STUDY OF RESERVOIR SEDIMENTATION, IMPACT ASSESSMENT AND DEVELOPMENT OF CATCHMENT AREA TREATMENT PLAN FOR KODAR RESERVOIR IN CHHATTISGARH STATE

PDS UNDER HYDROLOGY PROJECT PHASE-II

FINAL REPORT (2010-2013)

BY
NATIONAL INSTITUTE OF HYDROLOGY
REGIONAL CENTRE, BHOPAL (M.P.)
&
WATER RESOURCE DEPARTMENT, RAIPUR
GOVT. OF CHHATTISGARH

PDS Under HP-II

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PREFACE

The process of sedimentation in reservoir embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction of sediment. The study of erosion and sediment yield from catchments is of utmost importance as the deposition of sediment in reservoir reduces its capacity, and thus affecting the water availability for the designated use. The assessment of present capacity of the reservoir will be helpful to determine the loss in capacity, the rate of sedimentation and its pattern, development of modified operation plan etc. In most of the water resources projects, the forested catchment area which is the source of endowment for reservoir is subjected to degradation due to lack of conservation measure and non-implementation of catchment area treatment plan. It is therefore necessary to understand the erosion processes with the help of sediment modeling in the catchment areas to identify the vulnerable areas and necessity and intensity of conservation measures. The scientific approach adopted using the appropriate methodologies for conservation natural resources in the catchment areas will be an innovation for tackling the problems of erosion from catchment, sedimentation of reservoir, non-availability of water in the tail reaches of the command areas and increase the efficiency of the project. The methodologies developed during the course of the study will be helpful in resolving similar type of issues in the state scientifically.

The Purpose driven Study (PDS) titled "Study of Reservoir Sedimentation, Impact Assessment and Development of Catchment Area Treatment Plan for Kodar Reservoir in Chhattisgarh State" has been awarded to WRD, Govt. of Chhattisgarh, Raipur and NIH, Regional Centre Sagar under HP II with the objectives of the present available capacity of reservoir, assessment of soil erosion and need of soil conservation measures, determination of priority areas for soil conservation measures, sediment modeling, development of catchment area treatment plan and impact assessment analysis will be of great help as environmental degradation in the project areas can be controlled and the life of the reservoir may be extended by the measures adopted on the basis of technical knowledge and scientific research. This study may be used as guidelines for planning soil conservation measures for sustainable development and reduction of environmental degradation in catchment areas of water resource projects in the region.

The final report prepared by Sri R. K. Jaiswal, Scientist-C as P.I. and Sh. Ravi Galkate, Scientist-D as Key Person, Sh. T. Thomas, Scientist-C as Co-PI and Dr. Surjeet Singh, Scientist-D as Co-PI from National Institute of Hydrology and Sh. S.V. Bhagwat, Superintending Engineer as PI, Sh. D. K. Sonkusale, Deputy Director as key Person, Sh. Akhilesh Verma, Executive Engineer, Sh. R. K. Sharma, Sub Divisional Officer, Sh. J. N. Vishwakarma, Assistant Engineer and Sh. J. K. Dass, Sub Engineer from Water Resources Department, Raipur (Chhattisgarh). The report is the results of three and half years research works conducted by both organizations for this PDS.

(R. D. Singh)
Director

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channel (*CH_N2*) is the most important from runoff and sediment modeling respectively. After manual changes in the sensitive parameters, rewritten of files and simulation run were carried out to determine computed runoff, sediment etc. from different sub-watersheds. The observed and computed values of runoff/sediment were compared using goodness of fit parameters including root mean absolute error (*RMAE*), integral square error (*ISE*), Nash-Sutcliffe efficiency, scatter plot and graphical representation.

After successful validation, the model parameters with suitable modification wherever required were implemented on whole Kodar catchment. The impact assessment analyses on runoff and sediment have been carried out by generating two different scenarios prior and after application of soil conservation measures as Pre-BMP and Post-BMP. The results indicated that maximum sediment load found in the month of Sept 2011 which was 2.97 t/ha under monthly rainfall of 743 mm in Kodar reservoir catchment during the period of implementation of model (2010 to 2012). If suitable soil conservation measures and BMP applied in the catchment, the sediment entry in the reservoir can be reduced to 1.63 t/ha under same rainfall condition. The BMP and CAT plan have little impact on runoff pattern from the catchments of Koma and Kodar reservoir, but able to reduce significantly the sediment transported through channels which otherwise deposited in Kodar reservoir if no measures were taken. The results of the study and methodology suggested in the PDS can beneficially be used in other water resources projects for reduction of useful storages, increase in water availability, social and economical development of weaker section of society and generation of employment through conservation measures. The proposed methodology can be used as guidelines for assessment of expected soil loss and suitable conservation measures for sustainable development in design of new water resource projects. During the course of PDS, extensive field visits were made and two knowledge dissemination workshops were organized to get feedback from stakeholders, government department, technocrats etc. Overwhelming response have been received during the interaction and need of regular estimation of reservoir revised capacities, development and implementation of scientifically designed CAT plan and awareness for soil and water conservation measures in mass were identified as the key issues for sustainable development of water resources.

CHAPTER- 1 – INTRODUCTION

1.0 General

The catchment and contributing areas which are the source of endowment for any water resource projects are generally neglected and most of developmental activities concentrated in command areas resulting higher rate of soil erosion and sediment load, environmental degradation and inequitable development. Amongst several causes of soil erosion and loss of nutrients, the major ones are improper and unwise utilization of watershed resources without any proper vision, which is observed more in developing countries (FAO, 1985). Soil being one of the potential resources of an area demands proper conservation and management. It could be possible when its degree of degradation can be assessed and soil conservation strategies are to be planned according to the severity of soil erosion and environmental problems in the catchment of reservoir. An efficient catchment area treatment (CAT) plan consists of division of catchment in small watersheds, assignment the priority of conservation considering all important parameters responsible for soil erosion and degradation and finally the development of well planned conservation measures for different watersheds in the catchment. In order to plan soil conservation measures and to assess the impact of catchment area treatment plan, it is necessary to compute sediment transport from sub-watersheds, transport of sediment load to the reservoir and revised capacities of reservoir at regular interval.

1.1 Soil Erosion

The soil erosion may be defined as detachment and transportation of soil. It is a well-established fact that reservoirs formed by dams, weirs or barrages on rivers are subjected to sedimentation. The process of sedimentation embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction of sediment. The study of erosion and sediment yield from catchments is of utmost importance as the deposition of sediment in reservoir reduces its capacity, and thus affecting the water availability for the designated use. The eroded sediment from catchment when deposited on streambeds and banks causes breaching of river reach. Land degradation due to soil erosion affects agriculture productivity, water quality and quantity, hydrological and environmental systems as various causing ecological imbalance and subsequent siltation and flood problems. According to a survey conducted by the Indian Council of Agricultural Research (ICAR) 174 million ha of India's total 329 million ha are affected by land degradation. A rough estimate of soil erosion and sedimentation for India reveals that about 5300 million tones 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%. The fertility status and the productivity of soil as a medium for biomass production depends largely on the top soil which, besides being a producer of biomass, is important for many other well-known important functions.

The soil erosion is globally recognized as a severe problem for human sustainability (Lal, 1998). Syriyaprasit & Shrestha (2008) emphasized that erosion may cause disasters such as siltation of reservoirs and flooding during rainfall events and shifts initial land suitability and capabilities. According to an estimate, a sixth of the world's soils are affected by water erosion, which has emerged as an issue for conservation efforts in 21st century (Walling and Fang, 2003 and Reich et al., 2000). A broad estimate of soil erosion nationwide showed that about 5334 local available materials with involvement of society especially women and weaker section of society.

1.3 Soil Investigation

The physical and chemical properties of soil play important role in movement of soil on and beneath the earth, erosion processes, recharge, pollutant transport, rainfall-runoff and sediment modeling etc. The process of soil erosion by water begins with the detachment of individual soil particles from the soil mass and other than raindrop impact depends on the physical and chemical properties of the soil. The texture, structure, water retention capability, etc. play an important role in determining whether the soil is susceptible to erosion by various agents of erosion or not. Soil texture is a soil property of very high importance. Sandy soil have higher infiltration rate, but are easily detached whereas clay soils cannot be detached easily but produce higher runoff rate and increased erosion. Silty soils and fine sands are most erodible since their resistance to both detachment and transportation are relatively low. The infiltration rate of the soil and the amount of runoff that results when infiltration capacity is exceeded are crucial for the rate of erosion. The extent of soil erosion results from the relationships between infiltration and runoff which is amongst others determined and modified by rainfall intensity, land cover and soil properties.

For the application of soil erosion and sediment model, spatial distributions of soil properties in the watershed are required. Different indices for determination of soil erodibility have been established and the most common is the soil erodibility factor (*K*) in the Universal Soil Loss Equation (USLE) and Revised USLE. For estimation of K-value, percentage of silt and sand, soil structure and permeability of soil are the basic inputs. The displacement and movement of soil under the forces of water or air mainly depend upon cohesive forces between the particles of soil mass. It is therefore necessary to determine the psychical and chemical soil properties through in-situ and laboratory tests for soil erosion studies, rainfall-runoff and sediment modeling, recharge analysis and pollutant transport etc. In the study, infiltration test using double ring infiltrometer, saturated hydraulic conductivity using Guelph permeameter, particle size analysis using sieve shaker and pipette analysis, specific gravity using density bottle and dry density using core cutter have been carried out and results of these analysis have been used in for soil erosion, sediment modeling and development of CAT plan for the study area.

1.4 Watershed Prioritization

Comprehensive land development procedures attract special attention in many countries that enable soil and water conservation, better and productive land use and optimum and effective use of available natural resources. The severity is indicated by the priority delineation of a watershed that is determined considering many factors, the important among them being the annual soil loss, slope, sediment yield, sediment transport, erosivity, morphometric analysis etc. The prioritization of watershed helps in taking up soil conservation measures on the priority basis in which recent technology of Remote Sensing and Geographic Information System plays important role because of easy handling and manipulation of spatial information and data. The remotely sensed data has the advantage of providing synoptic view and large area coverage, which impart knowledge about conditions on the earth surface that charge in landscape over time. GIS has held in making a number of useful suggestions for the development of the

AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team thus reducing bias in decision making. AHP allows organizations to minimize common pitfalls of decision making process, such as lack of focus, planning, participation or ownership, which ultimately are costly distractions that can prevent teams from making the right choice. AHP is very useful when the decision-making process is complex, for instance, by being unstructured. Indeed, when the decision cycle involves taking into account a variety of multiple criteria which rating is based on a multiple-value choice, AHP splits the overall problem to solve into as many evaluations of lesser importance, while keeping at the same time their part in the global decision.

1.4.1.1 Steps of the analytical hierarchy process (AHP)

1. **Decomposing**

   The goal is to structure the problem into humanly-manageable sub-problems. To do so, iterating from top (the more general) to bottom (the more specific), split the problem, which is unstructured at this step, into sub-modules that will become sub-hierarchies. Navigating through the hierarchy from top to bottom, the AHP structure comprises goals (systematic branches and nodes), criteria (evaluation parameters) and alternative ratings (measuring the adequacy of the solution for the criterion). Each branch is then further divided into an appropriate level of detail. At the end, the iteration process transforms the unstructured problem into a manageable problem organized both vertically and horizontally under the form of a hierarchy of weighted criteria. By increasing the number of criteria, the importance of each criterion is thus diluted, which is compensated by assigning a weight to each criterion.

2. **Weighing**

   Assign a relative weight to each criterion, based on its importance within the node to which it belongs. The sum of all the criteria belonging to a common direct parent criterion in the same hierarchy level must equal 100% or 1. A global priority is computed that quantifies the relative importance of a criterion within the overall decision model.

3. **Evaluating**

   Score alternatives and compare each one to others. Using AHP, a relative score for each alternative is assigned to each leaf within the hierarchy, then to the branch the leaf belongs to, and so on, up to the top of the hierarchy, where an overall score is computed.

4. **Selecting**

   Compare alternatives and select the one that best fits the requirements.

1.5 Catchment Area Treatment Plan

The catchment area of a basin consists of different land uses, slopes, drainage densities, conservation practices etc. Preparation of management plan for catchment requires to scientifically formulating the risk scenario in different part or sub-catchments in the basin. Under CAT, aspects, like land use-land cover, physiography and relief, area under different slope classes, and drainage pattern with details of tributary wise lengths and catchments are

HEC-6 (Hydrologic Engineering Center) model is a hydrodynamic, one-dimensional open channel flow and sediment-transport model designed by the US Army Corps of Engineers to simulate changes in river profiles due to erosion and deposition over long time periods or for single event. The GSTAR-1D (Generalized Sediment Transport for Alluvial River) model is a one dimensional river model developed by the Environmental Protection Agency and Bureau of Reclamation. In the present study, Soil and Water Analysis Tool (SWAT) will be used for runoff and sediment modeling from the Kodar catchment and described here.

1.6.1 SWAT model

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) is a distributed parameter and continuous time simulation model supported by USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory, Texas. The SWAT model has been developed to predict the response to natural inputs as well as the manmade interventions on water and sediment yields in un-gauged catchments. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on un-gauged watersheds (in fact the usual situation).

SWAT model has been designed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT is a continuous time model operating on daily time step and sub-daily time scale. The equations in SWAT focuses on soil water balance. SWAT simulates the water balance, along with plant growth, sediment erosion and transport, nutrient dynamics, and pesticides. The details of SWAT model including its capabilities, application, data required, data format is available in Neitsch, 2001. The runoff volume in SWAT model is estimated by Soil Conservation Services (SCS) curve number technique (USDA, 1972) and sediment yield using Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977). The model permits the incorporation of management practices on the land surface, including fertilizer application, livestock grazing, and harvesting operations. The sub-basin components of SWAT can be placed into eight major divisions—hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Dhar & Majumdar, 2006).

- Hydrology - Surface runoff, Percolation, Lateral Subsurface Flow, Groundwater Flow, Evapotranspiration, Snow melt and Transmission Losses
- Weather - Precipitation, Air Temperature, Solar Radiation, Wind Speed and Relative humidity.
- Sedimentation - Sediment Yield.
- Soil temperature - Daily average soil temperature is simulated at the center of each soil layer for use in hydrology and residue decay.
- Crop growth
- Nutrients - Nitrogen and Phosphorus

CHAPTER 2.0 – REVIEW OF LITERATURE

2.1 Reservoir Sedimentation Study

Reservoir sedimentation process is a universal phenomenon, which has been considered as a most critical environmental hazard of modern time (Jain and Kothyari, 2000). The range of problems caused by reservoir sedimentation is varied and wide. Apart from loss of capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance lead to increase in their associated cost (Kothyari et al., 2002; Siyam et al., 2005). White (1978) examined a variety of measuring techniques for determining reservoir surface areas extracted from Landsat MSS near-IR imageries of different scales and compared their accuracy with field data. He concluded that none of the measuring techniques used was able to measure the reservoir water spread with consistent accuracy and no reason was attributed. Mangond et al (1985) employed digital classification techniques to estimate the water spread of the Malaprabha reservoir using Landsat MSS data and reported a discrepancy of 8.29 % from the actual water spread. This discrepancy was attributed to the probable misclassification of boundary pixels. Suvit et al (1988) used digital techniques in which density slicing of Landsat MSS near-IR (0.8- 1.1 μm) data were used to extract the water spreads of the Ubolratana reservoir of five different dates. The ability to map and estimate water spread from satellite data is well understood, and different techniques such as visual interpretation of satellite imagery, density slicing, and digital classification of water bodies have been employed for the delineation of water bodies (i.e. Work and Gilmer, 1976, Thiruvengadachari et al, 1980; Jain and Goel, 1993, Goel and Jain, 1996, Jain and Kothiyari, 2000, Jaiswal et al, 2008, Thomas et al 2009).

2.2 Development of Catchment Area Treatment Plan

Drainage basins, catchments and sub-catchments are the fundamental units for the management of land and water resources (Moore et al., 1994). Catchments have been identified as the planning units for administrative purpose to conserve these precious resources (FAO, 1985; 1987; Honore, 1999; Khan, 1999). The development of CAT plans includes the identification of environmentally stressed sub-watershed, suggestions of suitable measures of soil and water conservation, society involvement for protection and production of resources and make the region self sustainable and ultimately creating the environment for overall development of society. Tyagi and Joshi (1994) developed catchment area treatment plan for Himalayan region and suggested contour bunding, graded bunding, bench terracing, strip cropping and mixed cropping for soil conservation. Tyagi and others (1994) have described erosion conservation measures for the Himalayan region. Measures include contour bunding, graded bunding, bench terracing, strip cropping, contouring and mixed cropping. Pandey et al. (2007) divided Karso watershed of Hazaribagh, Jharkhand (India) into 200 × 200 m grid cells and average annual sediment yields were estimated for each cell of the watershed to identify the critically prone areas of watershed for development of CAT plan.

2.4 Soil Erosion and Sediment Modeling

For prioritization of watersheds and development of catchment area treatment plan, soil erosion has been considered the most important criteria and several authors have dealt the theory of soil erosion and sedimentation in rivers. Musgrave (1947) suggested one of the earliest and most successful equations for sediment yield. He accounted for soil erodibility, vegetal cover, land slope, channel length and rainfall intensity. Work in the early 1930's through 1960's led to the development of Universal Soil Loss Equation (USLE) by W. H. Wischmeier and first published in 1958 (USDA) Agriculture Handbook 282). Over the next 20 years he refined and improved the USLE and published the results of his efforts in 1978 in Agriculture Handbook 537, which is still a standard reference. The planners and mangers sometimes more interested to know the spatial distribution of soil erosion rather than absolute values and in such cases, the use of remote sensing and geographic information system (GIS) makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Millward and Mersey, 2001 and Wang et al, 2003).

After invention of USLE model, Several scientist many models for soil loss estimation have been developed by Nearing et al. (1989); Adinarayana et al. (1999);D'Ambrisio et al. (2000); Veihe et al. (2001) Shen et al. (2003). Empirical soil erosion models in combination with soil, climate, vegetation and topography information have been implemented using remote sensing (Dwivedi et al., 1997; Hill and Scutt, 2002; Babun and Yusuf, 2001; Fu et al., 2005). Coupling GIS and USLE/RUSLE has been shown in many cases to be an effective approach for estimating the magnitude of soil loss and identifying spatial locations vulnerable to soil erosion (Fu et al., 2006; Lim et al., 2005). The GIS tool for classification of Landsat-TM imagery has been used to estimate the crop management factor for USLE is in the research done by Miillword and Mersy (1999); Zhang (1999). De Jong (1994) has shown that satellite data can be used for producing vegetation related factors in soil erosion modeling that again compiled by Leprieur et al. (2000). The normalized difference vegetation index (NDVI) was found the most useful for computation of K factor by Symeonakis and Drake (2004) and Tateishi et al. (2004).

Joglekar (1965) and Varshney (1975) have suggested a number of enveloping curves for the prediction of sediment yield for different catchment areas in India. Correlation studies conducted by Jose et al (1982) revealed that area alone does not have any significant association with sediment production rate and hence it calls for multivariate analysis involving a number of climatic and physiographic parameters. Mishra et al (1991) and Bundela et al (1995) have developed statistical models on a spatial basis for small watersheds in river Damodar. Nema et al (1978) worked out some parameters of Universal Soil Loss Equation from runoff plot study conducted at Soil Conservation Demonstration and Training Centre (ICAR), Vasad. Values for 'K' factor and 'R' factor for soil and climatic conditions at Vasad and 'C' factor for Mung, Groundnut and Cowpea were worked out. Prasad and others (1994) have reported soil conservation measures in a semi arid region of Rajasthan.

Ram Babu et al (1978) computed and presented the monthly, seasonal and annual erosion index values for 44 stations situated in northern, central, western, eastern and southern rainfall zones of India. Raghuwanshi and Bhatia (1987) applied the Universal Soil Loss Equation for predicting soil loss from Chaukhutia catchment of Ramganga river in Uttar Pradesh. Singh et. al. (1981) and Narayana (1983) have estimated the soil erosion due to water and wind for India and

and Engle, 1998; Saleh et al. 2000; Neitsch et al. 2001; Santhi et al. 2001; Weber et al 2001; Fohrer et al. 2001; Tripathi et. al., 2004; Arnold and Fohrer 2005; Santhi et al. 2006, etc.). Fohrer et al. (1999) have successfully calibrated and validated the SWAT on 'Aar' gauged watershed using the land use map derived from satellite images. Srinivasan et al. (1998) calibrated the SWAT model for a sub-watershed (Mill Creek watershed) of Richland-Chambers (RC) lake using the sediment data from 1988 to 1994 and concluded the variation of 2 to 9 % in accumulated sediment. Pikounis et al (2003) investigated the hydrological effects of specific land use changes in a catchment of the river Pinios in Thessaly (Ali Efenti catchment), through the application of the SWAT model on a monthly time step. Behera and Panda (2006) used SWAT model for the evaluation of management alternatives for a small agricultural watershed (Kapagri watershed) of eastern India. Pandey et al (2008) applied AVSWAT model for identification of critical sub-watersheds and development of best management practices in a watershed of eastern India and reported that the conservation tillage practice may the best as for sediment yield point of view.

Both the SWAT (Soil & Water Assessment Tool) and the SWIM (Soil and Water Integrated Model) models are river basin scale models that quantify water and sediment-transport processes for the hill slopes, the catchments and for the river network. The SWAT was developed by the USDA Agricultural Research Service (Neitsch et al. 2002) to quantify the impact of land management practices in large, complex watersheds. The SWAT model estimates runoff volume by using the Soil Conservation Service (SCS) curve number technique (USDA-SCS, 1972). Erosion and sediment yield are estimated for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977). SWAT uses Manning's equation to define the rate and velocity of flow. Water is routed through the river network using the variable storage routing method or the Muskingum routing method. The sediment delivery ratio is estimated using a power function of the peak flow velocity. Erosion is estimated as a function of the sediment delivery ratio, the channel erodibility factor (similar to the soil erodibility factor K used in the USLE equation) and a channel cover factor (similar to the soil factor C in the USLE equation). The SWIM model was developed by Krysanova and Wechsung (2000) at the Potsdam Institute for Climate Impact Research, Germany. The model uses a very similar approach to flow and sediment routing in comparison to the SWAT model.

CHAPTER 3.0: STUDY AREA

The Kodar reservoir which is constructed on river Kodar, a tributary of river Mahanadi has been selected for the systematic and scientific study of reservoir sedimentation, sediment yield from catchment areas, prioritization of catchment for soil conservation measures, sediment modeling in the inflowing rivers and analysis of change in land use on erosion and sedimentation.

3.1 Kodar Reservoir

The Kodar reservoir is constructed across river Kodar, a tributary of river Mahanadi. The dam is constructed on Raipur – Sambalpur national highway at a distance of 65 km from Raipur near village Kowajhar in Mahasamund district. The base map showing location of Kodar reservoir has been given in Fig 3.1. The catchment area of the river up to dam site is 317.17 km^2. and mean annual rainfall in the catchment area is about 1433.1 mm. The dead storage capacity and gross storage capacity of reservoir are 11.33 Mm^3 and 160.35 Mm^3 respectively.

The length of earthen dam is 2363 m with a maximum height of 23.32 m, a waste weir 183m long to pass designed flood and head regulators on both the flanks to feed the canal system. Two canals of length 23.30 km (Left Bank Canal) and 10.60 km (Right Bank Canal) are envisaged from the sluices located on left and right flanks of the earthen dam to provide irrigation to 16,066 ha and 7,406 ha respectively. The reservoir was first impounded in the year 1976-77 and now it is necessary to revise original elevation-area-capacity table for efficient management of available water. The topography of the catchment area of Kodar river is undulating and agriculture area is more from where soil loss is more due to lack of conservation measures, therefore the erosion from the catchment and rate of sedimentation in the reservoir may be more than the designed rate. The salient features of Kodar reservoir have been presented in Table 3.1. The original elevation capacity table of Kodar reservoir has been presented in Table 3.2 and elevation capacity curve in Fig 3.2.

Table 3.1: Salient features of Kodar reservoir

I.	**GENERAL DATA**	
1	District	Raipur
2	Tahsil	Mahasamund
3	River	Kodar
4	Location	Near village Kowajhar Latitude : 21^0 11' 50" N Longitude : 82^0 10' 40" E
5	Name of River Basin	Mahanadi Basin
6	Year of start	1976-77
II.	**HYDROLOGICAL DATA**	
1.	Mean rainfall (over 43 year since 1934 to 1976 of Mahasamund)	
	a) Annual Rainfall	1433.1 mm
	b) 75% dependable rainfall	1209.0 mm
	c) Monsoon rainfall	1395.7 mm
III.	**FLOOD**	
	i) By Dicken's formuila	1467 m^3/sec
	ii) By Unit Hydrograph for Charoda rain gauge station (with 10.83 inches rainfall)	1802 m^3/sec
	iii) Moderated flood discharge	623 m^3/sec
IV.	**RESERVIOR**	
1	Catchment area	317.17 sq. km
2	Geology	Hilly and steep
3	Mean monsoon yield (Mean rainfall is 96% of annual rainfall)	210.03 Mm^3
4	Mean Annual yield	218.8 Mm^3
5	75% dependable yield	164.83 Mm^3
6	75% dependable yield with 0.9 diminishing factor	147.83 Mm^3
7	Gross storage capacity :	160.35 Mm^3
8	Dead storage capacity	11.33 Mm^3
9	Live storage capacity	149.02 Mm^3
10	Percentage of gross storage to 75% dependable yield	97.59 %
11	Percentage of dead storage to gross storage	7.06 %
12	Full reservoir level (F.R.L.)	295.236 m
13	Maximum water level (M.W.L.)	298.165 m
14	Top bund level (T.B.L.)	298.990 m
15	Dead storage level (D.S.L.)	286.040 m
15	Minimum draw down level	288.68 m
17	Lowest river bed	275.87 m.
18	Water spread area at F.R.L.	3584.25 ha
19	Water spread area at M.W.L.	4248.86 ha
V.	**DAM**	
1	Length of earth dam	2361 m
2	Maximum height of dam	23.32 m
3	Top width of earth dam	4.577 m
4	Length of waste wei	183 m
VI.	**CANALS**	
1	a. Length of Left Bank Main Canal	23.30 km.
	b. Head discharge (L.B.C.)	12.52 cumecs
	c. Length of R.B.C.	10.6 km

CHAPTER 4.0: WORK ELEMENTS AND DATA USED

4.1 Work Elements

The work elements under the PDS are as follow:

- Data collection and preparation of inventory
- Establishment of gauging and sediment sampling site
- Monitoring of hydrological and hydro-meteorological data
- Generation of various thematic maps of catchment using GIS.
- Processing and analysis of hydrological and hydro-meteorological data
- Assessment of sedimentation in the reservoir
- Assessment of present land use with the help of remote sensing data
- Evaluation of soil properties in the catchment area
- Estimation of soil loss from the catchment
- Prioritization of environmentally stressed areas in the catchment
- Development of catchment area treatment plan
- Development of sediment prediction model
- Impact assessment analysis on sediment yield
- Interim report preparation (yearly) and Final report submission
- Dissemination of knowledge, findings and application of the management plan to field engineers and common people through preparation of Manual, leaflets, booklets and organizing workshops

In order to fulfill the objectives of the PDS, various work elements have been distributed between National Institute of Hydrology, RC Bhopal and Water Resources Department, Govt. of Chhattisgarh.

4.2 Data Used

4.2.1 Meteorological data

For the study, meteorological data including maximum, minimum temperature, relative humidity, wind speed and sunshine hours from 1971 to 2011 of Indira Gandhi Agriculture University, Raipur have been collected. Rainfall data of five rain gauge stations in and around Kodar reservoir catchment have been collected. The detail information of Rain gauge stations and data availability has been presented in Table 4.1.The thiesen polygon of the catchment of Kodar reservoir has been prepared and it has been observed that Kodar, Bagbahara and Bartunga RG stations have impact on Kodar reservoir and hence the analysis have been performed on these stations only.

4.2.2 Remote sensing data for sedimentation and landuse analysis

In the present study, eight dates LISS III data of Path 102 and Row 57 of IRS P6 satellite have been used for sedimentation study using digital image processing technique of remote sensing data. The dates have been selected in such a way so that the whole range of live storage is covered at equal intervals. Two LISS IV data of IRS P6 have been used for identification of landuse in the study area- The details of satellite data has been presented in Table 4.2.

CHAPTER 5.0- METHODOLOGY

5.1 General

The methodology for the present study included preparation of inventory on meteorological data, rainfall, soil information, soil tests, collection and analysis of sediment samples, reservoir sediment analysis, land use detection, sediment modeling, identification of priority sub-catchments and development of catchment area treatment plan and application of rainfall-runoff-sediment modeling for impact assessment analysis. Various steps used to achieve the objectives of the purpose driven study are presented below.

1. Preparation of inventory on hydrology, meteorology, geology, land use, soil, reservoir elevations and other details.
   a) Collection of field information, rainfall, reservoir details, reservoir levels, land use pattern, river system and other statistics of the study area.
   b) Collection of information on topography, geology, geomorphology, land use, demography etc.
   c) Collection of meteorological data on temperature, relative humidity, solar radiation, wind velocity etc.
   d) Collection of information of soil type, soil depth and other soil properties in the catchment area. Soil testing for infiltration, hydraulic conductivity, texture analysis, bulk density etc.
   e) Procurement of remote sensing data on the basis of reservoir levels.
2. Instrumentation, collection of hydrological and sediment data of Kodar rivers.
   a) Establishment of gauge-discharge and sediment sampling sites.
   b) Regular collection and monitoring of sediment samples.
3. Preparation of thematic maps on drainage, soil type, land use, contours, villages, road network, geology in GIS environment.
   a) Preparation of base map of Kodar reservoir includes river network and reservoir.
   b) Generation of thematic maps of catchment area, contour, soils, land use, geology, road and rail network, villages etc. in GIS environment and development of Digital Elevation Model for the study area.
4. Estimation of revised reservoir capacity using remote sensing technique.
   a) Digital image analysis of remote sensing data.
   b) Estimation of revised capacity.
5. Application of sediment prediction model.
   a) Analysis of hydro-meteorological, discharge and sediment samples.
   b) Application of suitable sediment yield model.
6. Prioritization of catchment area based on soil loss using geomorphological characteristics, Universal Soil Loss Equation (USLE), sediment yield etc.
   a) Determination of present land uses in the catchment area from remote sensing data and generation of various thematic maps representing the factors of USLE in sub-catchments.

As a GIS package, ILWIS allows to input, manage, analyze and present geographical data. ILWIS is a Windows-based, integrated GIS consisting of:

- Display of raster and multiple vector maps in map windows
- Display of tables in table windows
- Interactive retrieval of attribute information
- Image processing facilities
- Manipulation of maps in a Map Calculator
- Manipulation of tables in a Table Calculator
- Script language to perform 'batch' jobs

ILWIS functionality for vector includes: digitizing with mouse and/or digitizer, interpolation from isolines or points, calculation of segment or point density, pattern analysis. ILWIS functionality for raster includes: distance calculation, creation of a Digital Elevation Model (DEM), calculation of slope/aspect, deriving attribute maps, classify maps, manipulating maps with iff-statements, with Boolean logic, crossing maps, etc. For satellite imagery: creation of histograms, color composites, sampling and classification, filtering, multi-band statistics. ILWIS also provides import and export routines, editing of point, segment, polygon and raster maps, change of projection/coordinate system of maps, and output with annotation. The latitudes and longitudes, scale, legend, compass showing north direction etc. can be easily added on the output map. ILWIS 3.0 and 3.6 have been used in the present study to generate different raster maps and tables.

5.2.2 Arc GIS

The Arc GIS is a versatile software of ESRI, USA includes a suite of integrated applications that allow to perform GIS tasks, from simple to advanced, including mapping, geographic analysis, data editing and compilation, data management, visualization, and geo-processing. The important applications of ARC GIS software are as follows:

- Mapping and visualization with Arc Map
- Data management with Arc Catalog
- Editing and data compilation
- Table and attribute information
- Geoprocessing
- 3D visualization with Arc Globe and Arc Scene
- The geo database
- GIS Servers and services

ArcGIS provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. ArcGIS is an integrated family of GIS software products for building a complete GIS.

ArcGIS Desktop is the primary seat used by GIS professionals to compile, author, and use geographic information and knowledge. It is available at three functional levels—Arc View, Arc Editor, and Arc Info. ArcGIS Desktop includes an integrated suite of comprehensive desktop applications—Arc Map, ArcCatalog, ArcToolbox, and ArcGlobe. Each application has a rich set of GIS tools and operators. ArcGIS Desktop is a sediment sapling site on river Kodar near Koma village has been upgraded for collection of discharge and sediment data from 2010 to 2012.

5.4 Revised Capacity using Remote Sensing and GIS

The basic principle of revised capacity estimation using remote sensing and GIS is that when the sedimentation occurred in a reservoir its water spread reduced with respect to its original area before impoundment and the revised water spreads at different levels can be computed with the help of image analysis technique of GIS software. In the present study, the digital image analysis has been carried out using Integrated Land and Water Information System (ILWIS 3.0). All images were geo-referenced with the help of index map/Survey of India toposheets, so that they can be overlaid and linked with latitude/longitude and geographical area can be computed. In remote sensing technique, the transmittance characteristics of different objects recorded by sensors are used to distinguish various land uses on the earth surface. The remote sensing images consist of digital numbers and need to be converted in radiance values according to radiance characteristics of different sensors. These radiance values can be used to make a relative comparison. The radiance $L(\lambda)$ can be computed using following equation:

$$L(\lambda) = L_{min}(\lambda) + [L_{max}(\lambda) - L_{min}(\lambda)] * \frac{Q_{cal}}{Q_{cal,max}} \quad \text{....5.1}$$

The minimum radiance $L_{min}(\lambda)$ and maximum radiance $L_{max}(\lambda)$ of a sensor can be obtained from its radiometric characteristics. The radiometric characteristics of different sensors in IRS 1D/P6 LISS III sensors are given in Table 5.1 (NIH, 2003-04).

Table 5.1: Radiometric characteristics of various bands of IRS 1D/P6 sensors.

S.N.	Band	Wavelength range	Satellite radiance for LISS III of IRS 1D/P6	
			L_{min}	L_{max}
1.	Band II	0.52-0.59	-2.8	296.8
2.	Band III	0.62-0.68	-1.2	204.3
3.	Band IV	0.77-0.86	-1.5	206.2
4.	Band V	1.55-1.70	-0.37	27.19

In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorption and reflectance are low. The reflectance of water in the visible region scarcely rises above 5%. The absorption of water rises rapidly in the near-IR where both, the reflectance and transmittance are low. The normalized difference water index (*NDWI*), normalized difference vegetation index (*NDVI*), band ratio, NIR (*Band III*) and false color composite (*FCC*) have been used to identify the water pixels in the images. The *NDWI*, *NDVI* and band ratio (*BR*) can be written as:

$$NDWI = \left[\frac{GREEN - NIR}{GREEN + NIR}\right] \quad \text{....5.2}$$

$$NDVI = \left[\frac{RED - NIR}{RED + NIR}\right] \quad \text{....5.3}$$

$$BR = \frac{GREEN}{NIR} \quad \text{....5.4}$$

chemical and biological processes, and replenishes the ground water supply to wells, springs and streams (Rawls et al, 1993; Oram, 2005).

Infiltration is critical because it supports life on land on our planet. The ability to quantify infiltration is of great importance in water resources management. Prediction of flooding, erosion and pollutant transport all depend on the rate of runoff which is directly affected by the rate of infiltration. Quantification of infiltration is also necessary to determine the availability of water for crop growth and to estimate the amount of additional water needed for irrigation. Also, by understanding how infiltration rates are affected by surface conditions, measures can be taken to increase infiltration rates and reduce the erosion and flooding caused by overland flow. For estimation of infiltration characteristics of soil, empirical and physical models have been developed. The empirical models include Kostiakov, Horton, and Holtan, and approximate physically based models like those of Green and Ampt and Philip. Empirical models tend to be less restricted by assumptions of soil surface and soil profile conditions, but more restricted by the conditions for which they were calibrated, since their parameters are determined based on actual field-measured infiltration data (Hillel, 1998; Skaggs and Khaleel, 1982). In the present analysis, the double ring infiltrometer has been used and infiltration curve and rate of infiltration for soils on different sites have been determined. The Kostiakov's, modified Kostiakov's, Horton's and Philip's two-term models have been applied which may be used to understand the infiltration process in the catchment of Kodar reservoir.

5.6.1.1 Kostiakov's model

Kostiakov (1932) and independently Lewis (1938) proposed the following empirical infiltration equation based on curve fitting from field data.

$$F_p = K_k t^\alpha \quad \text{....5.6}$$

where, F_p is the cumulative infiltration at any time t after infiltration starts, and K_k and α are the constants. Criddle et al. (1956) used the following logarithmic form of the equation to determine the parameters K_k and α of model.

$$\log F_p = \log K_k + \alpha \log t \quad \text{....5.7}$$

The major drawback of Kostiakov's model was that it predicts the rate of infiltration as infinity at time t equals zero and reaches zero at time equals infinity. In actual field condition, after some time, the infiltration rate reaches a study rate (Philip, 1957a, b, c; Haverkamp et al., 1987; Naeth et al, 1991). Israelson and Hanson (1967) also developed the modified Kostiakov's equation and applied it for estimation of irrigation infiltration.

5.6.1.2 Modified Kostiakov's model

The modified Kostiakov's model can be expressed as:

$$F_p = Bt^n + i_c \quad \text{....5.8}$$

where, F_p is the cumulative infiltration at any time t, i_c is the asymptotic steady infiltration flux and B and n are characterizing constants. The Kostiakov and modified Kostiakov equations tend to be the preferred models used for irrigation infiltration, probably because these models are less restrictive as to the mode of water application than some other models.

The constant A can be measured by determining the intercept and S by measuring the slope of the best-fit line of plot between F_p/t and $t^{-1/2}$. The best-fit infiltration model for a site or in the region can be evaluated by comparison of observed rate of infiltration and computed rate of infiltration using model parameters. In the present analysis integral square error (ISE), root mean square error (RMSE) and efficiency (η) have been used for selection of best-fit infiltration model for the site and the region. The *ISE* is a measure of system performance formed by integrating the square of the system error over a fixed interval of time; smaller the *ISE* value closer is the match. The *RMSE* is the square root of the mean-squared-error. The *RMSE* ranges from 0 to infinity, with 0 corresponding to the ideal. The efficiency indicates the deviation of initial and remaining variance expressed in percentage. The formulae for computation of *ISE*, *RMSE* and efficiency are given below.

a) Integral Square Error (ISE):

$$ISE = \frac{\left[\sum_{t=1}^{n} \{I_o(t) - I_c(t)\}^2\right]^{0.5}}{\sum_{t=1}^{n} I_o(t)} \quad \text{....5.15}$$

b) Root Mean Square Error (RMSE):

$$RMSE = \left[\frac{\sum_{t=1}^{n} \{I_o(t) - I_c(t)\}^2}{n}\right]^{0.5} \quad \text{....5.16}$$

c) Efficiency

$$\eta = \frac{IV - RV}{RV} \quad \text{....5.17}$$

$$IV = \sum_{t=1}^{n} \left[I_o(t) - \bar{I}_o\right]^2 \quad \text{....5.18}$$

$$RV = \sum_{t=1}^{n} \left[I_o(t) - I_c(t)\right]^2 \quad \text{....5.19}$$

where, $I_o(t)$ and $I_c(t)$ are the observed and computed rate of infiltration or cumulative infiltration at any time *t*, *n* is the no. of observation, *IV* is the initial variance and *RV* is the remaining variance.

5.6.2 Hydraulic conductivity

The hydraulic conductivity is the measure of the ability of the soil to transmit water, and depends on properties of both soil and water. It is defined as the volume rate of flow of water through a unit area of the soil under a unit gradient. The measurement of hydraulic conductivity is also of considerable importance for irrigation, drainage and evaporation studies. In the project, the field saturated hydraulic conductivity has been measured using Guleph permeameter. The Guleph permeameter is essentially an "in hole" Mariotte bottle constructed of concentric transparent plastic tubes. The apparatus consists of a tripod assembly, support tubes and lower air tube fittings, reservoir assembly; well head scale and upper air tube fittings and auxiliary tools. The reservoir assembly provides a means of storing water and measuring the outflow rate. The Guleph permeameter method measures the steady state liquid recharge necessary to maintain a constant depth of liquid in an uncased cylindrical well finished above the water table. The Richard analysis is the basis for calculation of the field saturated hydraulic conductivity.

5.6.4 Apparent Specific Gravity

Specific gravity (G) is defined as the ratio of the weight of a given volume of soil solids to the weight of an equal volume of water. Apparent specific gravity (G_a) refers to the soil mass instead of the soil particles and takes into account the voids within the soil mass. Apparent specific gravity is defined as the ratio of the weight of a given volume of soil mass to the weight of an equal volume of water. Apparent specific gravity is related to the specific gravity by the following relation:

$$G_a = (1-\eta)G \qquad \text{....5.24}$$

where, η is the porosity of the soil. The density bottle is used to determine sp. gravity for a wide range of material from clay to sand and gravel smaller than 10 mm sizes. The specific gravity is determined using the following equation in laboratory.

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} \qquad \text{....5.25}$$

where, M_1 is mass of empty bottle, M_2 is mass of the bottle +dry soil, M_3 is mass of bottle + soil + water and M_4 is mass of bottle filled with water.

5.6.5 Dry density

The dry density is used in water balance model for water resources management. The in situ dry density has been determined with the help of core cutter. The method is widely used for the determination of the field density of fine-grained natural or compacted soil free from aggregates. By measuring unit weight and moisture content and using empirical relations, various strength, deformation, permeability and consolidation parameters can be estimated. This also entails knowing the composition of soil. The cylindrical core cutter is used for determination of dry density γ_d in gm/cm^3 on field. The following equations are used for computation of bulk density and dry density of soil.

$$\gamma_d = \frac{100\gamma_b}{100 + w} \qquad \text{....5.26}$$

$$\gamma_b = \frac{W_1 - W_2}{V} \qquad \text{....5.27}$$

where, W_1 is weight of cutter + soil in gm, W_2 is weight of core cutter in gm, V is volume of core cutter and w is moisture content. The results of detailed investigation have been used in soil erosion, prioritization and sediment modeling studies.

The prioritization of sub-watersheds is an essential element for development of catchment area treatment plan and management of watersheds. Before taking up any catchment area treatment plan, first question arise that which area should be treated first and by prioritization, the planners and mangers may be able to identify the stressed areas of watershed where immediate attention are required. In the present prioritization approach, Saaty's approach of analytical hierarchal approach has been used for selection of priority watersheds.

5.7.2 Priority assessment

Since EHPs depends on several factors and vary significantly, it is necessary to convert this variation in the same range for all EHPs by normalization to ensure that no layer exerts an influence beyond its determined weight. The normalized weight for an EHP for a watershed is determined by the following equation:

$$W_{ij} = \left[\frac{NUB_i - NLB_i}{OUB_i - OLB_i}\right]\left[EHP_{ij} - OLB_i\right] \quad ....5.30$$

where, W_{ij} is the normalized value of i^{th} EHP of j^{th} watershed, NUB_i and NLB_i are the normalized upper bound and lower bound for i^{th} EHP. OUB_i and OLB_i are the original upper bound and lower bound for i^{th} EHP. EHP_{ij} is the original value of i^{th} EHP for j^{th} sub-watershed. Generally, the normalized range is generally considered in the range of 0 to 1. The equation can be converted as:

$$W_{ij} = \left[\frac{EHP_{ij} - OLB_i}{OUB_i - OLB_i}\right] \quad ....5.31$$

After estimating the normalized values of all EHPs (W_{ij}) for all the sub-watersheds and Saaty's weight for each EHP (X_i), the final priority of a sub-watershed (F_j) can be determined using the following equation.

$$F_j = \sum_{i=1}^{n} X_i W_{ij} \quad ....5.32$$

On the basis of final priority, all sub-watersheds of Kodar catchment has been grouped in five classes of priority namely very high, high, moderate, low and very low on the basis of priority ranking. For assessment of priority, the Kodar reservoir catchment has been divided into 67 sub- watersheds (SW-1 to SW-67). The following nine erosion hazard parameters (EHPs) have been used for prioritization of sub-watersheds for development of catchment area treatment plan and discussed here.

1. Soil loss using USLE/RUSLE approach (*SL*)
2. Sediment production rate (*SPR*)
3. Sediment yield (*SY*)
4. Sediment transport index (*STI*) and stream power index (*SPI*)
5. Slope (*SI*)
6. Drainage density (D_d)
7. Channel frequency (C_f)
8. Form factor (R_f)
9. Circulatory ratio (R_c)

5.7.3 Soil loss (*SL*) using USLE and RUSLE model

For estimation of soil losses from Kodar reservoir catchment, Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) models have been used. Both USLE and RUSLE group the numerous physical and management parameters that influence erosion under six factors, which can be expressed numerically. The USLE and RUSLE model can be expressed by the following equation:

contents, textural property and permeability. The Nomagraph for determination of K is given in Fig 5.1.

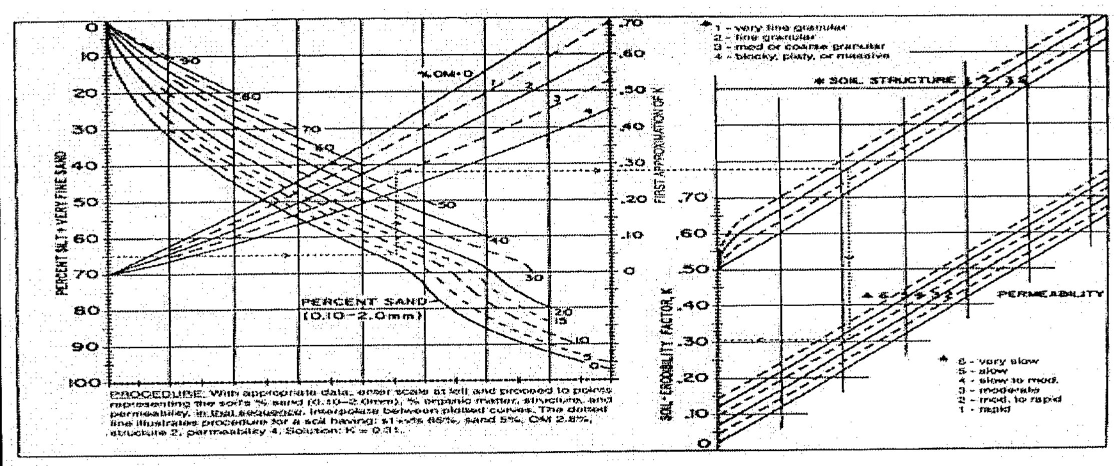


Fig. 5.1: Nomograph for determining the soil erodibility factor (USDA, 1978)

In case of USLE, the standard values for different soils in Indian condition have been used. During application of RUSLE, following equation given by Wischmeier et al. (1971) has been used:

$$100K = 2.1M^{1.14}(10^{-4})(12-a)+3.25(b-2)+2.5(c-3) \quad \text{....5.36}$$

where, M is the percent of silt, very fine sand and clay [(% of very fine sand+% of silt)*(100-% of clay)], a is the organic matter, b is the structure of the soil (very fine granular=1, fine granular=2, coarse granular=3, lattic or massive=4) and c is the permeability of the soil (fast=1, fast to moderately fast=2, moderately fast =3, moderately fast to slow=4, slow=5, very slow=6). For determination of organic matter from organic carbon a factor 1.724 has been used (BUB, 2007; Wayne et al, 2003).

5.7.3.3 Slope length factor (L)

Slope length is important mainly with respect to the increase in the flow of water on slope. The slope length factor is the ratio of soil loss from the field slope length to that from 22.13 m length plots under identical conditions. Slope length is defined as the distance from the point of origin of overland flow to the point where either slope gradient decreases enough that soil deposition begins, or the runoff waters enters a well defined channel. The L-factor can be computed using the following equation:

$$L = \left(\frac{\lambda}{22.10}\right)^m \quad \text{....5.37}$$

where, λ is the field slope length and can be worked out as; λ = (level difference/slope)*100 and m is the exponent varies from 0.2 for slope less than 1%, 0.3 for slope from 1% to 3%, 0.4 for slope from 3% to 5% and 0.5 for slope more than 5% slope.

5.7.3.6 Support practice factor (P)

Conservation practice conditions consist mainly in the methods of land use and tillage, and the agro technology. The *P*-factor in USLE is expressed as a ratio, which compares the soil loss from the investigated plot cultivated up and down the slope gradient. The amount of soil loss from a given land is influenced by the land management practice adopted. The value of *P* ranges from 1.0 for up and down cultivation to 0.25 for contour strip cropping of gentle slope. In case of RUSLE model, the agricultural area of catchment has been divided in different slope ranges and according to slope, the values of P-factor have been assigned. For other land uses, standard values considering no conservation measures have been given. The Table 5.2 indicated the *P*-factor values for different land uses used in USLE and RUSLE models.

Table 5.2: P-factor values for different land uses and slope

S.N.	Land use	Slope (%)	P- Factor	
			USLE model	RUSLE model
1.	Dense forest	All slope	0.8	0.8
2.	Agriculture	0 % to 2 %	1.0	0.6
		2 % to 5 %	1.0	0.5
		5 % to 8 %	1.0	0.5
		8 % to 12 %	1.0	0.6
		12 % to 16 %	1.0	0.7
		16 % to 20 %	1.0	0.8
		More than 20 %	1.0	0.9
3.	Scrub	All slope	1.0	0.8
	Settlement	All slope	1.0	1.0
	Water body	All slope	1.0	1.0

All the thematic maps have been generated in ILWIS GIS for USLE and RUSLE model separately. After multiplication of thematic maps *R*, *K*, *LS*, *C* and *P-factors*, the annual and seasonal soil loss maps giving spatial distribution of soil losses have been generated.

5.7.4 Sediment production rate (*SPR*)

The geomorphological parameters beside climatological and human interference govern runoff and sediment yield from the sub-catchments and can be used for identification of priority areas for soil conservation measures. With the invention of high speed computers and GIS, it has become easy to compute various linear, areal and relief based geomorphological parameters for soil erosion modeling and planning for soil conservation works. For assessing soil erosion and sediment yield, various empirical models based on geomorphological parameters have been developed in the past (Mishra et al., 1984; Josh and Das, 1984).

Choudhary and Sharma (1998) used geomorphological characteristics such as drainage density, bifurcation ratio, relief ratio etc. for assessment of soil erosion and prioritization of sub-watersheds. The Universal Soil Loss Equation-Sediment Deposit Rate (USLE-SDR) predictions remain widely used for estimating annual soil loss at the catchment scale in un-gauged drainage basins (e.g. Trimble and Crosson, 2000; Angima et al., 2003; Martin et al., 2003; Lu et al., 2004; Boellstorff and Benito 2005; Fu et al., 2005; Onyando et al., 2005).

$$STI = \left[\frac{A}{22.13}\right]\left[\frac{\sin(Sl)}{0.0896}\right]^{1.3} \quad ....5.45$$

where, A is the upstream catchment area and Sl is the slope steepness in degree. Unlike the length-slope factor in the Universal Soil Loss Equation (USLE) it is applicable to three-dimensional surfaces (Burrough et al., 1998). The stream power index (*SPI*) takes into account both a local slope geometry and site location in the landscape combining data on slope steepness and specific catchment area. The stream power index can be expressed as;

$$SPI = \ln(A * \tan(Sl)) \quad ....5.46$$

The stream power index can be used to describe potential flow erosion and related landscape processes. As specific catchment area and slope steepness increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power index and erosion risk increase. The stream power index controls potential erosive power of overland flows, thickness of soil horizons, organic matter, pH, silt and sand content, plant cover distribution. The stream power index can be used for selection of sites for soil conservation measures to reduce the effect of concentrated surface runoff.

5.7.7 Average slope (*Sl*)

The slope is an important topographical factor responsible for degradation of watershed. The steep slope causes more and more soil erosion resulting development of gullied lands and loosing the fertility and moisture holding ability of soils. For generation of slope map, the contour map and point elevation map of Kodar catchment and nearby area have been used. Using the inbuilt sub-routine of ILWIS, the slope map for the region is generated. Using the *iff* statement, the slope map for each of sub-watershed have been generated and using statistics of that map, the average soil loss from sub-watersheds have been computed separately.

5.7.8 Geomorphological parameters

Knowledge of landscape morphology along with the hydrologic processes is required to conceptualize the generation of runoff and sediment loss from precipitation events. The geomorphology of the watershed governs the erosion status and can be used for formulation of CAT plan. In the present study, various geomorphological parameters including drainage density (D_d), Channel frequency (C_f), Form factor (R_f) and Circulatory ratio (R_c) indicative of runoff and erosional processes have been used as EHPs in Saaty's AHP method.

5.7.8.1 Drainage density (D_d)

The drainage system shows the geomorphologic status of the region and an important indicator of the linear scale of land-form elements in stream eroded topography. If the drainage density in any watershed is more, it indicates that more water may go downstream as direct surface runoff if appropriate measures are not adopted. Also there may be more soil erosion because of entry of eroded soil in the drainage very soon after detachment. Therefore, in watershed management and planning, those areas should be treated on priority basis and both soil and water conservation measures are needed. For determination of drainage density of sub-watersheds, the drainage map of each sub-watershed prepared separately and using histogram, the total length of drainage may be obtained. The drainage density of sub-watershed may be estimated using area of that watershed in the following equation maintained catchment area treatment plan helps in sustainable development of the catchment area while providing the appropriate soil and water conservation measures. The soil and water conservation measures required in CAT plan can be classified in to three broad groups as, mechanical measures, agronomic measures and biological measures being described below:

5.8.1 Mechanical measures

Engineering/mechanical measures of soil and water conservation include various engineering techniques and structures constructed across the direction of the flow of rainwater with the objective of division of long slopes in to a series of shorter ones in order to reduce the velocity of runoff water thereby reduce the soil and water losses. Mechanical protection measures (engineering measures) are the first line of defense against soil erosion and water runoff. Agronomic measures (vegetative measures) provide second line of defense. Vegetative (agronomic) methods can usually control erosion if they are applied soon enough, but areas that have already been seriously damaged may need mechanical methods of repair. Soil and water conservation measures must be simple and low cost. The important principles to be kept in mind while planning mechanical measures are: (Haridas, V. R. 2005).

a. Increasing the time of concentration of runoff and thereby allowing more runoff water to be absorbed and held by the soil.
b. Intercepting a long slope into several short ones so as to maintain less than a critical velocity for the runoff water.
c. Protection against damage due to excessive water runoff.

There are various mechanical measures of which some of the important measures are described below. It is always better to go for only the earthen structures with the locally available materials instead of high cost masonry structures.

5.8.1.1 Check dam

Check dam is a small barriers built across the direction of water flow on shallow rivers and streams (up to third order) with medium slopes. The structures will reduce runoff velocity, hence minimizing erosion and improving ground water recharging capacity and for the purpose of water harvesting. Ideally a check dam is located in a narrow stream with high banks. There are different types of check dams. Check dams range in size, shape and cost. It is possible to build them out of easily available materials. It is even possible to build some of these dams at a very little cost. Check dams are proposed where water table fluctuations are very high and the stream is influent or intermittently effluent. The catchment areas vary widely but an average area of about 25 ha should be there. The parameters needed to be considered for the construction of check dams are slope, soil cover and its thickness and hydrological conditions such as rock type, thickness of weathered strata, fracture, depth to the bed rock etc.

5.8.1.2 Gully plug

Gully Plugs are built using local stones, clay and bushes across small gullies and streams running down the hill slopes carrying drainage to tiny catchments during rainy season. Gully Plugs help in conservation of soil and moisture. The sites for gully plugs may be chosen whenever there is a local break in slope to permit accumulation of adequate water behind the bunds. Gully erosion occurs when the shape of the terrain concentrates water flow over or converted into level - step - like fields constructed by cutting and filling. This measure reduces the slope considerably. It also helps in the uniform distribution of soil moisture, retention of soil and manure and also in the better application of irrigation water.

5.8.1.7 Contour bunding

Contour bund is the most popular soil conservation measure in the country and is practiced on a large scale in different states. Contour bund consists of constructing narrow-based trapezoidal embankments (bunds) across the slope and along the contours (contour lines) of the fields on fields where the slope is not very steep and soil is fairly permeable to impound runoff water behind them so that all the impounded water is absorbed gradually into soil profile for crop use. A series of such bunds divide the area in to strips and act as a barrier to the flow of water, as a result of which the amount of velocity of runoff are reduced, resulting in reduced soil erosion.

5.8.1.8 Graded bunding

Graded bunds consist of small bunds constructed with a slope of 0.1 to 0.4 % in order to dispose of excess water through the graded channels which lead to naturally depressed area of the land. These are recommended for area more than 600 mm rainfall having highly impermeable soils. The purpose of graded bunding is to make run-off water to trickle rather than to rush out. Graded bunding is restricted to 6 % slope and in specific cases it may be extended to a slope of 10 %. The height of bund should be at least 45cm and top width may vary with height of the bund. Grassed water ways are necessary to prevent erosion downstream and failure of the bunds.

5.8.1.9 Land leveling

Land leveling and farm bunding were the predominant form of land management practiced in watershed management. Land leveling helped in soil and water conservation. During heavy rainfall velocity of water was reduced due to leveled fields. This, ultimately, reduced the chance of soil erosion. When water started flowing slowly along the fields the infiltration augmented ground water level. Farm bunds were created to prevent erosion of top soil and to retain rainwater in the farms of cultivation.

5.8.2 Agronomic measures

Agronomic measures of soil and water conservation help in reducing the impact of raindrops through interception and thus reduce splash erosion. These practices also help in increasing infiltration rate and thereby reduce runoff and overland flow. Reduction in runoff and soil losses is achieved through land management practices and associated agronomic practices. The plant canopy protects the soil from the impact of the rain drop and the grasses and legumes produced dense sod which helps in reducing soil erosion and the vegetation provides organic matter to soil.

5.8.2.1 Contour forming

This consists in carrying out different agricultural operations like ploughing, planting and inter-culture in horizontal lines across the sloping land. Such practices help in retaining rainwater and retarding erosion. These measures are effective when land slope is about 2% and less. The ridges and furrows, and the rows of the plants placed across the slope form a continuous layout of miniature reservoirs and barriers to the water moving along the slope. The barriers are small

5.8.3.6 Mulching

Mulch is simply a protective layer of a material that is spread on top of the soil. Mulches can either be organic such as grass clippings, straw, bark chips, and similar materials or inorganic such as stones, brick chips, and plastic. The use of organic mulches has the advantage of minimizing the impact of rain drops and controlling splash, reducing evaporation, controlling weeds, reducing soil temperature during day time, encouraging microbial growth and adding nutrients to the soil.

5.8.3.7 Land preparation

Land preparation including post harvest cultivation and preparatory tillage, influences intake of water in the soil and obstruction to surface flow. Ploughing at right angles to the direction of slope is best for soil and water conservation. The formation of appropriate seed beds/ ridges and furrows matching to the spacing requirements of the crops will control erosion and increase water use efficiency.

5.8.4 Biological measures

Biological measures are preferred in catchment area treatment plan as they are eco-friendly, sustainable and cost effective. The underlying principle here is that soil erodes only if it is bare and expose to erosive forces and if the soil can be kept under a permanent or near-permanent cover of vegetation, then little or no erosion will occur. The soil is protected as the energy of plants or percolating down to the water table. A great range of biological conservation measures have been develop and used. In case of grazing land, this can simply amount to ensuring that the land is never over grazed and that sufficient cover is always retained to protect the soil. For crop land, the problem is more complicated as it is difficult to cultivate without exposing the land to the wind and rain for at least part of the year but mulches can be used.

5.8.4.1 Agroforestry

Agroforestry is a system that combines the production of trees with agricultural crops, animals and other resources simultaneously or sequentially on the same unit of land. The positive effects of tree on soil include, amelioration of erosion, primarily through surface litter cover and under story vegetation, maintenance or increase of organic matter and diversity through continuous degeneration of roots and decomposition of litter, nitrogen fixation, enhancement of physical soil properties such as soil structures, porosity and moisture retention due to the extensive root system and the canopy cover and enhanced efficiency of nutrient use because the tree-root system can intercept, absorb and recycle nutrients in the soil that would otherwise be lost through leaching.

5.8.4.2 Grazing management

The various method of controlled grazing include, early versus deferred grazing wherein the deferred grazing is postponing or delaying grazing to enable the vegetation to grow well and produce abundant seeds for the regeneration of grazing lands; rotational grazing which includes the year long grazing in blocks and components with the aim to give rest to part of the land and hence provide full opportunity for the vegetation to grow and develop well; deferred rotational grazing aims at achieving both objectives of providing grazing to domestic livestock and providing rest to grazing land for regeneration.

Table 5.3: Criteria adopted in suggesting soil and water conservation measures

Structure	Slope (%)	Drainage	Soil	Land use/ Land cover	Geomorphological land form	Advantage
Bench Terracing	6-10%	_	Shallow Soil not having permeability	Agriculture Field	Steep slope, low rainfall	Uniform impounding of water, Reduced the existing steep slope to mild slope.
Contour Farming	2-10%	_	Alluvial and black deep lateritic soils	Agriculture Field	Area where runoff is 10% of precipitation lower point of natural Depressions	Prevention of soil erosion, increased supply of moisture to the plant, control flash floods
Strip Cropping	< 3	_	All type	Agriculture Field	Gently sloping land	Shortening length of slope , reducing velocity of runoff,
Land leveling	any slope	_	Non Shallow Soil		Agricultural Land with rainfall	Reduce the velocity of water, reduced the chance of soil erosion
Check dam	more than 3%	3rd order & higher stream	Sandy Gravel zone	waste land on either bank, forest land	Buried pediment	Surface water harvesting life irrigation, Drinking water facility, partially recharges structure.
Vegetative barriers	Perpendicular to the dominant slope less than 10%	_	All type	Agriculture Land	On crop land fields where water or wind erosion is a problem, or where water to be needs conserved.	Facilitate benching of sloping topography, reduced surface runoff, divert runoff to a stable outlet, provide wildlife habitat
Farm Pond	1-2%	_	Semi Pervious to impervious, All soil except in light textured soils	Single crop area	Area where runoff is 10% of precipitation lower point of natural depressions.	Life saving irrigation , drinking water for live stock horticulture development recharge to ground water
Boulder Bund	2-3%	1st to 3nd	severe soil erosion semi pervious to pervious	Single crop area	Buried pediment (M),Buried pediment (S),Buried pediplain, pediment	Soil conservation runoff retardant, delay recharge of water, Recharge to ground water.

Contd…

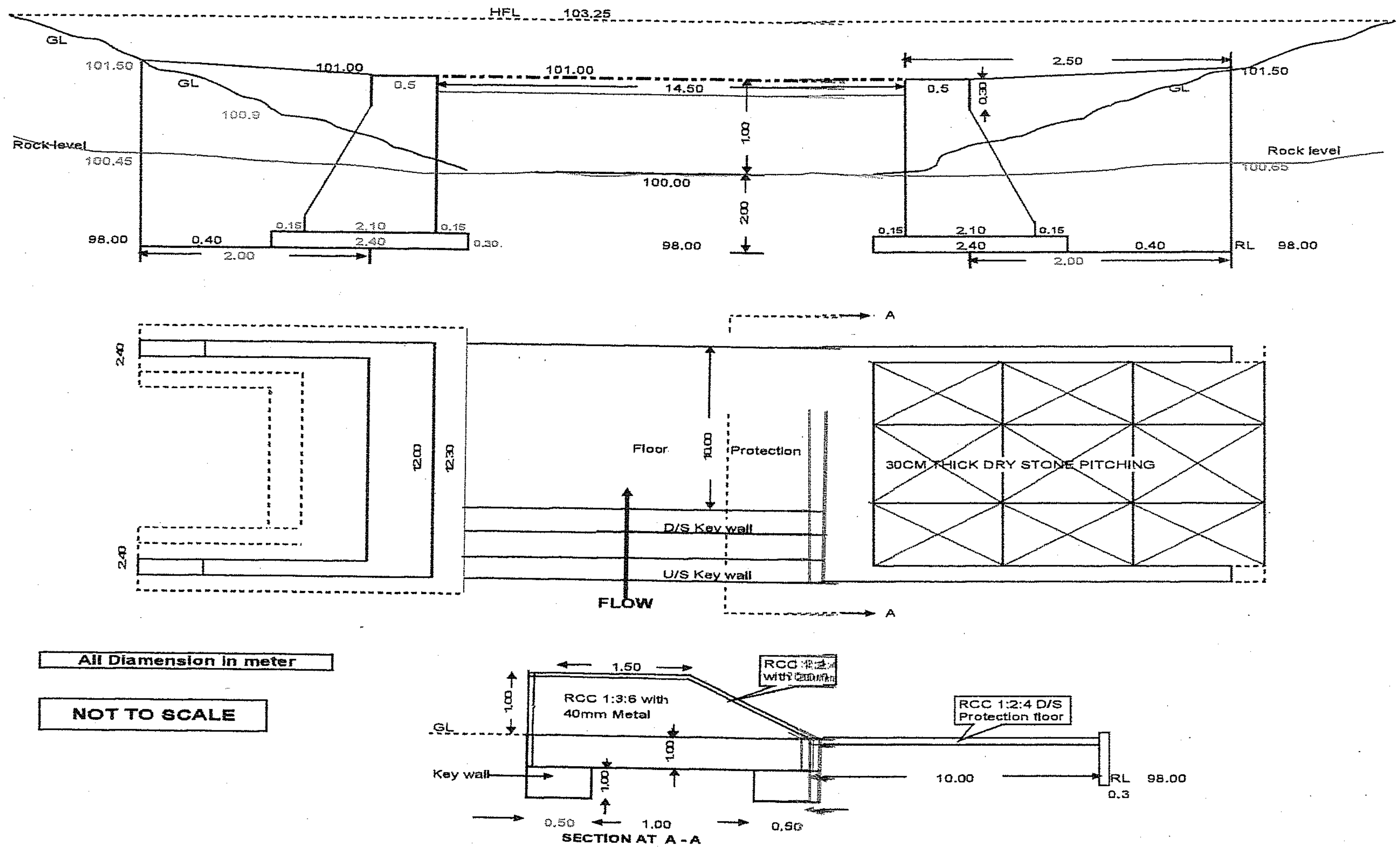


Fig. 5.2: Sketch, x-section and other details of a check dam

5.9.1 Design flood

The check dams have been proposed on small tributaries of river Koadr where gauging data are not available and discharge calculation through unit hydrograph is not possible. Hence, the following the highest value obtained from following three methods has been considered the design flood.

i-By using Dicken's formula

$$Q = CM^{3/4} \qquad ....5.49$$

Where, Q is the discharge in m^3/sec, C is a constant equal to 18.0 for the study area and M is the catchment area in km^2.

ii-Rainfall intensity based criteria

In this criterion, runoff due to rain fall of 0.75 cm/hour for 24 hours can be adopted for the catchment up to 500 km^2. In case of catchment area more than 500 km^2, the rainfall intensity is to be increased to 1.5 cm/hour for 24 hours. The following equation may be used to compute the flood discharge:

$$Q = 2.0833A \quad \text{for catchment up to 500 km}^2 \qquad ....5.50$$

$$Q = 4.1667A \quad \text{for catchment more than 500 km}^2 \qquad ....5.51$$

iii- Manning's equation at observed HFL

In this method, Manning's equation is used to compute velocity at H.F.L., which in turn employed to estimate the flood discharge. According to Manning's equation, the flood discharge is the product of area and velocity. The velocity can be computed using following equation.

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad ....5.52$$

where, V is the flow velocity in m/sec, n is Manning's constant, R is hydraulic mean depth equal to the ratio of wetted area and wetted perimeter and S is slope. The highest of above three are considered the designed flood estimation.

5.9.2 Afflux

For computation of afflux in meter, the maximum value obtained from following three criterions has been used.

i- At the maximum flood discharge

$$H = \left[\frac{V^2}{2g} + 0.015\right]\left[\frac{A^2}{a^2} - 1\right] \qquad ....5.53$$

Where, H is the afflux in m, V is the velocity at maximum flood discharge (m^3/sec), A is the total area up to H.F.L (m^2), a is the obstructed area (m^2) and g is the acceleration due to gravity (m^2/sec).

$L = H / 0.11$ 5.59

$L = CL * H$ 5.60

The designed thickness of floor (T) can be computed from the following equation:

$T = 1.2H / (\rho - 1)$ 5.61

5.10 Application of SWAT Model

SWAT model is a continuous time model that operated on daily and sub-daily basis. Studies conducted earlier shown that the model is efficient in predicting runoff, sediment, agriculture chemical yields in gauged and un-gauged catchments (Srinivasan *et al.*, 1993, 1998; Srinivasan and Arnold, 1994; Cho *et al.*, 1995; Rosenthal *et al.*, 1995; Bingner, 1996; Bingner *et al.*, 1997; Peterson and Hamlett, 1998; Arnold *et al.*, 1999a,b; Tripathi *et al.*, 2003). SWAT model is an ARC GIS based distributed model and data on climate, soil, land use, management practice, topography etc. are required for preparation of model. The key procedures for application of SWAT model are given below:

- Load or select the ArcSWAT extension
- Delimited the watershed and define the HRUs
- Edit SWAT databases (optional)
- Define the weather data
- Write the default input file
- Edit the default input files (optional)
- Setup and run SWAT (Specify the simulation period, ET calculation method etc)
- Apply a calibration tool (optional)
- Analyze, plot and graph SWAT output (optional)

5.10.1 Preparation of Data Base for SWAT Model

The SWAT model requires both static and dynamic data. The static data consists of contour map, drainage map, soil map, land use map with detail properties of soil and weather generator data, while dynamic data includes climatic data consists of rainfall, temperature, wind speed etc. and hydrological data includes observed runoff, sediment and chemical concentration in water at the outlet. In the study, the SWAT model has been applied on Koma G/D site where gauging of runoff and sediment have been carried out and after calibration and validation the model will be applied for whole Kodar reservoir catchment. The documentation on SWAT model is available in ARCSWAT_Documentation.pdf in ArcSWATHELP folder when the model is installed in computer. The example data and formats for input files are available in Example Data folder.

The digital elevation model (DEM) or prepared sub-watershed map can be used for delineation of sub-watersheds in ARC GIS interface of SWAT model. The contour map or DEM, drainage map, watershed map, soil map and land use map can be used for generation of hydrological response units (HRUs). The long term meteorological data on monthly basis are required for generation of weather generation sub-model in SWAT. The weather generator is used for generation of requisite meteorological data during model setup and run. The weather generator consists of the site specific location and elevation details, mean, standard deviation of maximum and minimum temperature on monthly basis. Monthly mean, standard deviation, discharges, reservoirs, subbasin data and watershed data can be edited. With the help of '*Database*' menu, user defined weather generator, soil, land use, fertilizers, pesticides, tillage, urban and septic WQ data can be added to the data base of SWAT model. In this menu various parameters can be edited in graphical user interface, where description of parameters and their ranges are available. After editing the required parameters of SWAT model, rewriting of files with the help of '*Rewrite SWAT Input Files*' sub menu in '*Edit SWAT Input*' menu are necessary to change these parameters in respective files. After rewriting the files, model is ready for simulation. As SWAT model contains several parameters affecting the hydrological processes of nature, it is necessary to restrict no. of parameters which can be optimized for obtaining satisfactory results with the help of sensitivity analysis.

5.10.4 Sensitivity Analysis

Sensitivity analysis limits the number of parameters that need optimization to achieve good correlation between simulated and measured data. The method of analysis in the SWAT model called ParaSol is based on the method of Latin Hypercube One-factor-at-a-Time (LHOAT). ParaSol method combines the objective functions into a global optimization criterion and minimizes both of them by using the Shuffled Complex (SCE-UA) algorithm (van Griensven et al., 2006). The sensitivity analysis in SWAT model can be carried out with or without observed data. Before carrying out the sensitivity analysis, a simulation run may be conducted with default parameter values. The simulation run has been used as default directory and various parameters of flow, sediment and water quality parameters can be selected along with their lower, upper ranges and variation method for sensitivity analysis. In the sensitivity analysis, one be one each factor is taken into consideration and its value is changed by replacement, multiply by a percent or added by some value. The final result of sensitivity analysis give a list of parameters along with their ranking where the parameter with a maximum effect obtains rank 1, and parameter with a minimum effect obtains rank which corresponds to the number of all analyzed parameters. Parameter that has a global rank 1, is categorized as "very important", rank 2 to 6 as "important", rank 7 to 41 as "slightly important" and rank 42 (i.e. flow 27) as "not important" because the model is not sensitive to change in parameter (Van Griensven et al., 2006).

5.10.5 Calibration of SWAT Model

The model calibration is performed for setting up the parameter values of a simulation model to predict the runoff or other outputs from rainfall and other inputs with certain degree of accuracy. The calibration of a watershed model, especially a conceptual one, is complicated by the fact that values for a large number of parameters or coefficients must be estimated (Jacomino and Fields, 1997; Srinivasan et al., 1998; Motovilov et al., 1999; Carrubba, 2000). After creating new SWAT project, the HRUs have been generated for Koma G/D and Kodar reservoir catchments. The calibration has been done for Koma G/D site where discharge and sediment data for the year 2010 have been collected by WRD, Raipur. After generating the HRUs, weather generator station which were created after setting up SWAT model were loaded and all the files were written with default values. In calibration process, various model parameters modified one by one and after rewriting the files, the SWAT model run was executed. The results of model run were saved and exported to Excel file and compared with observed data. The Nash-Suctliff efficiency (η), root mean absolute error (*RMAE*), integral squared error (*ISE*), relative error in areas in the watershed may be the areas of high erosion, excessive slope, environmentally stressed areas with concentrated development activities. The priority sub-watersheds or whole basin can be selected as target area for implementation of BMP. Various BMPs can be selected depending upon the goals required to be achieved from implementation of soil conservation measures. According to a BMP, the set of parameters need to be changed in different inputs. For example, to minimize channel bank erosion, it is necessary to implement channel stabilization or riparian buffer and/or filter strip may be added in *hru* file by giving the width of filter strip. Some BMPs have been given in Table 5.4 including agronomic and mechanical measures for soil and water conservation. After changing the necessary parameters in their respective files, these files are needed to be rewritten and simulate the run again and save it as another scenario. The comparison of runoff, sediment or water quality parameters with base line results can be made to see the impact of implementation of BMPs using SWAT model.

Table 5.4: Some Best Management Practices for control of erosion

S.N.	Conservation measures	Purpose	Selection criteria	Name of Variable affected	File of model
1.	Stream bank stabilization	• Reduce sediment load in stream • Maintain channel capacity	Main stream	CH_COV CH_EROD	.rte .rte
2.	Gully plug	• Reduce ephemeral gully erosion • Reduce velocity of flow • Trap sediment • Stabilize steep slopes	Sub basin with slope more than 5%	CH_N1	.sub
3.	Conservation or recharge structure	• Increase groundwater recharge • Facilitate sediment settling	-	CH_K1 CH_N1	.sub .sub
4.	Conservation tillage	• Reduce erosion • Moisture conservation	All croplands	EFFMIX, DEPTIL, CN2	.mgt .mgt .mgt
5.	Terraces	• Reduce overland flow and conduct runoff to a safe outlet • Reduce sheet erosion	All croplands	CN2, P-factor	.mgt
6.	Manure incorporation	-	All waste application field	FRT_SURFACE	.mgt

CN2: Initial SCS runoff curve number for AMC II, CH_COV: channel cover factor
CH_COV: Channel cover factor, CH_EROD: Chanel erodibility factor
CH_N1: Manning's N value for tributary channel, CH_K1: Eff. Hydraulic conductivity in tributary channel,
EFFMIX: Mixing efficiency of tillage operation DEPTIL: Depth of mixing by tillage operation
FRT_SURFACE: Friction of fertilizer applied to top 10 mm soil

*Sourec: SWAT Advance manual, Texas A&M Agrilife, Texas, USA

CHAPTER 6.0- ANALYSIS OF RESULTS

6.1 Creation of GIS Database

For scientific analysis and detailed study, the collection and analysis of available data is important to understand the cause and the magnitude of problems. The GIS based data base of Kodar reservoir catchment has been prepared using ILWIS GIS software consists of various themes including drainage, contours, digital elevation model, road and rail network, villages, geology, geomorphology; soil etc. The ARC GIS has been used for preparation of various thematic maps for SWAT modeling.

6.1.1 Drainage and road rail network map

The drainage map of the Kodar catchment has been prepared from survey of India topo-sheets 64 K/4 and 64K/8. The drainage map of the Kodar dam catchment has been presented in Fig. 6.1. The Kodar dam has been constructed on river Kurar near Kowajhar village in Mahasamund district. The river Kurar is the fifth order stream as per Strahler's classification system. The catchment of Kodar reservoir lies between 80° 10'N to 80° 25'N longitude and 20° 0'E to 20° 15'E latitude. The road network of the study area consisting of all major roads in the catchment of Kodar reservoir is given in Fig. 6.1. National highways NH-6 & NH-215 pass through the study area and rail network consists of single line BG rail line from Raipur to Vishakapattanam. Most of the villages in the catchment of Kodar reservoir are connected by metal roads and transportation facilities are good.

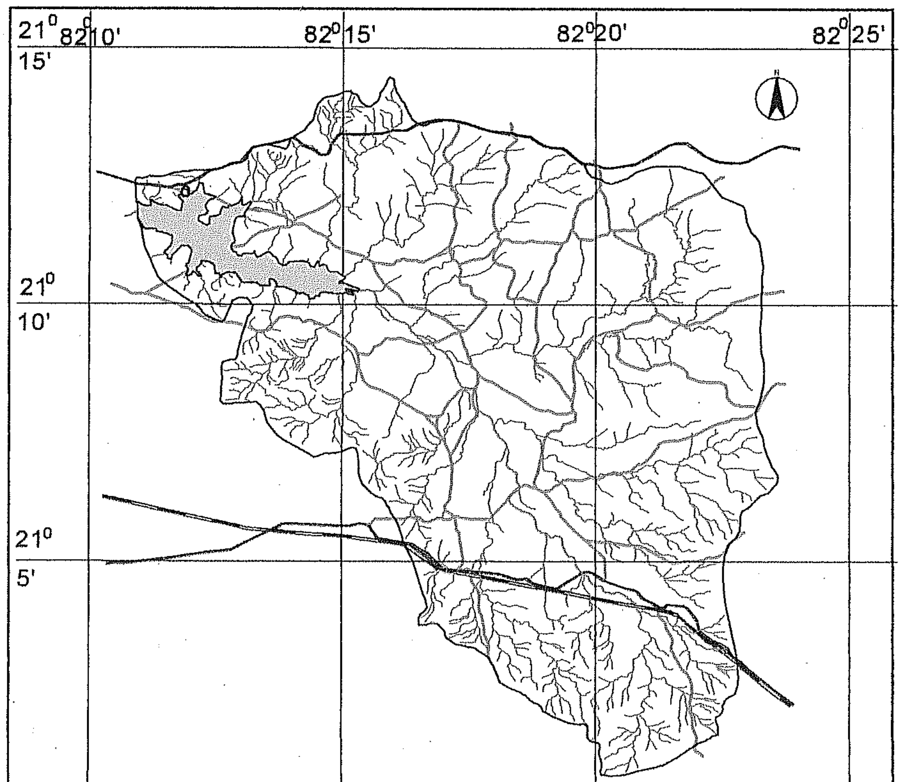


Fig. 6.1: Drainage and road-rail network in the study area

6.1.2 Geology

The geology of the study area consists of old age granite and glauconitic quartz with few basic dykes in the upstream of Kodar river act as barrier of ground water flow. The geological map of the study area is presented in Fig. 6.2 and area under each category in Table 6.1. It has been observed that more than 96 % area of Kodar catchment has been covered by granite and ground water availability in these rocks are confined with faults and lineaments only. The availability of groundwater is poor in the catchment of Kodar reservoir.

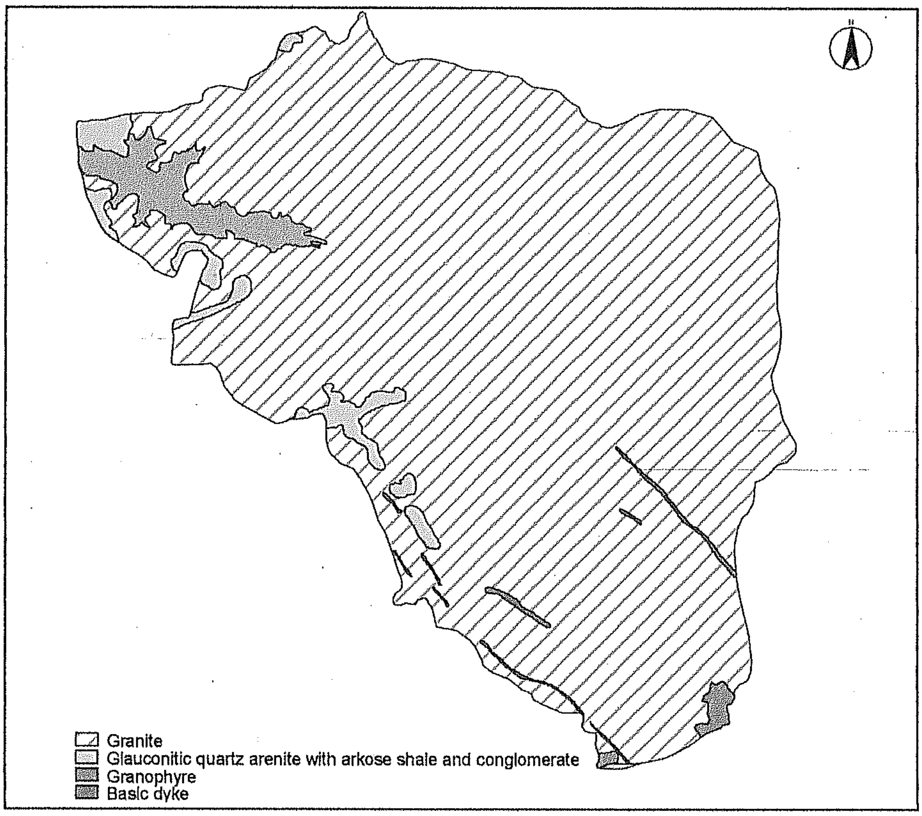


Fig. 6.2: Geology of Kodar reservoir catchment (Not to scale)

Table 6.1: Distribution of geological features in Kodar catchment

S.N.	Geological unit	Area (km^2)	Percentage
1.	Granite	296.45	96.34
2.	Glauconitic quartz Arenite with Arkose Shale and Conglomerate	8.32	2.70
3.	Basic dyke	1.64	0.53
4.	Granophyre	1.30	0.42
	Total	307.71	100.00

6.1.3 Geomorphology

The geomorphology map of the study area has been prepared using LISS III data of IRS P6 satellite. The tone, color, texture and association have been used to identify various geomorphological units in the catchment of Kodar reservoir. The Kodar catchment consists mainly pediplane buried moderated and pediplane weathered moderate with structural hills in the form of inselberg, mesa, butte and residual hills. The spatial distribution of different geomorphological units in the study area has been presented in Fig 6.3 and Table 6.2.

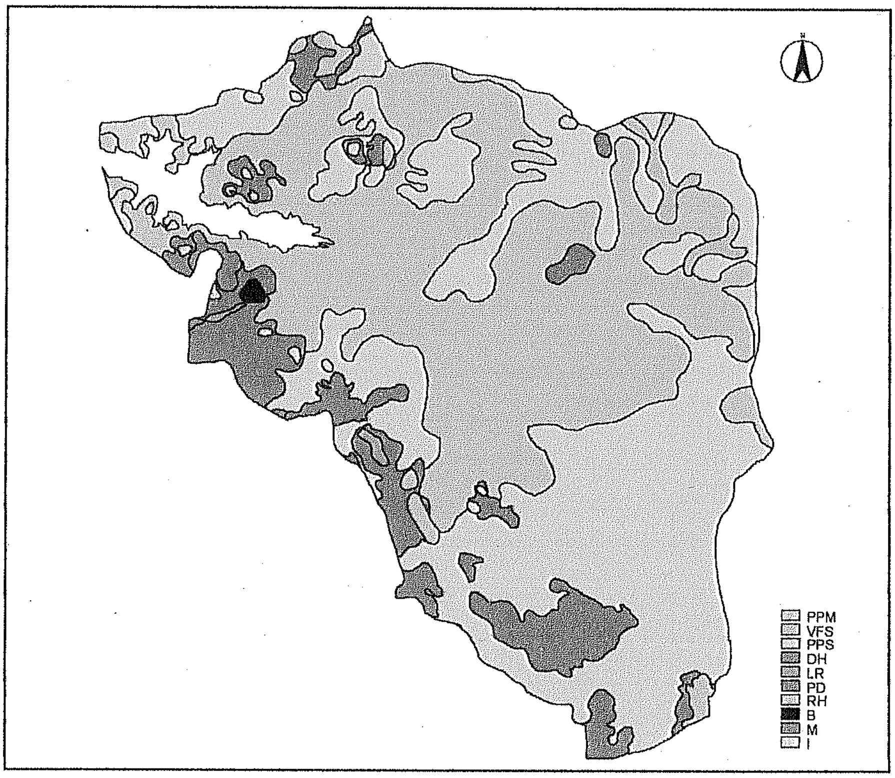


Fig. 6.3: Geomorphology map of Kodar reservoir catchment

Table 6.2: Geomorphological features present in Kodar catchment

S.N.	Geomorphological unit	Symbol	Area (km^2)	Percentage
1.	Butte	B	0.49	0.16
2.	Denudational hills	DH	4.29	1.39
3.	Inselburg	I	1.79	0.58
4.	Linear ridge	LR	0.73	0.24
5.	Mesa	M	1.45	0.47
6.	Piedmont slope	PD	32.49	10.56
7.	Pediplane buried moderate	PPM	126.87	41.23
8.	Pediplane weathered shallow	PPS	132.16	42.95
9.	Residual hills	RH	3.75	1.22
10.	Valley fill shallow	VFS	3.68	1.20
	Total		307.71	100

6.1.4 Soil map

The soil map of the study area has been prepared from the soil map of National Bureau of Soil Survey & Land Use Planning (NBSS&LUP). The soils are mainly red and yellow color with low in necessary nutrients nitrogen (N), phosphorus (P) and potash (K) necessary for good agriculture yield. The soils in the study area are slightly deep to deep, well drained loamy soil and mixed loamy soil subjected to moderate to severe erosion. The soil map of the study area is depicted in Fig. 6.4. The areas of different soils present in the study area have been depicted in Table 6.3.

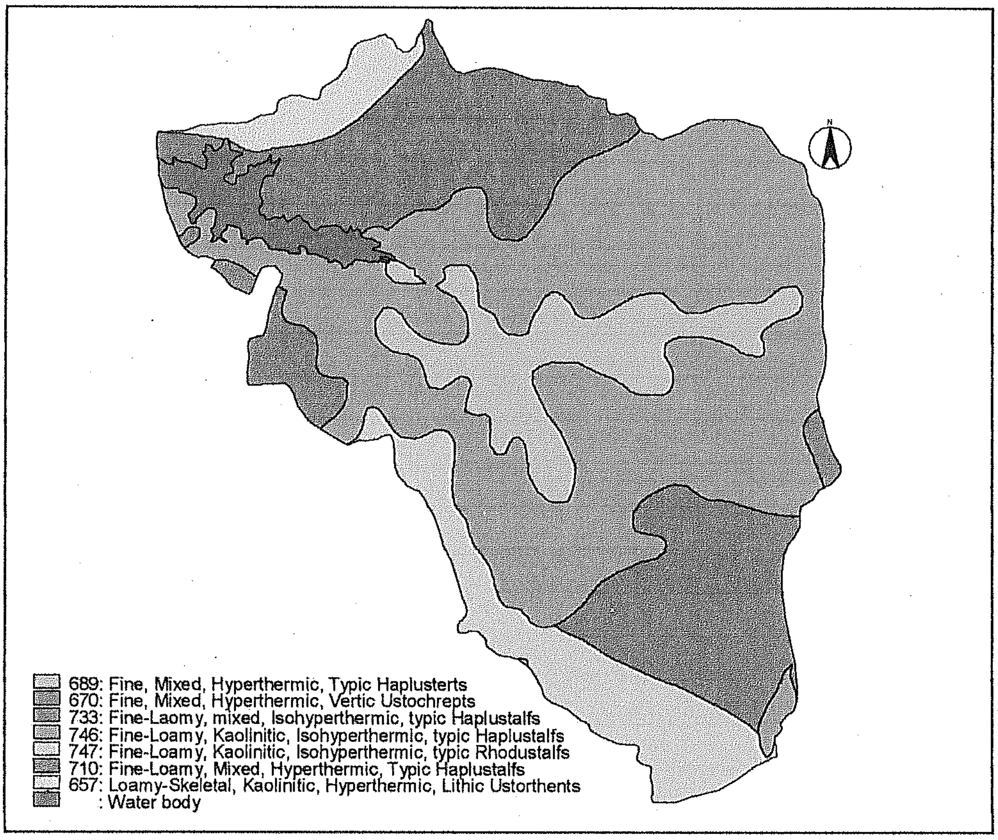


Fig 6.4: Soil map of Kodar reservoir catchment

Table 6.3: Soil types present in Kodar catchment

Soil unit	Code	Area (km^2)	Percentage
Fine-Loamy, Kaolinitic, Isohyperthermic, typic Haplustalfs	746	147.99	48.09
Fine, Mixed, Hyperthermic, Vertic Ustochrepts	670	44.52	14.47
Fine-Laomy, mixed, Isohyperthermic, typic Haplustalfs	733	36.53	11.87
Fine, Mixed, Hyperthermic, Typic Haplusterts	689	31.30	10.17
Fine-Loamy, Kaolinitic, Isohyperthermic, typic Rhodustalfs	747	30.49	9.91
Fine-Loamy, Mixed, Hyperthermic, Typic Haplustalfs	710	7.25	2.36
Loamy-Skeletal, Kaolinitic, Hyperthermic, Lithic Ustorthents	657	9.62	3.13
Total		307.17	100

6.1.5 Village map

The village map for the catchment of Kodar reservoir has been prepared from the SOI toposheet and information from WRD, Raipur. The village map of Kodar catchment is given in Fig. 6.5. Many villages have been found in the middle reach and near Kodar reservoir. Koma, Patherpali, Saraipali, Khallari, Nawadih, Kherwar, Patewa, khallari etc are some of the important villages in the catchment. The agriculture is main occupation of people in the area and paddy is the main crop in kharif season. The farmers take paddy in rabi season where ground water availability is good.

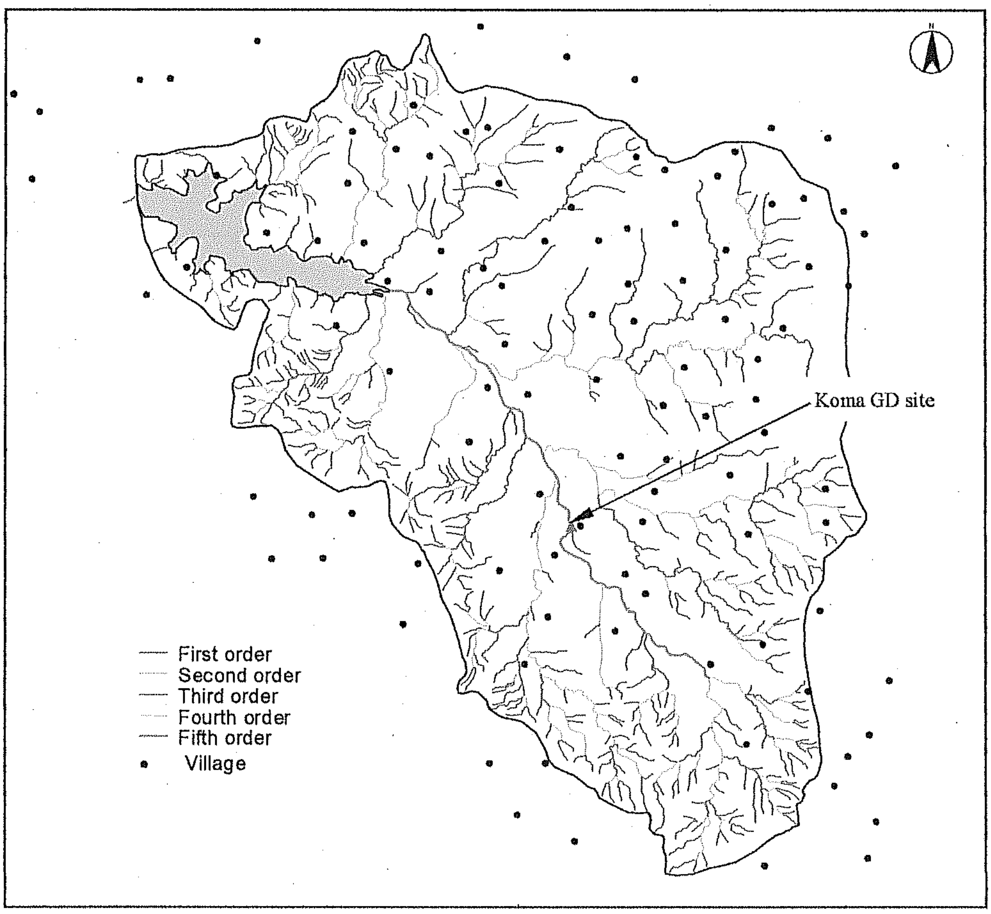


Fig 6.5: Location map of villages in and around Kodar reservoir catchment

6.1.6 Contour map

The contour map of the study area has been prepared from SOI toposheets and presented in Fig. 6.6. The general slope of the study area has been observed from south-west to north-east direction towards river Kodar. The elevation ranges from 280 m to 570 m. The general topography of the area consists of undulating plains, hilly track and localized valleys. The central part of catchment is more or less flat suitable for agriculture.

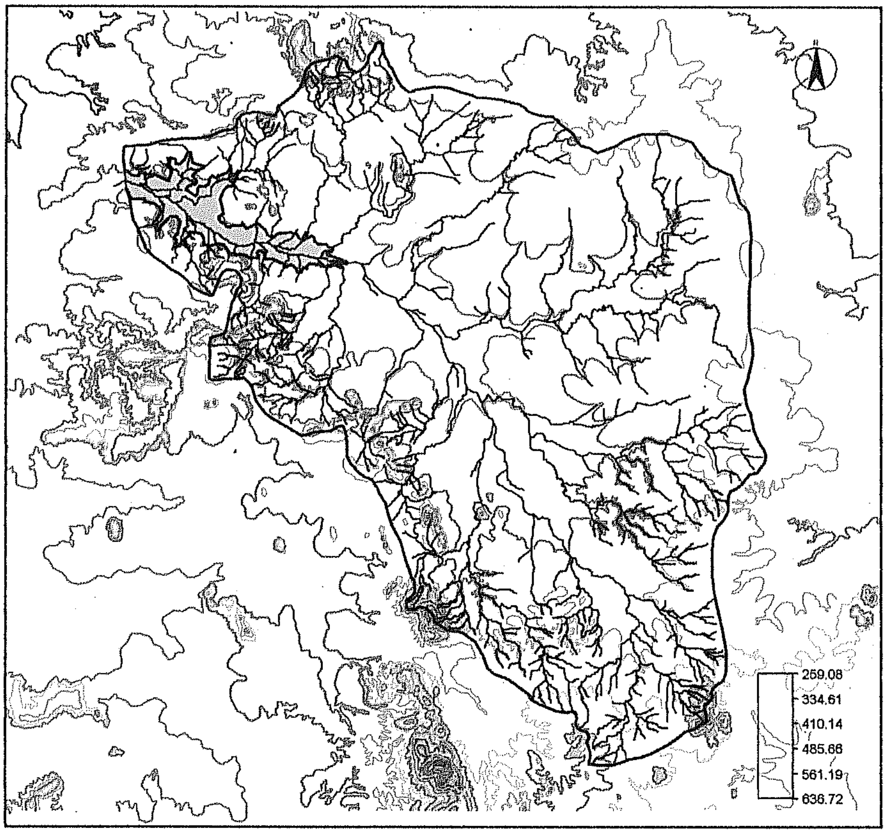


Fig. 6.6: Contour map of Kadar reservoir catchment

6.1.7 Digital elevation model (DEM) and shadow map

The digital elevation model for the study area has been generated using contour and point elevation maps. The contour interpolation of contour map and rasterize operation for point elevation has been performed to get two separate raster maps. The 'iff' statement of ILWIS has been used to combine both the raster maps to get the DEM. This map has elevation values for all the pixels in the area. Also, this DEM can be visualized in a three dimensional space by creating a 3D geo-reference. The digital elevation model of the study area has been presented in Fig. 6.7. A shadow map of the study area has been prepared and given in Fig. 6.8.

6.2 Up-gradation of Gauging and Sediment Sampling Site

An extensive survey of the study area has been made and a G/D site near Koma village has been selected for collection of sediment samples and measurement of discharge data. The site has been upgraded and sampling for discharge measurement and sediment data from 2010 to 2012 have been collected and analyzed.

6.3 Collection and Analysis of Meteorological Data

Meteorological data plays an important role for setting up various parameters in sedimentation and prioritization studies. In the present study rainfall data of five surrounding stations of Kodar reservoir have been collected. The thiesen polygon map for Kodar reservoir have been prepared and presented in Fig. 6.9.

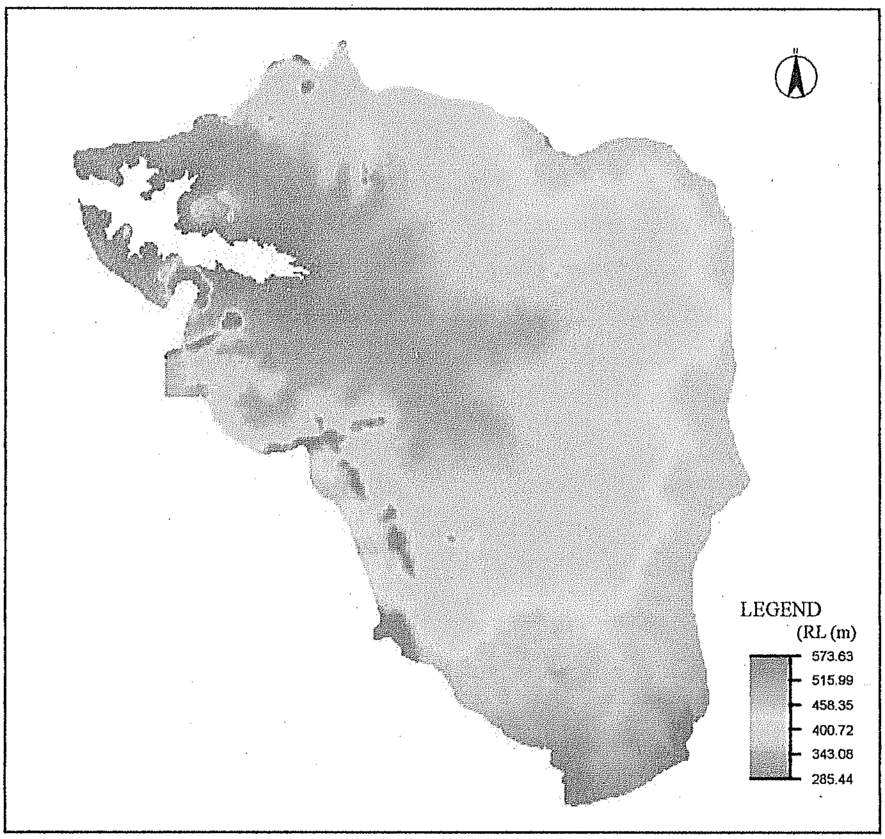


Fig. 6.7: digital elevation model for Kodar reservoir catchment

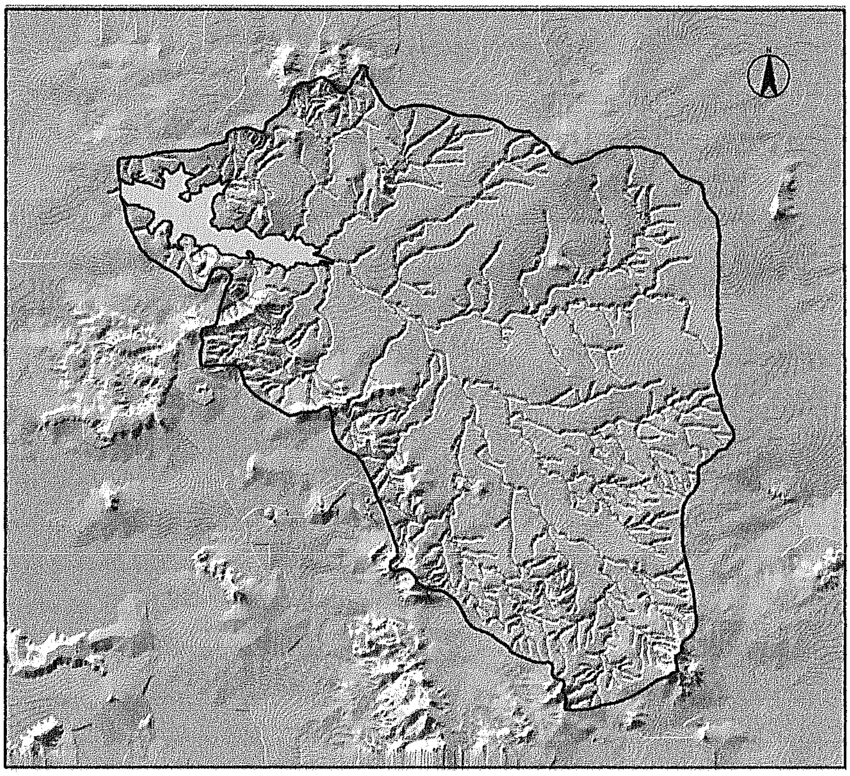


Fig. 6.8: Shadow map of the study area

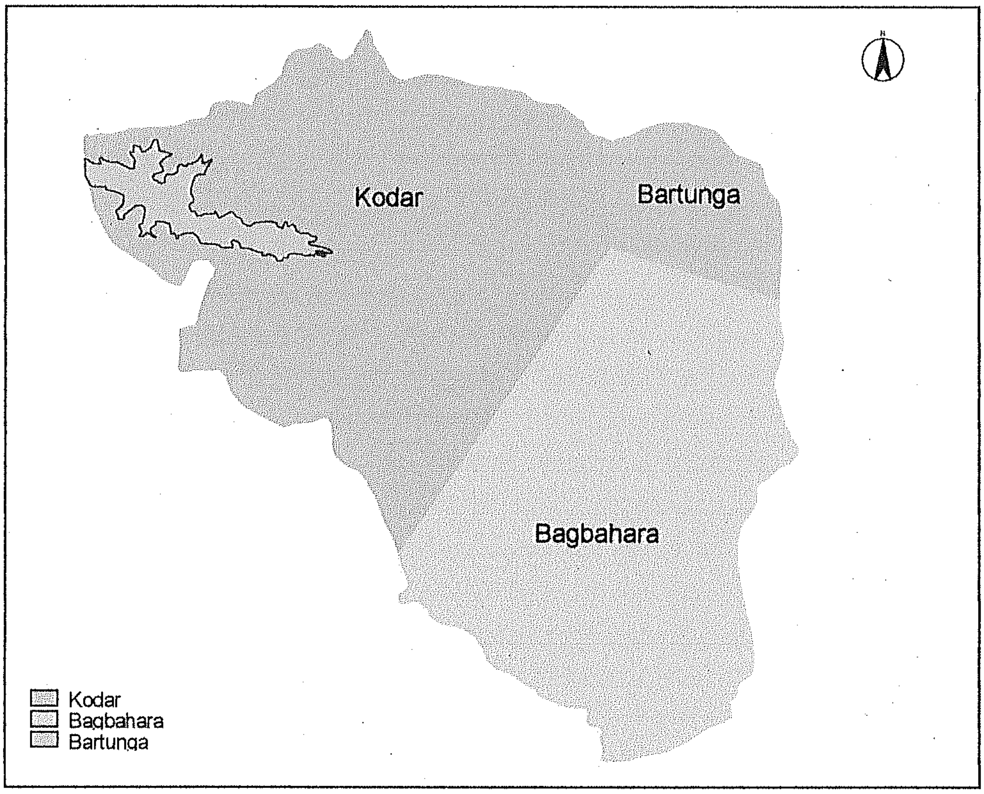


Fig.6.9: Thiesen polygon for Kodar reservoir catchment

From the analysis, it has been observed that Kodar, Bagbahara and Bartunga RG stations have impact on Kodar catchment and hence used for analysis. The weight of Kodar, Bagbahara and Bartunga RG stations has been computed as 0.50, 0.42 and 0.08 respectively. The statistical parameters including mean, standard deviation, coefficient of correlation for seasonal and monsoon months have been computed and presented in Table 6.4. The results of analysis suggested good correlation of seasonal rainfall between Bagbahara v/s Bartunga and Kodar v/s Bagbahara while least correlation in Koadr v/s Bartunga RG stations. The rainfall in the study area concentrated mainly in the month of July, August and September. The meteorological data of Raipur has been collected from Indira Gandhi Agriculture University, Raipur consists of daily minimum and maximum temperature, wind speed, relative humidity and sunshine hour from 1971 to 2012. The monthly average and standard deviation of each parameter has been computed. The mean monthly maximum temperature in the study area varies from 44.2 ^{0}C in the month of May to 24.1 ^{0}C in January. Similarly, mean monthly minimum temperature ranges from 8.4^{0}C in the month of January to 28.6 ^{0}C in the month of June. The variation of mean monthly minimum temperature, maximum temperature, wind speed and relative humidity has been presented in Fig. 6.10.

6.4 Sedimentation study of Kodar Reservoir

For estimation of revised capacities at different levels of Kodar reservoir, *NDWI*, *NDVI* and band ratio (*BR*) followed by slicing methods of image classification has been used to differentiate the water pixels from other land uses. Different selected remote sensing data has been purchased from National Remote Sensing Centre Hyderabad have been imported in ILWIS GIS and georeferencing of each scenes have been performed to extract revised area directly in sq. m.

Table 6.4: Seasonal and monthly statistics of rainfall for R.G. stations in Kodar catchment

a. Seasonal

Statistics	Kodar	Bagbahara	Bartunga
Mean	910.00	893.54	970.90
St. deviation	303.23	285.51	368.48
Coeff. of Skewness	0.66	0.27	1.21
Maximum	1532.1	1438.3	1991.1
Minimum	476.0	456.4	466.0
Median	855.0	884.4	915.7
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.714	0.400
Bagbahara		1.000	0.817
Bartunga			1.000

b. June

Statistics	Kodar	Bagbahara	Bartunga
Mean	139.26	173.55	190.70
St. deviation	126.78	118.96	141.18
Coeff. of Skewness	1.75	1.46	1.04
Maximum	474.7	496.3	481.0
Minimum	0.0	42.8	34.9
Median	114.0	162.2	148.0
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.910	0.708
Bagbahara		1.000	0.805
Bartunga			1.000

c. July

Statistics	Kodar	Bagbahara	Bartunga
Mean	331.06	299.82	344.94
St. deviation	148.98	151.15	181.76
Coeff. of Skewness	0.23	0.62	1.64
Maximum	594.0	642.8	892.1
Minimum	70.0	71.2	70.0
Median	310.0	264.1	341.0
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.804	0.782
Bagbahara		1.000	0.907
Bartunga			1.000

d. August

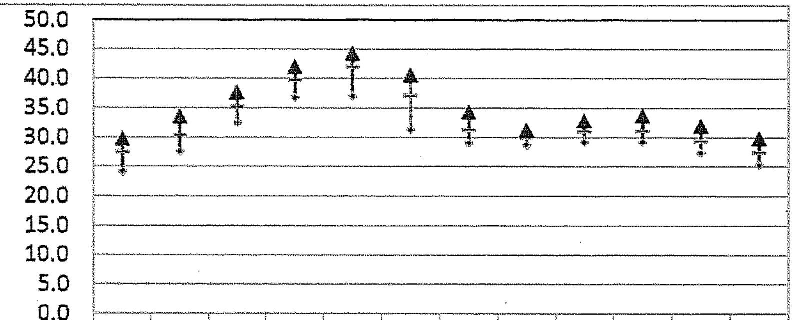
Statistics	Kodar	Bagbahara	Bartunga
Mean	256.28	257.69	245.79
St. deviation	105.30	133.12	155.47
Coeff. of Skewness	0.80	1.76	0.67
Maximum	526.7	618.4	612.0
Minimum	91.0	126.2	0.0
Median	245.0	223.7	236.0
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.327	0.300
Bagbahara		1.000	0.690
Bartunga			1.000

e. September

Statistics	Kodar	Bagbahara	Bartunga
Mean	145.93	147.50	169.41
St. deviation	106.67	102.07	182.68
Coeff. of Skewness	0.83	1.67	2.68
Maximum	375.0	454.4	794.0
Minimum	16.0	12.6	18.0
Median	111.0	137.1	148.0
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.644	0.510
Bagbahara		1.000	0.871
Bartunga			1.000

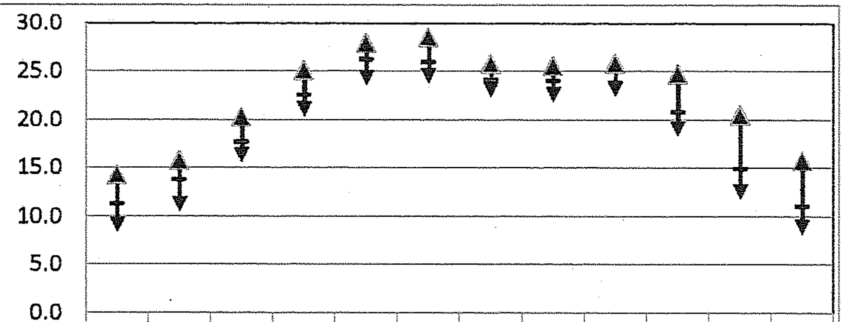
f. October

Statistics	Kodar	Bagbahara	Bartunga
Mean	37.47	14.98	20.06
St. deviation	51.25	24.34	42.67
Coeff. of Skewness	2.12	1.18	2.81
Maximum	184.0	61.5	162.0
Minimum	0.0	0.0	0.0
Median	14.0	0.0	0.0
Coefficient of correlation			
	Kodar	Bagbahara	Bartunga
Kodar	1.000	0.642	0.330
Bagbahara		1.000	0.234
Bartunga			1.000



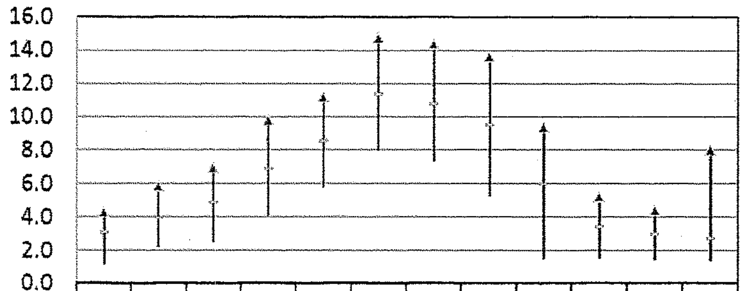
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average	27.	30.	35.	39.	41.	37.	31.	29.	31.	31.	29.	27.
Min	24.	27.	32.	36.	37.	31.	29.	28.	29.	29.	27.	25.
Max	29.	33.	37.	42.	44.	40.	34.	31.	32.	33.	31.	29.

Mean monthly maximum temperature (°C)



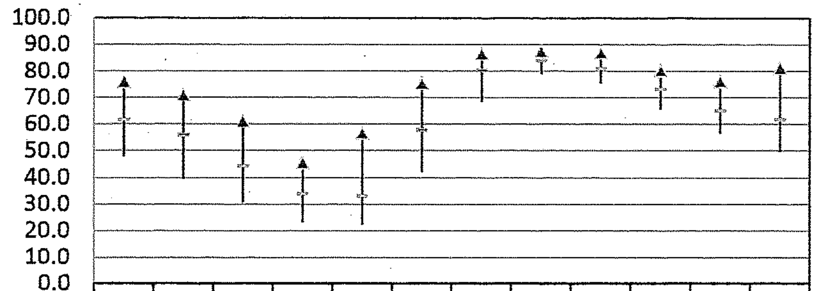
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average	11.2	13.8	17.6	22.5	26.2	25.9	24.1	24.0	23.9	20.8	14.9	11.0
Min	8.4	10.5	15.5	20.3	23.6	23.7	22.3	21.8	22.4	18.3	11.8	8.2
Max	14.3	15.7	20.3	25.1	28.0	28.6	25.8	25.6	25.8	24.8	20.5	15.7

Mean monthly minimum temperature (°C)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average	3.1	3.9	4.9	6.9	8.5	11.	10.	9.5	6.0	3.4	3.0	2.7
Min	1.1	2.2	2.5	4.1	5.8	8.0	7.3	5.2	1.4	1.5	1.4	1.3
Max	4.3	5.8	6.9	9.8	11.	14.	14.	13.	9.4	5.2	4.4	8.0

Mean monthly relative humidity (%)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average	61.	55.	44.	34.	33.	57.	80.	84.	81.	73.	65.	61.
Min	47.	39.	30.	22.	22.	42.	68.	78.	75.	65.	56.	49.
Max	75.	71.	61.	45.	56.	75.	86.	87.	86.	80.	76.	81.

Mean monthly wind speed (km/day)

Fig. 6.10: Variation of monthly maximum temperature, minimum temperature, relative humidity, wind speed

The False Color Composite (FCC) and masked out water spread of Kodar reservoir for few selected dates have been presented in Fig. 6.11. The satellite data at dead storage level (D.S.L.) i.e. 286.04 m and at full supply level (F.S.L.), i.e. 295.24 m were not available. To compute revised spread area on these levels, a graph has been plotted between reservoir elevation and revised water spread area. The best fit line using revised water spreads has been presented in Fig. 6.12. The following equation has been obtained for computation of revised water spreads area in sq. km. using reservoir levels (L) in m.

$$Area = 0.10132L^2 - 57.60799L + 8040.25633 \qquad \text{....6.1}$$

The revised water spreads at D.S. L. (286.04 m) and F.R.L. (295.24 m) have been computed as 4.301 km^2 and 26.088 km^2 respectively and using eq. 6.1. From the analysis, the revised bed level for Kodar reservoir has been worked out as 285.55 m. as compared to original river bed of 275.67 m. This indicated that the dead storage from 285.55 m to 275.67 m has been filled up with the sediment deposits. The revised storages between different levels have been worked out using revised water spread areas which ultimately gave revised cumulative capacities at these levels. The computation of revised volumes and percentage loss in volumes has been presented in Table 6.5 & 6.6. The original and revised capacity curves for Kodar reservoir has been depicted in Fig. 6.13. The sedimentation analysis of Kodar reservoir indicated that 24.94 Mm^3 of gross storages and 4.89 Mm^3 of dead storage have been lost in 32 years (1976-77 to 2008-09).

The revised capacity curve developed in the analysis may be used for reservoir operation and allocation of water for different uses. Considering the uniform loss in the storages, it can be concluded that 0.78 Mm^3 of gross storage and 0.15 Mm3 of dead storage of Kodar reservoir have been lost each year with average rate of 0.25 $Mm^3/100\ km^2$/year. The sedimentation rate computed from remote sensing approach has been compared with the Khosla's formula and Joglekar's equation (Mutreja, 1986 & Subramanya, 2008). These equations may be written as:

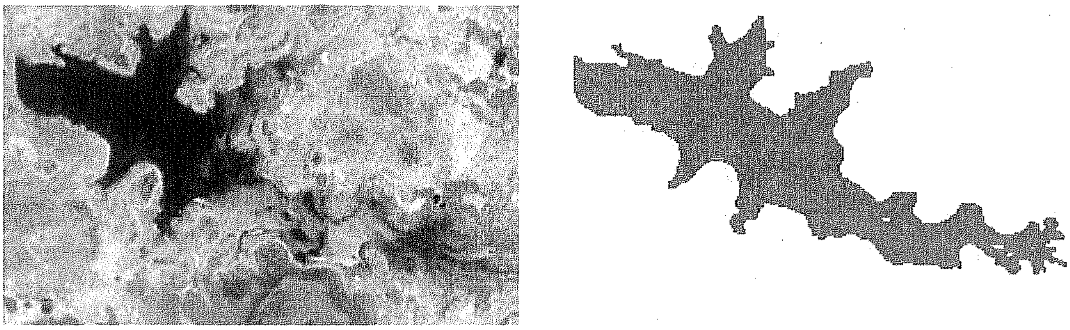
Khosla's formula

$$Q_s = \frac{0.323}{A^{0.28}} \qquad \text{...6.2}$$

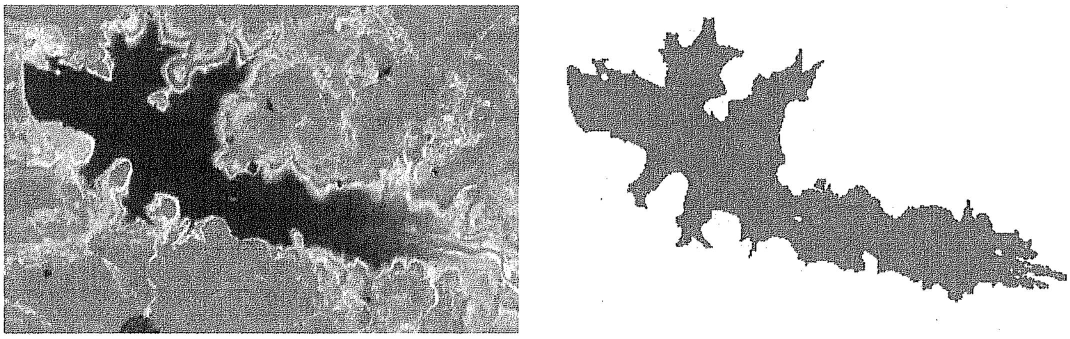
Joglekar's equation

$$Q_s = \frac{0.597}{A^{0.24}} \qquad \text{...6.3}$$

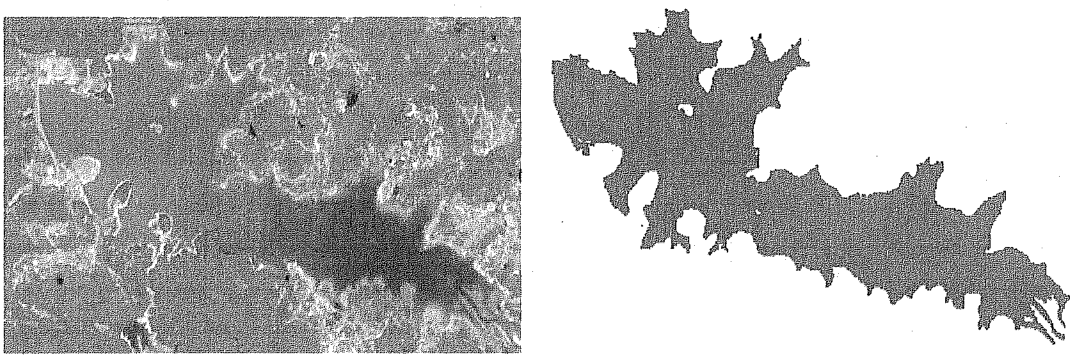
where, Q_s is annual silting rate from 100 km^2 of watershed area ($Mm^3/100\ km^2$/year) and A is the catchment area (km^2). As the catchment area of Kodar reservoir is 307.17 sq. km, the rate of sedimentation has been computed from Khosla's formula and Joglekar's equation are 0.06 $Mm^3/100\ km^2$/year and 0.15 $Mm^3/100\ km^2$/year respectively. It has been proved that Khosla's formula gives rate of siltation on lower side, but the present rate of siltation in Kodar reservoir is more than the results obtained from Joglekar's equation. Therefore, it is necessary to take appropriate soil conservation measures in the Kodar catchment to reduce the intake of silt and sediment into Kodar reservoir. The prioritization of sub-watersheds for stressed sub-watersheds and scientifically developed CAT plan may be helpful to reduce the rate of siltation in Kodar reservoir. It may be recommended that all the major and medium reservoirs should be monitored regularly (5 years interval) using remote sensing approach.



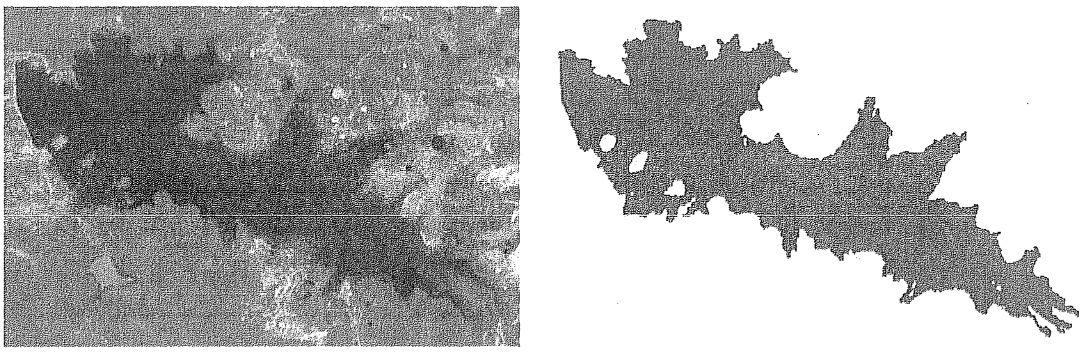
May 09, 2009 (Res. Level: 287.39 m)



Oct 29, 2008 (Res. Level: 289.37 m)



Oct 24, 2009 (Res. Level: 291.69 m)



Oct 11, 2007 (Res. Level: 295.16 m)

Fig 6.11: False color composite and extracted water spread on different dates for Kodar reservoir

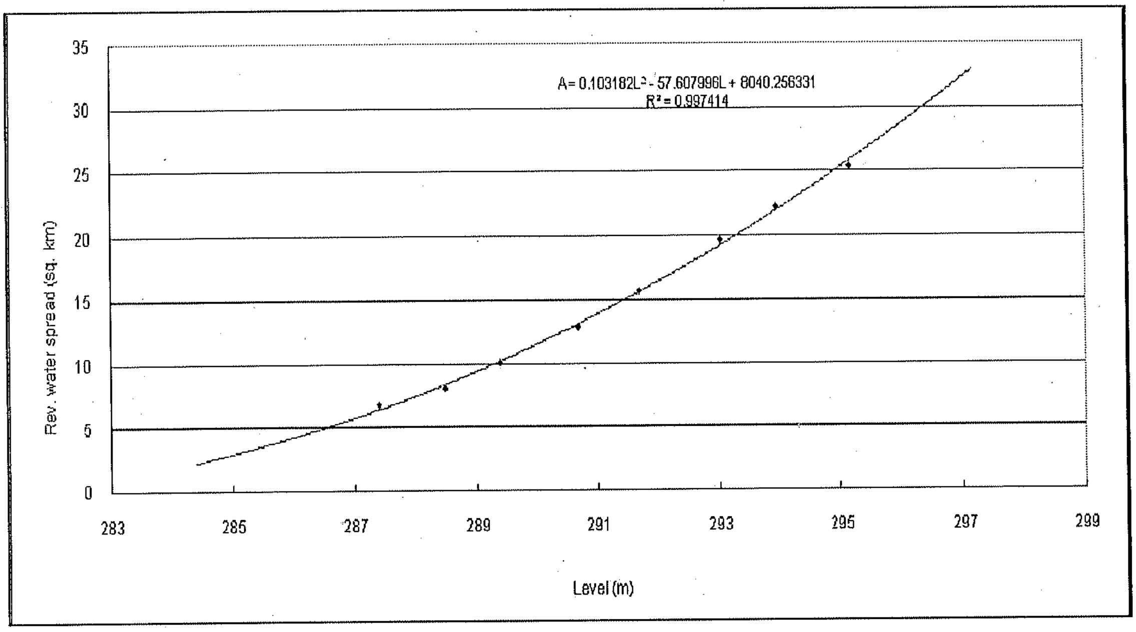


Fig 6.12: Graph for computation of revised water spread area

Table 6.5: Computation of revised volume in Kodar reservoir

Date of Pass	Reservoir Elevation (meter)	Revised Area (km²)	Revised Volume (Mm³)	Original Cumu. Capacity	Original Volume (Mm³)	Loss in Volume (Mm³)	% Loss in Volume
Original River Bed	275.67			0			
Revised River Bed	281.55	0					
			6.444		11.330	4.886	43.12
DSL *	286.04	4.301		11.330			
			7.181		8.457	1.276	15.09
9-May-09	287.39	6.407		19.787			
			8.119		10.137	2.018	19.91
22-Mar-09	288.49	8.400		29.924			
			8.161		9.982	1.821	18.25
29-Oct-08	289.37	10.175		39.906			
			15.213		17.827	2.614	14.66
14-May-08	290.68	13.113		57.733			
			14.492		16.289	1.797	11.03
24-Oct-09	291.69	15.620		74.022			
			23.334		26.030	2.696	10.36
3-Mar-08	293.03	19.271		100.052			
			18.747		20.200	1.453	7.19
15-Jan-08	293.94	21.961		120.252			
			29.125		33.982	4.857	14.29
11-Oct-07	295.16	25.837		154.234			
			4.595		6.116	1.521	24.86
FSL *	295.337	26.088		160.350			

6.5 Land Use Classification

The land use classification of the study area has been performed using supervised classification technique of LISS IV data. Using spectral signatures of various land uses, sample sets for different land uses have been prepared. The maximum likelihood technique of classification has been used for generation of land use map of Kodar catchment. A field visit of the study area has been conducted for collection of field truth data and classified image was compared with the field information. The classified map of the study area has been depicted in Fig. 6.14, while area under different land uses has been presented in Table 6.7. From the analysis, it has been observed that the Kodar catchment is an agriculture watershed covering nearly eighty percent with agriculture and dense forest on the ridges only. Several small water bodies in the form of village tanks have been found in Kodar catchment which is used for bathing, cattle, recreation and other house hold work.

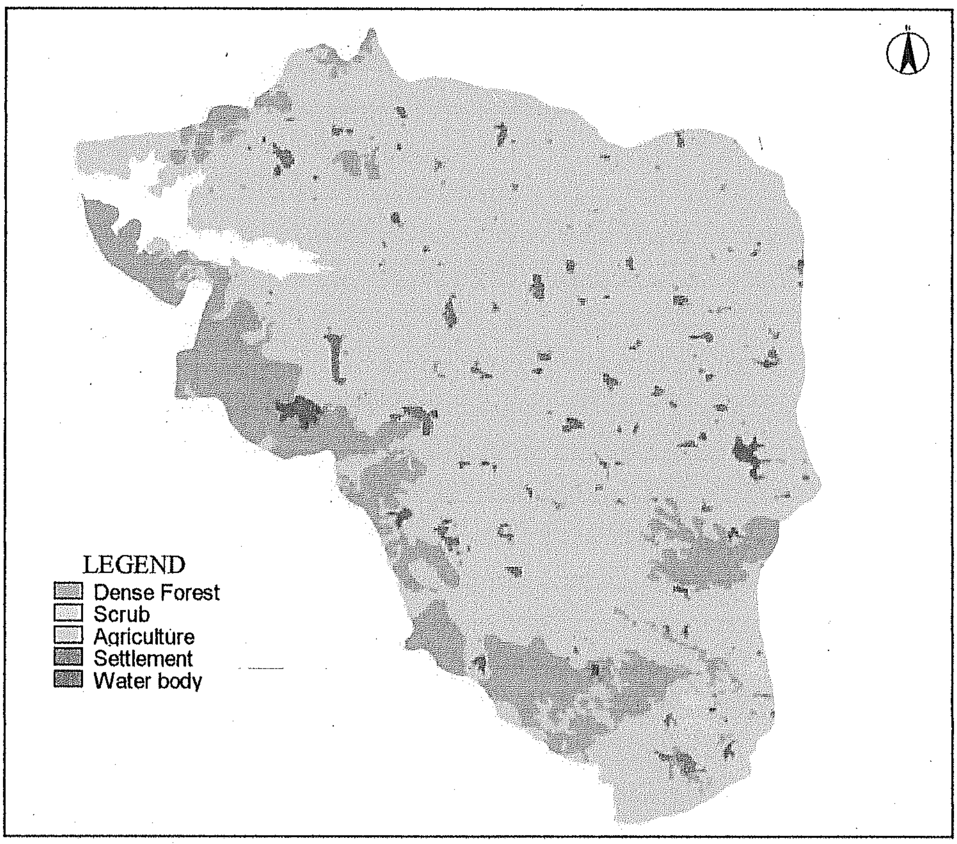


Fig. 6.14: Land use map in the catchment of Kodar reservoir

Table 6.7: Different land uses in Kodar catchment

S.N.	Land use	Area (km^2)	Percentage
1.	Agriculture	243.86	79.39
2.	Dense Forest	48.38	15.75
3.	Scrub	1.22	0.40
4.	Settlement	7.88	2.57
5.	Water body	5.81	1.89
6.	Total	307.17	100.00

6.6 Results of Soil Investigation

The soil properties including soil texture (percent of silt, clay and sand), soil depth, infiltration capacity and hydraulic conductivity are important parameter for detachment and movement of soil from catchment and modeling. In the present study, considering the spatial distribution of various soils in the study area, detail soil investigation consisting of in-situ soil tests including infiltration test using double ring infiltrometer, saturated hydraulic conductivity test using Guelph permeameter, bulk density and dry density using core cutter method and laboratory tests consisting of textural analysis using sieve and pipette analysis and sp. gravity using density bottle have been conducted on eleven sites in Kodar reservoir catchment. The map showing Sites in the study area has been presented in Fig. 6.15 and their details in Table 6.8.

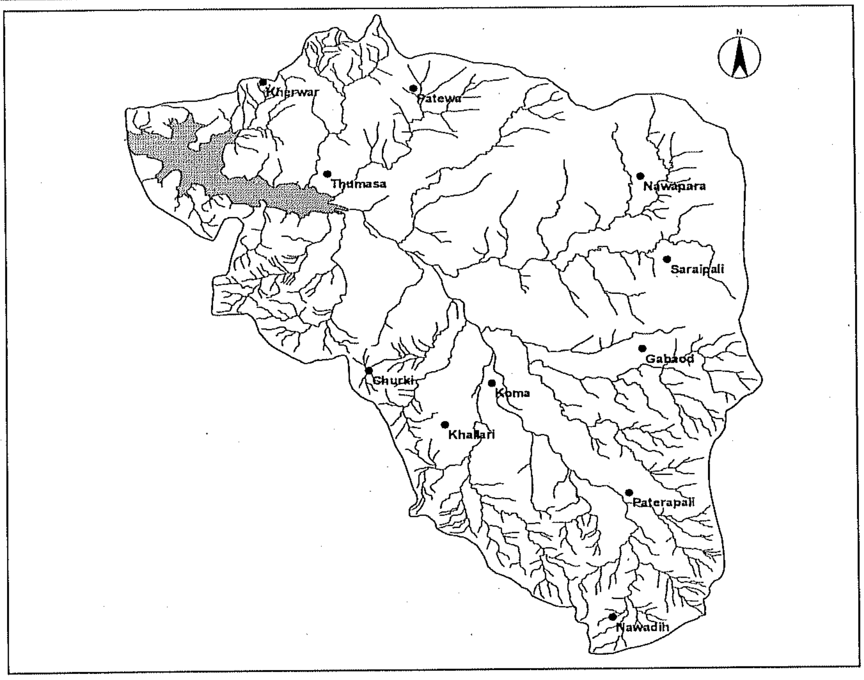


Fig. 6.15: Sites selected for detail soil testing in Kodar catchment

Table 6.8: Name and location of soil testing sites in Kodar catchment

S.N.	Site	Name of village	Latitude	Longitude	Soil No.	Land use
1.	Site-1	Kherwar	$21^{0}13'$	$82^{0}14'$	657	Forest
2.	Site-2	Patewa	$21^{0}13'$	$82^{0}17'$	670	Agriculture
3.	Site-3	Thumsa	$21^{0}11'$	$82^{0}15'$	670	Forest
4.	Site-4	Nawapara	$21^{0}11'$	$82^{0}21'$	746	Agriculture
5.	Site-5	Gabaud	$21^{0}07'$	$82^{0}21'$	746	Forest
6.	Site-6	Khalari	$21^{0}06'$	$82^{0}17'$	746	Agriculture
7.	Site-7	Saraipali	$21^{0}09'$	$82^{0}22'$	689	Agriculture
8.	Site-8	Koma	$21^{0}06'$	$82^{0}18'$	689	Agriculture
9.	Site-9	Paterapali	$21^{0}04'$	$82^{0}21'$	733	Scrub
10.	Site-10	Churki	$21^{0}07'$	$82^{0}16'$	747	Scrub
11.	Site-11	Nawadih	$21^{0}02'$	$82^{0}20'$	747	Forest

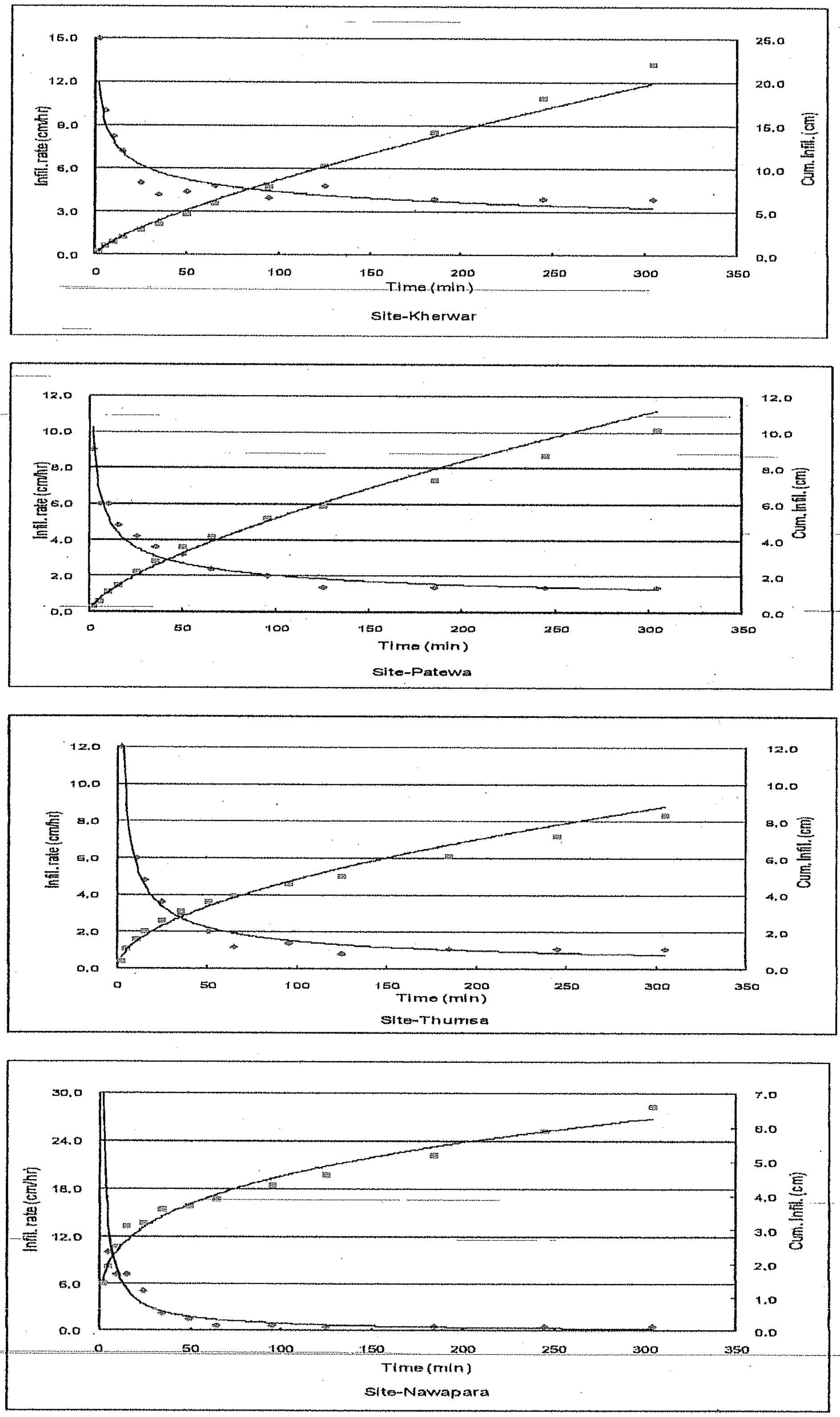


Fig. 6.16: Infiltration curve for few sites in Kodar reservoir catchment

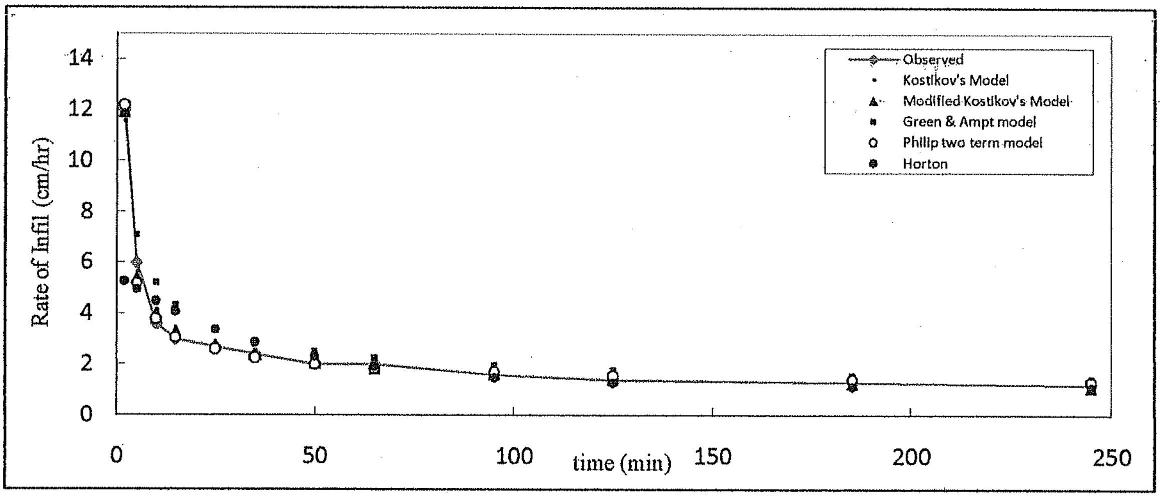
Table 6.9: Parameters of various infiltration models

Site	Kostiakov's model		Modified Kostiakov's Model			Horton's model			Philip's two term model	
	K_K	α	B	n	i_c	f_c	f_o	k	S	A
Kherwar	0.261	0.759	0.211	0.081	0.111	3.9	9.368	0.045	0.288	0.056
Patewa	0.417	0.588	0.268	0.634	-0.129	1.4	6.343	0.032	0.174	0.04
Thumsa	0.555	0.465	0.915	0.361	-0.774	0.9	8.817	0.045	0.507	-0.001
Nawapara	1.332	0.267	1.393	0.26	-0.17	0.5	5.665	0.04	0.575	-0.014
Gaboud	0.442	0.61	0.487	0.595	-0.176	2.0	11.679	0.34	0.292	0.04
Khalari	0.387	0.639	0.411	0.595	-0.146	1.6	8.657	0.025	0.333	0.049
Saraipali	0.347	0.373	0.394	0.37	-0.087	0.3	3.918	0.036	0.305	-0.01
Koma	0.994	0.397	1.593	0.297	-1.016	0.5	13.671	0.035	0.771	-0.004
Paterapali	0.521	0.458	0.78	0.386	-0.349	0.7	14.03	0.065	0.45	0.002
Churki	0.254	0.6	0.23	0.619	0.044	1.1	5.484	0.026	0.269	0.013
Nawadhi	0.235	836	0.247	0.826	-0.027	4.0	8.82	0.011	0.166	0.098

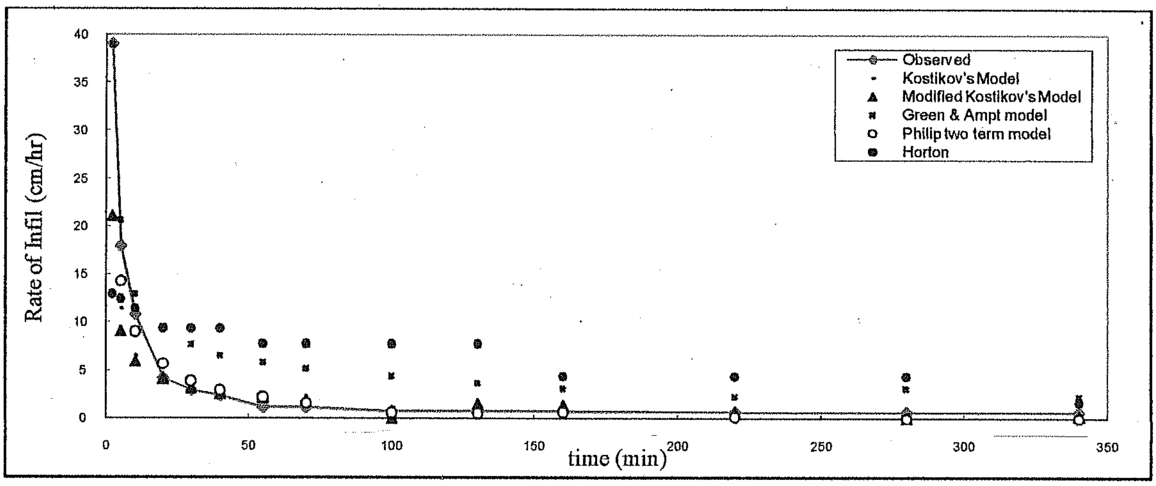
Table 6.10: Performance evaluation of various infiltration models

Site	Kostikov's model			Modified Kostikov's model			Philip's two term model			Horton's Model		
	RMSE	*ISE*	η	*RMSE*	*ISE*	η	*RMSE*	*ISE*	η	*RMSE*	*ISE*	η
Kherwar	0.12	0.02	99.42	0.08	0.01	99.76	0.03	0.01	99.60	0.56	0.09	62.86
Patewa	0.30	0.07	96.83	0.08	0.02	99.97	0.36	0.10	72.45	0.30	0.08	74.55
Thumsa	0.19	0.06	85.08	0.03	0.01	99.60	0.25	0.09	73.28	0.43	0.12	82.81
Nawapara	0.02	0.02	97.84	0.05	0.01	97.61	0.15	0.45	73.77	0.89	0.51	9.68
Gaboud	0.04	0.01	99.86	0.04	0.01	99.84	0.23	0.05	95.01	0.43	0.08	86.44
Khalari	0.32	0.07	86.79	0.03	0.01	99.86	0.75	0.17	28.59	0.47	0.10	78.03
Saraipali	0.02	0.01	99.21	0.05	0.31	94.37	0.05	0.03	93.18	0.74	0.34	40.33
Koma	0.29	0.07	67.29	0.10	0.03	96.12	0.46	0.12	18.89	1.42	0.26	57.62
Paterapali	0.06	0.02	98.62	0.03	0.01	99.66	0.17	0.05	86.91	0.50	0.12	87.84
Churki	0.02	0.01	99.87	0.01	0.00	99.95	0.03	0.01	99.73	0.58	0.18	51.97
Nawadhi	0.31	0.04	98.06	0.33	0.04	97.90	0.21	0.27	98.03	0.58	0.09	-

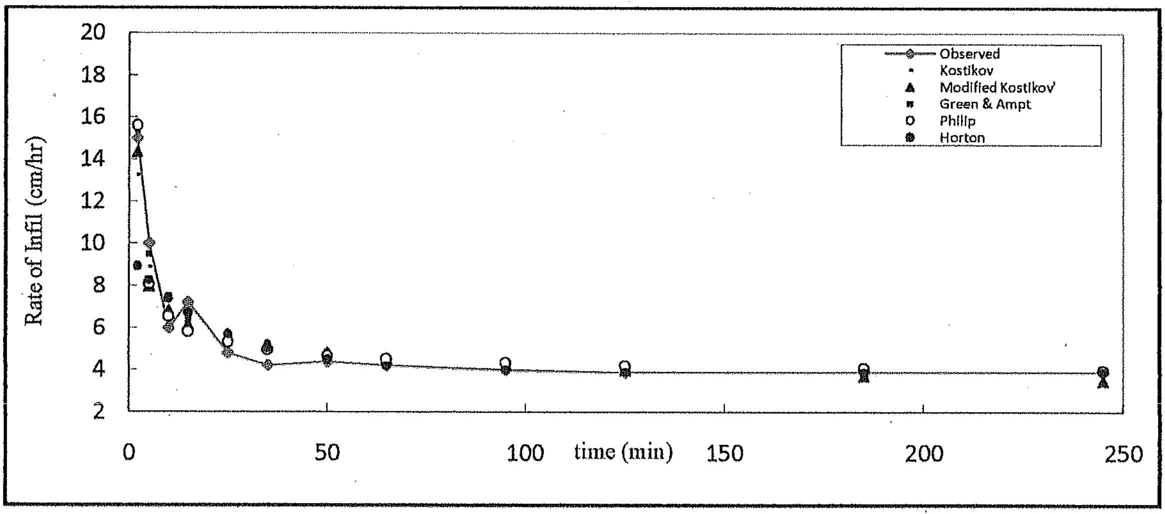
RMSE = Root mean square error, ISE = Integral square error and η = efficiency in percentage



Site- Churki



Site- Nawapara



Site- Kherwar

Fig. 6.17: Observed and computed rate of infiltration from various models at few sites in Kodar reservoir catchment

Table 6.11: Best fit infiltration rate models and their equations

S.N.	Name of village	Land use	Soil No.	Best fit infiltration model	Equation (F_p in cm/hr and t in min)
1.	Kherwar	Forest	657	Modified Kostikov's	$F_p = 0.211t^{0.801} + 0.211$
2.	Patewa	Agriculture	670	Modified Kostikov's	$F_p = 0.268t^{0.634} - 0.129$
3.	Thumsa	Forest	670	Modified Kostikov's	$F_p = 0.915t^{0.361} - 0.774$
4.	Nawapara	Agriculture	746	Kostikov's model	$F_p = 1.332t^{0.267}$
5.	Gabaud	Forest	746	Kostikov's model	$F_p = 0.442t^{0.610}$
6.	Khalari	Agriculture	746	Modified Kostikov's	$F_p = 0.411t^{0.595} - 0.146$
7.	Saraipali	Agriculture	689	Kostikov's model	$F_p = 0.347t^{0.373}$
8.	Koma	Agriculture	689	Modified Kostikov's	$F_p = 1.593t^{0.297} - 1.016$
9.	Paterapali	Scrub	733	Modified Kostikov's	$F_p = 0.78t^{0.386} - 0.349$
10.	Churki	Scrub	747	Modified Kostikov's model	$F_p = 0.23t^{0.044} + 0.619$
11.	Nawadih	Forest	747	Kostikov's model	$F_p = 0.235t^{0.836}$

Table 6.12: Saturated hydraulic conductivity and other parameters in Kodar catchment

S.N	Name of village	Hydraulic conductivity (K_s) (cm/hr)	Metric flux otential (ϕ_m) (cm²/sec)	Sorptivity (S) cm/sec$^{-1/2}$	α (cm^{-1})
1.	Kherwar	34.07	0.001	0.010	15.808
2.	Patewa	7.77	0.004	0.024	0.564
3.	Thumsa	15.38	0.001	0.008	3.551
4.	Nawapara	11.94	0.005	0.038	0.615
5.	Gaboud	25.31	0.005	0.030	1.520
6.	Khallari	2.37	0.000	0.006	1.520
7.	Saraipali	7.77	0.004	0.026	0.564
8.	Koma	0.10	0.000	0.001	1.520
9.	Paterapali	10.50	0.003	0.025	1.072
10.	Churki	5.18	0.003	0.016	0.564
11.	Nawadih	88.95	0.047	0.105	0.528

Table 6.13: Soil texture of soils in Kodar reservoir catchment

Site	Village	Percentage of				Type of soil
		Gravel	Sand	Silt	clay	
Site-1	Kherwar	2.0	70.2	27.8	-	Sandy Loam
Site-2	Patewa	5.3	69.4	23.5	1.8	Sandy Loam
Site-3	Thumsa	1.6	74.8	23.0	0.6	Sandy loam
Site-4	Nawapara	1.5	37.1	58.1	3.3	Silt Loam
Site-5	Gabod	14.1	37.2	48.7	-	Silt Loam
Site-6	Khallari	1.1	40.5	55.3	3.1	Silt Loam
Site-7	Saraipali	1.9	36.3	61.8	-	Silt Loam
Site-8	Koma	2.8	35.8	61.4	-	Silt Loam
Site-9	Paterapali	24.1	53.7	20.1	2.1	Sandy Loam
Site-10	Churki	22.4	70.2	7.4	-	Sandy
Site-11	Nawadih	2.9	73.2	23.9	-	Sandy Loam

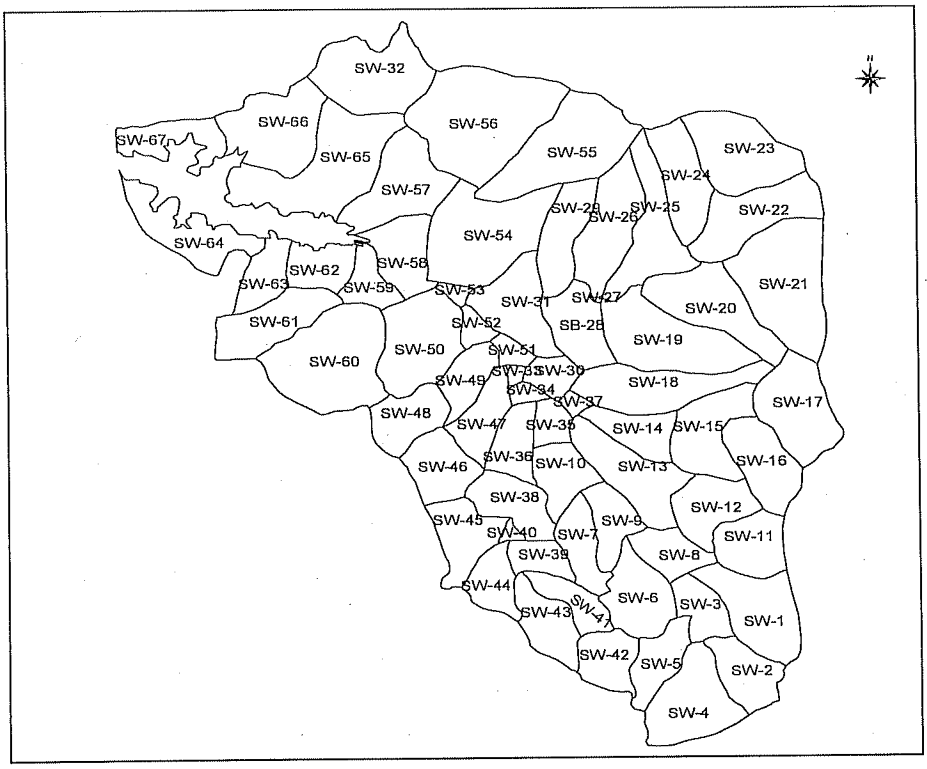


Fig 6.18: Sub-watershed map of Kodar reservoir catchment.

6.7.1 Soil loss estimation using USLE and RUSLE models (*SL*)

In the present study, soil loss from the Kodar catchment has been estimated using USLE and RUSLE model. ILWIS software has been used for generation of various factor maps.

6.7.1.1 USLE model

Various maps representing spatial distribution of different factors *R*, *K*, *L*, *S*, *C* & *P* have been prepared in ILWIS GIS and soil loss distribution have been estimated using USLE model. The theissen map of Kodar catchment has been prepared and it has been observed that Kodar catchment is affected by Kodar, Bagbahara and Bartunga R.G. stations. The weights and *R*-factor for different RG stations have been presented in Table 6.15 The value of annual and seasonal *R*-factor for kodar reservoir catchment has been obtained as 429.39 $MJmmha^{-1}hr^{-1}$ and 402.94 $MJmmha^{-1}hr^{-1}$ respectively. The *K*-factor maps for Kodar catchment has been prepared on the basis of soil type present in the study area (Table 6.16).

Table 6.15: Computation of *R*-factor for Kodar catchment

Rain gauge station	Weight	Annual rainfall (mm)	Annual R-factor ($MJ\ mm\ ha^{-1}hr^{-1}$)	Seasonal rainfall (mm)	Seasonal R-factor ($MJ\ mm\ ha^{-1}hr^{-1}$)
Kodar	0.50	960.68	427.73	909.99	403.99
Bagbahara	0.48	951.81	424.51	891.67	396.97
Bartunga	0.02	1063.66	465.11	970.90	427.68
Kodar Catchment		985.82	429.39		402.94

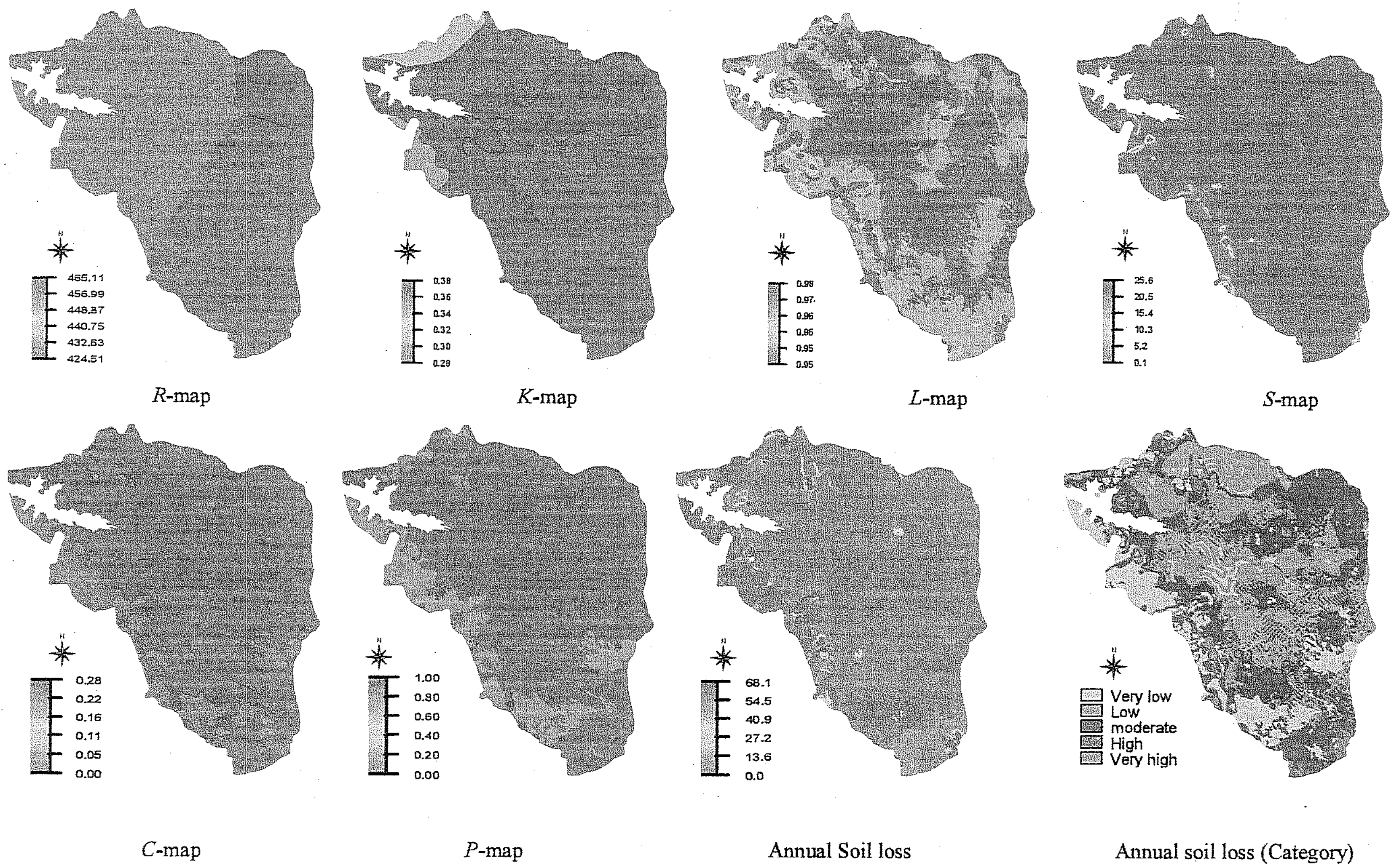


Fig. 6.19: *R*, *K*, *L*, *S*, *C* & *P*-factor map and annual soil loss map for Kodar reservoir catchment using USLE model

From the analysis, it has been observed that the average annual and seasonal soil loss from Kodar reservoir catchment is 7.06 t/ha/yr and 6.62 t/ha/yr respectively. A classification has been performed on the basis of rate of erosion. The study area has been divided in five classes on the basis of rate of erosion as 0.0 to 1.0 t/ha/yr (V. low), 1.0 to 3.0 t/ha/yr (Low), 3.0 to 5.0 t/ha/yr (Moderate), 5.0 to 8.0 t/ha/yr (High) and more than 8.0 t/ha/yr (V. high).

6.7.1.2 RUSLE model

The RUSLE model which is a revised form of USLE model has been applied for estimation of soil loss from Kodar catchment. In RUSLE model, the same *R*-factor map has been used as it was used in USLE model. For determination of *K*-factor map, the results obtained from analysis of soil textural analysis, infiltration test, saturated hydraulic conductivity test and nutrient analysis has been used. The average values of various factors including *M*, *a*, *b*, *c* and resulting K-values have been presented in Table 6.18. The overland flow length map for *RUSLE* model has been generated using DEM hydro processing facility of ILWIS 3.6. The overland flow length map of the study area has been given in Fig. 6.20. The slope length map and slope map have been used to determine SL-factor.

Table 6.18: Computation of *K*-factor for soils in the study area

Nomenclature	% Fine sand	% Silt	% Clay	*M*	*a*	*b*	*c*	*K* Factor
657 &670	11.03	11.32	1.80	2668.59	1.62	3	1	0.15
689	8.60	23.87	12.22	2850.38	2.03	3	1	0.20
710	6.30	5.41	0.00	1171.00	1.62	3	3	0.09
733	4.47	14.12	2.14	1819.22	1.21	3	3	0.15
746	3.20	26.87	3.22	2910.32	1.97	3	2	0.20
747	10.03	19.83	0.00	3086.00	0.86	3	2	0.24

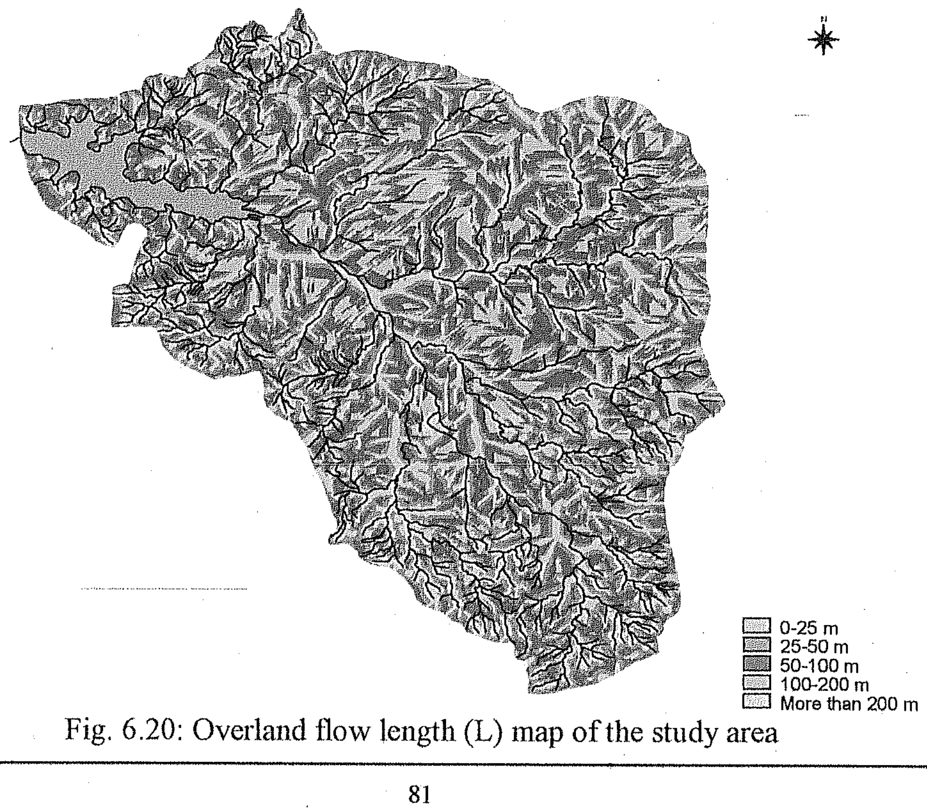
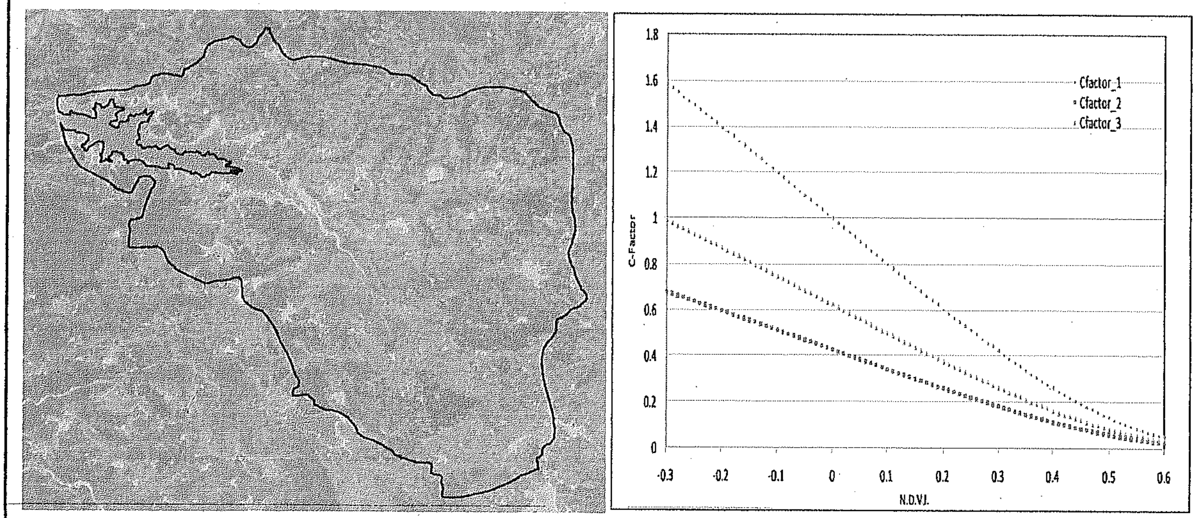


Fig. 6.20: Overland flow length (L) map of the study area

For determination of *C*-factor map of the study area, the NDVI image generated from LISS III data for the study area has been used. The *C*-factor-map using equation 5.13 has been prepared and a graph between NDVI and *C*-factor values has been plotted. From the analysis of graph, it has been observed that the some of the *C*-factor values were above the limiting value of *C*- factor. Therefore, a correction factor of 0.6246 has been applied to keep all the values between 0 and 1. The NDVI image and graph between NDVI and C-factor have been presented in Fig 6.21.



NDVI Image

Graph between NDVI and C-factor

Fig. 6.21: NDVI map and a graph between NDVI and C-factor.

For determination of *P*-factor map, the slope of the study area in agricultural land has been divided into different classes and accordingly *P*-factor values as given in the Table 5.2 have been assigned for each slop class. For other land uses, the standard values considering no conservation measures have been given in attribute table for generation of *P*-factor map. After integration of *R*, *K*, *SL*, *C* and *P* factor maps, an erosion map for Kodar reservoir catchment has been obtained. The *R*, *K*, *SL*, *C*, *P* and annual soil loss map of for Kodar reservoir catchment have been given in Fig. 6.22 and distribution in different classes in Table 6.19.The results obtained from the analysis indicated that the average annual and seasonal rate of soil loss from the Kodar reservoir catchment is 7.78 t/ha/year and 7.32 t/ha/year respectively using RUSLE model. Slope is one of the important factor for assessment of soil loss, distribution of soil loss in different slope classes have been estimated and a matrix of soil loss classes and slope classes in Kodar catchment has been determined and presented in Table 6.20. From the analysis of matrix, it has been observed that the higher slope areas contribute more soil erosion. Similarly, the forested land and barren areas contributes more soil erosion due to high slope and absence of effective conservation practices. It is therefore, necessary to apply mechanical and biological measures of soil conservation in forested and scrub land uses while agronomic measure may further reduces the soil loss from agricultural area. The soil loss map for each sub-watershed has been determined using '*iff*' statement and histogram operation of ILWIS. The annual soil loss from sub-watersheds in Kodar catc`hment varies between 0.51 t/ha/yr in sub-watershed SW-27 and 73.21t/ha/yr in sub-watershed SW-44 using RUSLE model. In the present study, the results obtained from RUSLE model have been used in prioritization analysis.

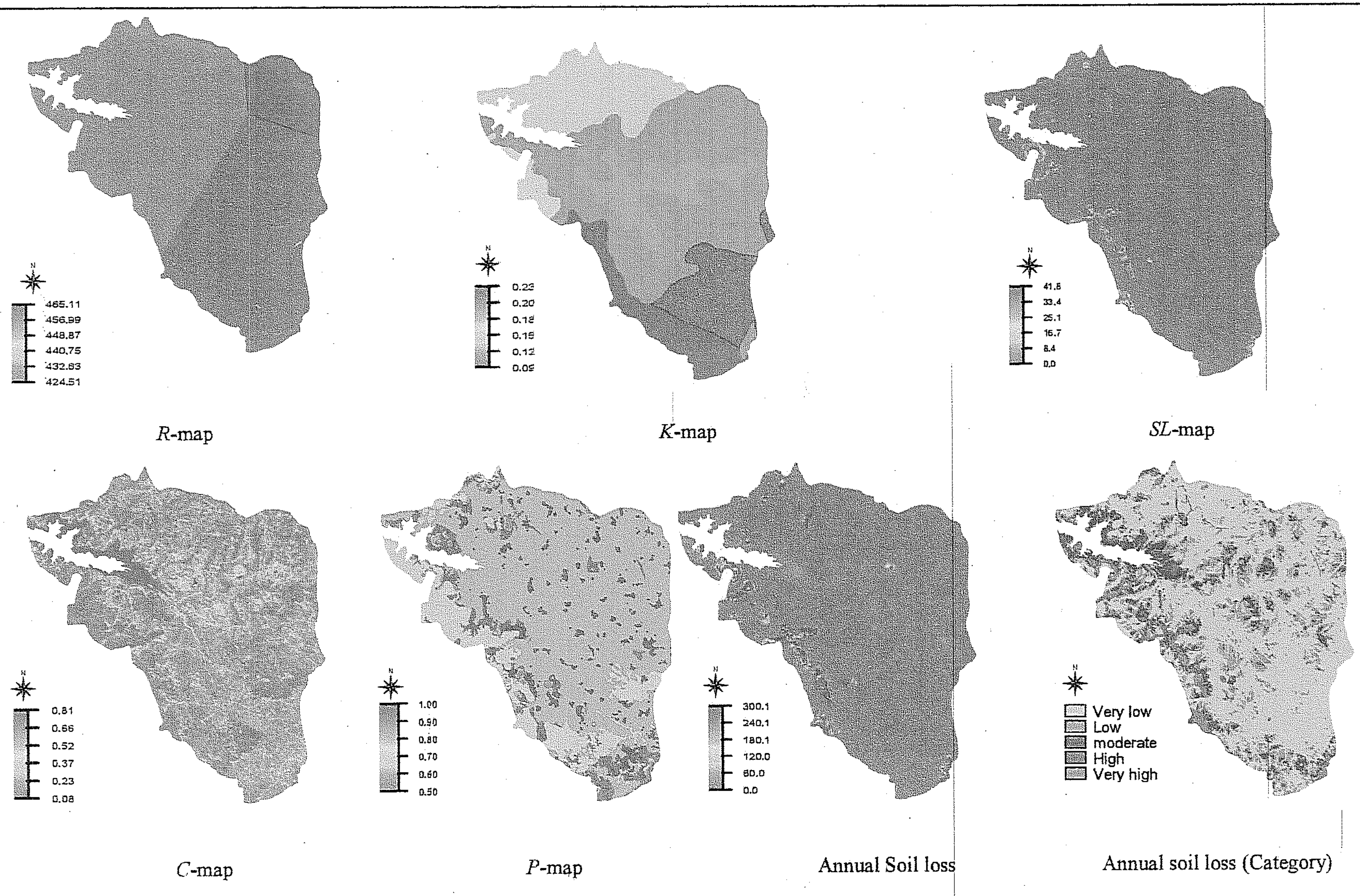


Fig. 6.22: *R, K, SL, C* & *P*-factor map and annual soil loss map for Kodar reservoir catchment using RUSLE model

Table 6.19: Soil loss under various classes in Kodar reservoir catchment

Soil loss class	Area (sq. km)	Percentage
Very Low (0 to 1 t/ha/yr)	97.05	31.59
Low (1 to 3 t/ha/yr)	137.94	44.91
Moderate (3 to 5 t/ha/yr)	35.49	11.55
High (5 to 8 t/ha/yr)	15.87	5.17
Very high (More than 8 t/ha/yr)	20.82	6.78
Total Area (km^2)	307.17	100

Table 6.20: A matrix of slope class and soil loss for Kodar reservoir catchment

Soil Loss→ Slope ↓	Very Low (0 to 1 t/ha/yr)	Low (1 to 3 t/ha/yr)	Moderate (3 to 5 t/ha/yr)	High (5 to 8 t/ha/yr)	V. High (More than 8 t/ha/yr)	Total Area (Sq. km.)
Nearly level slope (0 to 1 %)	82.12	99.12	20.02	7.02	3.61	211.89
Very gentle slope (1 to 3 %)	14.38	36.25	12.62	5.95	3.63	72.82
Gentle slope (3 to 5%)	0.33	2.14	2.05	1.61	1.26	7.38
Moderate slope (5 to 10%)	0.10	0.43	0.77	1.18	2.81	5.30
Strong slope (10 to 15%)	0.03	0.00	0.03	0.10	2.04	2.21
Steep slope (15 to 35%)	0.08	0.00	0.00	0.01	4.69	4.78
Very steep slope (More than 35%)	0.01	0.00	0.00	0.00	2.78	2.79
Total area (Sq. km.)	97.05	137.94	35.49	15.87	20.82	307.17

6.7.2 Estimation of sediment production rate (*SPR*)

For estimation of sediment production rate, a geomorphological model proposed by Josh & Das, 1983 has been used. Various geomorphological parameters including watershed area, perimeter, basin length, form factor, circulatory ratio and compactness coefficient for different sub-watersheds have been computed in GIS environment and resultant SPR for all the sub-watersheds have been estimated and presented in Table 6.21. The sediment production rate (SPR) from sub-watersheds of Kodar catchment ranges from 0.13 (ha-m/100 sq km/year) from SW-64 to 5.05 (ha-m/100 sq km/year) from SW-38. From SPR point of view, sub-watershed SW-38 needs immediate attention, while sub-watershed SW-64 can be considered at last for soil and water conservation.

6.7.3 Estimation of sediment yield (*SY*)

For estimation of sediment yield from sub-watersheds of Kodar catchment, a simple regression model quoted in literature (Kumar, 1985, Rao & Mahabaleswara, 1990) has been used. This model uses rainfall, slope, land use and some geomorphological parameters for computation of sediment yield. The annual rainfall for each sub-watershed has been estimated using the thiesen weights of rain gauge stations. From the analysis of sediment yield, it has been observed that minimum sediment yield from sub-watershed SW-27 was 0.01 $Mm^3/km^2/yr$, while sub-watershed SW-32 produces maximum sediment yield which as 0.244 $Mm^3/km^2/yr$ which was maximum among all the sub-watersheds in Kodar catchment (Table 6.22)

6.7.4 Estimation of sediment transport index (*STI*) and sediment power index (*SPI*)

The sediment transport index and sediment power index for each pixel of Kodar catchment has been computed using sub-routines available in ILWIS 3.7 software. The input maps used for this analysis were digital elevation model and flow accumulation map from which both indices have been derived. After determining the indices, *iff* statement has been used to extract indices maps for each sub-watershed and histogram operation were used to estimate the average sediment transport index and sediment power index. The spatial distribution of sediment power index and sediment transport index in Kodar catchment has been presented in Fig. 6.23. From the analysis, it has been observed that average sediment transport index in the sub-watersheds of Kodar catchment varies from 0.01 in sub-watershed SW-13 to 22.82 in sub-watershed SW-44. The variation of *STI* and *SPI* among the sub-watersheds has been presented in Fig. 6.24. It has been observed that the variation in sediment power index (*SPI*) is not significant and hence sediment transport index (*STI*) has been used in priority analysis.

6.7.5 Estimation of average slope (*Sl*)

The slope of each pixel in Kodar catchment has been computed using digital elevation model determined from contour map and point elevations. From the slope map of the study area, the slope map of each sub-watershed has been extracted using *iff* statement and histogram operation has been applied to obtain area under different slope which ultimately led to estimation of average slope for the sub-watershed. The slope map of the study area has been given in Fig. 6.25. The average slope in the sub-watersheds of Kodar catchment ranges from 0.00 % in SW-27 to 11.63 % in SW-44.

6.7.6 Estimation of geomorphological parameters

The geomorphology plays an important role in erosion process and geomorphological parameters are the indicator of the development stage of landforms in the watershed. In the prioritization analysis, drainage density (D_d), Channel Frequency (C_f), Circulatory ratio (R_c) and Form factor (R_f) have been used. The ILWIS software has been used to delineate drainage and catchment boundary of each sub-watershed and histogram operation has been used to estimate the length and areal aspects. The computation of drainage density and channel frequency for sub-watersheds in Kodar catchment has been presented in Table 6.23. Circulatory ratio and Form factor for sub-watersheds have already been given in Table 6.21.

Sub-Watershed No.	Annual rain *P* (cm)	Area *A* (km2)	Drainage density (*Dd*) (km/km2)	Average slope *Sl* (friction)	Protected forest *F1* (sq. km)	Open forest *F2* (sq. km)	Cultivated land *F3* (sq. km)	Grass & Pasture *F4* (sq. km)	Waste land *F5* (sq. km)	Vegetation index *F*	Sediment yield (*SY*) Mm3/sq. km/yr
SW-34	95.95	0.64	1.28	0.01	0.00	0.00	0.64	0.00	0.00	0.60	0.081
SW-35	95.18	1.57	1.06	0.00	0.00	0.00	1.53	0.00	0.00	0.60	0.095
SW-36	95.47	3.01	1.21	0.01	0.00	0.00	2.86	0.00	0.00	0.60	0.124
SW-37	95.18	0.51	1.82	0.01	0.00	0.00	0.51	0.00	0.00	0.60	0.086
SW-38	95.21	4.01	0.71	0.05	0.27	0.00	2.95	0.00	0.00	0.57	0.125
SW-39	95.18	2.02	1.89	0.01	0.07	0.00	1.95	0.00	0.00	0.59	0.128
SW-40	95.18	0.35	2.54	0.00	0.00	0.00	0.32	0.00	0.00	0.60	0.085
SW-41	95.18	2.52	2.91	0.01	2.17	0.00	0.35	0.00	0.00	0.26	0.023
SW-42	95.18	3.22	3.35	0.01	1.98	0.00	1.24	0.00	0.00	0.36	0.058
SW-43	95.18	3.69	2.40	0.01	2.76	0.00	0.84	0.00	0.00	0.30	0.034
SW-44	95.18	2.81	3.41	0.12	1.44	0.00	1.20	0.00	0.00	0.39	0.090
SW-45	95.36	4.16	2.82	0.08	2.19	0.00	1.91	0.00	0.00	0.39	0.092
SW-46	96.07	4.15	2.71	0.07	1.67	0.00	2.13	0.00	0.00	0.43	0.113
SW-47	96.07	3.32	1.03	0.01	0.14	0.00	3.10	0.00	0.00	0.58	0.117
SW-48	96.07	3.86	2.93	0.06	2.59	0.00	1.10	0.00	0.00	0.33	0.056
SW-49	96.07	2.85	2.38	0.03	0.26	0.00	2.24	0.00	0.00	0.56	0.168
SW-50	96.07	7.18	0.71	0.02	0.52	0.00	6.47	0.00	0.00	0.57	0.139
SW-51	96.07	0.94	1.18	0.00	0.00	0.00	0.93	0.00	0.00	0.60	0.070
SW-52	96.07	1.02	1.48	0.00	0.00	0.00	0.95	0.00	0.00	0.60	0.061
SW-53	96.07	0.51	3.22	0.00	0.00	0.00	0.51	0.00	0.00	0.60	0.099
SW-54	96.07	9.94	1.04	0.00	0.00	0.00	9.65	0.00	0.00	0.60	0.165
SW-55	96.09	9.56	1.35	0.01	0.00	0.00	9.21	0.00	0.00	0.60	0.198
SW-56	96.07	13.05	1.52	0.01	0.00	0.00	12.25	0.00	0.00	0.60	0.234
SW-57	96.07	6.66	1.41	0.02	0.47	0.00	5.89	0.00	0.00	0.57	0.174
SW-58	96.07	4.18	1.18	0.00	0.00	0.00	4.14	0.00	0.00	0.60	0.132
SW-59	96.07	2.29	1.06	0.00	0.00	0.00	2.20	0.00	0.00	0.60	0.107
SW-60	96.07	10.49	2.45	0.03	6.41	0.00	3.04	0.00	0.00	0.34	0.069
SW-61	96.07	5.27	3.98	0.06	3.92	0.00	1.35	0.00	0.00	0.31	0.062
SW-62	96.07	2.98	1.36	0.02	0.07	0.00	2.87	0.00	0.00	0.59	0.149
SW-63	96.07	2.85	2.45	0.10	1.82	0.00	1.02	0.00	0.00	0.35	0.061
SW-64	96.07	5.41	1.58	0.06	4.61	0.00	0.80	0.00	0.00	0.27	0.029
SW-65	96.07	10.67	1.03	0.02	0.33	0.00	9.91	0.00	0.00	0.59	0.189
SW-66	96.07	7.35	2.67	0.02	2.11	0.00	5.00	0.00	0.00	0.48	0.151
SW-67	96.07	3.78	1.33	0.02	0.24	0.00	3.33	0.00	0.00	0.57	0.143

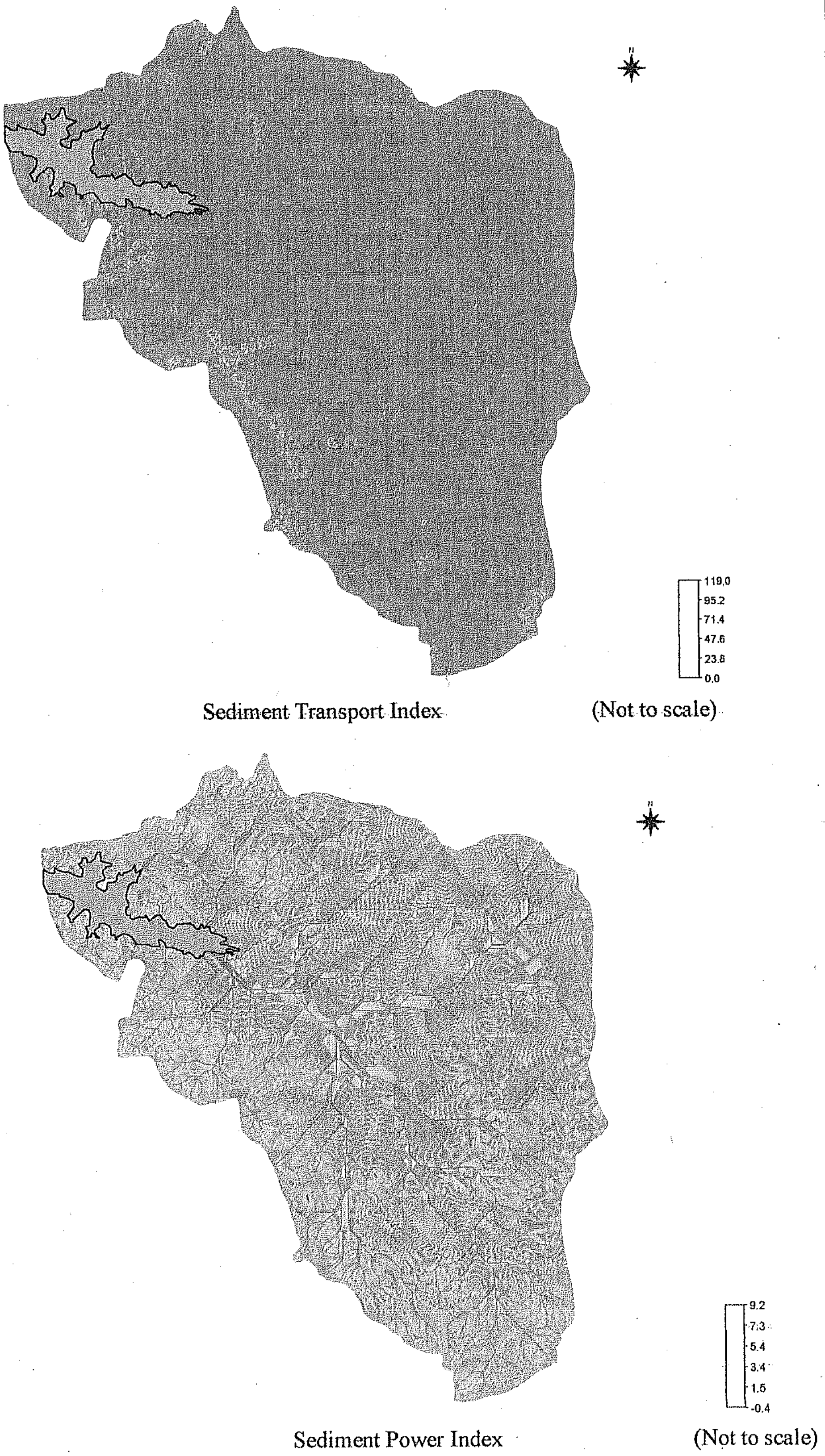


Fig 6.23: Spatial distribution of STI and SPI in Kodar reservoir catchment

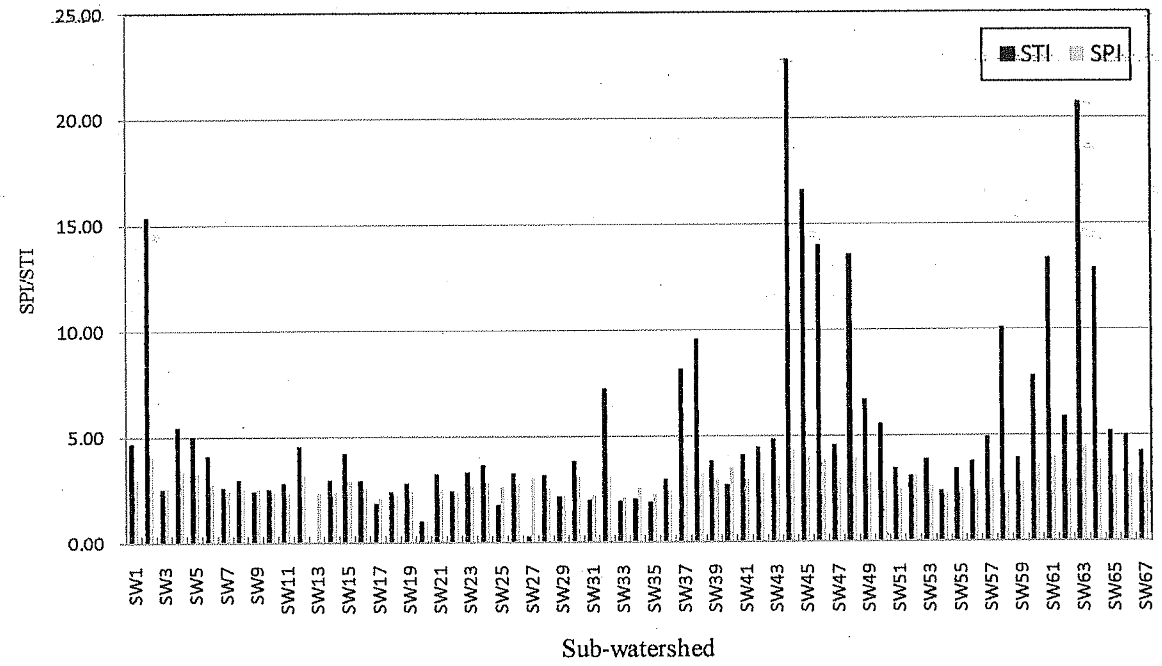


Fig. 6.24: Variation of STI and SPI in sub-watersheds of Kodar catchment

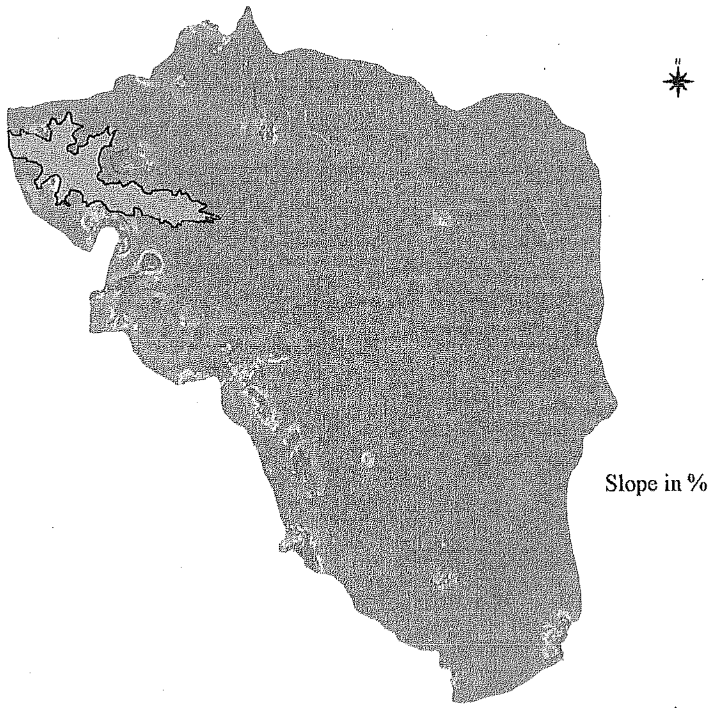


Fig. 6.25: Slope map of Kodar catchment

Table 6.23: Computation of drainage density and channel frequency for sub-watersheds in Kodar catchment

Sub basin	Area (km^2)	Perimeter (km)	First Order (Length in km)		Second Order (Length in km)		Third Order (Length in km)		Fourth Order (Length in km)		Fifth Order (Length in km)		Total No.	Total length (km)	Drainage Density (km/ km^2)	Channel Frequency (No./ km^2)
			No.	Length	No.	Length	No.	Length	No.	Length	No.	Length				
SW-1	6.32	11.41	17	8.16	5	4.38	2	2.91	1	1.34			25	16.80	2.66	3.95
SW-2	3.71	8.26	13	8.14	3	1.95	1	1.93					17	12.02	3.24	4.58
SW-3	2.72	7.39	2	2.29					1	2.89			3	5.18	1.90	1.10
SW-4	6.39	10.67	17	9.86	4	2.72	2	1.28	1	1.65			24	15.52	2.43	3.76
SW-5	3.29	8.67	7	4.93	3	2.17	1	1.65					11	8.75	2.66	3.34
SW-6	4.87	9.62	13	7.77	2	3.22	1	2.01					16	13.00	2.67	3.28
SW-7	3.18	8.88	4	1.90	1	3.48							5	5.38	1.69	1.57
SW-8	2.94	7.40									1	2.57	1	2.57	0.87	0.34
SW-9	3.10	8.29	1	1.44							1	2.33	2	3.77	1.21	0.64
SW-10	3.39	8.00	1	1.01							1	2.49	2	3.50	1.03	0.59
SW-11	4.06	7.72	8	5.05	2	2.47	1	0.09					11	7.61	1.88	2.71
SW-12	4.32	8.95	7	5.91	1	1.84	1	2.37					9	10.12	2.35	2.09
SW-13	6.06	12.20	5	3.28	1	0.62	1	5.50					7	9.41	1.55	1.15
SW-14	3.23	8.51	1	1.03					1	3.35			2	4.38	1.36	0.62
SW-15	5.39	11.17	5	5.78	1	0.51	1	0.94	1	2.18			8	9.40	1.75	1.49
SW-16	4.92	9.22	8	7.40	2	3.03	1	1.25					11	11.68	2.38	2.24
SW-17	6.56	10.39	12	6.56	4	4.03	1	1.64					17	12.23	1.86	2.59
SW-18	6.55	13.91	4	5.05	1	3.54							5	8.58	1.31	0.76
SW-19	8.28	13.15	5	4.83	2	3.37	1	1.94					8	10.14	1.22	0.97
SW-20	6.73	12.42	3	2.77	1	4.25							4	7.02	1.04	0.59
SW-21	10.17	13.45	3	7.54	1	0.18							4	7.72	0.76	0.39
SW-22	6.22	12.10	8	5.11	2	0.69	1	3.09					11	8.88	1.43	1.77
SW-23	7.11	10.71	5	4.73	2	2.92							7	7.65	1.08	0.98

Sub basin	Area (km^2)	Perimeter (km)	First Order (Length in km)		Second Order (Length in km)		Third Order (Length in km)		Fourth Order (Length in km)		Fifth Order (Length in km)		Total No.	Total length (km)	Drainage Density (km/ km^2)	Channel Frequency (No./ km^2)
			No.	Length	No.	Length	No.	Length	No.	Length	No.	Length				
SW-48	3.86	8.01	13	7.84	3	1.49	1	1.97					17	11.29	2.93	4.41
SW-49	2.85	7.78	5	3.57		0.00	1	3.21					6	6.78	2.38	2.10
SW-50	7.18	10.72	2	1.47	1	3.66		0.00					3	5.13	0.71	0.42
SW-51	0.94	4.17		0.00		0.00		0.00			1	1.10	1	1.10	1.18	1.07
SW-52	1.02	4.43		0.00		0.00		0.00			1	1.52	1	1.52	1.48	0.98
SW-53	0.51	3.15	1	0.51		0.00		0.00			1	1.13	2	1.64	3.22	3.92
SW-54	9.94	14.16	4	5.51	1	0.62	1	4.25					6	10.38	1.04	0.60
SW-55	9.56	13.85	7	5.97	2	1.89	1	5.08					10	12.94	1.35	1.05
SW-56	13.05	14.50	14	13.48	3	4.23	1	2.11					18	19.82	1.52	1.38
SW-57	6.66	12.31	4	4.45	1	0.55	1	4.39					6	9.39	1.41	0.90
SW-58	4.18	10.29	2	2.15		0.00		0.00			1	2.77	3	4.92	1.18	0.72
SW-59	2.29	7.70		0.00		0.00		0.00	1	2.42			1	2.42	1.06	0.44
SW-60	10.49	12.96	21	14.98	6	6.54	3	1.47	1	2.73			31	25.72	2.45	2.96
SW-61	5.27	10.48	27	13.92	9	3.73	1	3.33					37	20.98	3.98	7.02
SW-62	2.98	7.59	3	2.10		0.00	1	1.97					4	4.07	1.36	1.34
SW-63	2.85	8.00	8	4.46	1	2.51		0.00					9	6.97	2.45	3.16
SW-64	5.41	16.50	16	6.90	2	1.66		0.00					18	8.56	1.58	3.33
SW-65	10.67	18.20	7	6.35		0.00		0.00			1	4.61	8	10.96	1.03	0.75
SW-66	7.35	12.50	21	13.49	4	5.07	1	1.09					26	19.66	2.67	3.54
SW-67	3.71	12.94	9	4.66	1	0.08		0.00					10	4.74	1.28	2.70

The weights for different EHPs obtained for priority assessment are given below:

SL	*SPR*	*SY*	*STI*	*SI*	D_d	C_f	R_f	R_C
0.33	0.07	0.20	0.16	0.11	0.06	0.04	0.03	0.02

The final priority of each watershed has been estimated using normalized values of each EHP and corresponding weight obtained from Saaty's AHP analysis. The computation of priority assessment has been presented in Table 6.26. From the analysis, it has been observed that the final priorities of sub-watersheds in Kodar catchment lie in the range of 0.12 to 0.74. The final priorities of sub-watersheds have been divided in five different ranges i.e. more than 0.30 as very high, 0.30 to 0.25 as high, 0.25 to 0.20 as moderate, 0.20 to 0.15 as low and less than 0.15 as very low priority, so that environmentally stressed areas can be identified for soil conservation measures. The sub-watersheds under each category have been depicted in Fig. 6.26 and Table 6.27.

From the Saaty's AHP analysis, the composite priority for SW-44 has been computed as 0.74 and identified as the top most priority watershed. Similarly, SW-41 may be considered at the last in conservation works. The AHP analysis suggested that more than 21 sub-watersheds covering 117 km^2 area of Kodar reservoir catchment comes under very high and high priority and hence a scientifically developed CAT plan consisting mechanical, biological and agronomic measures should be implemented immediately in these sub-watersheds and agronomic measures and other biological measures should be adopted in other sub-watersheds in phased manner. It has also been observed that 31 sub-watersheds with total area of 101.11 km^2 can be kept in low and very low priority where agronomic measures with development of awareness in farmers should be useful for conservation point of view. From the analysis, it has been observed that the sub-watersheds under very high and high priority are either on higher slope from where soil erosion are more or near the reservoir from where eroded material easily transported to the reservoir through dense network of drainage.

6.8 Development of CAT Plan

Conservation of natural resources is essential for sustainable development and such measures especially for soil and water carried out on a watershed basis is very useful for control of soil erosion. The scientifically developed catchment area treatment plan identifies environmentally stressed areas, necessity and intensity of mechanical and biological measures to arrest further soil erosion and conserve water with in the watershed. As the information regarding various factors affecting the status of watershed vary spatially, the RS and GIS play an important role for identification of areas suitable for soil conservation measures and type of treatment required. For development of CAT plan for environmentally stressed areas in Kodar reservoir catchment, interpretation of satellite data, derivation of secondary information from toposheets and field surveys have been used as basis. Various thematic layers such as geology, land use, soil, slope, drainage, geomorphology have been used for selecting different soil and water conservation measures in sub-watersheds of Kodar reservoir catchments. The combinations of different criterions for selection of soil and water conservation measures presented in Table 5.3 have been used as guiding principles for deciding the conservation measures in the field.

SW-25	3.50	0.04	0.40	0.05	0.149	0.61	1.78	0.08	0.91	0.08	0.85	0.02	0.33	0.01	0.17	0.00	0.33	0.13	0.16
SW-26	3.06	0.04	2.01	0.38	0.140	0.57	3.26	0.14	0.91	0.08	0.80	0.01	0.16	0.00	0.21	0.01	0.53	0.45	0.19
SW-27	0.51	0.00	2.21	0.42	0.000	0.00	0.28	0.01	0.01	0.00	7.18	1.00	19.40	1.00	0.38	0.04	0.53	0.47	0.14
SW-28	2.76	0.03	1.93	0.37	0.122	0.50	3.18	0.14	0.62	0.05	0.86	0.02	1.41	0.07	0.40	0.05	0.68	0.71	0.18
SW-29	2.38	0.03	2.09	0.40	0.121	0.50	2.17	0.09	0.58	0.05	0.83	0.02	0.68	0.03	0.25	0.02	0.54	0.48	0.17
SW-30	1.43	0.01	1.24	0.23	0.104	0.43	3.82	0.17	0.51	0.04	1.16	0.07	0.56	0.02	0.51	0.07	0.80	0.91	0.16
SW-31	2.11	0.02	3.01	0.59	0.123	0.50	1.98	0.09	0.28	0.02	0.95	0.04	0.75	0.03	0.98	0.16	0.60	0.58	0.18
SW-32	7.67	0.10	3.43	0.67	0.244	1.00	7.24	0.32	3.14	0.27	3.04	0.36	4.09	0.20	1.63	0.29	0.69	0.72	0.41
SW-33	0.99	0.01	2.08	0.40	0.071	0.29	1.94	0.08	0.12	0.01	2.36	0.25	2.94	0.14	0.58	0.08	0.68	0.72	0.14
SW-34	1.38	0.01	2.74	0.53	0.081	0.33	2.03	0.09	0.53	0.05	1.28	0.09	1.55	0.07	1.21	0.21	0.69	0.73	0.15
SW-35	1.88	0.02	1.71	0.32	0.095	0.39	1.90	0.08	0.50	0.04	1.06	0.05	0.64	0.02	0.68	0.10	0.75	0.82	0.15
SW-36	1.78	0.02	2.26	0.43	0.124	0.51	2.97	0.13	0.56	0.05	1.21	0.08	0.67	0.03	0.42	0.05	0.61	0.59	0.18
SW-37	1.03	0.01	2.00	0.38	0.086	0.35	8.17	0.36	0.55	0.05	1.82	0.17	1.94	0.09	0.64	0.10	0.70	0.75	0.19
SW-38	39.00	0.53	5.05	1.00	0.125	0.51	9.57	0.42	4.97	0.43	0.71	0.00	0.75	0.03	2.27	0.42	0.66	0.67	0.48
SW-39	1.15	0.01	2.75	0.53	0.128	0.53	3.82	0.17	0.74	0.06	1.89	0.18	1.48	0.07	0.98	0.16	0.65	0.66	0.21
SW-40	0.98	0.01	2.46	0.47	0.085	0.35	2.68	0.12	0.43	0.04	2.54	0.28	2.89	0.14	0.57	0.08	0.55	0.49	0.16
SW-41	1.75	0.02	1.92	0.36	0.023	0.09	4.11	0.18	1.10	0.09	2.91	0.34	3.17	0.16	0.27	0.02	0.50	0.41	0.12
SW-42	2.75	0.03	2.00	0.38	0.058	0.24	4.48	0.20	1.32	0.11	3.35	0.41	4.96	0.25	0.76	0.12	0.72	0.78	0.18
SW-43	2.31	0.02	2.14	0.41	0.034	0.14	4.83	0.21	1.25	0.11	2.40	0.26	2.98	0.15	0.25	0.02	0.58	0.54	0.14
SW-44	73.21	1.00	2.25	0.43	0.090	0.37	22.82	1.00	11.63	1.00	3.41	0.42	4.27	0.21	0.46	0.06	0.63	0.62	0.74
SW-45	42.43	0.58	2.76	0.53	0.092	0.38	16.63	0.73	8.15	0.70	2.82	0.33	3.37	0.17	0.79	0.12	0.56	0.51	0.53
SW-46	0.54	0.00	1.25	0.23	0.113	0.46	14.03	0.61	7.29	0.63	2.71	0.31	3.62	0.18	0.61	0.09	0.81	0.92	0.31
SW-47	1.90	0.02	2.17	0.41	0.117	0.48	4.57	0.20	0.78	0.07	1.03	0.05	0.30	0.01	0.32	0.03	0.54	0.48	0.18
SW-48	33.68	0.46	1.58	0.29	0.056	0.23	13.59	0.60	6.27	0.54	2.93	0.34	4.41	0.22	0.59	0.09	0.76	0.84	0.41

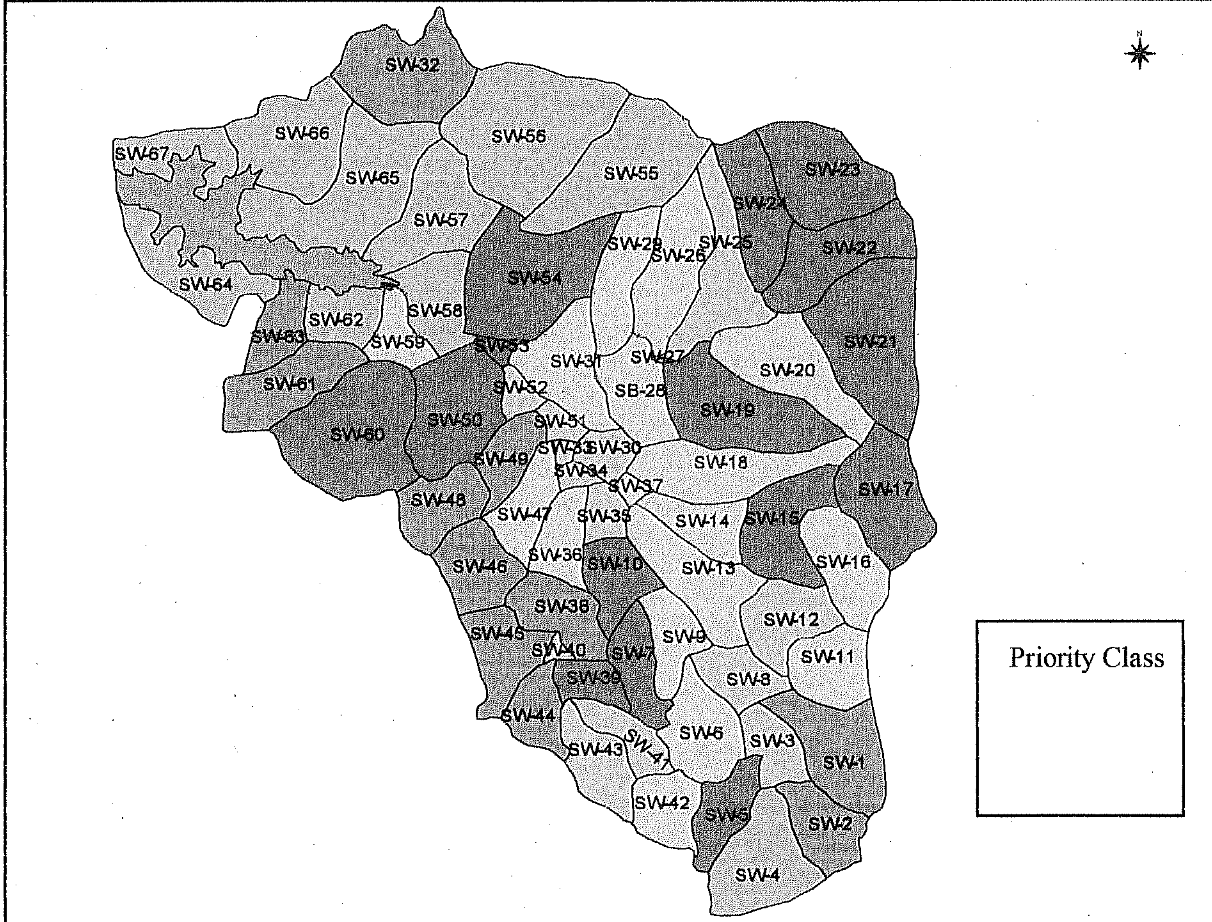


Fig. 6.26: Priority sub-watersheds in Kodar reservoir catchment using Saaty's AHP technique

Table 6.27: Area under each priority in Kodar catchment

S.N.	Priority Class	Range of final priority	No. of watershed	Watershed	Total area (sq. km)
1.	V. high	Up to 0.30	11	SW-1, SW-2, SW -32, SW-38, SW-44. SW-45, SW -46, SW-48, SW-49, SW -61 and SW-63	47.81
2.	High	0.30 to 0.25	10	SW-4, SW-55, SW-56, SW-57, SW-58, SW-62,SW-64, SW-65, SW-66 and SW-67	70.03
3.	Moderate	0.25 to 0.20	15	SW-5, SW-7, SW-10, SW-15, SW-17, SW-19, SW-21, SW-22, SW-23, SW-24, SW-39, SW-50, SW-53, SW-54 and SW-60	88.75
4.	Low	0.20 to 0.17	17	SW-6, SW-9, SW-11, SW-13, SW-14, SW-16, SW-18, SW-20, SW-26, SW-28, SW-29, SW-31, SW-36, SW-37, SW-42, SW-47 and SW-59	72.11
5.	V. low	Less than 0.17	14	SW-3, SW-8, SW-12, SW-25, SW-27,SW-30, SW-33, SW-34, SW-35, SW-40, SW-41, SW-43, SW-51 and SW-52	29.00
	Total				307.71

The drainage line treatment is very important and most relevant aspect in rain-fed areas. Checking the velocity of runoff, harnessing the rainwater lost through these drains and impounding them through various soil and water conservation measures would result in improving the water resources of an area. The mechanical measures for soil conservation measure were proposed only in very high and high priority watersheds. The areas under various agronomic and biological measures for agriculture, open forest and scrub lands have been finalized using cross facility of ILWIS and an attribute table in which suitable measures have been provided. Initially, land use, geomorphology, slope and soil maps have been crossed using cross facility of raster operation which provides a raster map having different combinations.

A column in histogram has been created and on the basis of different combinations in histogram, the suitable soil conservation measures have been suggested for different combinations of landuse, geology, geomorphology and soil in priority sub-watersheds. The attribute map operation has been used to give areas suitable for various agronomic and biological measures such as contour farming, bolder bunds, reforestation, agroforestry etc. The map showing CAT plan of the study area consisting of suitable areas for agronomic and biological soil conservation measures in different sub-watersheds has been presented in Fig. 6.27 (a), while location of different mechanical measures presented in Fig. 6.27 (b).

The agronomic and biological measures have been suggested in all sub-watersheds, while mechanical measures only in very high and high priority sub-watersheds of Kodar catchment. As the gram panchayats are considered the administrative units for implementation of various conservation works, the areas of various agronomic and biological measures and nos. of mechanical structures have been determined in different gram panchayats falling under various sub-watersheds of Kodar reservoir catchment. The areas under agronomic and biological measures and numbers of mechanical structures in different gram panchayats have been presented in Table 6.28 (a) and 6.28 (b). The results obtained from the study will be useful for planners and administrative bodies to implement conservation measures in different gram panchayats. Other agronomic measures such as contour farming; mulching; application of bio-fertilizers; minimum tillage etc. should be employed in all agriculture areas of the catchment. The CAT plan developed for the study area can be used as a model for prioritization and scientific development of CAT plan for other erosion prone areas in the state.

From the analysis, it has been observed that about 4152.59 ha area in Kodar catchment which is level land with agriculture found suitable for farm ponds. Considering the suitability and runoff availability, form ponds in these areas can be constructed to arrest excess flow of water and use of stored water during summer season. The CAT plan suggests 101.61 ha land for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land which will be beneficial for rural population for their additional income and environmental health of the watershed. Agronomic practices including such contour bunds, strip cropping and bench terracing etc. have been suggested according to slope in agricultural lands should be implanted through financial aids and generating awareness among the farmers through seminar, workshops and visits of other well conserved watershed. The CAT Plan suggests, 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams in Kodar catchment. The gram panchayats wise distribution of mechanical structures presented in the table may be helpful to the authorities for allocation of budget to construct these structures.

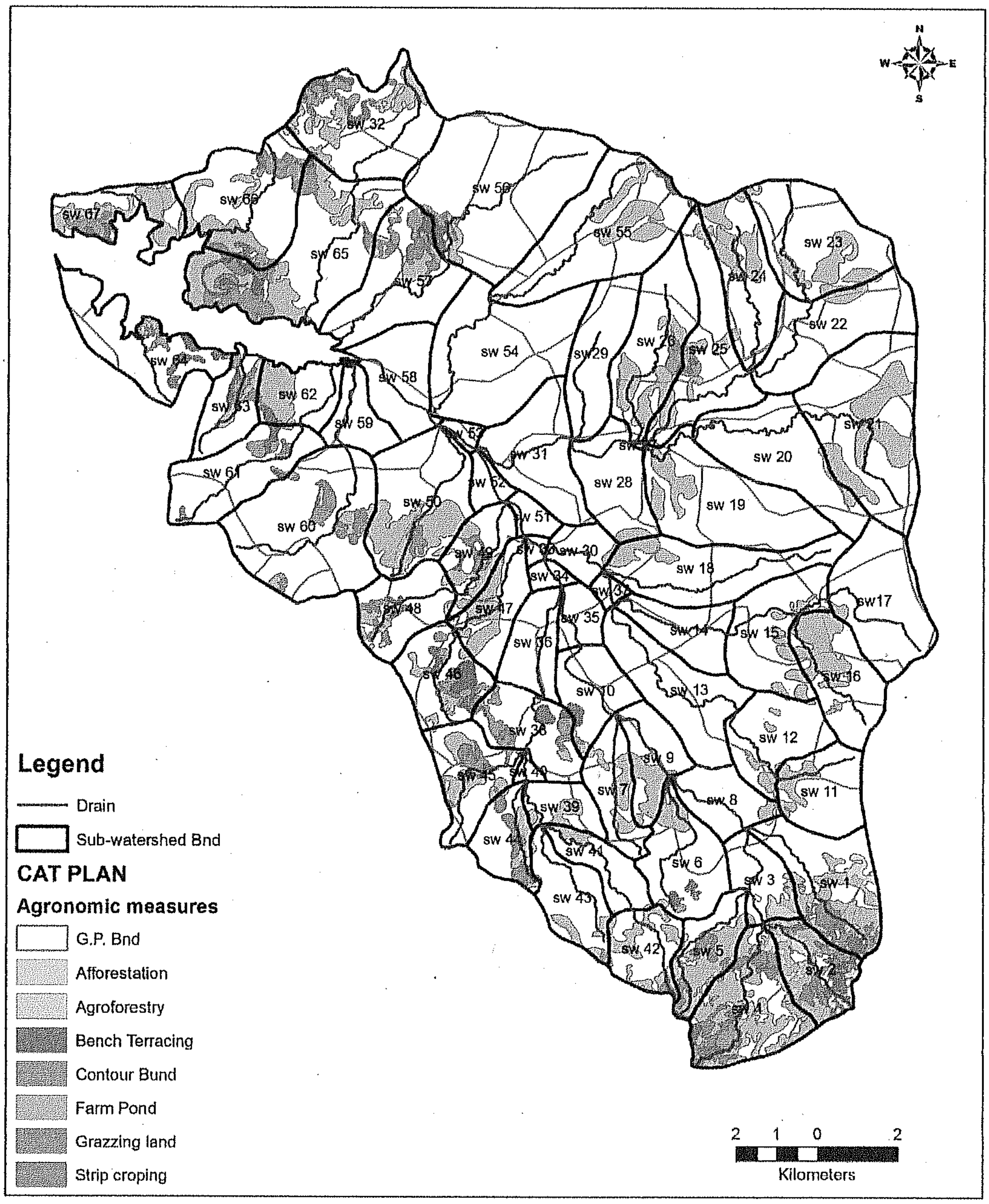


Fig. 6.27 (a): Agronomic and biological measures under CAT plan of Kodar reservoir catchment

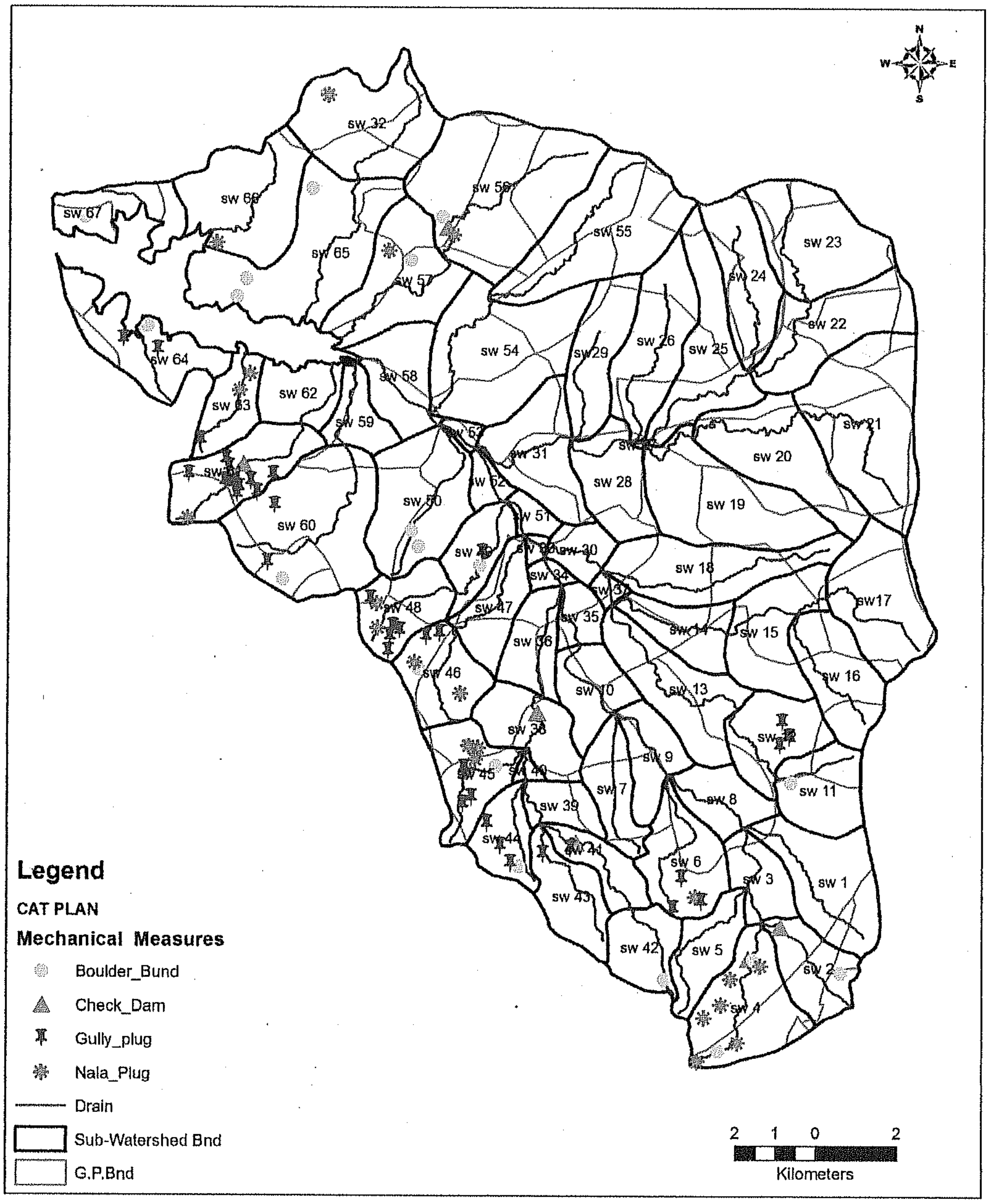


Fig. 6.27 (b): Mechanical measures under CAT plan of Kodar reservoir catchment

Table 6.28 (a): Agronomic and biological soil conservation measures under CAT plan of Kodar reservoir catchment

Sub-watershed	Gram Panhayat	Area under agronomic and biological soil conservation measures (ha)						
		Contour Bund	Bench Terracing	Strip cropping	Farm Pond	Afforestation	Agro forestry	Development of grazing land
SW-1	Bhimkhoj	-	37.73	-	85.91	19.38	85.91	-
	Junwani kalan	7.49	0.40	11.13	17.80	-	-	-
	Paterapali	-	-	-	-	2.15	-	-
	Tendulthak	-	19.82	-	-	7.10	-	-
SW-2	Bhimkhoj	0.01	-	8.67	62.85	31.30	5.66	0.84
	Ghunchapalika	2.90	40.61	-	8.28	22.47	-	-
	Junwani kalan	12.79	6.53	25.30	54.81	6.68	-	-
	Tendulthak	5.98	12.02	0.99	0.00	2.23	-	2.10
SW-3	Bhimkhoj	-	-	-	30.15	1.64	23.29	-
SW-4	Bhimkhoj	12.38	10.70	72.43	167.90	8.66	-	8.50
	Junwani kalan	15.12	-	25.93	120.68	-	-	-
	Bokramuda kala	0.08	-	2.40	1.17	-	-	-
	Ghunchapalika	-	-	-	5.27	-	-	-
SW-5	Bhimkhoj	-	3.93	44.16	161.42	-	-	-
SW-6	Bhimkhoj	4.03	14.23	-	4.59	-	-	-
	Kashibahara	-	-	-	22.39	-	-	-
	Paterapali	-	-	-	30.04	-	-	-
SW-7	Anwaradabri	-	-	-	13.44	-	-	-
	Kashibahara	-	-	-	59.91	-	-	-
SW-8	Bhimkhoj	-	-	-	0.85	-	-	-
	Paterapali	-	-	-	16.11	-	-	-
SW-9	Paterapali	-	-	-	2.88	-	-	-
	Anwaradabri	-	-	-	2.51	-	-	-
	Kashibahara	-	-	-	76.76	-	-	-
SW-10	Anwaradabri	2.35	12.06	3.04	5.70	-	-	-
SW-11	Bhimkhoj	-	-	-	34.03	-	-	-
	Dawanbod	-	-	-	25.82	-	-	-
	Siripatharimu	-	-	-	2.96	-	-	-
SW-12	Bhimkhoj	-	-	-	1.68	-	-	-
	Dawanbod	-	-	-	19.93	-	-	-
	Paterapali	-	-	-	16.31	-	-	-
SW-15	Dawanbod	-	-	-	29.97	-	-	-
	Gaboud	-	-	-	41.41	-	-	-
	Khusrupali	-	-	-	0.20	-	-	-
	Sukharidabri	-	-	-	3.81	-	-	-
SW-16	Dawanbod	-	-	-	61.42	-	-	-
	Gaboud	-	-	-	75.40	-	-	-
	Siripathari mu	-	-	-	3.71	-	-	-
	Sukharidabri	-	-	-	22.86	-	-	-
SW-17	Sukharidabri	-	-	-	12.34	-	-	-
SW-18	Barbaspur	-	-	-	14.79	-	-	-
	Kanharpuri	-	-	-	51.38	-	-	-
SW-19	Barbaspur	-	-	-	94.21	-	-	-
SW-20	Bhatgaon	-	-	-	8.31	-	-	-
	Nortora	-	-	-	13.65	-	-	-
SW-21	Barkel(Bazar)	-	-	-	6.44	-	-	-
	Bhatgaon	-	-	-	10.20	-	-	-
	Nortora	-	-	-	201.35	-	-	-
	Pachri (Pachur)	-	-	-	37.71	-	-	-
SW-22	Chhindpan	-	-	-	19.14	-	-	-
	Singhanpur	-	-	-	13.87	-	-	-
SW-23	Chhindoali	-	-	-	5.37	-	-	-
	Chhindpan	-	-	-	126.90	-	-	-
	Sindhauri	-	-	-	1.63	-	-	-
SW-24	Bawankera	-	-	-	25.72	-	-	-
	Chhindoali	-	-	-	2.88	-	-	-
	Sindhauri	-	0.52	-	101.68	-	-	-
SW-25	Sindhauri	-	2.53	-	5.08	-	-	-

Table 6.28 (b): Mechanical soil conservation measures under CAT plan of Kodar reservoir catchment

Sub-watershed	Gram Panhayat	No. of mechanical measures			
		Boulder Bund	Check Dam	Gully plug	Nala Plug
SW-2	Bhimkhoj	1	1		
SW-4	Bhimkhoj	1	1		4
SW-6	Junwani kalan	1			2
	Bhimkhoj			3	1
SW-11	Bhimkhoj	1			
SW-12	Dawanbod			3	
SW-32	Sirpur	1			1
SW-38	Anwaradabri		1		
SW-41	Bhimkhoj		1	1	
SW-42	Bhimkhoj	1			
SW-43	Bhimkhoj			1	
SW-44	Bhimkhoj	1		3	
SW-45	Bhimkhoj	1		3	2
	Khallari	1			2
SW-46	Khallari				1
	Onkarband	1		2	1
SW-48	Onkarband			4	2
	Soram			1	
SW-49	Pali	1		1	
SW-50	Pali	2			
SW-56	Torla				1
	Patewa	1	1		
SW-57	Khatta	1			
	Nawagaon				1
SW-60	Soram			1	
	Hadaband	1		1	
SW-61	Soram		1	9	
	Mohandi (Mohad)			1	1
SW-63	Soram			1	2
SW-64	Soram	1		2	
SW-65	Soram	3			
SW-66	Nawagaon				1
SW-67	Nawagaon	1			
TOTAL		21	6	37	22

6.9 Design of Check Dams under CAT Plan

The check dams are the major mechanical structures should be designed on the basis of scientific inputs and standard design procedure to get maximum benefits in the terms of

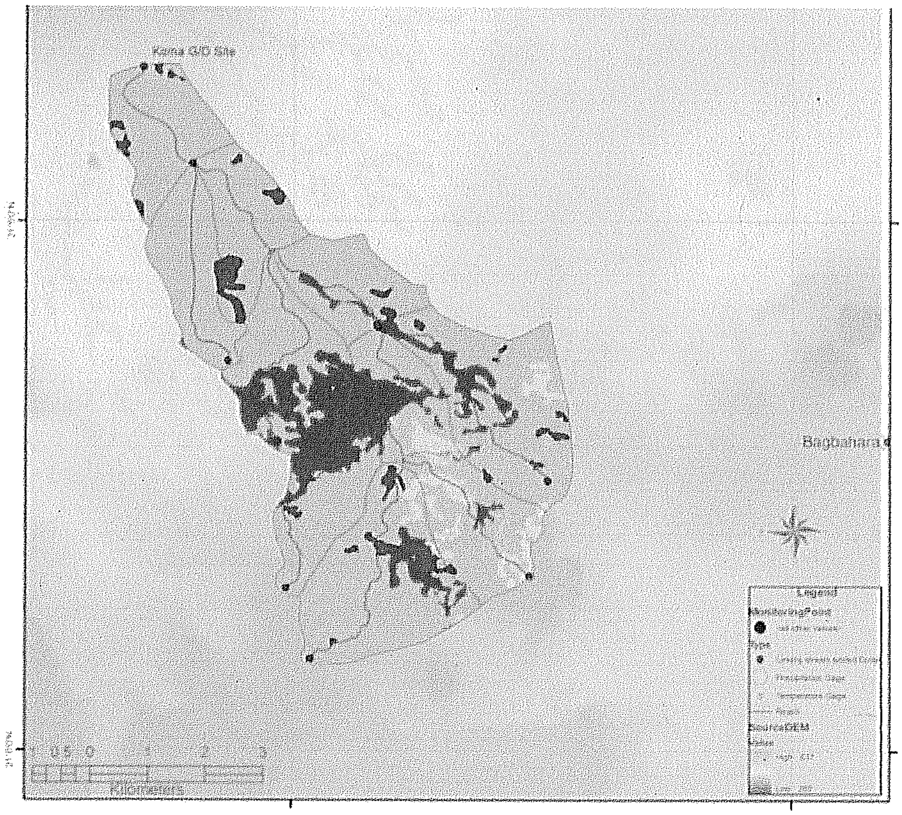


Fig 6.28: SWAT Model setup for Koma G/D site in Kodar reservoir catchment

The monthly statistics of meteorological data of Raipur have been used for weather generator presented in Table 6.30. After setting up of model, the weather generator for the study area was assigned and writing of files using default values were done. The results of sensitivity analysis to limit the parameters, calibration to set parameter values and validation with independent data to judge the model performance are given below.

6.10.1.1 Sensitivity analysis

The sensitivity analysis using observed data of runoff and sediment data of year 2010 and 2011 have been done. Initially a simulation run has been conducted using default parameters and saved as a default run. All important parameters affecting runoff and sediment with their lower, upper bound and variation method has been assigned and after writing all input and output files sensitivity run has been conducted. The results of sensitivity analysis provided sensitive parameters and their ranks (Table 6.31). From the analysis of sensitivity simulation, it has been observed that the threshold depth of water in shallow aquifer required for return flow to occur (GWQMN) is very important for runoff, while Manning's N for main channel (CH_N2) is the most important from sediment concentration point of view. The evaporation compensation factor (ESCO), curve number (CN2), surface runoff lag time (SURLAG), linear parameter for sediment retention (SPCON) and management factor (USLE_P) etc. are other important parameters which needed to be adjusted during calibration of model.

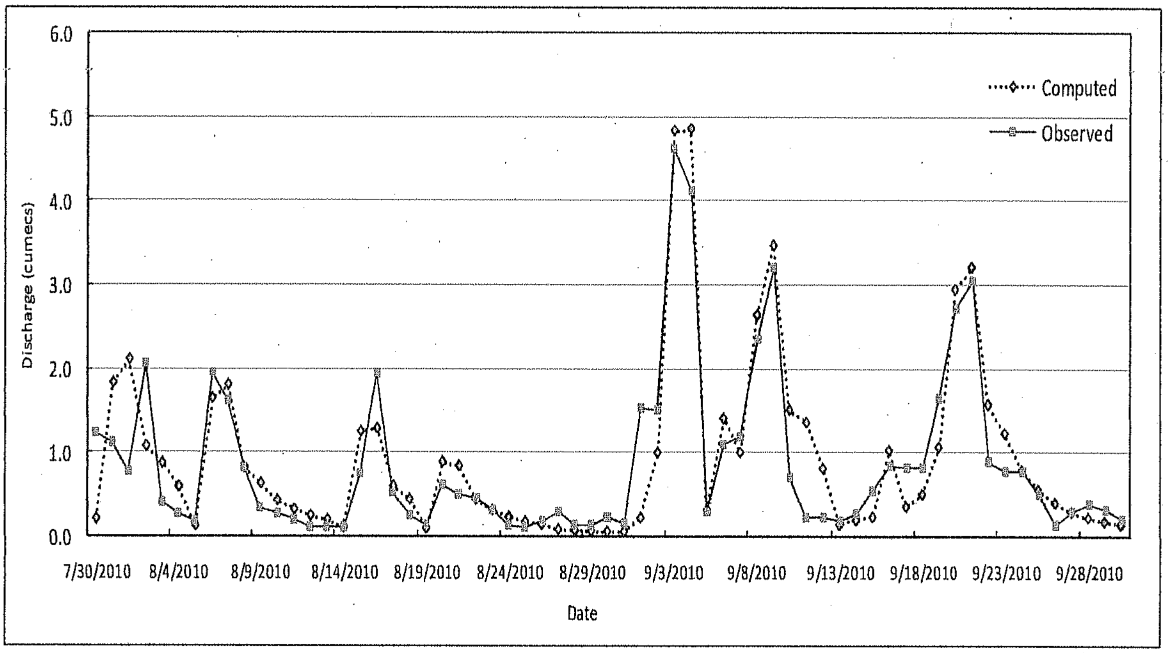
Table 6.30: Data for Weather generator in SWAT model.

Parameter*	Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	Mean	2.3	3.8	9.5	3.1	14.40	121.3	292.4	220.3	120.87	27.4	4.39	2.74
	St. Deviation	0.43	0.91	1.14	0.68	1.60	11.68	20.48	16.23	10.72	3.69	0.73	0.43
	Coeff. of skewness	0.00	2.20	1.72	1.56	2.16	3.31	2.88	2.77	3.14	3.39	1.44	0.55
	PR_W1	0.01	0.03	0.03	0.01	0.04	0.20	0.39	0.38	0.27	0.08	0.02	0.02
	PR_W2	0.09	0.00	0.06	0.08	0.13	0.40	0.59	0.61	0.48	0.22	0.06	0.06
	PCPD	0.53	0.79	1.05	0.53	1.89	8.84	16.79	16.26	10.74	3.58	0.95	0.74
	RAINHHMAX	0.00	0.00	0.00	0.00	0.020	0.12	0.05	0.23	0.12	0.03	0.00	0.00
Minimum temperature	Mean	10.9	13.3	17.2	21.9	25.5	25.2	23.4	23.3	23.2	20.3	14.5	10.7
	St. Deviation	0.72	2.48	1.33	1.30	0.95	1.20	0.18	0.15	0.19	1.79	1.51	0.56
Maximum Temperature	Mean	26.7	29.4	34.2	38.6	40.8	36.1	30.3	29.1	30.2	30.2	28.5	26.7
	St. Deviation	0.61	5.45	1.65	1.06	0.48	3.31	0.74	0.40	0.51	0.63	0.48	0.38
Relative humidity	Mean	59.9	54.2	43.1	33.2	32.2	56.2	78.1	81.8	78.9	71.3	63.2	60.2
	St. Deviation	1.2	10.6	4.9	2.3	1.5	13.4	3.0	1.1	1.9	3.0	2.0	0.8
Wind speed	Mean	0.31	0.61	0.69	1.13	1.60	2.22	2.02	1.45	0.40	0.41	0.39	0.37
	St. Deviation	0.3	0.7	0.4	0.8	0.5	0.9	0.6	1.0	1.4	0.5	0.2	0.2
Sunshine hour	Mean	7.9	8.7	8.9	9.1	8.3	4.4	2.7	2.9	5.5	7.9	8.2	7.8
	St. Deviation	0.4	1.6	0.3	0.4	0.7	1.6	0.5	0.6	1.5	0.6	0.4	0.5

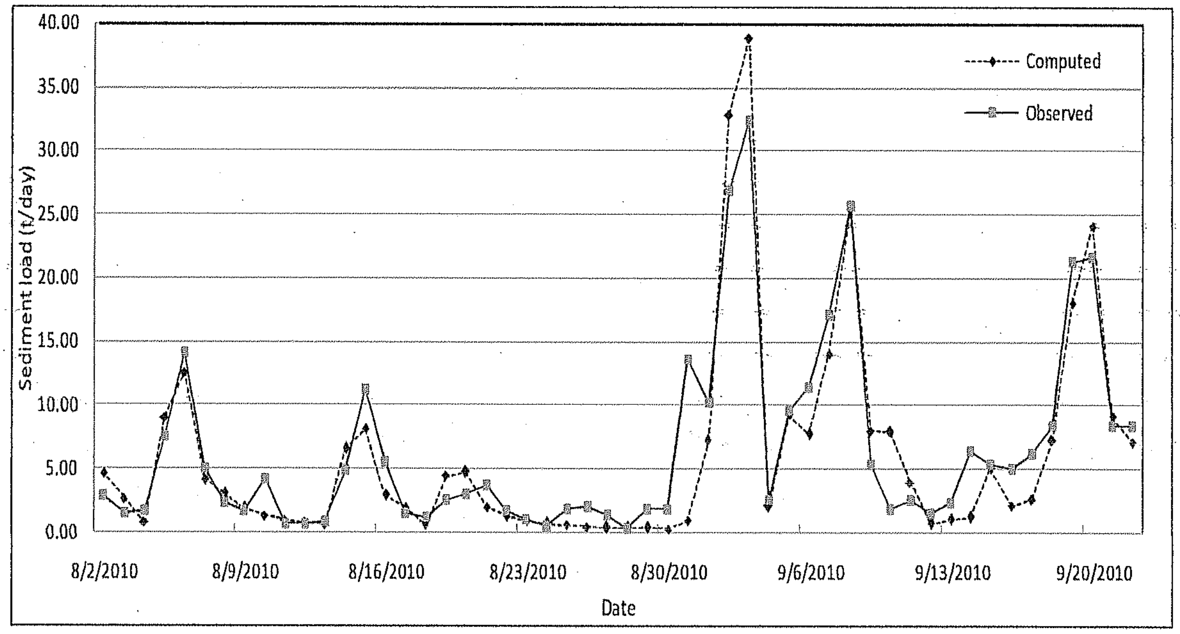
* Description and units of parameters- Rainfall in mm, Temperature in degree centigrade, Relative humidity in %, Wind speed in m/sec, PR_W1 is the probability of a wet day following a dry day, PR_W2 is the probability of a wet day following a wet day, PCPD is the average number of precipitation days, RAINHHMAX is the maximum 0.5 hour rainfall in mm in the month.

Table 6.32: Ranges and final values of SWAT model parameters selected during calibration

S.N.	Parameters	Description	File	Range	Calibrated Value
1	GWQMIN	Threshold depth of water in shallow aquifer required for return flow to occur	.gw	0 to 5000	400
2.	ESCO				
2	CN2	Initial SCS curve number for AMC II	.mgt	35 to 98	Forest – 55 Rice- 65 RNGB-61 Water-92 Urban- 70
4	EPCO	Plant uptake factor	.hru	0 to 1	0.01
5	ALPHA _BF (days)	Base flow Alpha factor 0 to 1	.gw	0 to 1	0.348
6	CH_N2	Manning's N value for main channel	.rte	0.014	-0.01 to 0.3
7	CH_K2	Effective hydraulic conductivity for main channel	.rte	5	-0.01 to 500
8	GW_DELAY(days)	Ground water delay	.gw	0 to 500	1
9	SPCON	Linear parameter for sediment retention	.bsn	0.0001 to 0.01	0.0012
10	SURLAG	Surface runoff lag time	.bsn	1 to 24	1
11	SPEXE	Exponent parameter for sediment retention	.bsn	1 to 1.5	1
12	CH_COV1	Channel erodibility factor	.rte	-0.05 to 0.6	0.2
13	CH_COV2	Channel Cover Factor	.rte	-.001 to 1	0.9
14	USLE_P	Management practice factor for MUSLE model	.mgt	Forest-0.8 Rice-1.0 Range-1.0 URLD-1.0	0 to 1
15	DEEPEST(mm)	Initial depth of water in deep aquifer	.gw	0 o 5000	1000
16	GW_REVAP	Ground water revap co-efficient	.gw	0.02 to .2	0.02
17	REVAPMN(mm)	Threshold depth of water in shallow aquifer to revap to occur	.gw	0 to 500	500
18	RCHRG_DP (friction)	Deep aquifer percolation friction	.gw	0 to 1	0.1
19	Operation parameters for Rice				
	Year	Operation	OP_Num	Heat Unit	Crop
	1	Irrigation	1	0.15	Rice
	1	Plant/being growing	2	0.15	Rice
	1	Auto Fertilizer	3	0.16	Rice
	1	Harvest & kill	4	0.12	Rice
	1	Irrigation	5	0.15	Rice
20	CH_ERODMO	Monthly erodibility factor	.rte	-	0 to 1

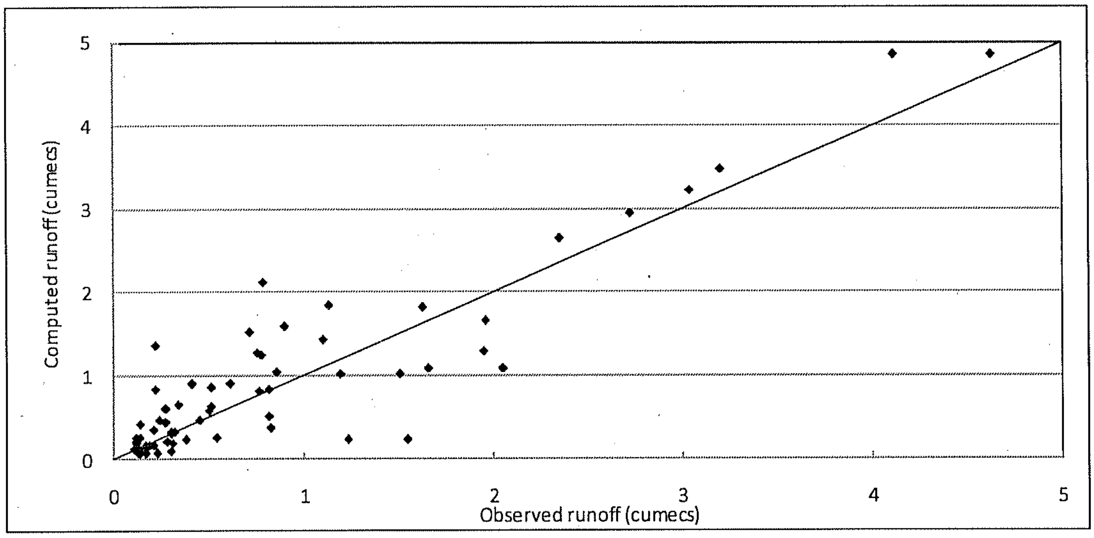


(a) Discharge

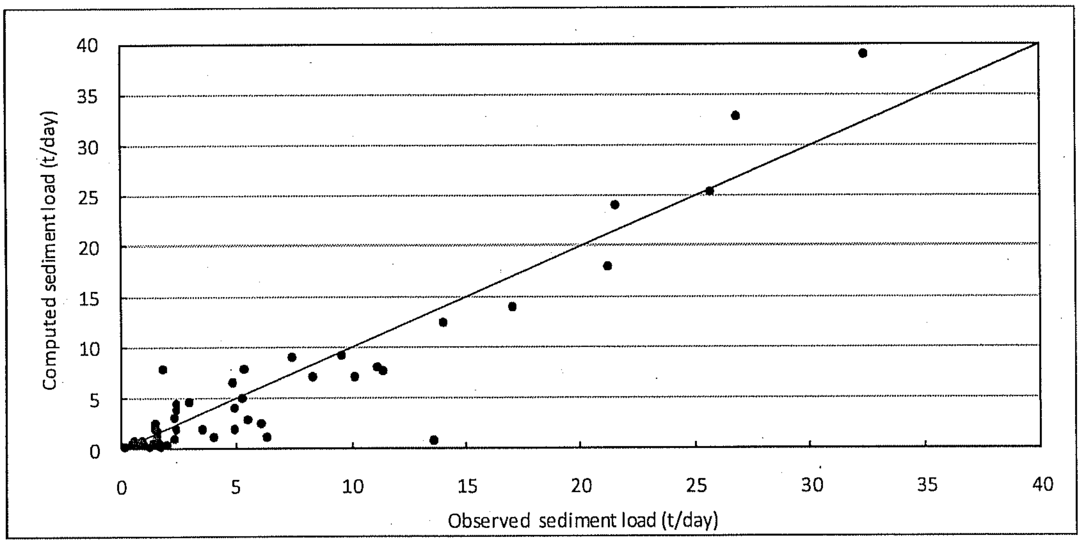


(b) Sediment load

Fig 6.29: Comparison of observed and computed discharge and sediment load at Koma G/D site during calibration.



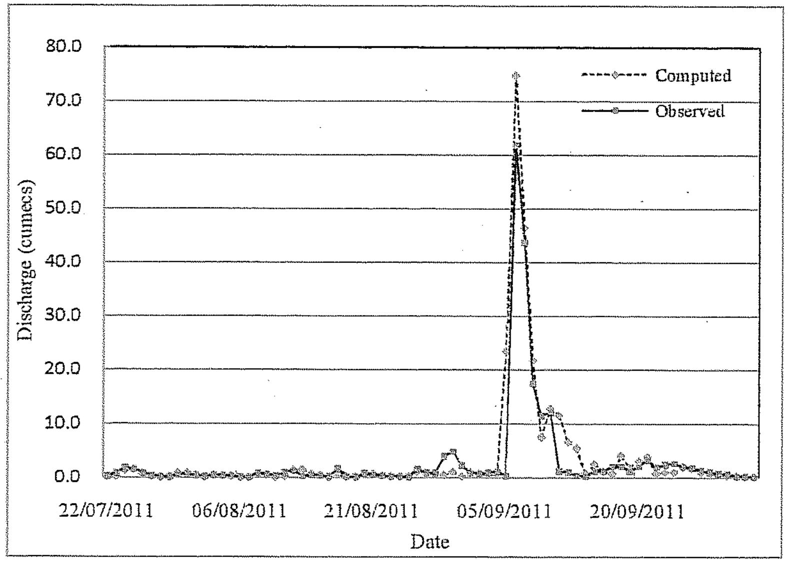
(a) Runoff



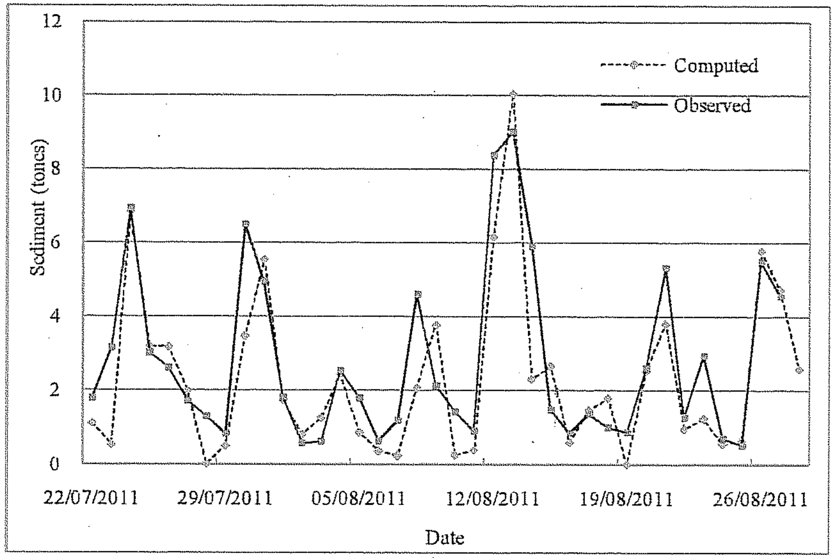
(b) Sediment load

Fig 6.30: Scatter graph between observed and computed discharge and sediment load.

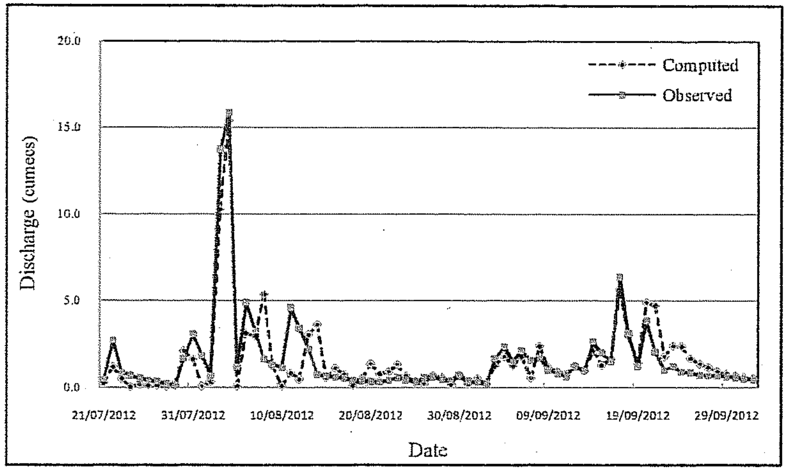
The *RMAE* is a measure indicting how close forecasts or prediction are to be eventual outcomes. The *ISE* is a measure of system performance formed by integrating the square of the system error over a fixed interval of time i.e. smaller the *ISE* closer the match. From the analysis of observed and computed data used in calibration, it has been observed that for runoff, Nash-Suctliff efficiency (η), root mean absolute error (*RMAE*), integral squared error (*ISE*), relative error in peak (*REP*) have been computed as 80.46 %, 0.54, 0.064 and -0.053 respectively. Similarly the fitting of the model was tested with observed sediment load and Nash-Suctliff efficiency (η), root mean absolute error (*RMAE*), integral squared error (*ISE*), relative error in peak (*REP*) were computed as 91.16 %, 2.55, 0.062 and -0.202 respectively. The *ISE*, *RMAE* and



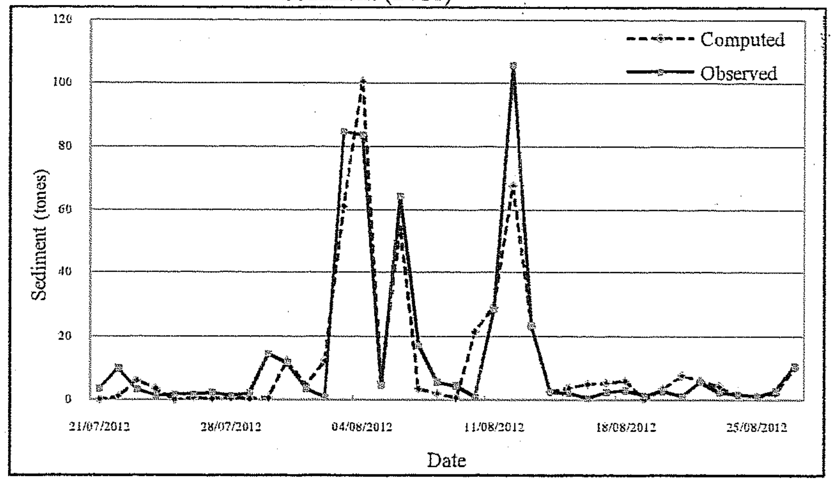
Discharge (2011)



Sediment (2011)



Discharge (2012)



Sediment (2012)

Fig 6.31: Comparison of observed and computed discharge and sediment load at Koma G/D site during validation.

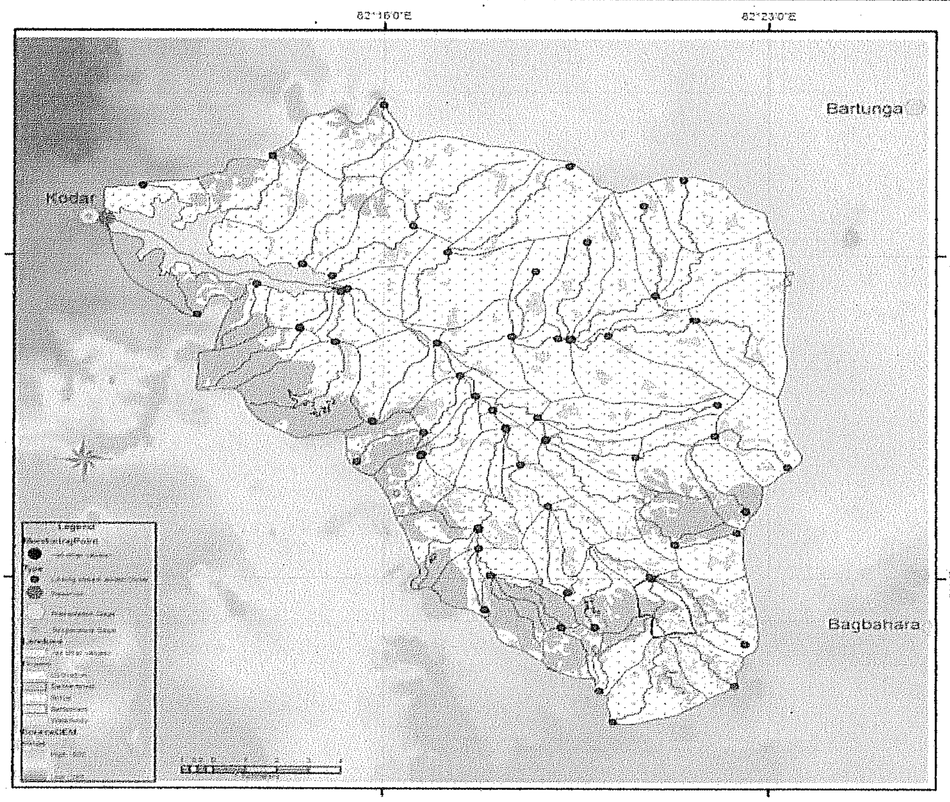


Fig. 6.32: SWAT model setup for Kodar catchment

6.11 Impact Assessment Analysis

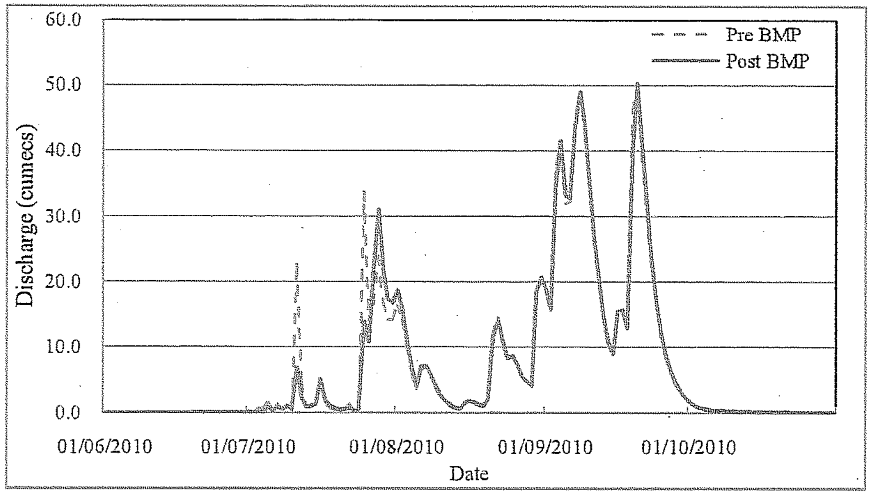
In the study, SWAT model for Kodar reservoir catchment has been set up to analyze the impact of proposed CAT plan on sediment load in the reservoir. In order to assess the impact of best management practices in all suitable areas with the help of agronomic and mechanical conservation measures, two scenarios have been considered in the analysis. In the first scenario, the base line data with no or minimum conservation practices have been considered and this may be called as Pre-BMP scenario. In the second scenario (Post-BMP), the effect of various mechanical, biological and agronomic measures such as gully plug, terraces, stream bank stabilization, conservation structures, afforestation etc applied in different sub-watersheds have been assessed by changing parameters in different files of SWAT model. The values of different parameters for Pre-BMP and Post-BMP scenarios have been presented in Table 6.32. All the modified files after making necessary changes were rewritten and simulation run were made.

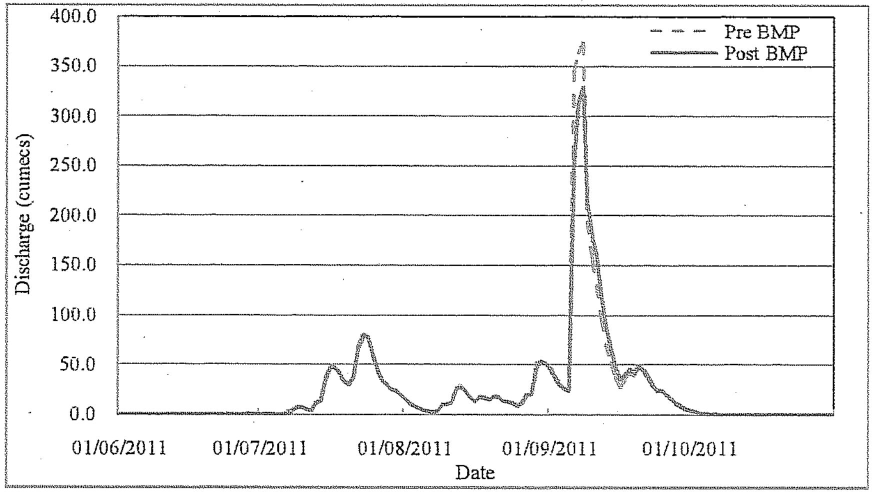
The outputs of Pre-BMP and Post-BMP have been exported to excel and compared to assess the effect of conservation measures. The graphical representation of runoff and sediment concentration for the year 2010 and 2011 for catchment up to Koma G/D site and Kodar catchment in the has been presented in Fig. 6.33 (a) & 6.33 (b) respectively. From the analysis of results, it has been observed that the soil conservation measures and best management practices suggested in Kodar reservoir catchment although produce little impact on runoff but able to reduce sediment load significantly. The monthly rainfall and rate of sediment in monsoon month of year 2010 and 2011 at Koma G/D site and Kodar reservoir catchment have been computed and presented in Fig 6.34.

Table 6.33: Parameters with their values in Pre-BMP and Post-BMP scenarios for Kodar basin.

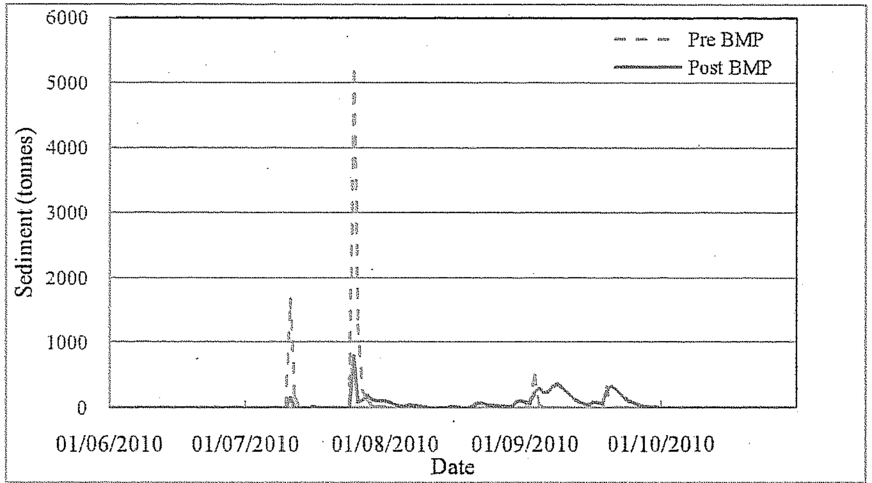
S.N.	Parameters	Description	File	Pre-BMP	Post-BMP
1.	CH_COV1	Channel erodibility factor	.rte	0.09	0.05
2.	CH_COV2	Channel cover factor	.rte	0.45	0.90
3.	CH_EROD	Monthly erodibility factor	.rte	Different values for different months	Reduced by 50%
4.	CH_N1	Manning's N value for tributary channel	.sub	0.09	0.15
5.	CH_K1	Effective hydraulic conductivity	.sub	250	300
6.	CN2	Curve number of SCS model	.mgt	Agriculture-65 Forest-55 Scrub-61 Urban-70	Agriculture-60 Forest-50 Scrub-56 Urban-65
7.	P factor	P-factor of USLE model	.mgt	Agriculture-1.0 Forest-0.80 Scrub-1.0 Urban-1.0	Agriculture-0.80 Forest-0.70 Scrub-0.75 Urban-0.90

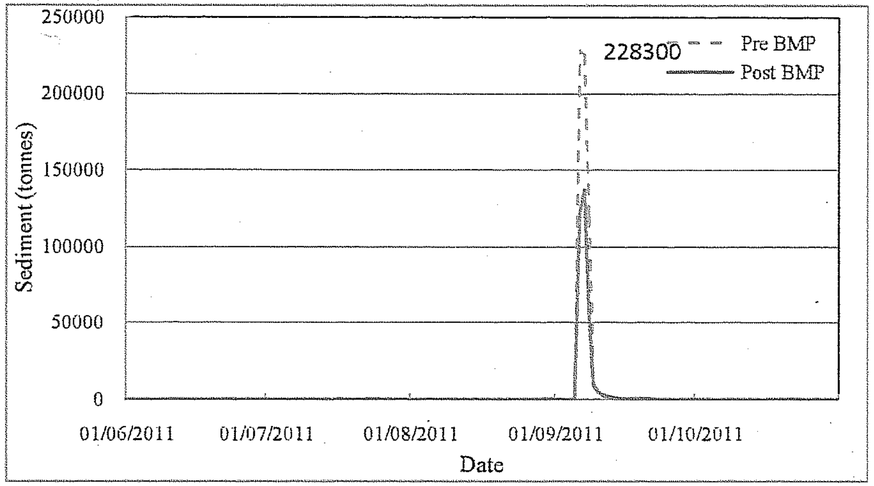
The results indicated that maximum sediment load found in the month of Sept 2011 which was 2.97 t/ha under monthly rainfall of 743 mm for Kodar reservoir catchment. If suitable soil conservation measures and BMP applied in the catchment, the sediment entry in the reservoir can be reduced to 1.63 t/ha under same rainfall condition. The sediment rate is more in Koma G/D catchment may be due to hilly region and less plain areas for deposition. The rate of sediment concentration depends mainly on rainfall amount, crop cover and soil condition etc. The BMP and CAT plan have little impact on runoff pattern from the catchments of Koma and Kodar reservoir, but able to reduce significantly the sediment transported through channels which otherwise deposited in Kodar reservoir if no measures were taken.





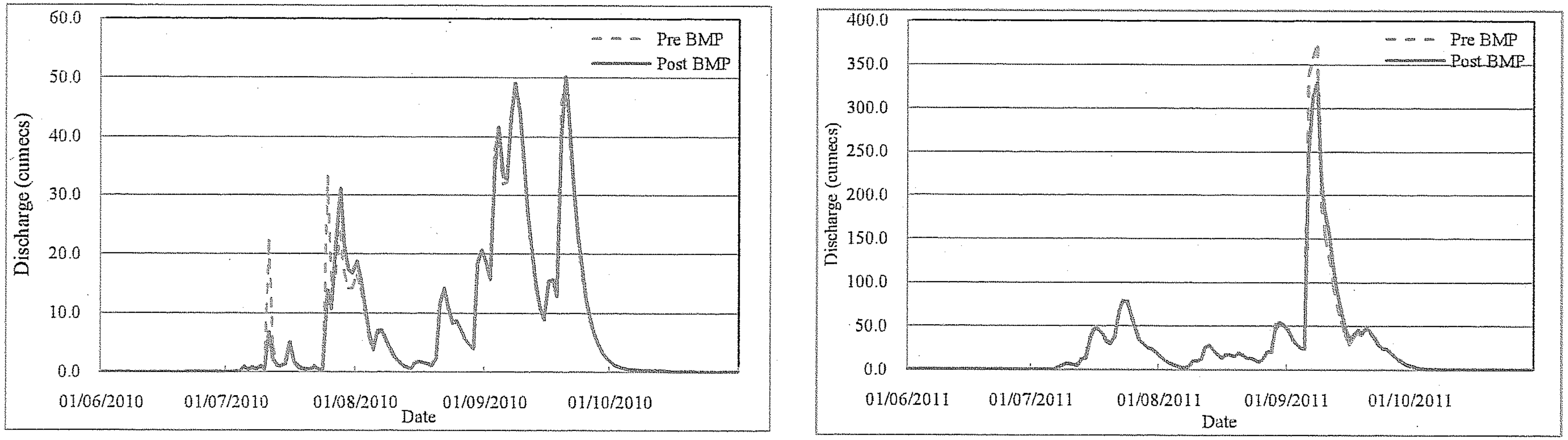
Comparison of Runoff



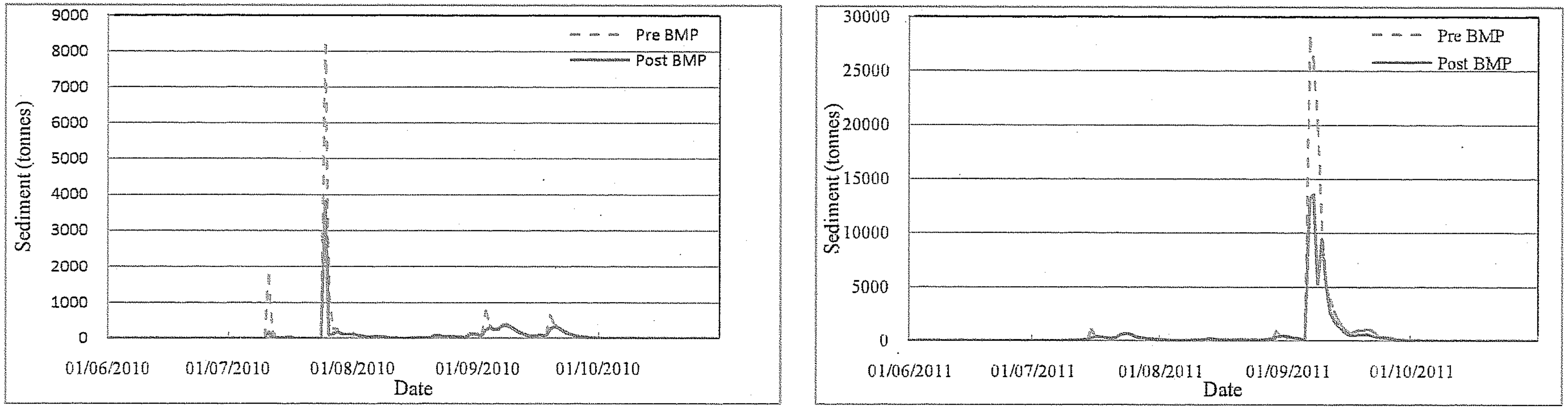


Comparison of sediment

Fig.6.33 (a): Impact of soil and water conservation measures on runoff and sediment yield (Pre BMP and Post BMP) up to Koma G/D site

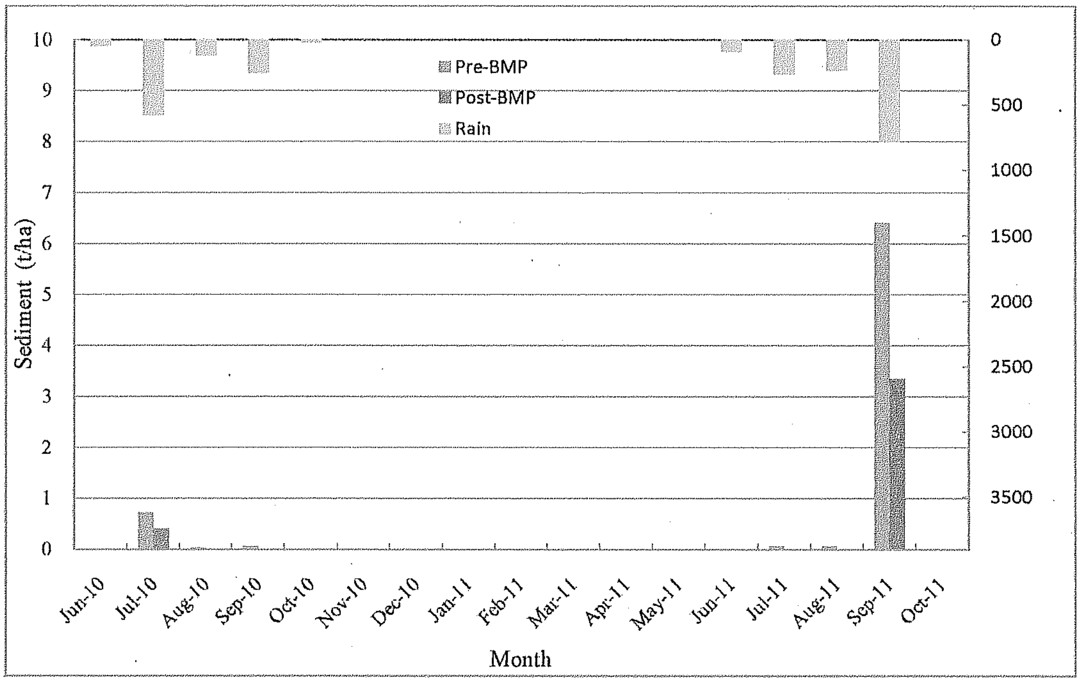


Comparison of Runoff

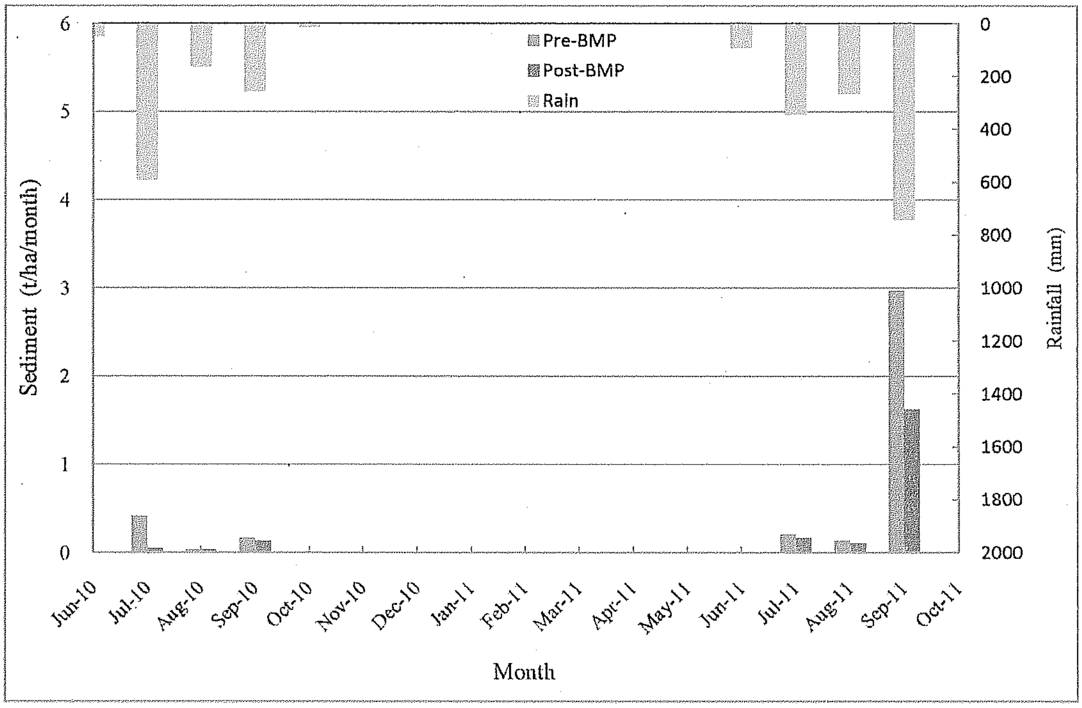


Comparison of Sediment

Fig. 6.33 (b): Impact of soil and water conservation measures on runoff and sediment yield (Pre BMP and Post BMP) for Kodar catchment



Monthly sediment load from Koma G/D site



Monthly sediment load from Kodar reservoir catchment

Fig. 6.34: Bar chart showing monthly sediment load in t/ha/month from Koma G/D site and Kodar reservoir catchment (Pre & Post-BMP)

CHAPTER 7.0- CONCLUSIONS AND RECOMMENDATION

The PDS under HP II has been undertaken to address reservoir sedimentation and soil erosion, development of integrated catchment area treatment plan with agronomic, biological and mechanical measures and development of model for measurement of sediment concentration. The soil erosion and sediment transport is spatial phenomena varies with space and time require inputs that vary with space and therefore a GIS database of study area has been developed which will be useful for further monitoring and implementation of conservation measures. The GIS base for the study consist of preparation and generation of various thematic maps including catchment and sub-watershed map, drainage, soil, geology, geomorphology, contour, DEM, villages etc. The Kodar dam has been constructed on river Kurar near Kowajhar village in Mahasamund district. The river Kurar is the fifth order stream as per Strahler's classification system. More than 96 of area in Kodar reservoir catchment is covered by granite and groundwater availability in these rocks are confined with faults and lineaments only. The piedmont slope and pediplane are the main geomorphological features found in the catchment which are susceptive higher rate of erosion. The soils in the study area are slightly deep to deep, well drained loamy soil and mixed loamy soil subjected to moderate to severe erosion. The elevation ranges from 280 m to 570 m. The general topography of the area consists of undulating plains, hilly track and localized valleys

7.1 Conclusions

Various meteorological and hydrological data for the PDS have been collected and runoff data and sediment samples at Koma G/D site were monitored. The thiesen polygon of the study area suggested that Kodar, Bagbahara and Bartunga RG stations have impact on Kodar reservoir catchment and weights of these stations were computed as 0.50, 0.42 and 0.08 respectively. The rainfall in the study area concentrated mainly in the month of July, August and September. The mean monthly maximum temperature in the study area varies from 44.2 ^{0}C in the month of May to 24.1 ^{0}C in January. Similarly, mean monthly minimum temperature ranges from 8.4^{0}C in the month of January to 28.6 ^{0}C in the month of June.

The assessment of revised capacity and distribution of sedimentation in the reservoir are important aspects for proper reservoir operation and to know the environmental status of necessity of CAT plan in the catchment. Eight LISS III images of different dates covering the whole range of live storage in Kodar reservoir have been used in the analysis. For estimation of revised capacities at different levels of Kodar reservoir, *NDWI*, *NDVI* and band ratio (*BR*) followed by slicing methods of image classification has been used to differentiate the water pixels from other land uses. The revised capacities between the levels and cumulative revised capacities at different levels have been computed and compared with original capacities to estimate the loss in storages. The sedimentation analysis of Kodar reservoir indicated that 24.94 Mm^3 of gross storages and 4.89 Mm^3 of dead storage have been lost in 32 years (1976-77 to 2008-09). Considering the uniform loss in the storages, it can be concluded that 0.78 Mm^3 of gross storage and 0.15 Mm3 of dead storage of Kodar reservoir have been lost each year with average rate of siltation as 0.25 Mm^3/100 km^2/year.

The land use analysis of Kodar reservoir catchment has been carried out with the help of digital image analysis of LISS IV imageries of pre and post monsoon period. The supervised quoted in literature (Kumar, 1985, Rao & Mahabaleswara, 1990) has been used. From the analysis of sediment yield, it has been observed that minimum sediment yield from sub-watershed SW-27 is 0.00 $Mm^3/km^2/yr$, while sub-watershed SW-32 produces maximum sediment yield which is 0.244 $Mm^3/km^2/yr$ which is maximum among all the sub-watersheds in Kodar catchment. The STI used in the priority analysis varies from 0.01 (Sw-13) to 22.82 (SW-44) indicated wide variation in transport characteristics. The average slope in the sub-watersheds of Kodar catchment ranges from 0.00 % in SW-27 to 11.63 % in SW-44.

The value of principal eigen value (λ_{max}) and consistency index (*CI*) in Saaty's AHP analysis have been estimated as 10.08 and 0.135 respectively. The consistency ratio for the present decisions has been computed as 9.3 %, which is less than 10 which implies that the decisions regarding comparative importance between the EHPs are acceptable. The soil loss (*SL*) has maximum weight as 0.33, while circulatory ratio (R_c) with weight of 0.02 exhibits the least importance in prioritization decision and in absence of other data soil loss can be used the criteria for prioritization. The AHP analysis suggested that more than 21 sub-watersheds covering 117 sq. km area of Kodar reservoir catchment falls under very high and high priority and a scientifically developed CAT plan consisting mechanical, biological and agronomic measures should be implemented immediately in these sub-watersheds. The results of analysis indicated that the sub-watersheds under very high and high priority are either on higher slope from where soil erosion are more or near the reservoir from where eroded material easily transported to the reservoir through dense network of drainage.

For development of CAT plan for environmentally stressed areas in Kodar reservoir various thematic layers such as geology, land use, soil, slope, drainage, geomorphology have been used for selection of soil and water conservation measures in sub-watersheds of Kodar reservoir catchments. It may be concluded that nearly 41 sq. km area in Kodar catchment is suitable for farm ponds. The CAT plan suggests 101.61 ha land can be used for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land which will be beneficial for rural population for their additional income and environmental health of the watershed. The mechanical measure under the CAT Plan of Kodar reservoir catchment includes 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams. Gram panchayats break up of agronomic, biological and mechanical measures have been provided in the study will be useful for administrative authority to take up these measures systematically. The design of check dams provided in the report will be helpful for implementing agencies for cost estimation and construction.

In the present study, ARC GIS based SWAT model has been applied for Kodar catchment up to Koma G/D site where discharge measurement and sediment sample collection were done for the year 2010 to 2012. The sensitivity analysis has been carried out to identify the important parameters and it may be concluded that the *GWQMN* (threshold depth of water in shallow aquifer required for return flow to occur) and *CH_N2* (Manning's N value for main channel) are the most important parameters for runoff and sediment modeling respectively. For calibration of SWAT model, the rainfall of Bagbahara RG station, runoff and sediment concentration at Koma GD site for the year 2010 have been used. The Nash-Suctliff efficiency (η) and root mean absolute error (*RMAE*) have been found as 80.46 % and 0.54 for runoff while the same have been computed as 91.16 % and 2.55 for sediment. The results of calibration indicated a reasonably for reducing the entry of silt load in reservoirs. It has also been felt that the monitoring of sediment in Kodar catchment should be continued for improvement of model and impact assessment analysis, if CAT plan is implemented. Water Resources Department, Govt. of Chhattisgarh has decided to implement the CAT plan suggested under this study through different rural employment guarantee schemes.

7.3 Recommendations

During the PDS expeditions, deliberation and discussions with technocrats and stakeholders, the following recommendations have been finalized.

- Regular assessment of revised capacities of reservoirs in the state (Bathymetric survey-15 years, RS &GIS-5 years).
- Identification of hot spot and development of CAT plan for project during design stage.
- The soil loss and slope can be considered the most suitable parameters for identification of environmentally stressed areas in the catchment
- Sediment sampling in Kodar catchment should be continued for strengthening of modal and few more sites should be started in other major rivers of state.
- Rural development, Agriculture, Gram Panchayats and other implementing agencies can use site specific recommendation for soil and water conservation structure suggested for Kodar reservoir catchment.
- CAT plan with scientific inputs should be developed and implemented for other water resources projects in the state with close coordination of scientific organizations, local population and implementing agencies.
- Development of rainfall-runoff-sediment model for impact assessment of applied CAT plan/environment degradation
- Replication of study in other water resources project
- Dissemination of knowledge through various means and development of awareness in rural population.
- Involvement of stakeholders in spreading the massage of soil and water conservation and awareness of application of agronomic measures in agriculture fields.

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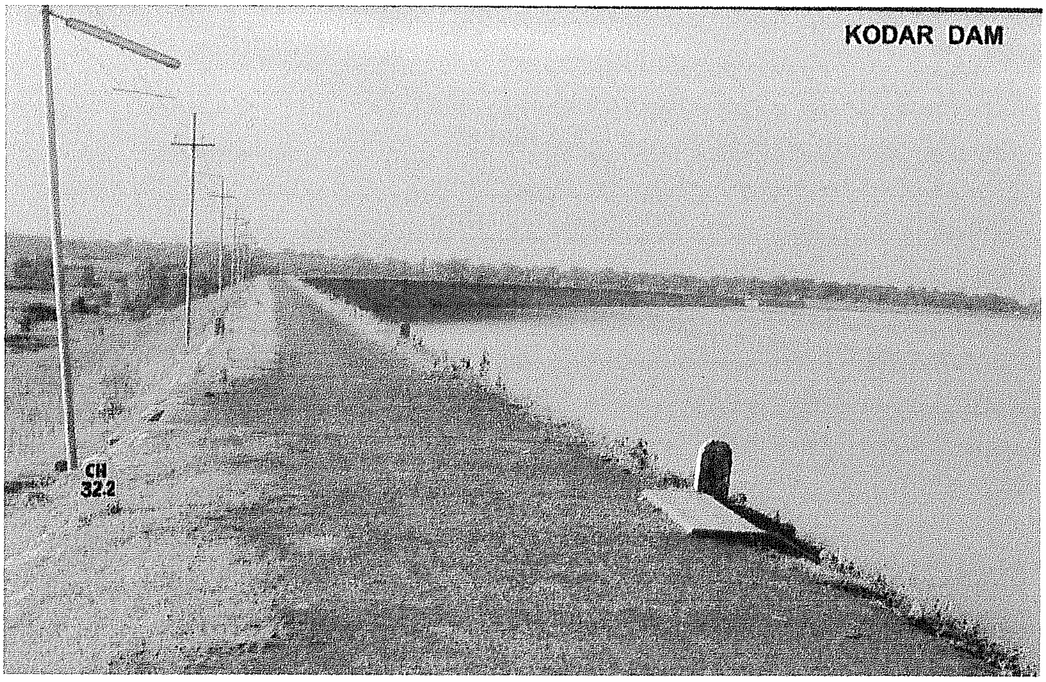
PDS Study Group

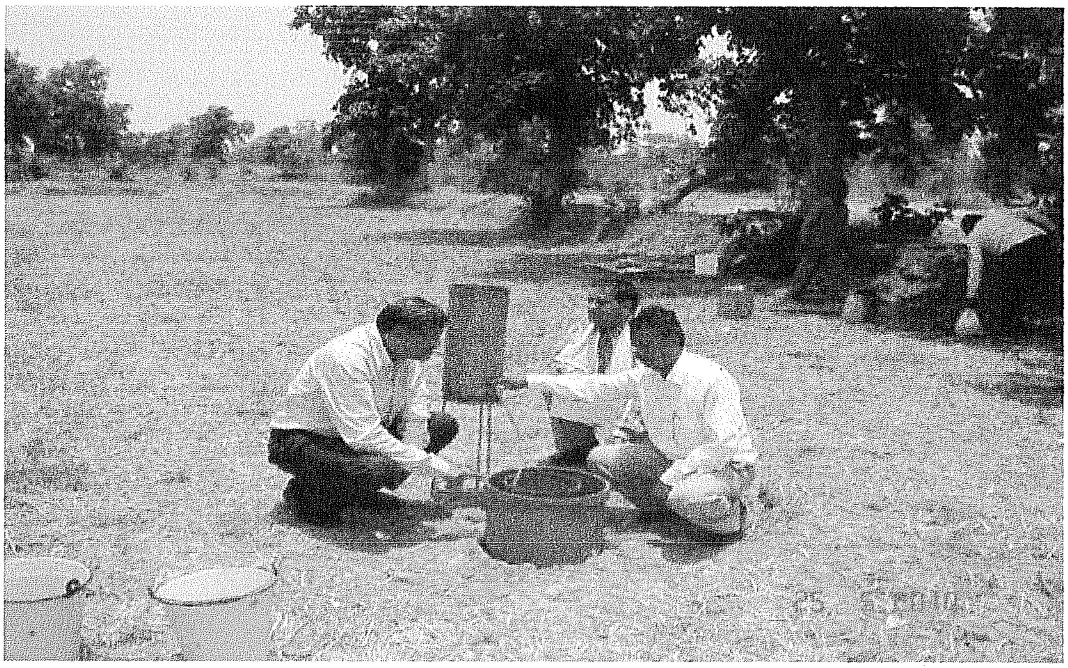
PHOTOGRAPHS



Pictorial view of Kodar Reservoir

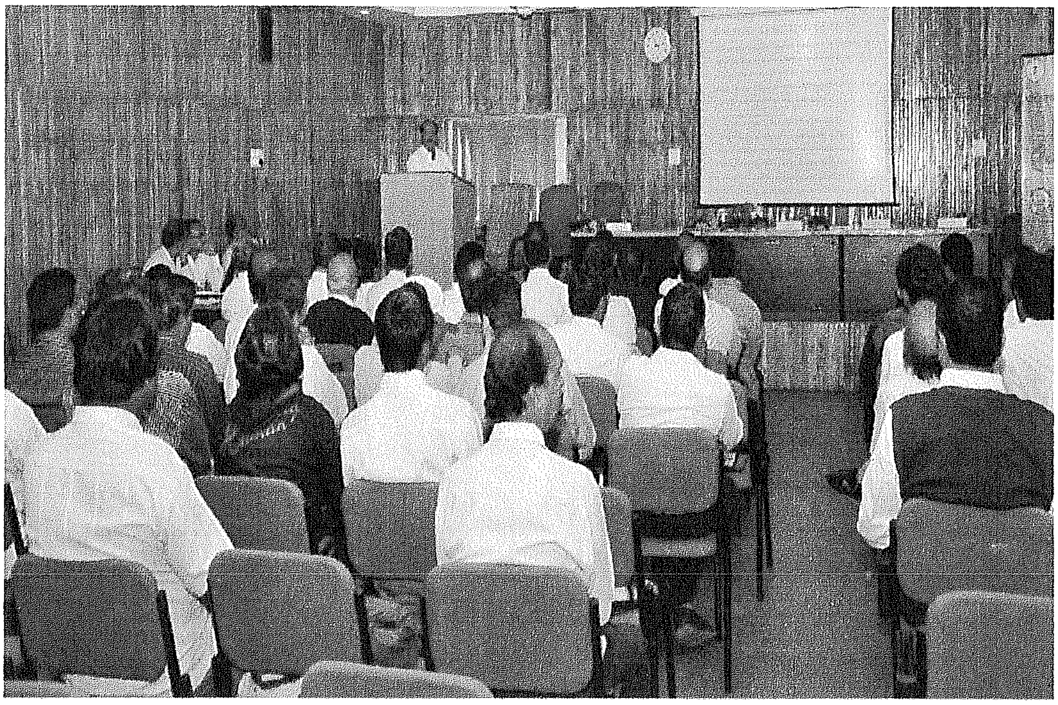
Kodar Main canal

Field discussion of officers for works under PDS



Soil testing in the field

A view of gathering during PDS workshop on Dec 09, 2011 at Raipur

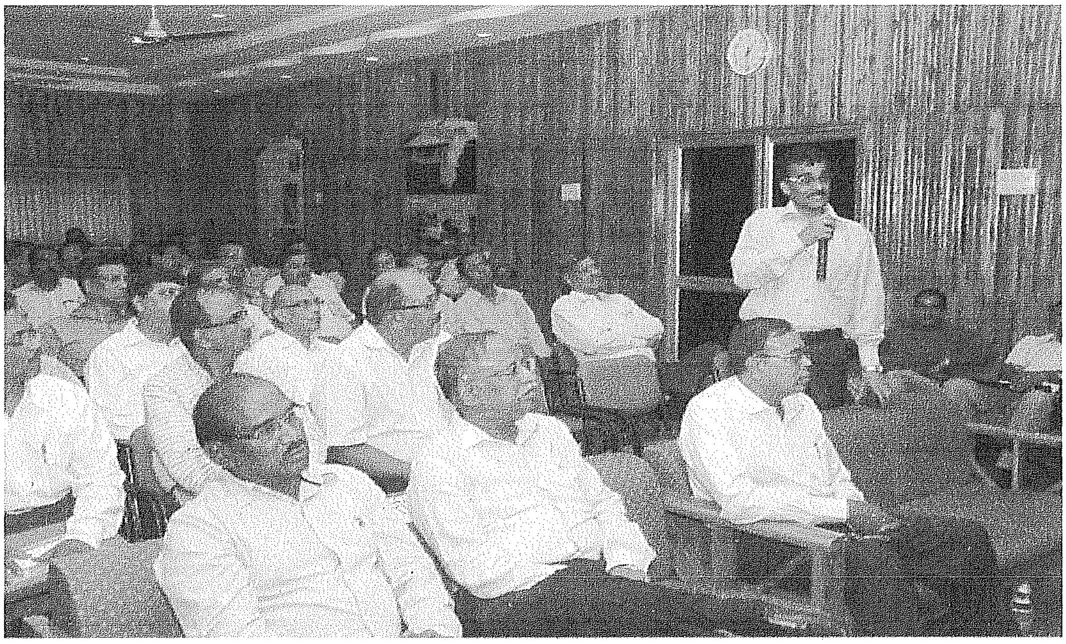


Presentation during PDS workshop on Dec 09, 2011

Inauguration of PDS workshop on June 28, 2013 at Raipur

Presentation on PDS deliverables during PDS workshop on June 28, 2013

An interactive session during PDS workshop on June 28, 2013



Feedback session during PDS workshop on June 28, 2013

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