						Total soil loss (t/ha/yr)
					R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	
1	1	Early Rice	Fallow	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	131.84	0.12	1.7	1	0.73	19.63	24.22	0.12	1.7	1	0.73	3.61	42.16
2	2	Early rice	Wheat	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	145.92	0.12	1.7	0.25	0.73	5.43	10.14	0.12	1.7	1	0.73	1.51	25.87
3	3	Early rice	Black gram	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	138.98	0.12	1.7	0.49	0.73	10.14	17.08	0.12	1.7	1	0.73	2.54	31.61
4	4	Early rice	Horse gram	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	138.98	0.12	1.7	0.45	0.73	9.31	17.08	0.12	1.7	1	0.73	2.54	30.78
5	5	Early rice	Fallow	Groundnut	453.83	0.12	1.7	0.28	0.73	18.92	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.36	0.73	2.56	37.61
6	6	Early rice	Niger	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	140.13	0.12	1.7	0.49	0.73	10.23	15.93	0.12	1.7	1	0.73	2.37	31.52
7	7	Early rice	Mustard	Fallow	453.83	0.12	1.7	0.28	0.73	18.92	115.21	0.12	1.7	0.3	0.73	5.15	40.85	0.12	1.7	1	0.73	6.08	30.15
8	8	Early rice	Fallow	Mustard	453.83	0.12	1.7	0.28	0.73	18.92	123.97	0.12	1.7	1	0.73	18.46	32.09	0.12	1.7	0.3	0.73	1.43	38.82
9	9	Early rice	Fallow	Potato	453.83	0.12	1.7	0.28	0.73	18.92	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.25	0.73	1.78	36.82
10	10	Early rice	Fallow	Vegetables	453.83	0.12	1.7	0.28	0.73	18.92	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.33	0.73	2.35	37.39
11	11	Rice	Fallow	Fallow	536.46	0.12	1.7	0.28	0.73	22.37	49.2	0.12	1.7	1	0.73	7.33	24.23	0.12	1.7	1	0.73	3.61	33.30
12	12	Rice	Fallow	Groundnut	536.46	0.12	1.7	0.28	0.73	22.37	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.36	0.73	2.56	28.75
13	13	Rice	Fallow	Mustard	536.46	0.12	1.7	0.28	0.73	22.37	41.34	0.12	1.7	1	0.73	6.16	32.09	0.12	1.7	0.3	0.73	1.43	29.96
14	14	Rice	Fallow	Potato	536.46	0.12	1.7	0.28	0.73	22.37	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.25	0.73	1.78	27.96
15	15	Rice	Fallow	Vegetables	536.46	0.12	1.7	0.28	0.73	22.37	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.33	0.73	2.35	28.53
16	16	Ragi	Fallow	Fallow	491.85	0.12	1.7	0.17	0.73	12.45	93.82	0.12	1.7	1	0.73	13.97	24.22	0.12	1.7	1	0.73	3.61	30.03
17	17	Ragi	Wheat	Fallow	491.85	0.12	1.7	0.17	0.73	12.45	107.9	0.12	1.7	0.25	0.73	4.02	10.14	0.12	1.7	1	0.73	1.51	17.98
18	18	Ragi	Black gram	Fallow	491.85	0.12	1.7	0.17	0.73	12.45	100.96	0.12	1.7	0.49	0.73	7.37	17.08	0.12	1.7	1	0.73	2.54	22.36
19	19	Ragi	Horse gram	Fallow	491.85	0.12	1.7	0.17	0.73	12.45	100.96	0.12	1.7	0.45	0.73	6.77	17.08	0.12	1.7	1	0.73	2.54	21.76
20	20	Ragi	Fallow	Groundnut	491.85	0.12	1.7	0.17	0.73	12.45	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.36	0.73	2.56	25.47
21	21	Ragi	Fallow	Mustard	491.85	0.12	1.7	0.17	0.73	12.45	85.95	0.12	1.7	1	0.73	12.80	32.09	0.12	1.7	0.3	0.73	1.43	26.69
22	22	Ragi	Fallow	Potato	491.85	0.12	1.7	0.17	0.73	12.45	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.25	0.73	1.78	24.69
23	23	Ragi	Fallow	vegetables	491.85	0.12	1.7	0.17	0.73	12.45	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.33	0.73	2.35	25.26
24	24	Maize	Fallow	Fallow	491.85	0.12	1.7	0.45	0.73	32.96	93.82	0.12	1.7	1	0.73	13.97	24.22	0.12	1.7	1	0.73	3.61	50.54
25	25	Maize	Wheat	Fallow	491.85	0.12	1.7	0.45	0.73	32.96	107.9	0.12	1.7	0.25	0.73	4.02	10.14	0.12	1.7	1	0.73	1.51	38.49

Contd...

Sl.No.	Cropping sequence	Kharif	Pre Rabi	Rabi	Kharif						Pre Rabi						Rabi						Total soil loss (t/ha/yr)
					R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	
26	26	Maize	Black gram	Fallow	491.85	0.12	1.7	0.45	0.73	32.96	100.96	0.12	1.7	0.49	0.73	7.37	17.08	0.12	1.7	1	0.73	2.54	42.87
27	27	Maize	Horse gram	Fallow	491.85	0.12	1.7	0.45	0.73	32.96	100.96	0.12	1.7	0.45	0.73	6.77	17.08	0.12	1.7	1	0.73	2.54	42.27
28	28	Maize	Fallow	Groundnut	491.85	0.12	1.7	0.45	0.73	32.96	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.36	0.73	2.56	45.98
29	29	Maize	Fallow	Mustard	491.85	0.12	1.7	0.45	0.73	32.96	85.95	0.12	1.7	1	0.73	12.80	32.09	0.12	1.7	0.3	0.73	1.43	47.19
30	30	Maize	Fallow	Potato	491.85	0.12	1.7	0.45	0.73	32.96	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.25	0.73	1.78	45.20
31	31	Maize	Fallow	Vegetables	491.85	0.12	1.7	0.45	0.73	32.96	70.22	0.12	1.7	1	0.73	10.46	47.82	0.12	1.7	0.33	0.73	2.35	45.77
32	32	Green gram	Fallow	Fallow	369.85	0.12	1.7	0.41	0.73	22.58	215.81	0.12	1.7	1	0.73	32.14	24.23	0.12	1.7	1	0.73	3.61	58.33
33	33	Green gram	Wheat	Fallow	369.85	0.12	1.7	0.41	0.73	22.58	229.89	0.12	1.7	0.25	0.73	8.56	10.15	0.12	1.7	1	0.73	1.51	32.65
34	34	Green gram	Fallow	Groundnut	369.85	0.12	1.7	0.41	0.73	22.58	192.21	0.12	1.7	1	0.73	28.62	47.83	0.12	1.7	0.36	0.73	2.56	53.77
35	35	Green gram	Niger	Fallow	369.85	0.12	1.7	0.41	0.73	22.58	224.1	0.12	1.7	0.49	0.73	16.35	15.94	0.12	1.7	1	0.73	2.37	41.31
36	36	Green gram	Mustard	Fallow	369.85	0.12	1.7	0.41	0.73	22.58	218.19	0.12	1.7	0.3	0.73	9.75	21.85	0.12	1.7	1	0.73	3.25	35.58
37	37	Green gram	Fallow	Mustard	369.85	0.12	1.7	0.41	0.73	22.58	207.94	0.12	1.7	1	0.73	30.97	32.1	0.12	1.7	0.3	0.73	1.43	54.98
38	38	Green gram	Fallow	Potato	369.85	0.12	1.7	0.41	0.73	22.58	192.21	0.12	1.7	1	0.73	28.62	47.83	0.12	1.7	0.25	0.73	1.78	52.99
39	39	Green gram	Fallow	Vegetables	369.85	0.12	1.7	0.41	0.73	22.58	192.21	0.12	1.7	1	0.73	28.62	47.83	0.12	1.7	0.33	0.73	2.35	53.56
40	40	Black gram	Fallow	Fallow	415.81	0.12	1.7	0.49	0.73	30.34	169.86	0.12	1.7	1	0.73	25.30	24.22	0.12	1.7	1	0.73	3.61	59.24
41	41	Black gram	Wheat	Fallow	415.81	0.12	1.7	0.49	0.73	30.34	183.94	0.12	1.7	0.25	0.73	6.85	10.14	0.12	1.7	1	0.73	1.51	38.70
42	42	Black gram	Niger	Fallow	415.81	0.12	1.7	0.49	0.73	30.34	178.15	0.12	1.7	0.49	0.73	13.00	15.93	0.12	1.7	1	0.73	2.37	45.71
43	43	Black gram	Mustard	Fallow	415.81	0.12	1.7	0.49	0.73	30.34	172.24	0.12	1.7	0.3	0.73	7.69	21.84	0.12	1.7	1	0.73	3.25	41.29
44	44	Black gram	Fallow	Mustard	415.81	0.12	1.7	0.49	0.73	30.34	161.99	0.12	1.7	1	0.73	24.12	32.09	0.12	1.7	0.3	0.73	1.43	55.90
45	45	Black gram	Fallow	Potato	415.81	0.12	1.7	0.49	0.73	30.34	146.26	0.12	1.7	1	0.73	21.78	47.82	0.12	1.7	0.25	0.73	1.78	53.90
46	46	Black gram	Fallow	Vegetables	415.81	0.12	1.7	0.49	0.73	30.34	146.26	0.12	1.7	1	0.73	21.78	47.82	0.12	1.7	0.33	0.73	2.35	54.47
47	47	Arhar	Fallow	Fallow	562.07	0.12	1.7	0.38	0.73	31.81	23.6	0.12	1.7	1	0.73	3.51	24.22	0.12	1.7	1	0.73	3.61	38.93
48	48	Arhar	Fallow	Groundnut	562.07	0.12	1.7	0.38	0.73	31.81	0	0.12	1.7	1	0.73	0.00	47.82	0.12	1.7	0.36	0.73	2.56	34.37
49	49	Arhar	Fallow	Mustard	562.07	0.12	1.7	0.38	0.73	31.81	15.73	0.12	1.7	1	0.73	2.34	32.09	0.12	1.7	0.3	0.73	1.43	35.58
50	50	Arhar	Fallow	Potato	562.07	0.12	1.7	0.38	0.73	31.81	0	0.12	1.7	1	0.73	0.00	47.82	0.12	1.7	0.25	0.73	1.78	33.59

Contd...

Sl.No.	Cropping sequence	Kharif	Pre Rabi	Rabi	Kharif						Pre Rabi						Rabi						Total soil loss (t/ha/yr)
					R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	R	K	LS	C	P	Soil loss (t/ha/yr)	
51	51	Arhar	Fallow	Vegetables	562.07	0.12	1.7	0.38	0.73	31.81	0	0.12	1.7	1	0.73	0.00	47.82	0.12	1.7	0.33	0.73	2.35	34.16
52	52	Groundnut	Fallow	Fallow	519.39	0.12	1.7	0.36	0.73	27.85	66.27	0.12	1.7	1	0.73	9.87	24.23	0.12	1.7	1	0.73	3.61	41.32
53	53	Groundnut	Fallow	Mustard	519.39	0.12	1.7	0.36	0.73	27.85	58.4	0.12	1.7	1	0.73	8.70	32.1	0.12	1.7	0.3	0.73	1.43	37.98
54	54	Groundnut	Fallow	Potato	519.39	0.12	1.7	0.36	0.73	27.85	42.67	0.12	1.7	1	0.73	6.35	47.83	0.12	1.7	0.25	0.73	1.78	35.98
55	55	Groundnut	Fallow	Vegetables	519.39	0.12	1.7	0.36	0.73	27.85	42.67	0.12	1.7	1	0.73	6.35	47.83	0.12	1.7	0.33	0.73	2.35	36.55
56	56	Ginger		Fallow	596.28	0.12	1.7	0.3	0.73	26.64	0	0.12	1.7	0.3	0.73	0.00	13.61	0.12	1.7	1	0.73	2.03	28.67
57	57	Turmeric		Fallow	596.28	0.12	1.7	0.35	0.73	31.08	0	0.12	1.7	0.35	0.73	0.00	13.61	0.12	1.7	1	0.73	2.03	33.11
58	58	Sweet potato	Fallow	Fallow	536.46	0.12	1.7	0.33	0.73	26.36	49.2	0.12	1.7	1	0.73	7.33	24.23	0.12	1.7	1	0.73	3.61	37.30
59	59	Sweet potato	Fallow	Groundnut	536.46	0.12	1.7	0.33	0.73	26.36	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.36	0.73	2.56	32.74
60	60	Sweet potato	Fallow	Mustard	536.46	0.12	1.7	0.33	0.73	26.36	41.34	0.12	1.7	1	0.73	6.16	32.09	0.12	1.7	0.3	0.73	1.43	33.95
61	61	Sweet potato	Fallow	Potato	536.46	0.12	1.7	0.33	0.73	26.36	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.25	0.73	1.78	31.96
62	62	Sweet potato	Fallow	Vegetables	536.46	0.12	1.7	0.33	0.73	26.36	25.6	0.12	1.7	1	0.73	3.81	47.83	0.12	1.7	0.33	0.73	2.35	32.53
63	63	Potato	Fallow	Fallow	562.07	0.12	1.7	0.25	0.73	20.93	23.6	0.12	1.7	1	0.73	3.51	24.22	0.12	1.7	1	0.73	3.61	28.05
64	64	Potato	Fallow	Groundnut	562.07	0.12	1.7	0.25	0.73	20.93	0	0.12	1.7	1	0.73	0.00	47.82	0.12	1.7	0.36	0.73	2.56	23.49
65	65	Potato	Fallow	Mustard	562.07	0.12	1.7	0.25	0.73	20.93	15.73	0.12	1.7	1	0.73	2.34	32.09	0.12	1.7	0.3	0.73	1.43	24.70
66	66	Potato	Fallow	Vegetables	562.07	0.12	1.7	0.25	0.73	20.93	0	0.12	1.7	1	0.73	0.00	47.82	0.12	1.7	0.33	0.73	2.35	23.28
67	67	Vegetables	Fallow	Fallow	453.83	0.12	1.7	0.33	0.73	22.30	131.84	0.12	1.7	1	0.73	19.63	24.22	0.12	1.7	1	0.73	3.61	45.54
68	68	Vegetable	Wheat	Fallow	453.83	0.12	1.7	0.33	0.73	22.30	145.92	0.12	1.7	0.25	0.73	5.43	10.14	0.12	1.7	1	0.73	1.51	29.25
69	69	Vegetable	Black gram	Fallow	453.83	0.12	1.7	0.33	0.73	22.30	138.98	0.12	1.7	0.49	0.73	10.14	17.08	0.12	1.7	1	0.73	2.54	34.99
70	70	Vegetable	Horse gram	Fallow	453.83	0.12	1.7	0.33	0.73	22.30	138.98	0.12	1.7	0.45	0.73	9.31	17.08	0.12	1.7	1	0.73	2.54	34.16
71	71	Vegetables	Fallow	Groundnut	453.83	0.12	1.7	0.33	0.73	22.30	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.36	0.73	2.56	40.99
72	72	Vegetables	Fallow	Mustard	453.83	0.12	1.7	0.33	0.73	22.30	123.97	0.12	1.7	1	0.73	18.46	32.09	0.12	1.7	0.3	0.73	1.43	42.20
73	73	Vegetables	Fallow	Potato	453.83	0.12	1.7	0.33	0.73	22.30	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.25	0.73	1.78	40.20
74	74	Vegetables	Fallow	Vegetables	453.83	0.12	1.7	0.33	0.73	22.30	108.24	0.12	1.7	1	0.73	16.12	47.82	0.12	1.7	0.33	0.73	2.35	40.77
75	75	Hybrid Napier			660.59	0.12	2.46	0.03	0.73	4.27	0	0.12	2.46	0.03	0.73	0.00	0	0.12	2.46	0.03	0.73	0.00	4.27
76	76	Fallow	Fallow	Fallow	434.82	0.12	1.7	1	0.73	64.75	152.04	0.12	1.7	1	0.73	22.64	23.03	0.12	1.7	1	0.73	3.43	90.82

**Total rainfall (mm) and resulting effective rainfall (mm) during *kharif* (June to October) at 80% and 60% probability levels using USDA Soil Conservation Service method**

Month	Rainfall at 80% probability level (mm)	Effective Rainfall (mm)	Rainfall at 60% probability level (mm)	Effective Rainfall (mm)
June	113.28	92.8	150.69	114.4
July	263.78	151.4	345.55	159.6
August	225.41	144.1	288.20	153.8
September	138.33	107.7	195.92	134.5
October	32.26	30.6	60.66	54.8
<b>Total</b>	<b>773.06</b>	<b>526.6</b>	<b>1041.02</b>	<b>617.1</b>

Total water available in *kharif* from cultivable land = Total cultivable land (ha) x Effective Rainfall (m)

$$= 304000 \times 0.5266 = 160086.4 \text{ ha-m (At 80% probability level)}$$

$$= 304000 \times 0.6171 = 187598.4 \text{ ha-m (At 60% probability level)}$$

## Appendix O

### Monthly and annual runoff yield from rainfall in Koraput district using USDA SCS Curve Number method from 1986 to 2012 (Runoff in mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1986	4.7	7.6	0.0	15.4	17.9	22.2	69.1	100.9	23.6	11.9	13.6	4.6	291.6
1987	3.7	6.8	18.0	8.3	26.7	19.8	74.0	48.5	34.7	36.9	34.4	34.4	346.2
1988	0.0	2.5	3.7	15.1	12.7	19.7	54.5	38.4	36.2	4.9	3.6	1.0	192.3
1989	0.0	0.0	15.0	4.0	15.0	41.4	49.3	41.9	27.4	41.6	0.0	3.1	238.7
1990	0.0	4.5	3.6	10.1	148.6	62.5	112.5	125.7	75.9	113.1	21.8	3.2	681.5
1991	0.0	0.0	4.8	9.7	1.1	49.1	268.8	68.3	25.7	26.9	14.2	2.9	471.4
1992	2.5	2.6	0.0	9.9	13.9	20.0	137.0	80.4	84.8	11.9	9.9	0.0	373.0
1993	0.0	3.6	5.5	6.8	13.8	19.3	90.5	87.4	56.0	9.6	0.4	0.0	292.9
1994	0.0	0.0	1.2	13.6	14.6	44.3	96.8	80.8	166.0	18.0	11.0	0.0	446.3
1995	7.2	3.5	7.9	11.3	106.0	19.7	217.2	42.1	137.5	48.8	2.6	0.0	603.7
1996	0.0	0.0	0.7	23.8	10.2	22.3	98.3	48.2	42.6	17.1	1.8	0.0	264.8
1997	11.5	0.0	3.9	23.7	26.8	0.0	52.4	37.8	23.2	31.4	8.3	5.3	224.3
1998	0.0	0.6	38.3	3.4	24.6	26.4	83.5	41.2	39.0	28.2	65.2	0.0	350.4
1999	0.0	2.2	0.0	0.0	37.8	208.7	32.6	29.2	36.1	11.1	4.6	0.0	362.3
2000	0.0	7.0	0.0	0.0	20.6	31.4	60.8	40.5	56.8	8.3	2.6	0.4	228.4
2001	2.9	0.0	8.5	25.2	9.3	72.8	161.3	73.3	40.0	21.6	14.5	0.0	429.5
2002	12.2	0.0	1.9	3.8	12.4	26.5	105.0	93.6	28.8	15.4	0.0	0.0	299.6
2003	0.0	8.2	12.9	9.2	8.3	22.8	69.6	117.4	68.1	66.7	9.8	19.4	412.3
2004	0.4	3.9	5.0	9.3	3.4	191.4	82.8	87.8	66.8	31.4	3.3	0.0	485.3
2005	7.1	2.7	2.8	17.2	13.0	53.0	77.2	37.2	166.5	26.1	7.4	0.0	410.3
2006	0.0	0.0	5.5	14.7	29.4	25.4	155.8	291.3	44.7	15.6	5.8	0.0	588.2
2007	0.0	2.5	0.2	12.5	12.1	226.5	22.6	51.7	69.9	33.1	3.4	0.0	434.4
2008	0.0	3.4	7.9	1.3	0.3	41.2	57.6	95.7	38.6	0.5	6.5	0.0	252.9
2009	0.0	0.0	6.8	0.0	11.0	4.2	100.0	41.4	16.9	4.5	18.0	0.0	202.7
2010	33.2	4.7	7.2	2.5	18.0	26.2	72.6	53.4	132.0	39.6	34.0	9.7	433.0
2011	0.0	3.3	0.0	24.2	5.5	38.4	66.2	77.0	54.7	2.7	0.0	9.1	281.1
2012	12.4	0.8	0.0	15.0	19.7	41.1	73.3	105.9	53.3	21.6	11.7	0.0	354.9
Avg.	3.6	2.6	6.0	10.7	23.4	51.0	94.1	75.4	61.0	25.9	11.4	3.4	368.6

**Total runoff yield from rainfall from June to February at 80% and 60% probability levels using Curve Number method**

<b>Month</b>	<b>Runoff at 80% probability level (mm)</b>	<b>Runoff at 60% probability level (mm)</b>
June	15.92	26.18
July	52.62	71.80
August	39.40	53.24
September	29.94	41.44
October	8.38	16.47
November	1.79	5.10
December	0	0
January	0	0
February	0	1.49
<b>Total</b>	<b>148.05</b>	<b>215.72</b>

Total water available in *rabi* from cultivable land = Total cultivable land (ha) x Runoff produced from rainfall (m)  
 = 304000 x 0.14805 = 45007.2 ha-m (At 80 % probability level)  
 = 304000 x 0.21572 = 65578.88 ha-m (At 60 % probability level)

## I. Equations for objective functions

### a) Minimization of soil loss

$$\begin{aligned}
 Z_1 = & 42.16 a_1 + 25.87 a_2 + 31.61 a_3 + 30.78 a_4 + 37.61 a_5 + 31.52 a_6 + 30.15 a_7 + 38.82 a_8 + 36.82 a_9 + 37.39 a_{10} + 33.30 a_{11} + 28.75 a_{12} + 29.96 a_{13} + 27.96 a_{14} \\
 & + 28.53 a_{15} + 30.03 a_{16} + 17.98 a_{17} + 22.36 a_{18} + 21.76 a_{19} + 25.47 a_{20} + 26.69 a_{21} + 24.69 a_{22} + 25.26 a_{23} + 50.54 a_{24} + 38.49 a_{25} + 42.87 a_{26} + 42.27 a_{27} + 45.98 a_{28} \\
 & + 47.19 a_{29} + 45.20 a_{30} + 45.77 a_{31} + 58.33 a_{32} + 32.65 a_{33} + 53.77 a_{34} + 41.31 a_{35} + 35.58 a_{36} + 54.98 a_{37} + 52.99 a_{38} + 53.56 a_{39} + 59.24 a_{40} + 38.70 a_{41} + 45.71 a_{42} \\
 & + 41.29 a_{43} + 55.90 a_{44} + 53.90 a_{45} + 54.47 a_{46} + 38.93 a_{47} + 34.37 a_{48} + 35.58 a_{49} + 33.59 a_{50} + 34.16 a_{51} + 41.32 a_{52} + 37.98 a_{53} + 35.98 a_{54} + 36.55 a_{55} + 28.67 a_{56} \\
 & + 33.11 a_{57} + 37.30 a_{58} + 32.74 a_{59} + 33.95 a_{60} + 31.96 a_{61} + 32.53 a_{62} + 28.05 a_{63} + 23.49 a_{64} + 24.70 a_{65} + 23.28 a_{66} + 45.54 a_{67} + 29.25 a_{68} + 34.99 a_{69} + 34.16 a_{70} \\
 & + 40.99 a_{71} + 42.20 a_{72} + 40.20 a_{73} + 40.77 a_{74} + 4.27 a_{75}
 \end{aligned}$$

### b) Minimization of investment

$$\begin{aligned}
 Z_2 = & 30630 a_1 + 67340 a_2 + 54420 a_3 + 53220 a_4 + 82570 a_5 + 55610 a_6 + 54340 a_7 + 64400 a_8 + 131170 a_9 + 111680 a_{10} + 35420 a_{11} + 87360 a_{12} + 69190 a_{13} + 135960 \\
 & a_{14} + 116470 a_{15} + 25080 a_{16} + 61790 a_{17} + 48870 a_{18} + 47670 a_{19} + 77020 a_{20} + 58850 a_{21} + 125620 a_{22} + 106130 a_{23} + 41660 a_{24} + 78370 a_{25} + 65450 a_{26} + 64250 a_{27} \\
 & + 93600 a_{28} + 75430 a_{29} + 142200 a_{30} + 122710 a_{31} + 23790 a_{32} + 60500 a_{33} + 75730 a_{34} + 48770 a_{35} + 47500 a_{36} + 57560 a_{37} + 124330 a_{38} + 104840 a_{39} + 23790 a_{40} \\
 & + 60500 a_{41} + 48770 a_{42} + 47500 a_{43} + 57560 a_{44} + 124330 a_{45} + 104840 a_{46} + 29340 a_{47} + 81280 a_{48} + 63110 a_{49} + 129880 a_{50} + 110390 a_{51} + 46440 a_{52} + 80210 a_{53} \\
 & + 146980 a_{54} + 127490 a_{55} + 229500 a_{56} + 190920 a_{57} + 89150 a_{58} + 141090 a_{59} + 122920 a_{60} + 189690 a_{61} + 170200 a_{62} + 95540 a_{63} + 147480 a_{64} + 129310 a_{65} \\
 & + 176590 a_{66} + 65050 a_{67} + 101760 a_{68} + 88840 a_{69} + 87640 a_{70} + 116990 a_{71} + 98820 a_{72} + 165590 a_{73} + 146100 a_{74} + 41900 a_{75}
 \end{aligned}$$

**c) Maximization of net return**

$$Z_3 = 8670 a_1 + 25960 a_2 + 27880 a_3 + 46080 a_4 + 56730 a_5 + 18690 a_6 + 14960 a_7 + 19900 a_8 + 158130 a_9 + 177620 a_{10} + 10430 a_{11} + 58490 a_{12} + 21660 a_{13} + 159890 a_{14} + 179380 a_{15} + 4920 a_{16} + 22210 a_{17} + 24130 a_{18} + 42330 a_{19} + 52980 a_{20} + 16150 a_{21} + 154380 a_{22} + 173870 a_{23} + 10740 a_{24} + 28030 a_{25} + 29950 a_{26} + 48150 a_{27} + 58800 a_{28} + 21970 a_{29} + 160200 a_{30} + 179690 a_{31} + 21210 a_{32} + 38500 a_{33} + 69270 a_{34} + 31230 a_{35} + 27500 a_{36} + 32440 a_{37} + 170670 a_{38} + 190160 a_{39} + 19210 a_{40} + 36500 a_{41} + 29230 a_{42} + 25500 a_{43} + 30440 a_{44} + 168670 a_{45} + 188160 a_{46} + 56660 a_{47} + 104720 a_{48} + 67890 a_{49} + 206120 a_{50} + 225610 a_{51} + 13560 a_{52} + 24790 a_{53} + 163020 a_{54} + 182510 a_{55} + 220500 a_{56} + 49080 a_{57} + 160850 a_{58} + 208910 a_{59} + 172080 a_{60} + 310310 a_{61} + 329800 a_{62} + 104460 a_{63} + 152520 a_{64} + 115690 a_{65} + 273410 a_{66} + 134950 a_{67} + 152240 a_{68} + 154160 a_{69} + 172360 a_{70} + 183010 a_{71} + 146180 a_{72} + 284410 a_{73} + 303900 a_{74} + 3100 a_{75}$$

**II. Equations for the constraints**

**a) Area constraints**

$$a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 + a_8 + a_9 + a_{10} + a_{11} + a_{12} + a_{13} + a_{14} + a_{15} + a_{16} + a_{17} + a_{18} + a_{19} + a_{20} + a_{21} + a_{22} + a_{23} + a_{24} + a_{25} + a_{26} + a_{27} + a_{28} + a_{29} + a_{30} + a_{31} + a_{32} + a_{33} + a_{34} + a_{35} + a_{36} + a_{37} + a_{38} + a_{39} + a_{40} + a_{41} + a_{42} + a_{43} + a_{44} + a_{45} + a_{46} + a_{47} + a_{48} + a_{49} + a_{50} + a_{51} + a_{52} + a_{53} + a_{54} + a_{55} + a_{56} + a_{57} + a_{58} + a_{59} + a_{60} + a_{61} + a_{62} + a_{63} + a_{64} + a_{65} + a_{66} + a_{67} + a_{68} + a_{69} + a_{70} + a_{71} + a_{72} + a_{73} + a_{74} + a_{75} \leq 304000 \text{ ha (Total cultivable area)}$$

**b) Land type constraints**

- $a_6 + a_{16} + a_{35} + a_{42} + a_{56} + a_{57} + a_{58} + a_{75} + a_{76} \leq 187000 \text{ ha (Upland)}$
- $a_2 + a_5 + a_8 + a_9 + a_{10} + a_{12} + a_{13} + a_{14} + a_{15} + a_{17} + a_{20} + a_{21} + a_{22} + a_{23} + a_{25} + a_{28} + a_{29} + a_{30} + a_{31} + a_{33} + a_{34} + a_{37} + a_{38} + a_{39} + a_{41} + a_{44} + a_{45} + a_{46} + a_{48} + a_{49} + a_{50} + a_{51} + a_{53} + a_{54} + a_{55} + a_{59} + a_{60} + a_{61} + a_{62} + a_{63} + a_{64} + a_{65} + a_{66} + a_{68} + a_{69} + a_{70} + a_{71} + a_{72} + a_{73} + a_{74} \leq 79000 \text{ ha (Medium land)}$
- $a_1 + a_3 + a_4 + a_7 + a_{18} + a_{19} + a_{24} + a_{26} + a_{27} + a_{32} + a_{36} + a_{40} + a_{43} + a_{47} + a_{52} + a_{67} \leq 266000 \text{ ha (Up and medium land)}$

➤  $a_{11} \leq 117000$  ha (Medium and low land)

**c) Irrigated area constraint**

➤  $a_2 + a_5 + a_8 + a_9 + a_{10} + a_{12} + a_{13} + a_{14} + a_{15} + a_{17} + a_{20} + a_{21} + a_{22} + a_{23} + a_{25} + a_{28} + a_{29} + a_{30} + a_{31} + a_{33} + a_{34} + a_{37} + a_{38} + a_{39} + a_{41} + a_{44} + a_{45} + a_{46} + a_{48} + a_{49} + a_{50} + a_{51} + a_{53} + a_{54} + a_{55} + a_{59} + a_{60} + a_{61} + a_{62} + a_{64} + a_{65} + a_{66} + a_{68} + a_{71} + a_{72} + a_{73} + a_{74} \leq 78200$  ha

**d) Grass cover constraint**

➤  $a_{75} \leq 5000$  ha

**e) Water constraints**

***Kharif* season**

➤  $1.2 a_1 + 1.2 a_2 + 1.2 a_3 + 1.2 a_4 + 1.2 a_5 + 1.2 a_6 + 1.2 a_7 + 1.2 a_8 + 1.2 a_9 + 1.2 a_{10} + 1.2 a_{11} + 1.2 a_{12} + 1.2 a_{13} + 1.2 a_{14} + 1.2 a_{15} + 0.4 a_{16} + 0.4 a_{17} + 0.4 a_{18} + 0.4 a_{19} + 0.4 a_{20} + 0.4 a_{21} + 0.4 a_{22} + 0.4 a_{23} + 0.5 a_{24} + 0.5 a_{25} + 0.5 a_{26} + 0.5 a_{27} + 0.5 a_{28} + 0.5 a_{29} + 0.5 a_{30} + 0.5 a_{31} + 0.25 a_{32} + 0.25 a_{33} + 0.25 a_{34} + 0.25 a_{35} + 0.25 a_{36} + 0.25 a_{37} + 0.25 a_{38} + 0.25 a_{39} + 0.25 a_{40} + 0.25 a_{41} + 0.25 a_{42} + 0.25 a_{43} + 0.25 a_{44} + 0.25 a_{45} + 0.25 a_{46} + 0.35 a_{47} + 0.35 a_{48} + 0.35 a_{49} + 0.35 a_{50} + 0.35 a_{51} + 0.65 a_{52} + 0.65 a_{53} + 0.65 a_{54} + 0.65 a_{55} + 1.2 a_{56} + 1.2 a_{57} + 0.53 a_{58} + 0.53 a_{59} + 0.53 a_{60} + 0.53 a_{61} + 0.53 a_{62} + 0.48 a_{63} + 0.48 a_{64} + 0.48 a_{65} + 0.48 a_{66} + 0.37 a_{67} + 0.37 a_{68} + 0.37 a_{69} + 0.37 a_{70} + 0.37 a_{71} + 0.37 a_{72} + 0.37 a_{73} + 0.37 a_{74} + 0.9 a_{75} \leq 160086.4$  ha- m

***Rabi* season**

➤  $0.55 a_2 + 0.65 a_5 + 0.45 a_8 + 0.48 a_9 + 0.37 a_{10} + 0.65 a_{12} + 0.45 a_{13} + 0.48 a_{14} + 0.37 a_{15} + 0.55 a_{17} + 0.65 a_{20} + 0.45 a_{21} + 0.48 a_{22} + 0.37 a_{23} + 0.55 a_{25} + 0.65 a_{28} + 0.45 a_{29} + 0.48 a_{30} + 0.37 a_{31} + 0.55 a_{33} + 0.65 a_{34} + 0.45 a_{37} + 0.48 a_{38} + 0.37 a_{39} + 0.55 a_{41} + 0.45 a_{44} + 0.48 a_{45} + 0.37 a_{46} + 0.65 a_{48} + 0.45 a_{49} + 0.48 a_{50} + 0.37 a_{51} + 0.45 a_{53} + 0.48 a_{54} + 0.37 a_{55} + 0.65 a_{59} + 0.45 a_{60} + 0.48 a_{61} + 0.37 a_{62} + 0.65 a_{64} + 0.45 a_{65} + 0.37 a_{66} + 0.55 a_{68} + 0.65 a_{71} + 0.45 a_{72} + 0.48 a_{73} + 0.37 a_{74} \leq 45007.2$  ha-m

**f) Nutritional and affinity constraints**

**Rice :**  $3 a_1 + 3 a_2 + 3 a_3 + 3 a_4 + 3 a_5 + 3 a_6 + 3 a_7 + 3 a_8 + 3 a_9 + 3 a_{10} + 3.5 a_{11} + 3.5 a_{12} + 3.5 a_{13} + 3.5 a_{14} + 3.5 a_{15} \geq 329615$  tonnes

**Ragi :**  $2 a_{16} + 2 a_{17} + 2 a_{18} + 2 a_{19} + 2 a_{20} + 2 a_{21} + 2 a_{22} + 2 a_{23} \geq 66780$  tonnes

**Maize :**  $4 a_{24} + 4 a_{25} + 4 a_{26} + 4 a_{27} + 4 a_{28} + 4 a_{29} + 4 a_{30} + 4 a_{31} \geq 47139$  tonnes

**Mung (Green gram) :**  $a_{32} + a_{33} + a_{34} + a_{35} + a_{36} + a_{37} + a_{38} + a_{39} \geq 5909$  tonnes

**Black gram:**  $a_3 + a_{18} + a_{26} + a_{40} + a_{41} + a_{42} + a_{43} + a_{44} + a_{45} + a_{46} + a_{69} \geq 14773$  tonnes

**Horse gram :**  $1.5 a_4 + 1.5 a_{19} + 1.5 a_{27} + 1.5 a_{70} \geq 42351$  tonnes

**Arhar :**  $2 a_{47} + 2 a_{48} + 2 a_{49} + 2 a_{50} + 2 a_{51} \geq 35456$  tonnes

**Ground nut :**  $2.5 a_5 + 2.5 a_{12} + 2.5 a_{20} + 2.5 a_{28} + 2.5 a_{34} + 2.5 a_{48} + 1.5 a_{52} + 1.5 a_{53} + 1.5 a_{54} + 1.5 a_{55} + 2.5 a_{59} + 2.5 a_{64} + 2.5 a_{71} \geq 5632$  tonnes

**Niger :**  $a_6 + a_{35} + a_{42} \geq 65880$  tonnes

**Mustard :**  $a_7 + 1.5 a_8 + 1.5 a_{13} + 1.5 a_{21} + 1.5 a_{29} + a_{36} + 1.5 a_{37} + a_{43} + 1.5 a_{44} + 1.5 a_{49} + 1.5 a_{53} + 1.5 a_{60} + 1.5 a_{65} + 1.5 a_{72} \geq 4550$  tonnes

**Vegetables :**  $25 a_{10} + 25 a_{15} + 25 a_{23} + 25 a_{31} + 25 a_{39} + 25 a_{46} + 25 a_{51} + 25 a_{55} + 25 a_{62} + 25 a_{66} + 20 a_{67} + 20 a_{68} + 20 a_{69} + 20 a_{70} + 20 a_{71} + 20 a_{72} + 20 a_{73} + 25 a_{74} + 20 a_{74} \geq 301004$  tonnes

**Sweet potato :**  $20 a_{58} + 20 a_{59} + 20 a_{60} + 20 a_{61} + 20 a_{62} \geq 22656$  tonnes

**g) Local suitability constraints**

$a_{56} \geq 10,000$  ha (Ginger)

$a_{57} \geq 5,000$  ha (Turmeric)

## **LIST OF PUBLICATIONS**

1. Naik, B. S., Paul, J. C., Panigrahi, B. and Sahoo, B. C. (2014). Agroclimatic situation and profitability study of traditional cropping pattern in Koraput district in Eastern Ghat Region of Odisha. *Journal of Soil and Water Conservation*, 13 (3): 277-281.
2. Naik, B. S., Paul, J. C., Panigrahi, B. and Sahoo, B. C. (2014). Soil loss from agricultural lands in Eastern Ghat of Odisha - a case study of Koraput district. *Journal of Soil and Water Conservation*, 13(4): 324-328.
3. Naik, B. S., Paul, J. C., Panigrahi, B. and Sahoo, B. C. (2015). Soil erosion assessment from farming lands of Eastern Ghat Region of Odisha. *Indian Journal of Soil Conservation*, 43(1): 33-37.

## CURRICULUM VITAE

**Name** : **Bhupendra Singh Naik**  
**Father's Name** : Late Balaji Naik  
**Date of Birth** : 02<sup>nd</sup> June, 1974  
**Permanent Address** : At-Kadopadar, PO-Dangariguda  
Via - Charbahal,  
Dist- Kalahandi  
Pin-766017 (Odisha)  
**Present Address** : ICAR-IISWC, Research Centre,  
Near POLA Paradise, Hospet Road,  
Bellary-583104, Karnataka.

### **Educational Qualification:**

<b>Degree</b>	<b>Institution</b>	<b>Year</b>
B. Tech	CAET, OUAT, Bhubaneswar	1996
M.Tech	CAET, OUAT, Bhubaneswar	1999

### **Experience:**

<b>Institute</b>	<b>Post held</b>	<b>From</b>	<b>To</b>	<b>Nature of work</b>
ICAR - IISWC	Scientist (SWCE)	2002	Continuing	Research, Training & Extension

### **Membership of the Professional bodies:**

1. Life member of Indian Association of Soil and Water Conservationists, Dehradun, Uttarakhand.
2. Member of Soil Conservation Society of India, New Delhi

### **Publications:**

Research Paper	<b>20</b>
Popular Articles	<b>16</b>
Technical Bulletins	<b>2</b>
Training Manual	<b>2</b>
Book	<b>1</b>
Publication in edited books	<b>5</b>
Technology brochure	<b>5</b>
Abstract in conference/seminar	<b>22</b>