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A Comprehensive Watershed Management Plan for a Degraded Watershed in Bundelkhand Region of Madhya Pradesh

FINAL REPORT
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PREFACE

From the margins of rural development practice and a limited focus on soil and water conservation, the concept of integrated watershed management has today emerged as the cornerstone of development in the dry and semi-arid region of India. The natural ecosystems are highly complex systems governed by both biotic and abiotic factors and have a high resilience for stability and regeneration. However, continued interference and relentless pressures on utilization of resources has led to an upset of this balance and if these issues are not addressed effectively and adequately in a holistic manner, will lead to major environmental problems such as depletion of vegetative cover, increase in soil erosion, decline in water table, and loss of biodiversity, all of which directly impact the our survival. Thus watershed development and efficient water management are the key to the sustainable development of our country. A watershed perspective looks at the whole landscape to address natural issues and offers an excellent scope for the assessment and management of the environmental problems like dwindling fresh water supplies, desertification and ecosystem impairment which are often the result of complex processes that require system-based thinking. A watershed plan does not need to offer all the answers, but it can lay out a long-term process towards finding answers and improving solutions. Watershed planning needs to be fully integrated with other planning and regulatory programs and the plan must establish a vision and context for the entire watershed.

The Bundelkhand region of Central India is extremely undulating terrain comprising of rocky outcrops and boulder-strewn plains with rugged looking landscape and ravine lands resulting from the active erosion of the unconsolidated alluvial material. The degradation of the dense forest cover on the ridges have resulted in massive loss of topsoil. Tumri watershed in Kesli block of Sagar district in Madhya Pradesh has been selected as a model watershed, for development of a comprehensive management plan. Much of the watershed suffers from acute ecological degradation due to deforestation resulting in massive loss of top soil and low water retentivity leading to low productivity and increased barren lands. This report is the culmination of three year field-oriented activities and regular interaction with the various decision makers and stakeholders involved and includes the preparation of watershed inventory as well as the data generation on hydrology, hydrometeorology, soil and land use, as no information pertaining to any of these aspects were being monitored in the watershed. Intensive field investigations were carried out to evaluate the hydrologic soil properties, land use pattern, topography, for instrumentation of raingauges, discharge measurement sites and location of sites for water storage structures.

The various components of significance analyzed during the course of the study include water budgeting, land capability classification, soil erosion, assessment of irrigation water requirement, watershed prioritization, rainfall-runoff modeling, and development of GIUH based flood hydrographs, identification of water storage sites, selection of zones for artificial recharge and development of an alternative land use plan. The management strategies including site specific soil and water conservation measures have been suggested and the revised irrigation water requirements based on the suggested land use plan evaluated. The impact assessment analysis of the conservation measures and management strategies have been carried out to asses the impacts on the soil erosion and water resources scenario of the watershed under suggested management plan and conservation practices. The study has been carried out by Sri T. Thomas, Scientist-B, Sri R. K. Jaiswal, Scientist-B, Sri R.V. Galkate, Scientist-C and Dr. S. Singh, Scientist-C under the able guidance of Dr. N.C. Ghosh, Scientist-F, Coordinator & Head, Regional Centre, Sagar.

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ABSTRACT

The challenge of managing environments becomes more complex as populations expand, various demands on natural resources increase and new technologies are developed, that knowingly or unknowingly destroy the environment. The restoration and maintenance of the physical, chemical and biological integrity of the environments require decision making that balance human and natural systems. Watershed management is increasingly being recognized by policy makers, resource managers, and communities as an effective way to achieve multiple goals substantially. The goal of watershed management is to plan and work towards an environmentally and economically healthy watershed that benefits all the stakeholders. Problem solving is a vital part of the watershed management, wherein a particular issue is addressed within the scope of wider landscape and ecosystem connections, in search for appropriate solutions. Watershed management planning and its proper implementation help in uplifting the socio-economic condition of habitants and upgrade the preservation of environmental regime. Watershed management program aims at integrated development since each sector of watershed is inter-linked with the other. While hydrology is an essential component, the land productivity is an equally important integral part of the watershed management process. Thus watershed management deals not only with the protection of the water resources but also with the capability and suitability of land and vegetative resources to be managed for the sustainable development.

The watershed analysis includes water budgeting studies, land capability classification, soil loss estimation, assessment of irrigation water requirement, watershed modeling, watershed prioritization, development of flood hydrographs using GIUH techniques, identification of sites for storage structures, selection of zones for artificial recharge, development of an alternative land use plan, irrigation water requirement for changed land use plan, suggestions for site specific soil and water conservation measures and assessment of its impact on the soil erosion and runoff processes in the watershed. The water budgeting of Tumri watershed reveals that rainfall is the major inflow component whereas surface runoff is the major outflow component and about 8.05 MCM water flows through the streams in a normal rainfall year which can be tapped at suitable

sites within the watershed so as to provide the much required irrigation water. The land capability classification has helped to identify land capability classes II to VII in the watershed and the capability classes II to IV are suited for agriculture whereas classes V to VII are not suited for agriculture.

Effective control of soil erosion requires an ability to predict the amount of soil loss, which would occur under alternate management strategies and practices. The Universal Soil Loss Equation (USLE) model has been applied to estimate soil loss from the watershed. The average soil loss from the watershed is 14.60 t/ha/ under the present land use and no conservation practices. Sensitivity analysis indicates that treatment measures on the agricultural land alone would reduce the rate of soil erosion from the current 14.60 t/ha/year to 11.52 t/ha/year. The irrigation water requirement of different crops in the watershed has been computed for the present cropping pattern and the gross irrigation water requirement during kharrif and rabi season is 1.058 and 5.169 MCM respectively.

Runoff is one of the important hydrologic variables used in most of the water resources applications. The SCS-CN model has been applied for gauged Nala sub-watershed and Tumri watershed and is able to simulate the flows with an efficiency of 80% and 93% in 2007-08 and 2008-09 respectively. The SCS-CN model has also been applied to the ungauged Tumri watershed and the seasonal surface runoff is estimated to be 8.05 MCM, 2.49 MCM and 7.23 MCM for the 2006-07 to 2008-09. The model can be used to estimate the surface runoff in future years on the basis of the observed daily rainfall in the watershed which can be used for planning of development of new water resources projects in the watershed.

Before taking up any watershed management program, first question arises that which area should be treated first and watershed prioritization helps to identify the stressed areas of watershed where immediate measures are required. The watershed has been divided into 19 sub-watersheds for prioritization and SW-8, SW-9, SW-11, SW-15, SW-16, SW-18 and SW-19 have been identified as the very-high and high priority watersheds and conservation measures should be initiated in these sub-watersheds immediately on a priority basis followed by treatment measures on moderate and low priority sub-watersheds. GIUH based Clark model have been used for the development of flood hydrographs for few storms in gauged Nala sub-watershed and ungauged Tumri watershed which will be useful for estimation of design flood in watershed. The parameters of the Clark model have been computed using geomorphological characteristics of the basin. The RMSE between the observed and computed flood hydrographs for few storm events varies between 0.11 to 1.83 for Nala sub-watershed.

The rugged topography and the location of the Tumri watershed in the upstream reaches of river Sonar limits the construction of medium or major water resources projects and as such small water storage structures are feasible for such terrain which require less investment and do not require clearances from various agencies. Seven well distributed sites have been identified in the watershed to create small water storage structures based on certain decision rules. The salient features of all the storage schemes including the elevation-area and elevation capacity curves have also been provided alongwith the priority analysis of these structures. Zones favorable for artificial recharge have also been demarcated after the analysis based on slope, land use, water table fluctuation, hydro geomorphologic characteristics. The analysis helps to identify 33.08 hectare as the most suitable zones for artificial recharge and various direct and indirect techniques of artificial recharge can be employed here.

Based on the best possible use and limitations of the land, an alternative land use plan has been developed for the watershed to take care of the various demands of the watershed community. Thrust has been given to increase the agricultural area based on suitability of land and availability of additional water in the storage structures. The barren and degraded lands may be used for developing grazing lands and agroforestry; and plantations may be encouraged in open forests to slowly convert them into dense forests with good canopy which will reduce the soil erosion to a great extent. Various area specific soil conservation measures including agronomic, mechanical, chemical and biological measures have been suggested for agricultural lands, grazing lands, agroforestry lands and forests. Similarly water conservation measures have been recommended separately for agricultural lands and forests.

The revised irrigation water requirements have been estimated based on the suggested land use plan for the watershed and the gross irrigation water requirement for crops is expected to increase from 1.056 MCM to 1.788 MCM in kharrif season whereas 6.533 MCM water is required for irrigation instead of 5.619 MCM in rabi season. The irrigation scheduling plan can be worked out on the basis of the computed ten-daily water requirements. The impact assessment analysis of the conservation measures and management strategies have been carried out to asses the impacts on soil erosion and water resources scenario in the watershed. The analysis indicates that the reduction in seasonal surface runoff varies between 16.1% and 54.6% whereas the soil loss from the watershed may reduce considerably to 1.33 t/ha/yr, if the suggested land use plan and recommended soil and water conservation measures are adopted in Tumri watershed. The study has tried to touch upon all the important elements responsible for various processes and a comprehensive plan has been prepared for the watershed which if implemented effectively can definitely arrest the ecological degradation and improve the overall health of the watershed and living conditions of the local inhabitants.

1.0 INTRODUCTION

Rainfed agriculture in India's semi-arid regions is characterized by low productivity, degraded natural resources, and widespread poverty. Most people living in these regions depend on agriculture and natural resource management for their livelihoods for which land and water resources development is imperative. The development aspect and the environment are interlinked and certain types of development produce negative impacts on the environment and primary productivity. The deterioration of the environment increases poverty and reduces the standard of living. The degradation of the environment is basically attributable to the increasing biotic pressure on the fragile eco-systems in the absence of adequate investments and appropriate management practices to augment and conserve the land and water resources. The need is for matching the available natural resources on one hand and needs of the people and maintenance of the ecosystem productivity in the region. Such a balancing act can be carried out at micro-levels such as on a watershed scale.

A watershed is a natural geo-hydrological unit of land, which collects water and drains it through a common point by a system of streams. It is a small catchment comprising of command area, recharge zone and a discharge zone. It is catchment whose surface characteristics, soil depth, geological structure topography and climate play an inter-related role in the determination of behavior of water, which flows over or through it. Rainfall carves out each watershed differently depending on the geology and structure and therefore each watershed develops a typical hydro-geomorphology. As the watersheds are bounded by water divides, the quantification and management of water resources is possible which is basic to the development of soil and vegetation. A watershed provides a limited surface area within which physical processes pertinent to the morphology and hydrology can be studies. The climatic variables, the water and sediment discharge, water storage and evapotranspiration of a watershed can be determined, which helps in the management of land, water, greenery and energy. A watershed approach is a flexible framework for managing water resource quantity and quality within watersheds. This approach includes stakeholder involvement and management actions supported by sound science and appropriate technology.

Watershed management deals with a wide spectrum of programs, and practices aimed at the production and protection of water supply and water based resources including the control of erosion, floods and the protection of aesthetic values associated with water in a drainage basin. Enhancement of area under cultivation and ecological balance is aimed to be restored, stabilization of degraded land prone to various forms of erosion, reduction in pollution abatement due to decrease in sediment in streams and reservoirs are also prime motive of watershed management. Sub-surface recharge results in increasing productivity of land. Watershed management planning and its proper implementation help in uplifting the socio-economic condition of habitants and upgrade the environmental regime preservation. In management practices man can do a little to change most of the characteristics of watershed surface cover and upto some extent the soil and slope can be manipulated to achieve desired change in hydrology of basin.. While hydrology is an essential component of the watershed management, the land productivity is also its important integral part. Thus watershed management deals with not only the protection of the water resources but also with the capability and suitability of land and vegetative resources to be managed for the sustainable development.

Planning and development of watersheds call for rigorous understanding about the occurrence and movement of water in the surface and sub-surface systems along with soil and nutrient losses in a small watershed. The watershed planning process works by using a series of cooperative, iterative steps to characterize existing conditions, identify and prioritize problems, define management objectives, develop protection or remediation strategies, and implement and adapt necessary actions. The outcomes of this process are documented or referenced in a watershed plan. A watershed plan is a strategy that provides assessment and management information for a geographically defined watershed, including the analyses, actions, participants, and resources related to developing and implementing the plan. Although each watershed plan emphasizes different issues and reflects unique goals and management strategies, some common features are included in every watershed planning process. The watershed planning process is iterative, holistic, geographically defined, integrated, and collaborative.

The goal of the watershed plan is the conservation of natural resources within the watershed in an integrated manner in which human needs are met in balance with the need to sustain the natural environment. The watershed plan is generally based on the principles of ecosystem approach, which considers the interconnection of the environment as the fundamental principle of watershed planning; *protection* of water systems wherein all land use and natural resource management activities recognize watershed systems such as streams, watercourses, groundwater, and lakes as natural features and attempts to protect natural functions of these systems and also to restore the functional character of ecosystems that have been degraded by previous land use activity; proactive resource management in which cost effective proactive management of natural resources is emphasized over cost intensive reactive management.

2.0 OBJECTIVES

1. Generation of database on hydro-meteorological, hydrological, soil, and process related parameters at watershed level and preparation of inventory.
2. Water budgeting studies for identifying and quantifying important components of the hydrological cycle in respect of the watershed.
3. Land capability classification and watershed prioritization for identification of vulnerable areas for conservation measures.
4. Watershed modelling for land and water management at watershed scale for estimation of runoff and sediment yield.
5. Identification of site specific soil and water conservation measures for improving the overall health of the watershed.
6. Impact assessment of proposed soil and water conservation/management practices on the hydrology of the watershed.

3.0 STUDY AREA

3.1 General

The Bundelkhand region is highly undulating with rocky outcrops and boulder-strewn plains with a rugged looking landscape. The region is characterized by rolling hills and fertile valleys in the northern part, which slopes down towards the Indo-Gangetic plains to the north. Spectacular ravine lands in the north and deep gorges in the south result from the active erosion of the unconsolidated alluvial material deposited by the main streams in the region, namely the Betwa, Dhasan and the Ken. These ravines and gorges are uncultivable and pose an increasing threat to nearby farmland as they continue to expand rapidly. Many important rivers have their origination here and the monsoon brings heavy flooding in most of the rivers whereas tributaries often become dry and the flow in the major rivers dwindles during the dry season.

Granites are the predominant rock formations in the Bundelkhand region and are of lower pre-Cambrian/Archaean period. Dharwarian, Vindhyan rocks, sandstone, shales and limestone of high quality, along with dykes, sills and the famous pink Archaean gneiss rocks, are also found at few places. In the southern extremes of Bundelkhand, commanding outcrops of limestone and sandstone form the backbone of the Vindhyan range. Most recent geologic deposits include alluvial deposits of clay, silt and sand of sub-aerial and fluvial origin and are more predominant near the Yamuna River and its tributaries. The Bundelkhand region was densely forested until the late 18^{th} century but the rising demands for wood and agricultural expansion, poor land management and ruthless commercial logging, have drastically reduced forested area in the region. The soil comprises of a mix of black and red soils, and are gravely with shallow depth, unable to retain moisture. Much of the region suffers from acute ecological degradation due to top-soil erosion and deforestation leading to low productivity of the land. Soil erosion is a persistent problem that is aggravated by the hilly landscape, high winds and the poor quality of the soils, leading to the widespread growth of gullies.

3.2 Description of the Watershed

The Tumri watershed is situated in the Kesli block of Sagar district approximately 72 km from the Sagar. Kesli block is one of the most underdeveloped blocks of Sagar district due to lack of communication facilities to the remote villages and is surrounded by Raisen and Narsingpur districts. The index map of the study area is given in Fig. 3.1. Agriculture and diary farming are the major occupation of the local population. The topography is highly undulating with steep hills on the ridges and flat top hillocks located

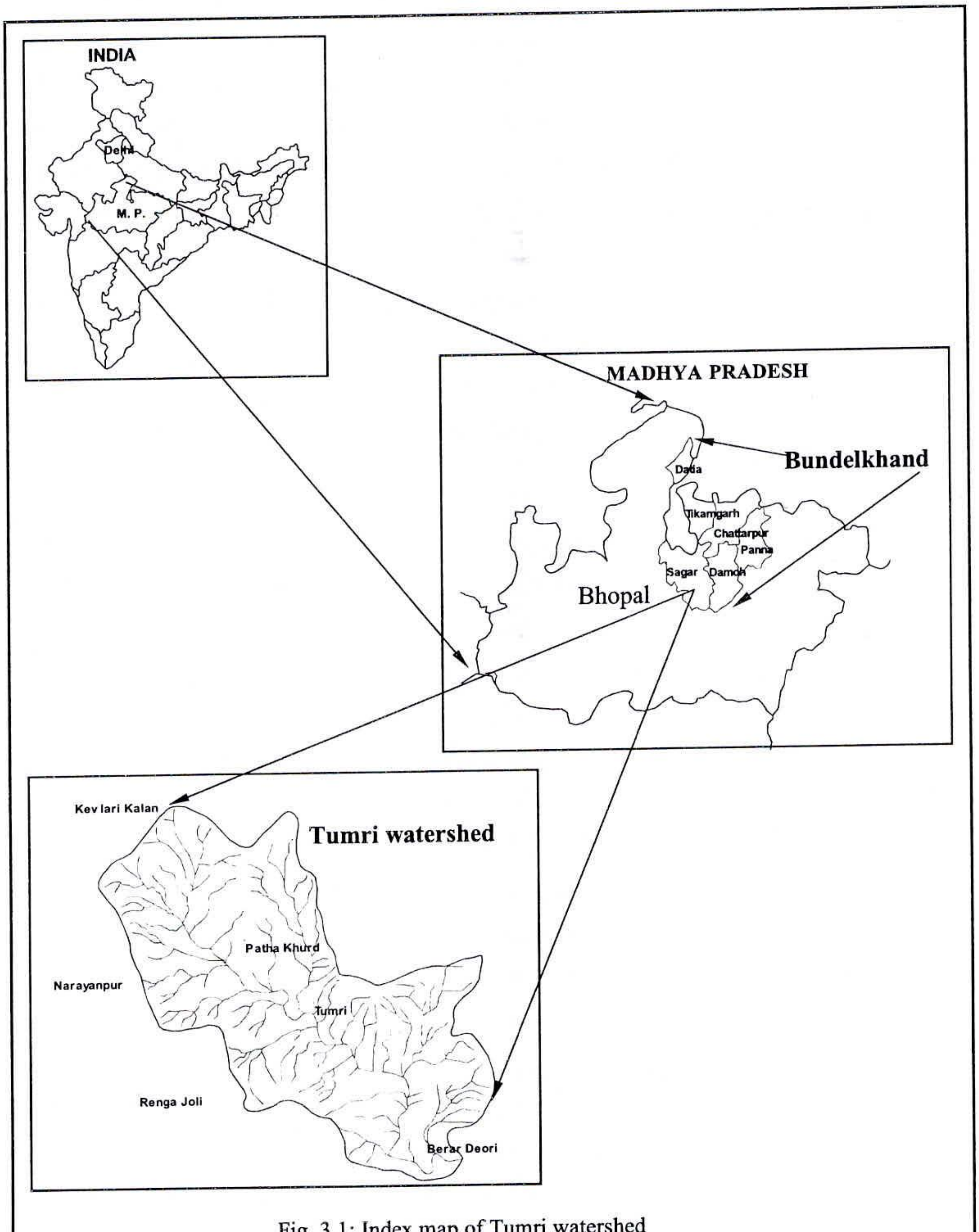


Fig. 3.1: Index map of Tumri watershed

at many places within the watershed. The river Chamak Dhol that passes through the watershed is one of the main tributaries of river Sonar. The watershed is elongated in shape and catchment area is 2391.28 ha and lies between latitudes 23° 23′ 25′′ and 23° 27′ 05′′ N and longitude 78° 42′ 30′′ and 78° 46′ 39′′. The main stream Chamak Dhol is a fourth order stream and traverses 11.50 km within the watershed and merges with river Sonar near Berar Veeran. The river flows only during the monsoon season and becomes dry soon after the withdrawal of the monsoon but flash floods occurs frequently at many places. Patha Khurd and Tumri are the important villages in the watershed. Only three tanks exist in the watershed two near Tumri village and one near Patha Khurd village with minimal water availability during summers. The geology comprises of basaltic formations with red soils in the forests and hillocks and alluvial and black soils near the river banks.

The climate is semi-arid and the average annual rainfall is about 1182.4 mm. The mean maximum temperature varies between 24.4 °C in January and 40.8 °C in May. The mean wind speed is 4.13 kmph in November to 8.45 kmph in July with the mean relative humidity varying between 27.3% in April and 84.5 % in August. The monsoon season prevails during mid-June to mid-October and 90% of the annual rainfall occurs during the monsoon period. The watershed boundaries comprises of steep hills covered with forests of mainly teak trees. Agriculture is practiced along the foothills, valleys and besides the river courses. The area is completely rainfed and the farmers generally go for crops of soyabean and wheat among other crops depending on the rainfall pattern. Dug wells are the main source of drinking water for human and livestock, most of which get completely dried up in summer season. The present land use pattern comprises of forests on the hills, agriculture on the plains and shrubs and barren areas along the flat-topped hillocks. Abundant wasteland is available for development of grasslands for fodder for the livestock. The local population is very poor and owing to the meager water resources development in the region, are forced to work as laborers in nearby stone crusher. Few villagers have adopted diary farming and send their produce to the nearby markets in Sagar.

4.0 INVENTORY OF THE WATERSHED

4.1 Thematic Maps in GIS

Thematic maps including base map, road network map, drainage map, contour map, Digital Elevation Model (DEM), soil type map, soil depth map, map showing the network of ground water observation wells and map showing the location of soil test sites have been prepared in ILWIS 3.0, a GIS software. The base map of the study area showing the road network and villages is given in Fig. 4.1. The drainage map of the Tumri watershed is presented in Fig. 4.2. The contour map and the DEM of the study area is given in Fig. 4.3 & 4.4 respectively.

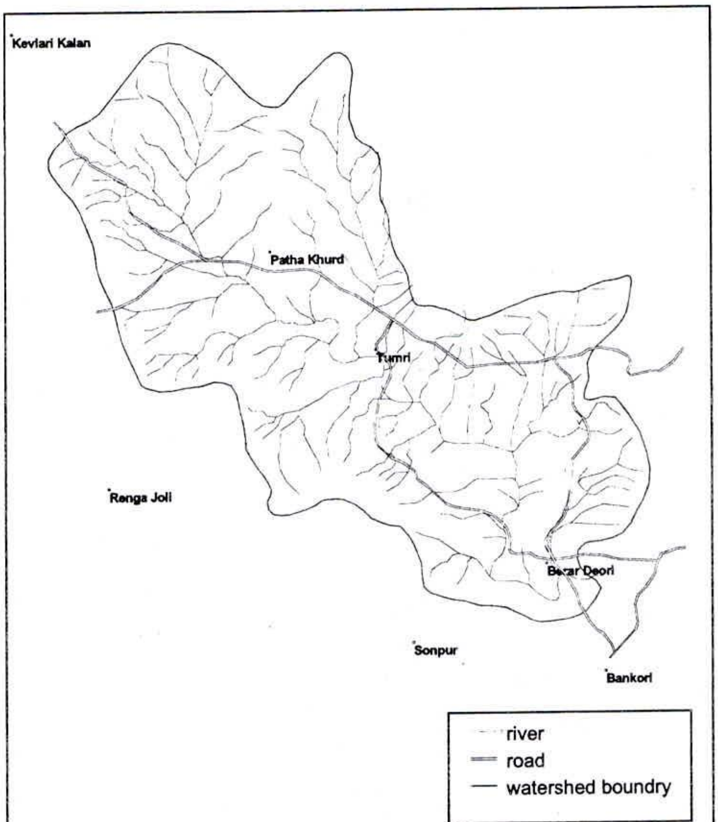


Fig. 4.1: Base map of the Tumri watershed

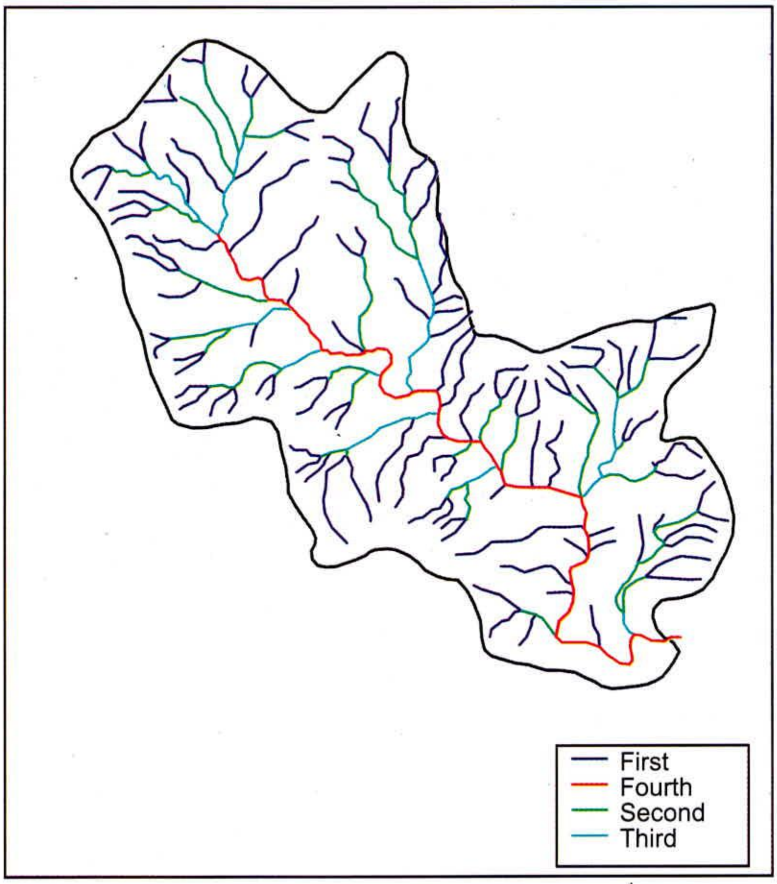


Fig. 4.2: Drainage map of Tumri watershed

4.2 Land Use & Agriculture

The information regarding land use and agriculture has been collected from the office of the Senior Agricultural Development Officer, Kesli block. Patha Khurd, Tumri and Berar Veeran are the important villages in the watershed. The information collected include land use details, area under various crops in kharrif and rabi seasons, area irrigated by surface water and ground water.

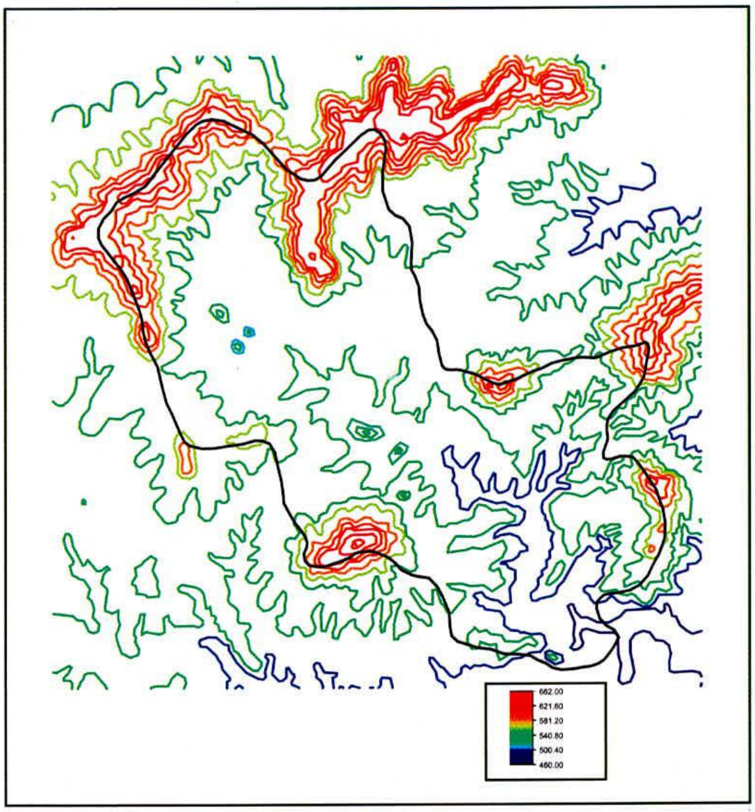


Fig. 4.3: Contour map of the study area

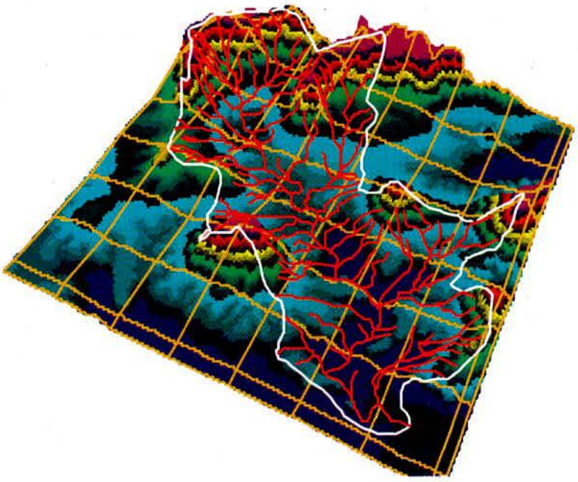


Fig. 4.4: Digital Elevation Model of the study area

4.3 Demographic Data

The population as per the 2001 census for the villages falling in the watershed is given below in Table 4.1.

Table 4.1: Population in the villages

S. No	Name of village	Males	Females
1.	Patha Khurd	601	541
2.	Tumri	317	290

4.4 Rainfall Data

The daily rainfall data from 1993-94 to 2006-07 for Kesli block of Sagar district, which is the only influencing station, have been collected from Land Records, Sagar and processed, checked for consistency and gaps filled up. The rainfall for the years 2007-08 and 2008-09 was monitored in the watershed using a self recording raingauge and ordinary raingauge located at Tumri village. The statistical details of the rainfall data have been evaluated and the average annual rainfall is 1182.41 mm with a coefficient of variation of 37.7%. The cross correlation structure between the monthly rainfall and seasonal rainfall indicated that July is the main rainfall month in the watershed as it has the maximum correlation with the seasonal rainfall. The seasonal departure analysis helped to identify five dry years with more than 25% rainfall deficiency namely, 1995-96, 1996-97, 2000-01, 2002-03 and 2007-08. The frequency of drought years in the watershed was evaluated based on the probability distribution of the seasonal rainfall. The rainfall corresponding to the 75% dependability has been found to be 807.95 mm. The exceedance frequency corresponding to the 75% of the mean seasonal rainfall has been computed as 69.42% and the study area can be considered to be drought prone since the probability of occurrence of the 75% of the normal seasonal rainfall is less than 80%. A self recording rain gauge has been installed in the watershed at Tumri village for recording the short-interval rainfall. The maximum and minimum temperature and relative humidity is also being monitored at Tumri along with the discharge data which is being monitored on Nala river near village Tumri.

4.4 Discharge Data

Even though river Chamak Dhol is an important tributary of river Sonar, gauge-discharge data is not being monitored by any authority. The river Chamak Dhol joins the river Sonar near Bedar Veeran which is also the outlet of the study area. However due to the rugged terrain and inapproachability during monsoon seasons due to floods and submergence, the discharge is being monitored upstream on a Nala tributary near Tumri village. The catchment under the Nala tributary is representative of the Tumri watershed with similar land use, soils and topographical features. A concrete weir has been constructed across the Nala tributary and the gauge-discharge data is being monitored regularly during the monsoon season.

5.0 GEOMORPHOLOGY OF THE WATERSHED

The geo-morphological characteristics are mainly useful in rationalization of the hydrological models of rainfall runoff process, which aim at development of scientific basis for predicting the model parameters of the ungauged watersheds from hydrologic and physiographic characteristics of the watershed. The quantification of the geomorphology of the drainage basins was first started by Horton (1945) and Strahler (1952) proposed a modification in Horton's ordering procedure. The different geomorphologic parameters used in hydrological studies have been described in detail in Interim Report-I (2006-07). The geo-morphological characteristics have been determined in GIS using ILWIS 3.0 and are given in Table 5.1.

Table 5.1: Geomorphologic characteristics of the watershed

S.No.	Characteristics	Values
1.	Catchment area	2391.28 ha
2.	Perimeter	25.550 km
3.	Length of main stream (L)	11.503 km

4.	Order of the watershed	4
5.	Length of watershed	8102.14 m
6.	Number of streams of first order Number of streams of second order Number of streams of third order Number of streams of fourth order	109 32 10 1
7.	Length of first order streams Length of second order streams Length of third order streams Length of fourth order streams	54092.79 m 19218.08 m 8047.45 m 9330.77 m
8.	Average length of streams of first order Average length of streams of second order Average length of streams of third order Average length of streams of fourth order	496.26 m 600.57 m 804.75 m 9330.77 m
9.	Total stream length of all orders	90689.09 m
10.	Total streams of all orders	152
11.	Wandering ratio	1.420
12.	Fineness ratio	3.549
13.	Bifurcation ratio	3.30
14.	Stream length ratio	0.64
15.	Drainage density	3.84 km/sq. km
16.	Length of overland flow	0.13 km
17.	Constant of stream maintenance	0.26 km
18.	Stream segment frequency	6.436 nos/km
19.	Average drainage area of first order streams Average drainage area of second order streams Average drainage area of third order streams Average drainage area of fourth order streams	0.124 sq.km 0.72 sq. km. 4.128 sq. km 23.78 sq. km
20.	Area Ratio	3.249
21.	Circulatory Ratio	0.455
22.	Elongation Ratio	0.68
23.	Basin Shape Factor	2.1
24.	Unity Shape factor	1.67

25.	Form factor	0.36
26.	Compactness Coefficient	1.48
27.	Basin Relief	160.20 m
28.	Relief ratio	0.077
29.	Relative Relief	6.225 %
30.	Ruggedness number	0.615

6.0 INFILTRATION AND HYDRAULIC CONDUCTIVTY OF SOILS

Soil is one of the important resources of the watershed and therefore it is imperative to determine the soil characteristics for various planning activities. The management policy for any watershed depends upon the flow characteristics from its catchment and infiltration and soil-water movement determine the rates and amounts of runoff generated in the stream. Infiltration process is invariably responsible for modifying precipitation and converting it into runoff and soil-moisture-storage and it is one of the major loss of precipitation, affecting the runoff of a basin by continuously affecting its magnitude, timing and distribution. The hydraulic conductivity is a measure of the ability of soil to transmit water, and depends on properties of both soil and water. Therefore, for the simulation of any hydrologic system, the infiltration process has to be taken care of invariably.

Fourteen sites have been selected based on the soil type, land use and are well distributed in the watershed. Infiltration tests have been conducted using the double-ring-infiltrometer whereas the field saturated hydraulic conductivity have been carried out by Guleph-permeameter. The Richard's analysis is the basis for calculation of the field saturated hydraulic conductivity. Soil depth and soil profile have also been evaluated at these test sites. The land use categories and soil type encountered at the various test sites are given in Table 6.1. The infiltration capacity curves at Site 1 and Site 4 are given in Fig. 6.1 and Fig. 6.2 respectively. The infiltration capacity map of the watershed is given as Fig. 6.3.

Table 6.1: Land use and soil types at the test sites

S.N	Site	Land use	Soil type
1.	Site 1,2,9,13	Forested	Red soil with gravels
2.	Site 3,10	Forested	Yellow & black soil
3.	Site 4	Agriculture	Red murrum with gravel
4.	Site 5,7,12,14	Agriculture	Black soil
5.	Site 6	Forested with grass cover	Reddish clayey loam
6.	Site 8	Forested with grass cover	Reddish loam
7.	Site 11	Barren	Yellow

Fig. 6.1: Infiltration curve at Site 1

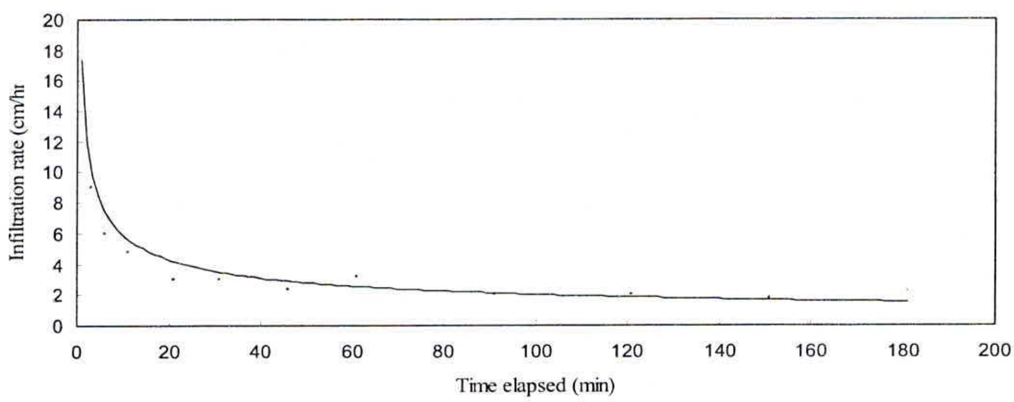
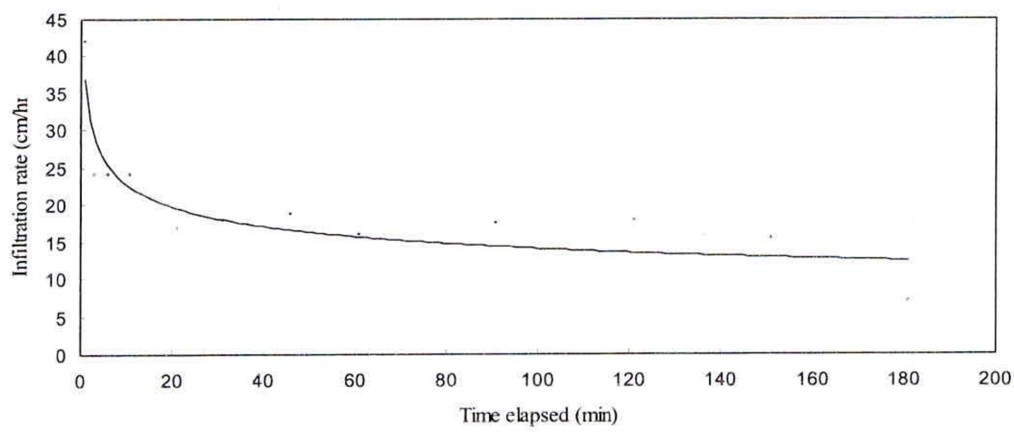


Fig.6.2: Infiltration curve at Site 4



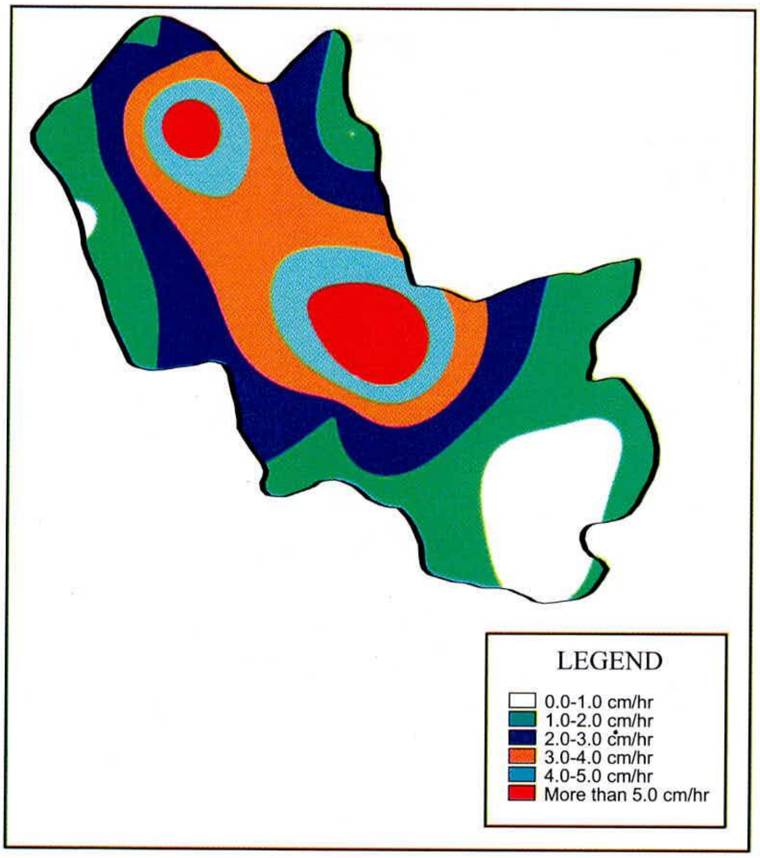


Fig. 6.3: Infiltration capacity map

The Horton's infiltration rate equation and Kostiakov's model for cumulative infiltration depth has been deduced from the experimental data and presented in Table 6.2.

Table 6.2: Horton's equation, Kostiakov's equation and saturated hydraulic conductivity at test sites

S. N	Test site	Horton's equation	Kostiakov's model	K_{ts}
1.	Site 1	$f = 1.8 + (30.0 - 1.80)e^{-2.20t}$	$F_p = 2.79 \times t^{0.65}$	3.29
2.	Site 2	$f = 5.6 + (60.0 - 5.60)e^{-1.26t}$	$F_p = 4.14 \times t^{0.80}$	2.26
3.	Site 3	$f = 1.6 + (6.00 - 1.60)e^{-2.15t}$	$F_p = 1.09 \times t^{0.77}$	3.45
4.	Site 4	$f = 7.0 + (42.0 - 7.00)e^{-1.03t}$	$F_p = 3.59 \times t^{0.98}$	2.72
5.	Site 5	$f = 1.2 + (6.00 - 1.20)e^{-0.72t}$	$F_p = 1.24 \times t^{0.84}$	6.06

6.	Site 6	$f = 1.0 + (6.00 - 1.00)e^{-3.24t}$	$F_p = 1.48 \times t^{0.66}$	3.61
7.	Site 7	$f = 4.0 + (36.0 - 4.00)e^{-1.82t}$	$F_p = 3.04 \times t^{0.76}$	2.10
8.	Site 8	$f = 1.4 + (6.00 - 1.40)e^{-2.48t}$	$F_p = 0.93 \times t^{0.71}$	0.59
9.	Site 9	$f = 8.2 + (66.0 - 8.20)e^{-1.61t}$	$F_p = 5.32 \times t^{0.87}$	8.03
10.	Site 10	$f = 0.14 + (0.60 - 0.14)e^{-0.65t}$	$F_p = 1.07 \times t^{0.73}$	4.46
11.	Site 11	$f = 2.20 + (30.0 - 2.20)e^{-2.53t}$	$F_p = 2.79 \times t^{0.65}$	5.94
12.	Site 12	$f = 0.6 + (30.0 - 0.60)e^{-2.13t}$	$F_p = 2.93 \times t^{0.52}$	2.42
13.	Site 13	$f = 1.20 + (36.0 - 1.20)e^{-1.43t}$	$F_p = 3.96 \times t^{0.77}$	4.57
14.	Site 14	$f = 0.8 + (36.0 - 0.80)e^{-1.69t}$	$F_p = 3.56 \times t^{0.49}$	2.22

7.0 WATER BALANCE

Constructing a water balance is one of the first tasks in understanding the water regime of a specific area which is a budgeting exercise to assess the portion of rainfall that becomes streamflow, evapotranspiration, and drainage. The water balance study serves as a means of solution to important theoretical and practical hydrological problems, on the basis of which, it is possible to evaluate quantitatively individual contribution of various sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to the changes in components of the system. As such water budgeting studies are crucial for understanding the behavior of the hydrologic system to plan the strategies for development and management of water resources.

The water balance of a watershed establishes that all water entering the basin during any given period of the time must either go into the storage within its boundaries, be consumed or flows out of the system during that period. The inflow and outflow components can vary depending on the geologic and hydrologic features of the watershed and are evaluated using proper methodologies. With the water balance data, it is possible to compare the individual sources of water in the system over different time periods and to establish the degree of their effect on variations in the water regime. Also the water balance enables the evaluation of one unknown component of the water balance from all other known components. The basic concept of the water balance is expressed in Eqn. 7.1

$$I = O + \Delta S \qquad \text{....... (7.1)}$$

where, I = inflows to the system, O = outflows from the system; ΔS = change in storage in the system

The broad components of the water balance can be divided more precisely into four groups namely inflows, water use, outflows and storages. Fig. 7.1 represents a simple 'box- model representation' of a water balance, which is represented by Eqn. 7.1 (Thornthwaite et al, 1955; 1957).

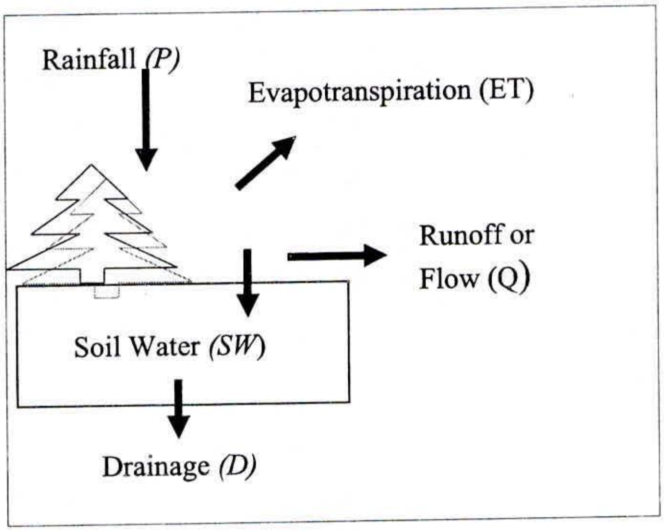


Fig. 7.1: Box model representation of a water balance

Water budgeting analysis for the Tumri watershed is conducted on seasonal basis to choose possible strategies for development and management of water resources in the watershed, using the water balance equation given by Eqn. 7.2 as,

$$P - Q_{dsro} - Q_b - E_t - ET_f - ET_c - D_{dom} - D_{liv} = \Delta S_s + \Delta S_g + U_w \qquad \text{....(7.2)}$$

where, P = rainfall, Q_{dsro} =direct surface runoff, Q_b = base flow, E_t = evaporation from tanks, ET_f = evapotranspiration from forest, ET_c = evapotranspiration from cropped areas, D_d = domestic usage, D_l = livestock needs, ΔS_s = change in surface water storages, ΔS_g = change in ground water storage, U_w = unaccounted water

7.1 Inflows into the System

Inflows represent the water income and it includes precipitation, surface water inflows, and groundwater inflows. The precipitation includes rainfall, and its all other forms like snow, dew, and hail. Except in areas with regular snowfall, this is practically equal to the rainfall. Groundwater and surface water inflows are the water flowing into the study area from surrounding areas and is highly dependent on the developmental activities of the surroundings from which these inflows are coming. If watershed based development is undertaken in the surrounding areas, water will be used there itself which can then reduce these inflows substantially. Since the present study area corresponds to a classical watershed bounded by ridges and with a single exit point, surface inflows are eliminated and groundwater inflows are also considered to be negligible. Therefore the rainfall is the only inflow term being considered in the water balance equation.

7.2 Water Use in the System

The water usage inside the system includes evaporative losses from water bodies such as ponds, tanks and reservoirs inside the study area, evapotranspiration uses by the plants, water use for domestic purposes, livestock needs and demands for non-agricultural purposes like industries, water sports etc.

7.2.1 Evaporation from water bodies

Some of the water stored in the water bodies like ponds, lakes, tanks and reservoirs will evaporate and be lost from the system. This evaporation takes place from the surface storages as well as from saturated soil surfaces. Evaporation is a pure loss since this quantity of water returns to nature and can be considered as the unproductive expenditure of water from the system and efforts should be initiated to reduce it. The actual evaporation from the tanks is estimated by multiplying the pan evaporation with the pan coefficient as given in Eqn. 7.3,

$$EV_{\tan k} = EV_{pan} * P_c \qquad \text{....... (7.3)}$$

where, $EV_{\tan k}$ = actual evaporation from tank (mm), EV_{pan} = evaporation from pan (mm), P_c = pan coefficient

The actual evaporation volume for a particular month is then computed by Eqn. 7.4 as,

$$VEV_{\tan k} = \frac{1}{2}(WSA_{sm} + WSA_{em})D_w EV_{\tan k} \qquad \text{....... (7.4)}$$

where, $VEV_{\tan k}$ = volume of actual evaporation from tank (cu. m), WSA_{sm} = water spread area at the start of the month, WSA_{em} = water spread area at the end of the month, D_w = average depth of water in the tank

7.2.2 Evapotranspiration

Evapotranspiration includes water utilized by all types of plants in the study area, including that used by crops, grasses and trees, and also includes both the rainfall and externally applied water used by plants. Evapotranspiration component represents the productive expenditure of water. It covers all types of plant matter on all kinds of land including crop area, pastures, forests, and wastelands. This vital component can be sub-divided into two sub-groups namely,

a) Evapotranspiration from cropped area
b) Evapotranspiration from non-cropped area

A further break up for different cropped areas and species is required in estimating the effective water utilization and in deciding on how to get the best out of productive water use. This information helps to assess the water being used to fulfill the basic needs and is an important starting point for watershed based development plan. Also a track of the externally applied water and its use is to be kept which includes the record of the quantity of water being applied for each of the crops and amount which is being actually utilized by the crops. This record is important in working out our watershed development plan and the arrangements to be provided for water use. In Tumri watershed evapotranspiration occurs both from cropped area and non-cropped area including forests.

7.2.2.1 Evapotranspiration from forested areas

The non-irrigated non-cropped area consists of the teak forests on the ridges surrounding the watershed for which the evapotranspiration needs are met by the monsoon rains, soil moisture storage and ground water. The potential evapotranspiration for the deep rooted trees has been estimated based on the Thornthwaite method given in Eqn. 7.5 as

$$ET = 1.6La\left(10\frac{Tn}{I}\right)^3 \qquad \ldots\ldots\ (7.5)$$

where, ET = monthly PET in cm, La = factor, to correct for unequal day length between months related to the latitude of the place, Tn = mean monthly air temperature in degree Celsius, a = an empirical constant given by Eqn. 7.6 as,

$$a = (675*10^{-9})J^3 - (771*10^{-7})J^2 + (179*10^{-4})J + 0.492 \qquad \ldots\ (7.6)$$

where, J = total of 12 monthly values of heat index j, j = monthly heat index

The monthly potential evapotranspiration, (PET) have been estimated and the correction factor applied for mean possible duration of sunlight hours, to arrive at the adjusted PET. The evapotranspiration from the forested areas is assumed to take place at the potential rate during the monsoon season which occurs generally from 15 June to 15 September due to the soil being saturated whereas during the remaining dry period, actual evapotranspiration is assumed to be 75% of PET, as the ground water table drops down considerably after the monsoon period. The actual evapotranspiration from non-cropped areas have been estimated using Eqn. 7.7 as,

$$ET_f = PET * D_f * R_f \qquad \ldots\ldots\ (7.7)$$

where, ET_f = actual evapotranspiration from forested areas (cm), D_f = daylight factor, R_f = factor for rain-period (1.0) and no-rain period (0.75)

Finally the actual evapotranspiration from the forested areas in the watershed is computed by Eqn. 7.8 as,

$$VET_f = A_f ET_f \qquad \text{....... (7.8)}$$

where, VET_f = volume of evapotranspiration from forested areas (cu. m), A_f = area under forests (sq. m)

7.2.2.2 Evapotranspiration from cropped areas

The evapotranspiration from cropped areas have been computed by the Penman-Monteith equation which is the only standard method for determining crop evapotranspiration as suggested by FAO, with a strong likelihood of correctly predicting ET_o in a wide range of locations and climates. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The method overcomes shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide. The FAO Penman-Monteith method to estimate reference evapotranspiration (ET_o) is given in Eqn. 7.9 as,

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \text{....... (7.9)}$$

where, ET_o = reference evapotranspiration [mm day^{-1}], R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature at 2 m height [°C], u_2 = wind speed at 2 m height [m s^{-1}], e_s = saturation vapor pressure [kPa], e_a = actual vapor pressure [kPa], $e_s - e_a$ = saturation vapor pressure deficit [kPa], Δ = slope vapor pressure curve [kPa °C^{-1}], γ = psychometric constant [kPa °C^{-1}]

The equation uses standard climatological records of solar radiation, air temperature, humidity and wind speed. The crop evapotranspiration have been computed on a ten-daily basis generally considering four crop growth stages namely, initial stage, development stage, growth stage and the final stage. The crop coefficients for the various crops which vary during the different stages of the crop growth have been used along with the Penman-Monteith (FAO) reference crop evapotranspiration values to arrive the crop evapotranspiration for each of the ten-daily period. The total crop evapotranspiration is arrived at by summing up the ten-daily crop evapotranspiration over the entire crop period.

7.2.3 Water use for domestic purposes and livestock

Water is an essential human need for drinking, cooking, washing, cleaning, and sanitation and for livestock. Water used for these purposes is not a productive expenditure like evapotranspiration but may classed as essential expenditure. This is a first priority and higher quality need, and so working out its magnitude as a component of the water balance is imperative. The drinking and sanitation water needs require special attention and they should be seen as part of the overall problem of improving water resource availability in a watershed. Three villages namely Tumri, Patha Khurd and Berar Veeran fall inside the watershed, but there are no inhabitants in the village Berar Veeran as they have migrated from there to Nanhi Deori due to the frequent floods during each monsoon season and subsequent droughts in non-monsoon season.

7.3 Outflows from the System

The outflows pertain to the water flowing out of the study area and away from the system control and is consists of two components namely, surface water outflow and groundwater outflow. In the watershed development plans, efforts are made to minimize these outflows as much as possible but these unutilized outflows are not necessarily losses and may be utilized by downstream regions. These outflows often have an important role in the downstream environment and perennial flows in the stream.

7.3.1 Surface water outflow

The surface water outflow at the outlet of the watershed has been estimated by the Soil Conservation Service Curve Number (SCS-CN) model. The SCS-CN model is based on a single parameter Curve Number (CN) which depends on the land use, land cover, soil type and the antecedent moisture conditions prevailing in the watershed. The composite curve number (CCN) is estimated for AMC-II condition. The direct surface runoff was estimated using the SCS-CN model given in Eqn. 7.10 and 7.11.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad \text{for } P > I_a \text{ ; and } Q = 0 \text{ for } P \le I_a \qquad \text{.......} \ (7.10)$$

$$S = \frac{25400}{CN} - 254 \qquad \text{.......} \ (7.11)$$

where, Q = direct surface runoff (mm), S = potential retention (mm), CN = curve number, I_a = initial abstraction $= 0.2S$ for general soils, $0.3S$ for AMC-I and black soils and $0.1S$ for AMC-III and black soils

7.3.2 Ground water outflow

The topography of the watershed being highly undulating there is significant elevation difference between the watershed outlet and the stream origination. Moreover the groundwater gets depleted within short periods due to the groundwater outflow from the watershed towards the downstream areas. The watershed boundary near the outlet of the watershed has been divided into different reach lengths and groundwater levels on both sides of the reach are being monitored. Depending on the hydraulic gradient, the groundwater outflow is determined using Eqn. 7.12 given as,

$$Q = TiL \qquad \text{.......} \ (7.12)$$

where, T = transmissivity (sq. m/day), i = hydraulic gradient, L = length of reach, Q = rate of flow (cu. m./day)

The hydraulic gradient of the ground water flow is given by Eqn. 7.13 as,

$$i = h / L \qquad \text{.......} \ (7.13)$$

where, h = difference in groundwater levels between observation well inside watershed and observation well downstream for particular reach (m), L = reach length (m)

7.4 Storages in the System

The storages being accumulated in the system can be considered to be composed of three main components namely surface storage, groundwater storage and root zone storage. The surface storages include all water stored on the surface in ponds, tanks and behind check dams. Groundwater storage includes all water stored as free water below the root zone of plants and root zone storage includes the moisture held in the soil in the root zone of plants. This component is not often considered as a storage element in the water balance, but it has an important role to play. These storage components represent the savings and are important in tiding over bad years in which rainfall may not be adequate.

As a part of the watershed development process efforts should be made to replenish these storages in good years as these storages are of utmost importance and act as cushion against the variations in rainfall. The increases or decreases in these storages help to identify whether the demands are being met from the annual water incomes or the storages are also being exploited alongside, for satisfying the demands. The important condition for sustainability of the water resource is that the storages should not decrease in average years but should increase sufficiently in good years to compensate for the additional withdrawals from the storages during the bad years.

Generally, at the end of summer season the surface storages are practically empty and soil moisture in the root zone may also be negligible. If the water balance is started and ended as per the water year from June to May, then both these storage terms remain unaffected. So only the change in groundwater storage needs to be accounted for. The water balance of the surface water storage tanks inside the watershed have been estimated and are given below. These tanks having small storage capacities get filled up at the start of the monsoon season and remains full till the withdrawal of the monsoon. The government tank near the stone quarry generally gets emptied by December due to the continuous seepage taking place from the earthen bund of the tank. Clay blanketing work has been carried out before the monsoon of 2007 due to which the seepage has completely stopped and the water now lasts till February.

7.5 Unaccounted Water

The unaccounted water is lumped together and worked as a residual term which practically means that all components in the water balance equations are computed and the difference in the water balance is taken as other outgoings.

7.6 Analysis and Results

7.6.1 Evaporation from water bodies

There are three tanks in the watershed and the evaporation from these tanks has been estimated separately. The evaporation from the missionary tank has also been computed and it is observed that a minimum quantity of water remains in the tank which provides drinking water to the large livestock population of Tumri and Patha Khurd villages. The evaporation from the missionary tank during 2007-08 is given in Table 7.1. The evaporation from the tank existing near village Patha Khurd has been estimated to be 0.007 and 0.087 MCM in monsoon and non-monsoon season respectively. The total evaporation from all these three tanks is 0.012 and 0.092 MCM in monsoon and non-monsoon season respectively.

7.6.2 Evapotranspiration from forested areas

The forested area which comprises of dense forests and open forests is one of the major land use components in the watershed. The watershed comprises of dense and open forests all along the hills on the ridge line and also sparsely inside on the flat topped hills. The monthly evapotranspiration for the study area have been computed by the Thornthwaite method as given in Eqn. 7.5 and adjusted for the daylight factor. The actual evapotranspiration has been considered equal to the potential rate in the monsoon months whereas the actual evapotranspiration is considered as 75% of the potential rate during the non-monsoon period. The monthly potential evapotranspiration in the study area is given in Table 7.2. The volume of actual evapotranspiration from the forested areas in the watershed computed using Table 7.2 and Eqn. 7.5 is 2.865 MCM and 2.439 MCM in monsoon and non-monsoon season respectively.

Table 7.1: Evaporation from the missionary tank (2006-07)

Month	Initial Depth (m)	Initial Area(sq. m)	Pan Evap (mm)	Pan Coeff.	Actual Evap (m)	Final Area (sq. m)	Evaporation (cu. m)
Jul	4.50	5240.00	164.0	0.80	0.13	5240.0	687.49
Aug	4.50	5240.00	143.0	0.80	0.11	5240.0	599.46
Sep	4.50	5240.00	167.0	0.80	0.13	5171.0	695.46
Oct	4.25	5171.03	165.0	0.80	0.13	5004.2	671.57
Nov	3.95	5004.29	123.0	0.80	0.10	4712.0	478.04
Dec	3.67	4712.00	103.0	0.80	0.08	4300.0	371.29
Jan	3.40	4300.00	113.0	0.80	0.09	3966.8	373.66
Feb	3.11	3966.80	135.0	0.80	0.11	3550.0	405.91
Mar	2.80	3550.00	193.0	0.80	0.15	3146.0	516.93
Apr	2.42	3146.00	241.0	0.80	0.19	2378.4	532.55
May	1.91	2378.40	293.0	0.80	0.23	1482.4	452.49
Jun	1.26	1482.40	237.0	0.80	0.19	400.0	178.45

7.6.3 Evapotranspiration from cropped areas

The evapotranspiration from cropped areas have been computed by the Penman-Monteith equation as suggested by FAO. The crop evapotranspiration (ET) have been worked out on a ten-daily basis generally considering four growth stages of the crop namely, initial stage, development stage, growth stage and the final stage. The total crop evapotranspiration is arrived at by summing up the ten-daily crop evapotranspiration over the entire crop period. The village-wise crop evapotranspiration is then added to get the total crop evapotranspiration for the study area for a particular crop. The reference evapotranspiration ET_o has been evaluated and is given in Table 7.3. The total crop evapotranspiration from the various crops grown in the watershed during kharrif and rabi season is given below in Table 7.4.

Table 7.2: Seasonal potential evapotranspiration from forested areas

Monsoon season			
Month	PET (cm)	Daylight factor	Adjusted monthly ET_f (cm)
Jun	28.63	1.13	32.37
Jul	16.78	1.16	19.47
Aug	13.11	1.12	14.69
Sep	13.81	1.02	14.13
Oct	12.96	0.99	12.87
Total monsoon PET			82.22
Non-monsoon season			
Nov	6.86	0.92	6.29
Dec	3.87	0.92	3.56
Jan	3.14	0.93	2.93
Feb	4.48	0.89	3.99
Mar	12.02	1.03	12.38
Apr	23.62	1.06	25.04
May	34.12	1.15	39.14
Total non-monsoon PET			83.48

7.6.4 Water use for domestic purposes and livestock

The domestic water consumption has been estimated based for the population in the villages in the watershed at the rate of 70 litres/capita/day. The domestic water use by the local population in the villages of the study area is given in Table 7.5. The main occupation of the population particularly in Patha Khurd village is diary farming. Owing to this there exist a considerable livestock population and sufficient drinking water is to be provided for them. The livestock water demand in the villages inside the study area is given in Table 7.6.

Table 7.3: Climate and reference crop ET_o data

Month	Maximum Temperature (deg.C)	Minimum Temperature (deg.C)	Humidity (%)	Wind Speed (km/day)	Sun Shine (hours)	Solar Rad. (MJ/m2/d)	ET_o (mm/day)
January	24.4	11.4	44.5	81.6	7.9	15.4	2.70
February	27.1	13.5	39.5	105.6	8.6	18.3	3.73
March	32.7	18.5	25	105.6	8.7	20.8	4.91
April	38	23.4	21	100.8	9	22.9	5.84
May	40.8	26.2	42.5	146.4	8.8	23.2	6.99
June	37.7	25.5	65	156	6.4	19.6	5.69
July	30.6	23.4	84	153.6	4.5	16.7	3.88
August	28.7	22.6	81.5	124.8	4.6	16.4	3.65
September	30.6	22.2	72	108	6.2	17.7	4.02
October	32	20.2	48.5	64.8	8.1	18.3	3.75
November	28.9	16.2	37.5	67.2	8.4	16.4	2.99
December	25.4	12.6	33	48	7.8	14.6	2.18

Table 7.4: Evapotranspiration of crops grown in Tumri watershed

Kharrif crops		
S. N	Name of the Crop	ET_{crop} (MCM)
1	Paddy	0.076
2	Jowar	0.451
3	Bajra	0.000
4	Macca	0.078
5	Kodon	0.241
6	Kutki	0.031
7	Arher	0.169
8	Udad	0.448
9	Til	0.151
10	Ramtil	0.088
11	Sava	0.019

Rabi crops		
S. N	Name of the Crop	ET_{crop} (MCM)
1	Wheat	1.345
2	Black Gram	0.055
3	Matar	0.040
4	Chana	0.854
5	Alsi	0.019
6	Potato	0.013
7	Rajgir	0.083
8	Masur	0.557
9	Tevda	0.032
10	Onion	0.006
11	Garlic	0.006

12	Parsa	0.020
13	Moong	0.000
14	Soyabean	0.511
Total		*2.285*

12	Groundnut	0.061
13	Arher	0.219
14	Others	0.010
Total		*3.239*

Table 7.5: Drinking water requirement for human consumption

S. No	Name of Village	Population (Nos.)	Monsoon (Jun-Oct) (cu. m)	Non-monsoon (Nov-May) (cu. m)	Monsoon (Jun-Oct) (MCM)	Non-monsoon (Nov-Feb) (MCM)
1	Patha Khurd	1142	12230.8	16947.3	0.0122	0.0169
2	Tumri	607	6500.97	9007.88	0.0065	0.0090
Total					0.0187	0.0260

Table 7.6: Livestock water requirement

S. No	Name of Village	Animals (Nos.)	Monsoon (Jun-Oct) (cu. m)	Non-monsoon (Nov-May) (cu. m)	Monsoon (Jun-Oct) (MCM)	Non-monsoon (Nov-May) (MCM)
1	Patha Khurd	1350	10327.5	14310	0.0103	0.0143
2	Tumri	525	4016.25	5565	0.0040	0.0056
Total					0.0143	0.0199

7.6.5 Stream flow from watershed

The surface water outflow from the system includes the direct surface runoff and the base flow. The direct surface runoff has been estimated by the SCS-CN model at the outlet of the watershed. The land use information of the watershed has been extracted from the satellite data, IRS-1D LISS-III merged with Pan geo-referenced satellite data. The digital image processing of the data was carried out to prepare the land use map of the Tumri watershed and the maximum likelihood classification (MLC) was adopted. Six land use classes identified based on the ground truth survey and digital classification include agriculture, barren, open forest, dense forests, water bodies and built up areas. The spatial distribution of all the six land use classes is given in the Table 7.7. The land

Table 7.7: Land use distribution Tumri watershed

Land Use Class	Area (sq. km.)	Area (%)
Agriculture	540.15	22.59
Barren land	706.14	29.53
Open forest	521.90	21.83
Dense forest	587.98	24.59
Water bodies	7.23	0.30
Built up areas	27.93	1.17

use map classified from satellite data is given in Fig. 7.2. The curve number for the watershed for the prevalent land uses and soil types for Antecedent Moisture Condition-II is 83.17. The direct surface runoff evaluated using the SCS-CN method from the watershed are given in Table 7.8.

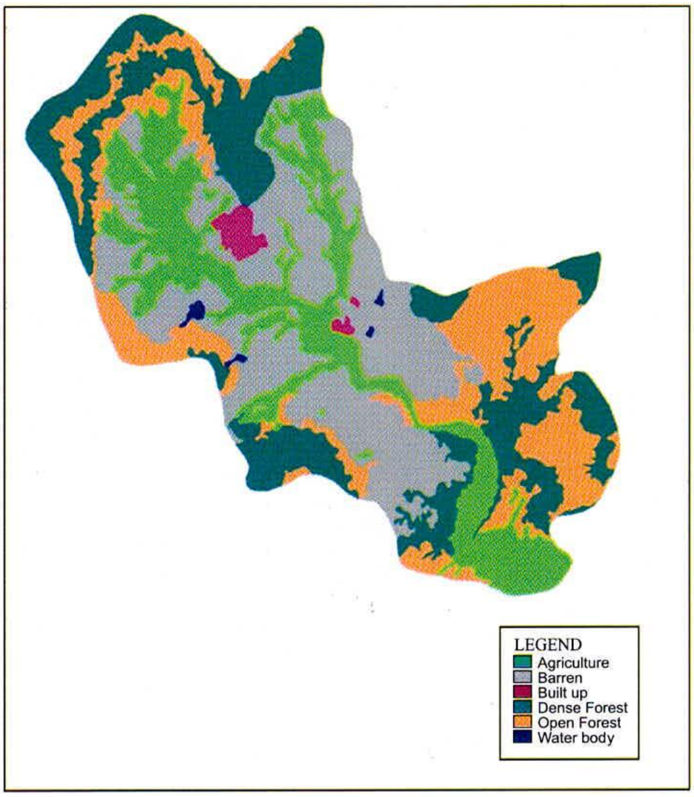


Fig 7.2: Land use map

Table 7.8: Seasonal rainfall and surface runoff from Tumri watershed

Rainfall (MCM)		Direct runoff (MCM)		Base flow (MCM)		Surface runoff (MCM)	
Monsoon	Non-monsoon	Monsoon	Non-monsoon	Monsoon	Non-monsoon	Monsoon	Non-monsoon
24.39	0.53	7.80	0.00	0.25	0.00	8.05	0.00

7.6.6 Groundwater outflow from watershed

The groundwater outflow from the watershed which is also of significant importance have been estimated using Eqn. 7.12 & 7.13. The groundwater levels are being monitored from a network of observation wells located inside and surrounding the watershed. For computation purpose, the downstream boundary of the watershed was divided into number of small reaches so that each reach has an observation well within and outside the watershed. The groundwater outflow from the watershed was then determined for each reach by using the gradient of water table and transmissivity of the aquifer system. The reach-wise outflows were then added to arrive at the total groundwater outflow taking place from the downstream boundary of the watershed. The groundwater outflow from the watershed is 2.241 MCM and 3.586 MCM during the monsoon and non-monsoon season respectively.

7.6.7 Change in storage in the system

The change in storages from the system includes the change in surface water storage and change in ground water storage. The change in surface storages includes the difference between storages between at the start and end of the particular season in all the tanks which have been evaluated by working out the water balance for each surface storage scheme independently. The change in groundwater storage includes difference between the ground water storages at the start and end of the particular season. The change in ground water storage has been evaluated by considering the difference between the ground water levels at the start and end of the season and the specific yield for the various types of formations in the watershed. The soil moisture storage has not been considered as the water year from June to May has been considered and generally, at the end of summer season the surface storages are practically empty and soil moisture in the root zone may be considered to be negligible. The change in surface water storage and ground water storage is given in Table 7.9.

Table 7.9: Change in surface and ground water storage in Tumri watershed

	Change in surface water storage (MCM)		Change in ground water storage (MCM)	
Year	Monsoon	Non-monsoon	Seasonal	Non-Monsoon
2006-07	0.02	0.01	15.586	17.556

7.6.8 Water balance of tanks

The water balance computations have been carried out for all the tanks and the outflow components from the government tank include evaporation, seepage and leakages which were monitored regularly whereas the outflow components from the missionary tank include evaporation, seepage and livestock demand. No leakage is observed from this missionary tank. The water balance of the missionary tank has been computed and is given in Table 7.10.

7.7 Water Budget of the Watershed

The water budget of the Tumri watershed has been carried out on a seasonal basis for monsoon season (June to October) and non-monsoon season (November-May). The water budget during the monsoon season yields an estimate of the major components and also helps to identify those components which can be utilized more effectively to conserve the precious water resources within the watershed. It can be seen from the analysis that about 8.05 MCM water flows down the streams unutilized during the monsoon season in a normal rainfall year. Some of this water can be tapped at suitable sites within the watershed so as to provide the much required irrigation water for bringing more areas under agriculture and creation of fisheries and agroforestry. The water budget computations for the Tumri watershed are given in Table 7.11.

Table 7.10: Water balance of the missionary tank

Mon	Initial Depth (m)	Spread Area (sq.m)	Volume (cu.m)	Pan Evapn (mm)	Pan Coeff.	Evapo-ration (m)	Seep-age (m)	Leak-age (m)	Live stock (m)	Inflow (m)	Depth Remain (m)
Jul	4.50	5240.0	12533.3	164	0.80	0.13	0.05	0.00	0.13	0.31	4.50
Aug	4.50	5240.0	12533.3	143	0.80	0.11	0.05	0.00	0.13	0.29	4.50
Sep	4.50	5240.0	12533.3	167	0.80	0.13	0.05	0.00	0.12	0.06	4.25
Oct	4.25	5171.0	11233.3	165	0.80	0.13	0.05	0.00	0.12	0.00	3.95
Nov	3.95	5004.2	9708.2	123	0.80	0.10	0.05	0.00	0.13	0.00	3.67
Dec	3.67	4712.0	8346.2	103	0.80	0.08	0.05	0.00	0.14	0.00	3.40
Jan	3.40	4300.0	7131.3	113	0.80	0.09	0.05	0.00	0.15	0.00	3.11
Feb	3.11	3966.8	5934.6	135	0.80	0.11	0.05	0.00	0.15	0.00	2.80
Mar	2.80	3550.0	4763.2	193	0.80	0.15	0.05	0.00	0.18	0.00	2.42
Apr	2.42	3146.0	3489.9	241	0.80	0.19	0.05	0.00	0.26	0.00	1.91
May	1.91	2378.4	2093.3	293	0.80	0.23	0.05	0.00	0.36	0.00	1.26
Jun	1.26	1482.4	836.7	237	0.80	0.19	0.05	0.00	0.56	0.00	0.40

Table 7.11: Water budget of Tumri watershed

Components		Values in MCM	
		Monsoon	Non-monsoon
Inputs	Rainfall	24.690	0.529
Outputs	Surface runoff (dsro & baseflow)	8.050	0.000
	Evaporation (Tanks)	0.012	0.092
	Domestic & livestock	0.033	0.046
	Evapotranspiration (forested & cropped)	5.150	5.739
	Groundwater outflow	2.241	3.586
Change in Storage	Change in storage (SW)	0.031	-0.019
	Change in storage (GW)	10.730	-12.205
Unaccounted water		-1.557	3.290

7.8 Results and Discussions

The various components for the water budget of the watershed which includes the inflow, outflow and storage components have been estimated independently and substituted in Eqn. 7.2 and the water budgeting carried out. Rainfall is the only input component whereas surface runoff and evapotranspiration from cropped and forested areas are the major outflow components. Other outflow components of significance include groundwater outflow, evaporation from tanks and domestic and livestock requirements. The change in ground water storage plays a significant contribution in the overall water budget of the watershed. During the monsoon season the ground water level in most of the dug wells gets recharged but the water level starts to deplete from the withdrawal of the monsoon. Very little water remains in the dug wells for drinking and irrigation by the end of winter season. The deep bore wells have failed at many locations during the summer season. Priority should be given to identify more sites for creating small surface water storage structures to meet the irrigation and drinking water demands in the watershed. Efforts should also be initiated to identify zones for artificial recharge in the watershed. The unaccounted water during the monsoon and non-monsoon season is -1.557 MCM and 3.290 MCM respectively and may include some of the components not considered during the water budgeting exercise.

8.0 LAND CAPABILITY CLASSIFICATION

The knowledge of potential and limitation of the land is a prerequisite in the preparation of a watershed management plan, as the basic principle of soil and water conservation is to use the land in a watershed according to its capability and treat the land according to its limitations. This principle provides the best technique to enhance the productivity from the available land resources and to plan for the appropriate land use. With the help of land capability classification, the best use of the land and essential soil conservation measures can be determined. The land capability classification indicates the hazards of soil and water erosion and difficulties to be encountered in land use, involves most intensive, profitable and safe use on available land, provides technical data and indicators for application to land use planning, and enables the cultivators to make the use of techniques and inputs available to each class of land .

8.1 Classification Criteria

8.1.1 Land use suitability classification

The land use suitability of a watershed can be determined by conducting the soil surveys including soil texture, soil depth, pH, salinity and field condition including drainage system, irrigation water availability and the overall climatic condition in the specific agro-ecological zone in the watershed (Gil, 1979). After determining the various details regarding soil, topography, climatic condition and irrigation water availability, the major land utilization groups designated in the watershed may be forest (F), pasture and range (P), crop land for annual and perennial crops, upland (U), low land /level lands (L_o), and waste lands (W). Based on major physical and land characteristics, the land use suitability classification is determined. The main two orders of land suitability include, S - land found suitable for specific use and N - land found unsuitable for specific use. These two orders can be further sub-divided into five classes each indicating the grade of suitability or non-suitability. These classes are namely,

S_1 - highly suitable, without moderate, significant limitations for a given use.

S_2 - moderately suitable, with moderate limitations for a given use.

S_3 - marginally suitable with severe limitation for a given use

N_1 - currently not suitable with limitations for a given use, which may however be overcome by adopted practices.

N_2 - permanently not suitable due to severe limitations that make it impossible for a given use.

Each of the above five classes can be further sub-divided in to additional sub-classes.

8.1.2 Land capability classification

The land capability map makes available in a simple and practical language, the technical data contained in a soil survey map, for application to land use planning. Before deciding land capability of a unit of land, the important factors that needs to be considered include, soil profile characteristics like soil texture, effective soil depth, permeability, drainage, nutrients, soil salinity, alkalinity, toxicity, and coarse soil fragments; external features of lands like water logging, slope, and erosion; and climatic factors like rainfall, and wind velocity. The land under different capabilities can be divided into groups, classes, sub-classes and units from higher to lower level of generalization.

8.1.2.1 Land capability group

In the land capability classification, the land can be classified into two broad groups, namely

A - Land suitable for cultivation which includes class I to IV lands, and

B - Land not suitable for cultivation, but very well suited to forestry, grassland and wild life. This includes class V to VIII lands.

8.1.2.2 Land capability classes

These classes are groups of capability sub-classes or capability units that have the same relative degree of hazard or limitation. The land capability classes are mapped as roman numbers from I to VIII. The risk of soil damage or limitation becomes progressively greater from class I to VIII. The classes show the location, amount and general suitability of the soil for agricultural use. The different colors used for different capability classes as per standard practices are,

Land capability class	Color notation	Land capability class	Color notation
I	Light green	V	Dark green
II	Yellow	VI	Orange
II	Red	VII	Brown
IV	Blue	VIII	Purple

8.1.2.3 Land capability sub-classes

Sub-classes are groups of capability units which have the same major conservation problems namely,

e - erosion and runoff

w - excess water

s - root zone limitations

c - climatic limitations

Land capability sub-classes provide information about the kind of conservation problems or limitations of the land. The class and sub-class together provide the information about the type of limitation and kind of problem in view for broader planning, and conservation studies. The sub-classes are indicated as suffix to land capability classes i.e. II_e indicates a land suited for agriculture with some soil conservation measures having problems of soil erosion.

8.1.2.4 Land capability units

A capability unit is a grouping of one or more individual soil-mapping units having similar potentials and continuing limitations or hazards. The soils in a capability unit are sufficiently uniform to produce similar kinds of cultivated crops and pasture plants with similar management practices and require similar conservation treatment and management practices under the same kind of vegetation cover. Also the land capability units have comparable potential for productivity, similar soil characteristics such as texture, depth, permeability, response to application of fertilizers, salinity, slope, erosion, drainage, climatic limitation etc. The land capability units are represented as ordinary numerals from 1 to 4 placed as subscripts to the sub-class letters. The numerals represent the following meanings,

1 - limitation of effective soil depth

2 - very heavy or light texture of soil

3 - nature of material restricting root zone

4 - salinity or alkalinity of soil

A land unit represented by IV_{e1} indicates a unit of land having severe limitation of soil erosion and effective soil depth suitable for agriculture with intensive soil conservation measures.

8.2 Methodology

For determination of land capability classification, the common parameters such as soil texture depth, slope and erosion which are recorded on a survey map for land capability form the basis of classification. However, local limitations such as salinity, alkalinity, water logging, climate are also taken in to account during determination of land capability classes. The land is classified into capability class according to each parameter with the help of standard rating table.

8.2.1 Soil type classification

For determination of distribution of soil types in the watershed, textural analysis of different types of soil presented have been performed. The spatial distributions of different soils are determined for land capability classification.

8.2.2 Soil depth classification

According to the depth of the soil at different test sites, the watershed can be divided in to different zones from d_1 to d_5. The depth range of various classes has been presented in Table 8.1.

Table 8.1: Soil depth classes for land capability classification

S.N.	Symbol	Name	Depth Range (cm)
1.	d_1	Very Shallow	0.0 to 7.5
2.	d_2	Shallow	7.5 to 22.5
3.	d_3	Moderately deep	22.5 to 45.0
4.	d_4	Deep	45.0 to 90.0
5.	d_5	Very Deep	Greater than 90.0

8.2.3 Slope classification

Slope classification is important in deciding the land capability classification. With the help of contour map of the watershed, a slope map may be prepared in percentage. Using the slope map, the watershed can be divided in to different slope-class zones from A to H. The slope range for different classes has been given in Table 8.2.

Table 8.2: Slope classes for land capability classification

S. N.	Symbol	Name	% Slope	Reading of Abney's Level
1.	A	Nearly level	0 to 1	0 to 35′
2.	B	Gently sloping	1 to 3	36′ to 1°44′
3.	C	Moderately sloping	3 to 5	1°44′ to 2° 52′
4.	D	Strongly sloping	5 to 10	2°52′ to 5° 43′
5.	E	Moderately steep	10 to 15	5°43′ to 8° 32′
6.	F	Steep	15 to 25	8°32′ to 14° 03′
7.	G	Very steep	25 to 33	14°03′ to 18° 16′
8.	H	Very very steep	Greater than 33	18°16′ to 26°34′

8.2.4 Soil erosion classification

The erosion status in the watershed is useful to determine the extent of soil conservation measures required in the watershed. In the erosion classification, the watershed can be divided into five classes of erosion from e_1 to e_5. Various erosion phases and their characteristics have been presented **in Table 8.3.**

8.2.5 Land permeability

If the information regarding, the rate of flow trough the soil at different places in the watershed are known, a permeability map can be generated using the Table 8.4.

Table 8.3: Soil erosion phases for land capability classification

S. N.	Symbol	Erosion Phase	Characteristics
1.	e_1	Not apparent or slight (sheet)	0 to 5% topsoil or original plough layer with a horizon removed.
2.	e_2	Moderate (sheet and rill)	25 to 75% topsoil removed.
3.	e_3	Severe (sheet, rill and small gullies)	76 to 100% topsoil and up to 25% sub soil removed
4.	e_4	Very severe (shallow gullies)	Gullied land
5.	e_5	Very very severe (gullies)	Very severely gullied land or sand dunes.

Table 8.4: Permeability classes of soil for land capability classification

S.N.	Symbol	Name	Rate of Flow (cm/hr)
1.	1	Very Slow	Less than 0.13
2.	2	Slow	0.13 to 0.50
3.	3	Moderately Slow	0.50 to 2.0
4.	4	Moderate	2.0 to 5.0
5.	5	Moderately Rapid	5.0 to 13.0
6.	6	Rapid	13.0 to 25.0
7.	7	Very Rapid	Greater than 25.0

8.2.6 Determination of capability of land

For determination of capability, limitation and proposed measures of conservation of each unit of land in a watershed, all the above maps are overlaid over each other and a final map of the watershed can be generated, in which each unit of land has a particular slope class, soil depth class, permeability class, erosion phase and other climatic limitation. On the basis of these classes, each unit of land can be given an appropriate land capability class. For example, a unit: $\frac{LS - d_4}{B - e_1}$, represents a unit having loamy sand, soil depth in the range of 45 to 90 cm, slope in the range of 1 to 3% and no apparent or slight (sheet) erosion. On the basis of above configuration the above land unit can be classified as II_e and on similar lines, all land units of watershed can be classified. The following checklist may be used for determination of land capability classification.

(i) Regardless of soil depths and other limiting factors, slope 7 classifies to: FP (protection of forest) and slope 6 classifies to: F (forest land).

(ii) Where soils are deeper than 90 cm and there is no soil limiting factor, the classification is straightforward as follows:

- Slope 5 classify to FT (for fruit or food trees).
- Slope 4 classify to C4 (IV).
- Slope 3 classify to C3 (III).
- Slope 2 classify to C2 (II).
- Slope 1 classify to C1 (I)

(iii) Regardless of soil depth, where soils have limiting factors preventing normal tillage, i.e., too stony, frequent flooding and severe dissection, the classification is as follows:

- Slope 5: F (forest land).
- Slope 1, 2, 3, 4: P (pasture)

(iv) Where the soils are shallower than 90 cm and without soil limiting factors, the classification will be done as follows:

- Slope 5: AF (soil depth not enough for 1.75 m wide orchard terraces). FT (enough for above treatment).
- Slope 4: P (soil depth not enough for 2 m wide hillside ditches), C4 (enough for above minimum treatment).
- Slope 3: P (soil depth not enough for 2 m wide hillside ditches), C3 (enough for above minimum treatment).
- Slope 2: P(soil depth not enough for 2 m wide hillside ditches), C2 (enough for above minimum treatment).

- Slope 1: P (soil depth below 15 cm), C1 (soil depth for above 15 cm).

Here, AF: Agroforestry, P: Pasture, C1-C2: Cultivable land.

8.3 Analysis and Results

The land capability classification serves as the basic information and tool for preparation of management plan for a watershed. As soil and water are the two important natural resources in the watershed, an integrated approach for sustainable development of a watershed should be envisaged, and the management plan should be prepared considering the land capability of each unit of soil and proper conservation measures should be adopted according to the limitation of soil. The Tumri watershed is a degraded watershed with high rate of erosion, undulating topography, low ground water availability and soil depth limitation. A considerable portion of the watershed is barren and using land capability classification, a comprehensive management plan can be prepared in which land use changes according to land capability can be suggested. For determination of land capability classes detailed surveys for soil depth, erosion classes, soil types, slope classes and permeability have been conducted in the watershed and maps prepared. All these maps have been generated in ILWIS 3.0 using point values and aerial maps. All maps have been crossed and suitable capability class assigned according to standard rating tables and suggested guidelines.

8.3.1 Soil type distribution

The soils in the Tumri watershed are mainly clayey loam, loamy sand and sandy gravel type. The clayey loam soil is found in the river beds, which is suitable for agriculture purposes, while the sandy gravel soil is predominantly found in barren areas where possibilities of pasture development and agroforestry exists. The map depicting the distribution of soil types in the Tumri watershed have been given in Fig. 8.1. The area under each soil type has been presented in Table 8.5.

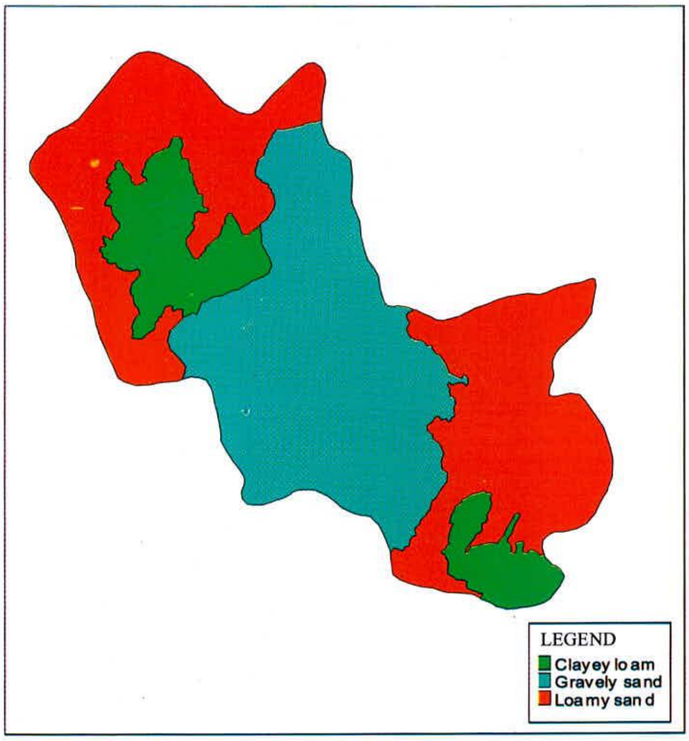


Fig. 8.1: Soil type distribution map

Table 8.5: Distribution of soils present in the Tumri watershed

S.N.	Name	Area (ha)	Percentage (%)
1.	Clayey loam	349.61	14.62
2.	Loamy sand	1097.40	45.89
3.	Gravely sand	944.27	39.49

8.3.2 Soil depth classification

For determination of spatial variation of soil depth in the watershed, the soil depth has been determined at 20 sampling sites in the watershed. The sites have been selected in such a way so that all the land uses have been covered and sites are well distributed uniformly in the watershed. A map of soil depth has been prepared as a point map in the ILWIS 3.0. A raster map showing the value of soil depth for each of the pixel of the watershed has been generated by ordinary Krigging operation. The slicing operation has been performed to determine the distribution of each class depth in the watershed and the soil depth map is given in Fig. 8.2. The area which falls under each soil depth class in the watershed has been presented in Table 8.6.

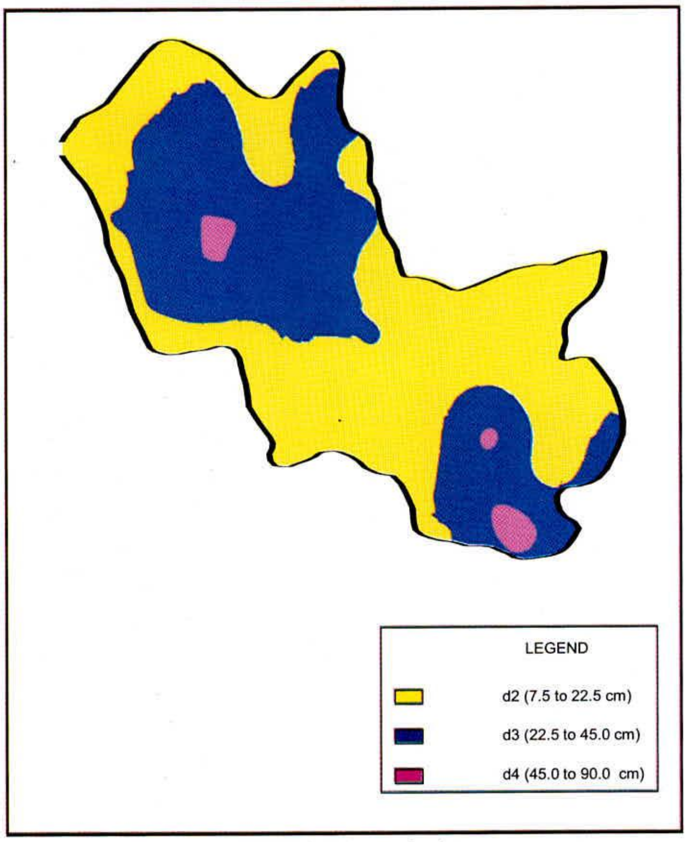


Fig. 8.2: Soil depth variation map

Table 8.6: Distribution of soil depth classes in the Tumri watershed

S.N.	Symbol	Class name	Depth Range (cm)	Area (ha)
1.	d_2	Shallow	7.5 to 22.5	1306.30
2.	d_3	Moderately deep	22.5 to 45.0	1035.00
3.	d_4	Deep	45.0 to 90.0	51.98

8.3.3 Slope classification map

For preparation of slope classification of map, the digital elevation map (DEM) of the watershed has been used and slicing operation performed to determine the distribution of different slope classes in the watershed. The slope classification map of the watershed has been presented in the Fig. 8.3. The slope in the Tumri watershed varies from 0% to 33% with slope classes varying between A and G. The distributions of different slope classes in the watershed have been presented in Table 8.7. From the analysis of slope classes, it can be seen that the topography of the watershed is highly undulating and nearly 84 % area of watershed falls in slope group C to F.

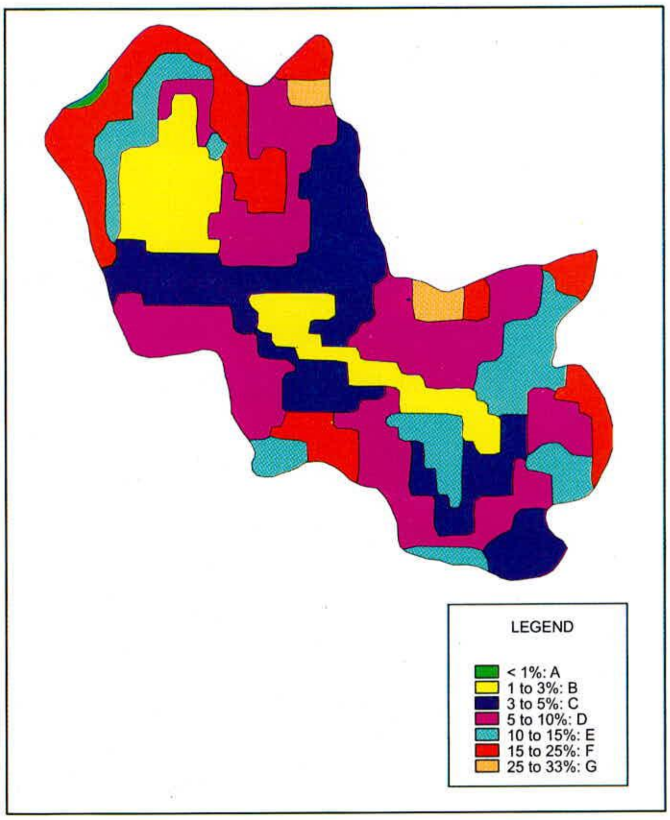


Fig. 8.3: Slope class map

8.3.4 Erosion class map

A detailed survey of the watershed has been carried out to ascertain the erosion status. The Tumri watershed is a degraded watershed and the erosion from forested area is moderate, while the cropping land is affected by severe erosion. The erosion is more from agriculture area because most of agricultural in the watershed is being taken up in the river bed or near the river tributaries without any soil

Table 8.7: Distribution of slope classes in the Tumri watershed

S. N.	Symbol	Name	% Slope	Area (hectare)
1.	A	Nearly level	0 to 1	6.64
2.	B	Gently sloping	1 to 3	321.03
3.	C	Moderately sloping	3 to 5	539.64
4.	D	Strongly sloping	5 to 10	757.35
5.	E	Moderately steep	10 to 15	331.33
6.	F	Steep	15 to 25	392.09
7.	G	Very steep	25 to 33	43.19

conservation measures. The watershed has abundant barren areas, where most of the top soils have been removed and rocky outcrops are visible. The area under various erosion classes is given in Table 8.8 and distribution map of the erosion classes in the watershed is given in Fig. 8.4.

Table 8.8: Distribution of erosion classes in the Tumri watershed

S. N.	Symbol	Erosion Phase	Area (hectare)	Percentage
1.	e_2	Moderate (sheet and rill)	993.33	41.54
2.	e_3	Severe (sheet, rill and small gullies)	847.47	35.43
3.	e_4	Very severe (shallow gullies)	550.48	23.02

8.3.5 Permeability class map

In order to obtain the permeability class map of the watershed, infiltration tests using double-ring infiltrometer have been conducted on 14 sites. The sites are well distributed in the watershed and covered all the land uses. Krigging and slicing operation have been performed in ILWIS 3.0 to obtain distribution of different classes of permeability. From the analysis, it has been observed that the permeability classes slow, moderately slow, moderate and moderately rapid classes exist in the watershed. The area under each permeability class is given in Table 8.9. The permeability distribution map of the watershed is given in Fig. 8.5. It has been observed that more than 50% watershed area falls in the category of moderate permeability rate.

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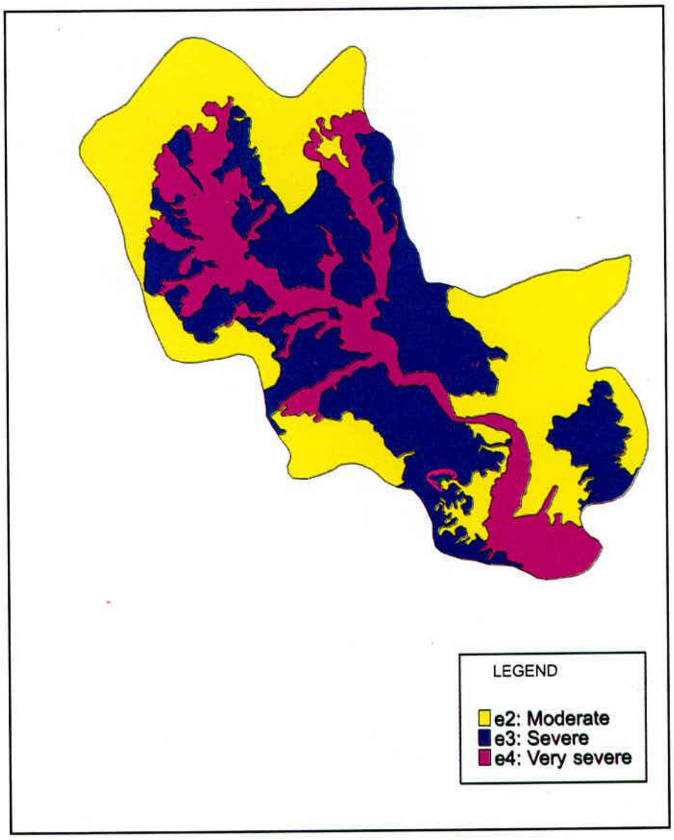


Fig. 8.4: Erosion class map

Table 8.9: Distribution of permeability classes in the Tumri watershed

S. N.	Symbol	Name	Rate of Flow (cm/hr)	Area (hectare)
1.	2	Slow	0.13 to 0.50	5.42
2.	3	Moderately Slow	0.50 to 2.0	954.00
3.	4	Moderate	2.0 to 5.0	1269.85
4.	5	Moderately Rapid	5.0 to 13.0	162.01

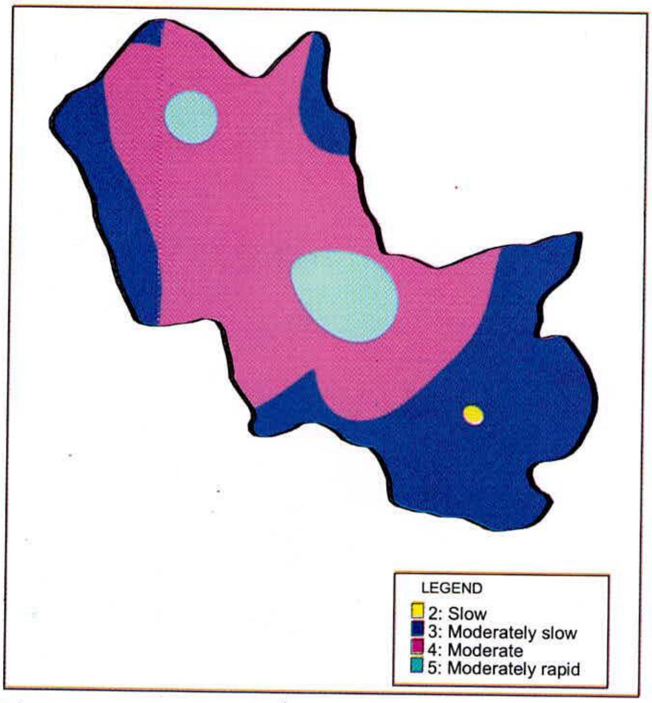


Fig. 8.5: Permeability class map of Tumri watershed

8.3.6 Land capability classification

For determination of land capability classification for the watershed, all maps including soil type, soil depth, slope class, erosion class and permeability maps have been crossed in GIS and using standard check lists and guidelines, a land capability has been assigned to each combination. Class II to VII has been found in the watershed. The area covered under each sub-class is given in Table 8.10. The land capability class map for Tumri watershed has been presented in Fig 8.6.

Table 8.10: Land capability classes

S.N	Land capability class	Area (ha)	S.N	Land capability class	Area (ha)
1.	IIe	178.93	7.	Ve	45.39
2.	IIes	153.50	8.	VIe	271.00

3.	IIIe	218.96	9.	VIes	77.52
4.	IIIes	452.87	10.	VIIe	16.82
5.	IVe	187.73	11.	VIIes	26.07
6.	IVes	762.21			

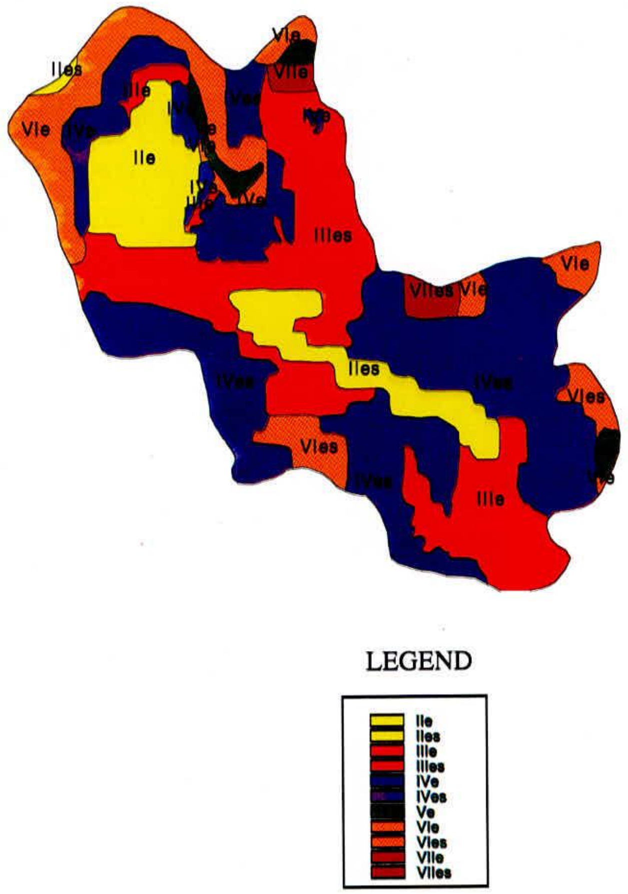


Fig. 8.6: Land capability classification map of Tumri watershed

9.0 ASSESSMENT OF SOIL EROSION

Soil erosion in India has been severe for centuries, but its impact on regional and national economy has only been acutely felt during recent decades. The high rate of population growth, both human and livestock has resulted in over exploitation of natural resources to meet the ever increasing demand for food, fodder and fuel. The increased competition on the same lands for these essentials is resulting in widespread damage to forests, pastures, and wastelands as well as to fallow and agricultural lands. Recent observations in India have brought to light the alarming fact that degradation of the watersheds is on manifold rise leading to watershed deterioration rendering fertile lands barren, reduction in storage capacity of the dams and hence reduction in their operational life. According to information published by Ministry of Agriculture (Govt. of India) in 1980, in India as many as 175 Mha (constituting 53 percent of India's geographical area) is subject to environmental degradation. In a recent overview of global erosion and sedimentation, Pimentel et al. (1995) state that more than 50% of the world's pasturelands and about 80% of agricultural lands suffer from significant erosion (Balakrishnan, 1986).

9.1 Methodology

In the present study, the Universal Soil Loss Equation (USLE), which is a well-known model for soil loss estimation from a watershed, has been used. The data storage and analysis was done using ILWIS 3.0.

9.1.1 The USLE model

Effective control of soil erosion requires ability to predict the amount of soil loss, which would occur under alternate management strategies and practices. The model with the greatest acceptance and usage is the USLE model developed by Agriculture Research Services (ARS) scientists W. Wischmeier and D. Smith. While newer methods are now becoming available, most are still founded upon principles of USLE. The USLE states that the field soil loss in tons per hectare, A, is the product of six causative factors as given by Eqn. 9.1.

$$A = RKLSCP \qquad \ldots\ldots. (9.1)$$

where, $R =$ rainfall erosivity index, $K =$ soil erodibility factor, $L =$ length of slope factor, $S =$ degree of slope factor, $C =$ cropping-management factor, $P =$ conservation practice factor, the R-term characterizes the level of attacking forces while the remaining terms characterize the level of resisting forces.

9.1.1.1 Rainfall erosivity index, R

The rainfall erosivity index implies a numerical evaluation of rainfall pattern, which describes its capacity to erode soil from an unprotected field. The various intensities involved in a specific rain, i.e., antecedent climatic and surface conditions, interaction effects, and extraneous variable all influence the erosion potential of a storm. Keeping the soil and slope parameters constant, studies indicated that the valuable combination of indicators of erosion loss from fallow soil is rainfall energy, a product term which measures the interaction effect of storm energy and maximum prolonged intensity, antecedent moisture index and total antecedent rainfall energy since the last tillage operation.

In India, simple relationship between erosivity index (R) and annual or seasonal rainfall (X) has been developed by Singh et al, 1981 after analyzing the data collected from 45 stations distributed in different rainfall zones throughout the country. The relationship can be expressed by the Eqn. 9.2 and Eqn. 9.3.

$$R_a = 79 + 0.363X_a \qquad \text{.......} \quad (9.2)$$

$$R_s = 50 + 0.389X_s \qquad \text{.......} \quad (9.3)$$

where, R_a = annual erosivity index, R_s = seasonal erosivity index, X_a =average annual rainfall (mm), X_s = average seasonal rainfall (mm)

9.1.1.2 Soil erodibility factor, K

The K factor, quantifies the cohesive character of soil type and its resistance to dislodging and transport due to raindrop impact and overland flow shear forces. The soil erodibility factor, as described by Wischmeier and Smith (1965) is a function of complex interaction of a substantial number of its physical and chemical properties. Even a soil with a relatively low erodibility factor may show signs of serious erosion when it occurs on longer or steep slopes or in localities with numerous high intensity rainstorms. Soils with a high natural erodability factor, show little evidence of actual erosion under gentle rainfall, or when the best possible management is practiced. For a particular soil, the erodibility factor K, is the rate of erosion per unit of erosion index from a standard plot of

22.13 m long under continuous fallow and tilled parallel to the uniform slope of 9 percent.

Investigations on the effects of the soil texture on erosion processes have shown that sandy soils are least susceptible to erosion (Holy, 1980). But clayey soils with low permeability have high content of colloidal particles and show a high level of consistency, and due to their cohesiveness character, they are resistant to detachment. Under situations where details of soil information are not available, Table 9.1 may be used. Knowing the organic matter content and textural class of the soil, the magnitude of soil erodability can be found.

Table 9.1: Soil erodibility factor (adapted from Vladimir et al, 1981)

Textural Class	Organic Matter Content (%)		
	< 0.5	2.0	4.0
Sand	0.05	0.03	0.02
Fine Sand	0.16	0.14	0.10
Very Fine Sand	0.42	0.36	0.28
Loamy Sand	0.12	0.10	0.08
Loamy Fine Sand	0.24	0.20	0.16
Loamy Very Fine Sand	0.44	0.38	0.30
Sandy Loam	0.27	0.24	0.19
Fine Sandy Loam	0.35	0.30	0.24
Very Fine Sandy Loam	0.47	0.41	0.35
Loam	0.38	0.34	0.25
Silt Loam	0.48	0.42	0.29
Silt	0.60	0.52	0.42
Sandy Clay Loam	0.27	0.25	0.21
Clay Loam	0.28	0.25	0.21
Silty Clay Loam	0.37	0.32	0.26
Sandy Clay	0.14	0.13	0.12
Silty Clay	0.25	0.23	0.19
Clay	0.13 to 0.20		

9.1.1.3 The topographic factor, LS

Steeper slopes produce higher overland flow velocities and longer slopes accumulate runoff from larger areas and also result in higher flow velocities. Thus, both result in increased erosion potential, but in a non-linear manner. Length of slope factor (L) is the ratio of soil loss from field slope length to that from a 22.13 m long plot on the field in meters. Value of the exponent is variable (0.2 to 0.5) and very rarely 0.9 for different locations and other conditions, average value being 0.5. Eqn. 9.4 is used for the computation of the length of slope factor given by,

$$L = \left(\frac{\lambda}{22.13} \right)^{0.50} \qquad \text{....... (9.4)}$$

Degree of slope factor (S) is the ratio of soil loss on actual gradient to that from 9% slope under otherwise identical conditions. Eqn. 9.5 suggested by Wischmeier and Smith (1965) has been used for evaluating the slope gradient factor,

$$S = \frac{\left[0.43 + 0.30G + 0.43G^2\right]}{6.613} \qquad \text{....... (9.5)}$$

where, G is the slope gradient in percent. For convenience L and S are frequently lumped into a single term. In the present study, Eqn. 9.6 defining the LS factor was used as given below,

$$LS = \left(\frac{\lambda}{22.13} \right)^{0.5} * \left[0.065 + 0.045G + 0.0065G^2\right] \qquad \text{....... (9.6)}$$

where, LS = slope length and slope gradient factor, λ = slope length (m,; G = slope gradient in percent

9.1.1.4 Cropping management factor, C

The C-factor is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. It measures the combined effect of vegetation cover and management variables. The vegetation cover protects the soil surface from direct impact of the falling raindrops and enhances the degree of infiltration, maintains roughness of the soil surface, slows down surface runoff, binds soil mechanically by root effects and improves physical, chemical and biological properties of soil. In most cases, the value of C is not constant over the year.

The effectiveness of plant cover in reducing erosion depends upon the height and continuity of the canopy, the density of ground cover and the root density. Meszek et. al., (1975) concluded that the forest with a dense canopy, good undergrowth and undisturbed litter have the most significant effect on the surface runoff and thereby on the intensity and course of erosion. Jaiswal (1982) determined the cropping management factor for different land use patterns in the Gagas sub-watershed of Upper Ramganga catchment and values of crop management factors proposed by him are listed below,

1. Cropland	0.32
2. Hay land and grazing land	0.21
3. Reserve forest and wood land	0.02
4. Rokhar and miscellaneous	1.00

Singh et. al., (1981) presented various experimental results conducted in India. The crop management factor obtained for some major crops by Gurmel Singh et. al., is given in Table 9.2.

9.1.1.5 Conservation practice factor, P

The conservation practice factor, P in the USLE model is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture. Practices included in this term are contouring, strip cropping and terracing. As a thumb rule, contouring reduces to one-half the soil loss caused by up-and-down hill farming, strip cropping to one-half that of contouring, and terracing to one-half that of strip cropping. The value of P ranges from 1.0 for up and down cultivation to 0.25 for contour strip cropping on gentle slope. In computing the P factor, only the cultivated area of the watershed is considered. Based on the results of intensive studies from runoff plots Wichmeier and Smith (1978) suggested the P factor values for various slopes as given in Table 9.3.

Table 9.2: Crop management factor at various locations in India

CROPS	A	B	C	D	E	F	G
Moong	0.27						0.45
Ground nut	0.19	0.41					0.42
Cowpea	0.16	0.39		0.17			
Green gram		0.39					
Black gram		0.54					
Soyabeen		0.42					
Guar		0.59	0.42				0.35
Maize		0.50		0.35	0.54		
Johar		0.62				0.64	
Johar + Arhar		0.33					0.28
Natural cover		0.14				0.12	
Fallow		1.0			1.0	1.0	1.0
Til		0.51					0.39
Bajra		0.61				0.40	
Paddy			0.28				
Pigeonpea			0.38				
Pomegranate with weed					0.08		
Pomgranate clean					0.56		

A: Vasad B: Kota C: Agra D: Kharagpur E: Dehradun F: Hyderabad G: Rehmankhera

Table 9.3: Conservation practice factor for different slopes

S. No.	Slope %	'P' value	Max. slope length
1.	1.0 – 2.0	0.60	131.2
2.	2.0 – 5.0	0.50	98.4
3.	5.0 – 8.0	0.50	65.6
4.	8.0 – 12.0	0.60	39.4
5.	12.0 – 16.0	0.70	26.2
6.	16.0 – 30.0	0.80	19.7
7.	20.0 – 25.0	0.90	16.4

9.2 Analysis and Results

The Universal Soil Loss Equation for estimation of soil erosion from a watershed area requires data on rainfall, soil, land use and land cover, degree of slope, length of slope, cropping pattern, and conservation practices followed in the agricultural fields. These data were collected from various departments/organizations in both spatial and non-spatial format. The spatial data input was done through digitization of maps collected from various user organizations and stored in ILWIS 3.0. The non-spatial data information was stored as tables and was converted into map form by attributing the related thematic maps to these tables.

9.2.1 Base map

A base map has been generated by digitizing the Survey of India (SOI) toposheet as reference map for all other purposes. The watershed is covered by 1:50,000 scale SOI topographic maps No. 54 L/ 15, 16. The watershed boundary was marked on the basis of the contours and the drainage lines available on the SOI topographic map. The map was polygonised and converted into raster format assigning the pixel size as that of IRS 1D LISS-III merged with Pan georeferenced digital data, i.e., 6.036 m. The total geographical area of the watershed is 2391.28 hectares including water spread area of 7.23 ha.

9.2.2 Rainfall

The annual rainfall data recorded at Kesli block near the watershed was used to compute the rainfall factor using the Eqn. 9.2. A table containing the rainfall factor, 'R' and raingauge station was then created and attributed with the rainfall polygon map to create the rainfall factor map and is given in Fig. 9.1. The geographical area covered by rain gauge station, rainfall and rainfall factor is given in Table 9.4.

Table 9.4: Rainfall factor in Tumri watershed

Raingauge station	Area (ha)	Rainfall factor
Kesli	2391.28	527.156

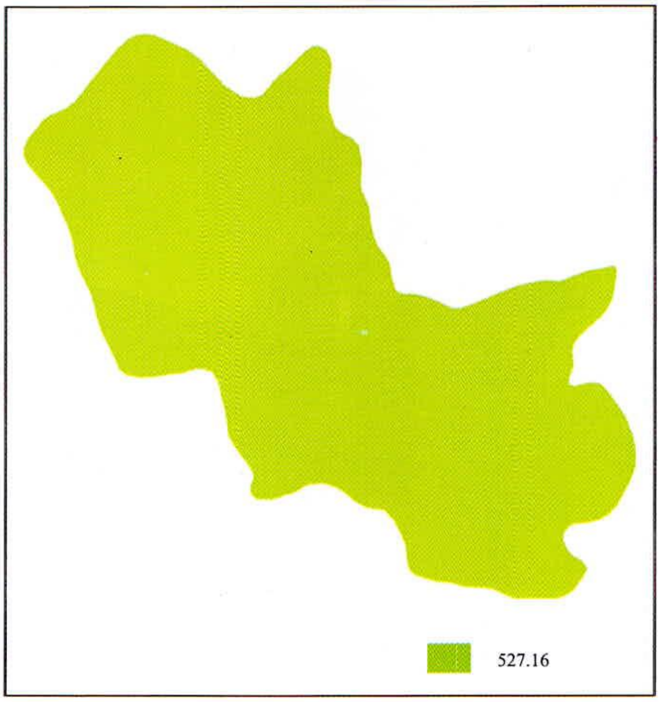


Fig 9.1: R-factor map of Tumri watershed

9.2.3 Soils

The soil map of Madhya Pradesh published by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Indian Council of Agricultural Research (ICAR), Government of India, Nagpur pertaining to the study area along with the actual soil information collected from the field observations was digitized in ILWIS 3.0 to prepare the soil map of the watershed. Three categories of soils predominant in the study area are clayey loam, fine sandy loam and sandy soil with gravels. The information on soil classification and organic matter contents were taken from the report on 'Soils of Madhya Pradesh for Optimizing Land Use' and 'Soil Series of India' published by NBSS&LUP. The organic matter (OM) contents in these soils are reported about 2%. The soil map was attributed to the table containing 'K' factor values to generate the 'kfactor' map. Fig. 9.2 shows the soil map and value of 'K' factor and the geographic area falling under each soil class has been given in Table 9.5.

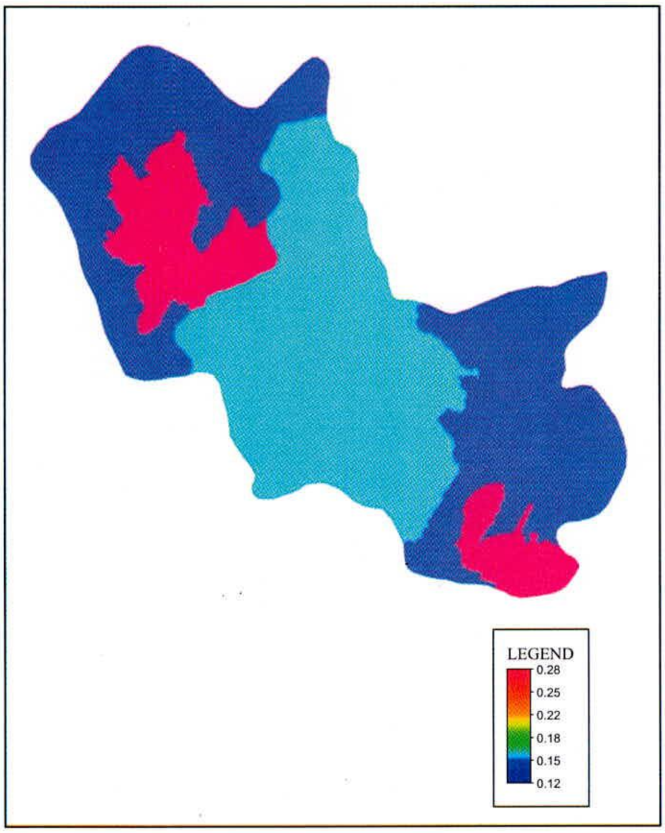


Fig 9.2: K-factor map of Tumri watershed

Table 9.5: Distribution of soil class and 'K' value in Tumri watershed

Soil class	Area (ha)	Area (%)	K-factor
Clayey loam	349.91	0.15	0.28
Fine sandy loam	1097.12	0.46	0.12
Sandy soil with gravel	944.27	0.39	0.05

9.2.4 Topography

Contour lines and spot heights given in the Survey of India topographic maps is the only source of information on topography of the study area. The contour lines were drawn on the topographic maps at 20 m intervals, but on undulating lands 10 m interval contour lines were also marked. These contours were digitized and the corresponding contour values were assigned. The spot height given in the SOI toposheets were also digitized and the Digital Elevation Model (DEM) map, was generated by interpolation operation in ILWIS 3.0.

The slope percentage of DEM map is also computed by considering the slope length to be same as the pixel size, i.e. 6.036 m for the calculation of 'L' factor. 'L' factor map was calculated using the Eqn. 9.4 by putting the value of the slope length and value of exponent as 0.20 to 0.60 for varying degrees of slope percentages and stored as 'L factor' in raster format and is shown in Fig. 9.3. The slope factor map, 'S' map was computed using Eqn. 9.5 by putting the value of the degree of slope and stored as 'S factor' in raster format and is shown in Fig. 9.4. The topography of the watershed is largely undulating with small hillocks and deep valleys at many places. The average slope of the watershed is 13 percent with maximum value of 46 percent. 1% of the total geographical is having 0 – 1 percent slope, 11% is having 1 – 3 percent slope, 24% is

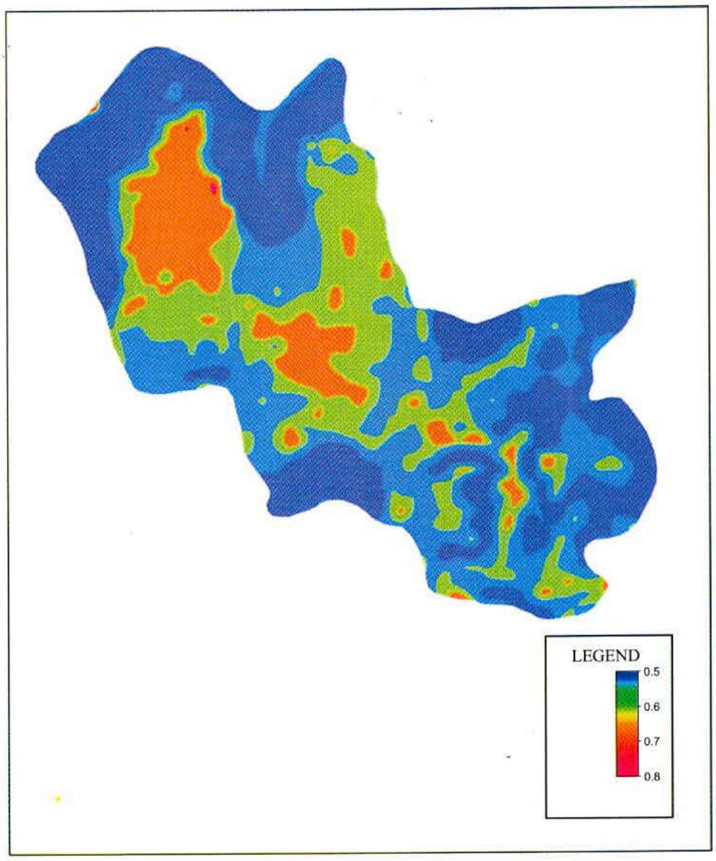


Fig 9.3: L-factor map of Tumri watershed

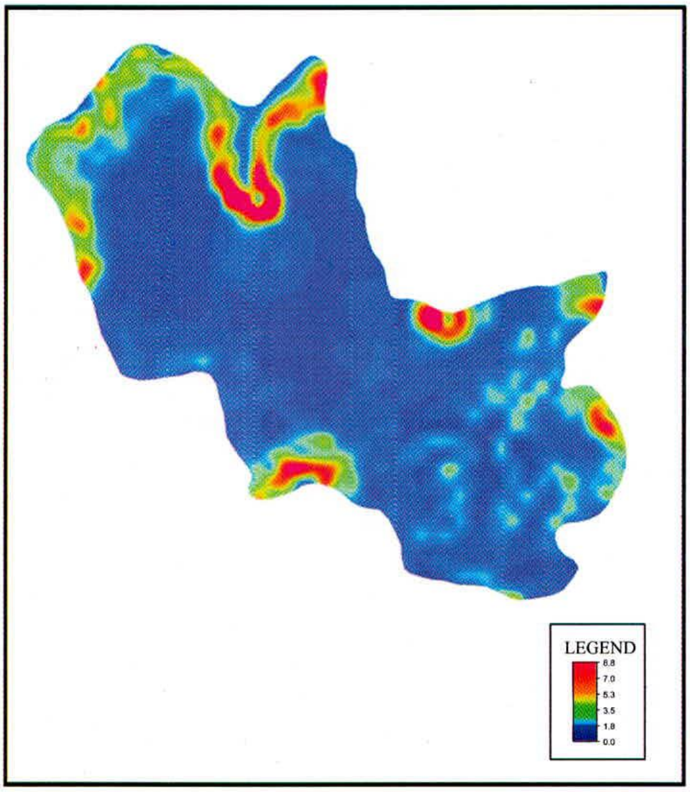


Fig 9.4: S-factor map of Tumri watershed

having 3-5 percent slope, 31% is having 5-10 percent slope and the rest 33% of the total geographical area is having more than 10 percent slope.

9.2.5 Land use

IRS 1D LISS-III merged with Pan geo-referenced satellite data was used for digital analysis and digital image processing of the satellite data was carried out to prepare the land use as explained in detail in Chapter 7 and the land use map is given in Fig. 7.2. For Indian conditions, Jaiswal (1982) and Singh et. al (1981) suggested the values of 'C' factor based on the field experiments conducted all over the country. The spatial distribution of all the land use classes along with the C-factor for the watershed is given in the Table 9.6. The land use map was attributed to Table 9.6 to create 'cfactor' map and the map thus generated is given in Fig. 9.5.

Table 9.6: Land use distribution Tumri watershed and 'C' factor

Land use class	Area (Sq. km.)	Area (%)	'C' factor
Agriculture	540.15	22.59	0.42
Barren land	706.14	29.53	1.00
Open forest	521.90	21.83	0.09
Dense forest	587.98	24.59	0.14
Water bodies	7.23	0.30	0.009
Built up areas	27.93	1.17	0.024

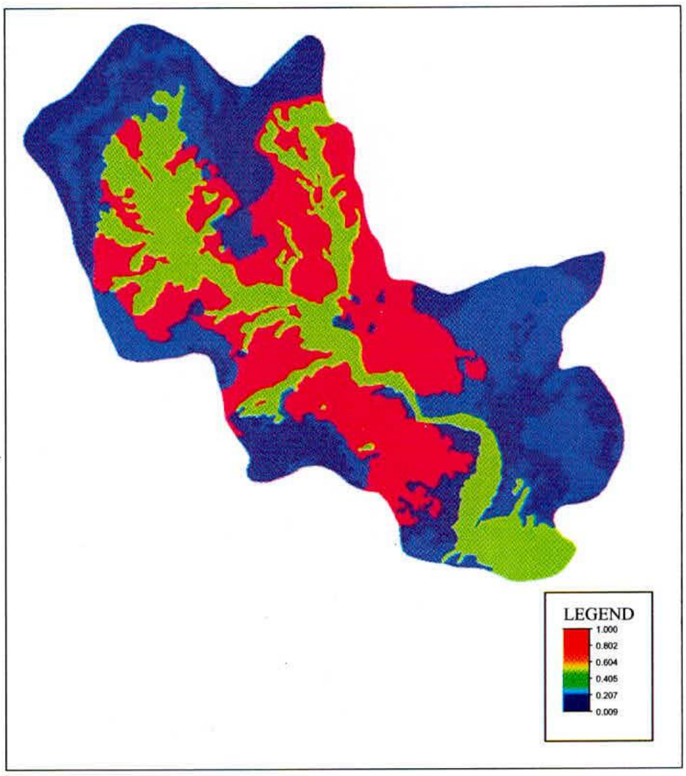


Fig 9.5: C-factor map of Tumri watershed

9.2.6 Conservation practice factor, P

The cultivators of the study area do not adopt any specific conservation practices in the agricultural fields and 'P' values have been assigned based on slope percent of the agricultural land. The agricultural lands were masked out from the land use map of Tumri watershed and values for 'P' factor were assigned according to the slope percentage of the agricultural land as shown in the Table 9.3. The non-agricultural lands (forest, scrub/bushes and barren/grazing land) were assigned value 1.0 for 'P' factor and the dense forested areas were assigned the value of 0.80 for 'P' factor. After assigning the 'P' factor values for agricultural and non-agricultural lands, the slope map was classified and attributed to P-factor values to create P-factor map and is given in Fig. 9.6.

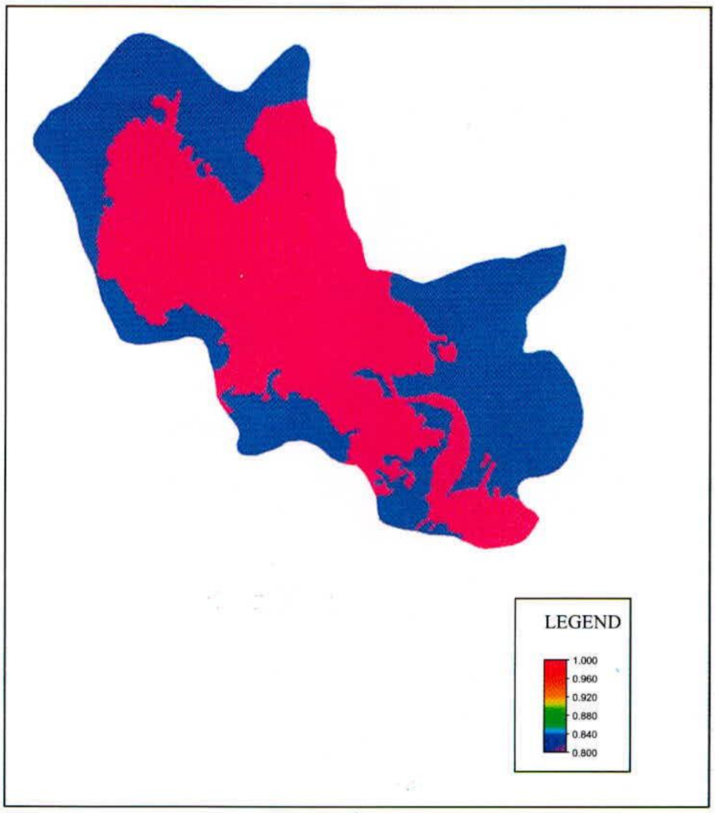


Fig 9.6: P-factor map of Tumri watershed

9.2.7 Calculation of expected soil loss (A)

All the factors required for soil erosion estimation as given in Eqn. 9.1 have been computed and stored as thematic maps in raster format. These maps are then multiplied together to generate the soil erosion map. The total soil loss from the watershed has been estimated by collecting histogram of the erosion map. Similarly, the geographical areas under different categories of erosion were then calculated by collecting histogram of the classified map. The sensitivity analysis was also done by assigning the barren land with forest cover; agricultural lands with good management practices, etc. to see the changes in the quantity of soil erosion from the watershed. This analysis is useful for planning the watershed management practices, such as afforestation, contour bunding, gully plugging, etc. The average soil erosion from the watershed is 14.60 t/ha/yr. The expected soil loss from the watershed before taking up conservation measures for various types of land uses is given in Table 9.7. The barren land is facing the maximum erosion of 34.56 t/ha/yr.

Table 9.7: Expected soil loss from various land use classes

Land use	Area (ha)	Average R-factor	Average K-factor	Average L-factor	Average S-factor	Average C-factor	Average P-factor	Erosion t/ha/yr
Agriculture	540.13	527.16	0.22	0.61	0.50	0.42	1.00	14.78
Barren	706.12	527.16	0.16	0.56	0.73	1.00	1.00	34.56
Built-up	27.92	527.16	0.26	0.53	0.75	0.02	1.00	1.30
Dense forest	587.83	527.16	0.13	0.50	3.31	0.011	0.80	0.97
Open forest	521.76	527.16	0.12	0.52	1.51	0.09	0.80	3.68
Water bodies	7.23	527.16	0.16	0.53	0.54	0.009	1.00	0.22

The expected soil loss map was further classified into defined groups of erosion intensities to create the classified soil loss map and is presented in Table 9.8. The soil erosion map shown in Fig. 9.7 gives the distribution of various categories of expected soil loss over the watershed.

Table 9.8: Expected soil loss from Tumri watershed (classified)

S. No.	Erosion rate tons/ha/year	Erosion Class	Area (Hectare)	Percent to Total Area
1	< 2.5	Low	892.71	37.33 %
2	2.5 – 10.0	Moderate	432.73	18.10 %
3	10.0 – 20.0	High	514.96	21.53 %
4	> 20.0	Very high	550.88	23.04 %

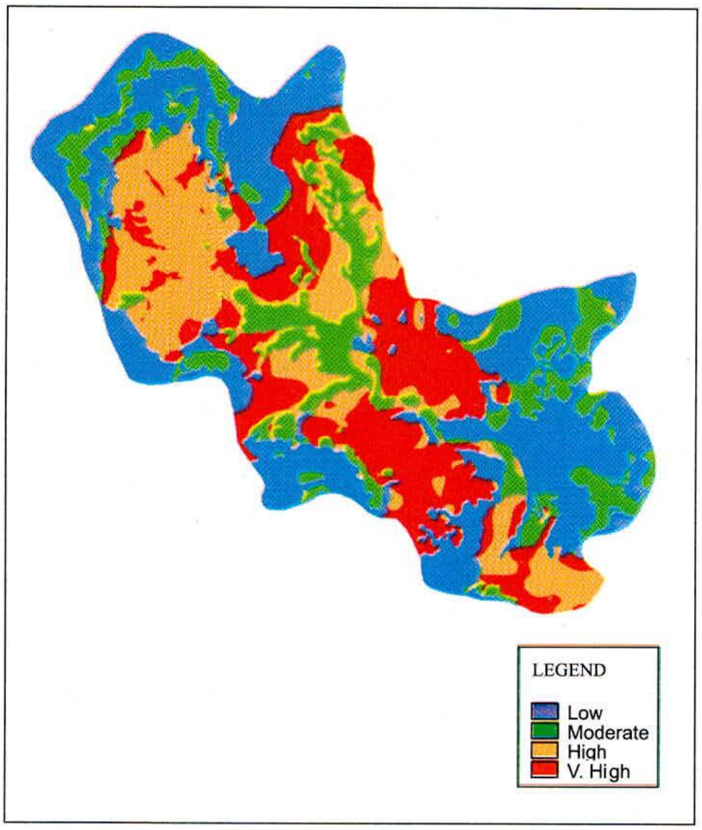


Fig. 9.7: Soil erosion map of Tumri watershed

9.2.8 Comparison of Results

Two empirical relations to estimate the quantity of sediment likely to deposit in the proposed reservoir, namely Joglekar's curve (Joglekar, 1960 & 1965) and Khosla's method (Khosla, 1953) were used to compare the results obtained form USLE model.

9.2.8.1 Soil erosion by USLE

The average rate of soil loss as estimated from USLE model in the Tumri watershed is 14.60 t/ha/yr and the annual soil loss is 34912.69 t/yr. This value can be converted in terms of volume by dividing with the specific gravity of the sediment load, (1.05 t/m^3). Thus, the total soil volume lost from the watershed is estimated to be 33250.18 m^3/year.

9.2.8.2 Joglekar's curve

Joglekar analyzed the data from the reservoirs located in Central India, Maharashtra and Vidarbha region and gave an equation of an enveloping curve given as,

$$Q_s = \frac{0.597}{A^{0.24}} \qquad \text{....... (9.7)}$$

where, Q_s = annual silting rate from 100 sq. km of watershed area (Mm^3/100sq. km), A = watershed area (sq. km)

for Tumri watershed, A = 23.91 sq. km, therefore

Q_s = 0.278686 Mm^3/100sq.km/year or 66633.83 m3/year or 69965.53 tons/year

(assumed sediment density: 1050 kg/m^3)

9.2.8.3 Khosla's method

Khosla analyzed the data from various reservoirs in India and abroad and observed that the annual rate of sediment deposition decreased with the age of reservoirs and plotted a curve between the annual sediment deposited and watershed area and suggested the following empirical formula given in Eqn. 9.8 as,

$$Q_s = \frac{0.323}{A^{0.28}} \qquad \text{....... (9.8)}$$

By applying the Khosla's formula, the annual sediment deposit for Tumri watershed was found to be

Q_s = 0.132801 Mm^3sq. km/year or 31752.64 m^3/year or 33340.27 tons/year

Thus the comparison of the expected annual soil loss from the Tumri watershed using USLE, Joglekar's curve and Khosla's formula is given in Table 9.9,

Table 9.9: Comparison of the expected soil loss by various methods

Method used	USLE	Joglekar's curve	Khosla's formula
Soil loss in tons/year	34912.69	69965.53	31752.64

9.3 Impact of Afforestation

The impact of the forest plantations in the Tumri watershed can be analyzed, but the temporal changes cannot be directly modeled in the GIS, but the changes in values of different parameters due to change in land use/land cover can be redefined. Expected soil loss in a watershed may be estimated by assigning the new values for cropping management practices, C-factor and P-factor for assumed alternate land cover. This analysis estimates the revised volume of soil loss if barren lands are converted into various options of land uses depending on the topography and feasibility which will help to estimate the reduction in the soil loss from the watershed.

9.3.1 Land use options for barren land

The land use of Tumri watershed comprises of six major land use classes identified through the digital analysis of the satellite data. The area under barren land is 706.14 ha., which is about 29.5 percent of the study area. Various options of land use have been tried to evaluate the impact of the land use changes on the soil loss from the watershed by changing the barren area into varying land uses. The modified soil loss on trying various options of land use changes is given in Table 9.10. The results indicate that adopting forest plantations in 50% barren lands in the watershed will reduce the soil loss from the current rate of 14.60 t/ha/year to 9.53 t/ha/year. The maximum reduction in soil erosion of about 70% can be achieved if each 50% of the barren lands are converted into pastures and forests.

9.3.2 Sensitivity analysis for various treatment options on agricultural land

The immediate impact of the soil conservation measures can be studied by considering the treatment of the agricultural lands only. The effect of treatment measures on the agricultural lands to arrest the soil erosion has been studied by systematically varying the agricultural area to be treated and evaluating the corresponding soil erosion. The change in soil erosion which can be achieved by adopting treatment measures on agricultural lands is given in Table 9.11. Steps should be initiated for taking up treatment measures to reduce the soil erosion from agricultural lands so that soil depth builds up over a period of time resulting in enhanced moisture retention and increased productivity.

Table 9.10: Change in soil erosion due to change in land use of barren lands

S. No.	Land use options (barren to other types of land use)	Soil erosion (t/ha/yr)	% change
1.	Present land use pattern	14.60	0.00
2.	25 % barren to dense forests	12.07	17.33
	50 % barren to dense forests	9.53	34.73
	75 % barren to dense forests	7.00	52.05
	100 % barren to dense forests	4.47	69.38
3.	25 % barren to pasture	12.06	17.40
	50 % barren to pasture	9.51	34.86
	75 % barren to pasture	6.97	26.71
	100 % barren to pasture	4.42	69.73
4.	25 % barren to agroforestry	12.12	16.99
	50 % barren to agroforestry	9.64	33.97
	75 % barren to agroforestry	7.16	50.96
	100 % barren to agroforestry	4.68	67.95
5.	25 % forested, 25 % pasture, 50 % barren	9.52	34.79
	25 % forested, 25 % pasture, 25 % agro-forestry, 25 % barren	7.07	51.58
	50 % forested, 50 % pasture	4.44	69.59

Table 9.11: Impact of treatment of agricultural areas on soil erosion

S. No.	Area treated (%)	Soil erosion (t/ha/yr)	Erosion reduction (%)	S. No.	Area treated (%)	Soil erosion (t/ha/yr)	Erosion reduction (%)
1.	0	14.60	0.00	7.	60	12.75	12.67
2.	10	14.29	2.12	8.	70	12.45	14.73
3.	20	13.99	4.18	9.	80	12.13	16.92
4.	30	13.68	6.30	10.	90	11.83	18.97
5.	40	13.37	8.42	11.	100	11.52	21.10
6.	50	13.06	10.55				

10.0 ASSESSMENT OF IRRIGATION WATER REQUIREMENT

Many areas around the world suffer from shortages of water due to the rapid growth of population, commercial and industrial activities but the agricultural sector usually holds the largest share of the water rights and becomes the target of other sectors when it comes to the issue of regional water supply reallocation. Irrigation consumes over 70% of the world's total water supplies (Seckler et al. 1999) and water requirement of crops depends on the climate and the type of crop. More water is required to produce crops in the arid region than in the humid region and paddy and sugarcane require much larger amount of water than finger millet and pearl millet.

There is actually a huge amount of data involved in estimating irrigation water demand, such as the soil, crop, climate, water distribution infrastructures, management practices and most of these related data are spatially distributed. Since these spatial complexities are very difficult to handle, they are usually combined into aggregated forms. Traditionally, irrigation water demand estimations have had to assume a particular soil type for each crop due to a lack of data (Knox et al. 1996). Average soil characteristics are used regardless of any non-uniform field soil distribution. The capture and management of the spatial variations in related data such as soil, climate, crops, and canal networks is the key to effective and efficient irrigation water demand estimations. The accurate estimation of irrigation water demand is also essential for developing a rational policy for sustainable water resources.

10.1 Methodology

GIS based analysis of the satellite data was used to identify the cropping pattern and its distribution along with the data provided by the Agriculture Department, Kesli in order to estimate irrigation requirements. The irrigation requirements were estimated as the difference between crop evapotranspiration and effective rainfall. Crop evapotranspiration have been evaluated as the product of reference evapotranspiration and the crop coefficient, while the reference evapotranspiration have been calculated using the FAO Penman-Monteith method. This entire consumptive use requirement needs to be satisfied but some of the requirement is partly met by the rainfall occurring during the crop growth period. Monthly effective rainfall was estimated from total monthly rainfall using method developed by the USDA Soil Conservation Service.

10.1.1 Crop evapotranspiration

Crop evapotranspiration have been evaluated as the product of reference evapotranspiration and the crop coefficient whereas the reference evapotranspiration have been calculated using the FAO Penman-Monteith method which is the sole standard method as suggested by FAO for estimating crop water requirements. It is a method with strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has provision for application in data-short situations and is given in detail in Chapter 7. The crop evapotranspiration have been worked out on a ten-daily basis generally considering various growth stages of the crop. The crop coefficients for the different crops which vary during the various stages of the crop growth have been used along with the Penman-Monteith (FAO) reference crop evapotranspiration values to arrive crop evapotranspiration for each of the ten-daily period. The total crop evapotranspiration is arrived at by summing up the ten-daily crop evapotranspiration over the entire crop period. The village-wise crop evapotranspiration is then added to get the total crop evapotranspiration for the study area for a particular crop.

10.1.2 Effective rainfall

The evaluation of effective rainfall involves measuring rainfall and/or irrigation losses to surface runoff, percolation losses beyond the root zone and the soil moisture uptake by the crop for evapotranspiration. Information is needed on rooting depth of crops. The analysis of the effective rainfall has been carried out on the basis of U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) method which has developed a procedure for estimating effective rainfall by processing long term climatic and soil moisture data. From total rainfall and monthly consumptive use, effective rainfall values were computed as given in Table 10.1. The monthly effective rainfall cannot exceed the rate of consumptive use and if it does, the lower value of the two is taken. The correction factor to be used when the net depth of water that can be stored in the soil at the time of irrigation is greater or smaller than 75 mm, is given in Table 10.2.

Table 10.1: Average monthly effective rainfall (USDA-SCS)

Monthly mean rainfall (mm)	Mean monthly consumptive use (mm)													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Mean monthly effective rainfall (mm)													
12.5	7.5	8	8.7	9	9.2	10	10.5	11.2	11.7	12.5	13	13	13	13
25	15	16.2	17.5	18	18.5	19.7	20.5	22	24.5	25	25	25	25	25
37.5	22.5	24	26.2	27.5	28.2	29.2	30.5	33	36.2	37.5	38	38	38	38
50	25	32.2	34.5	35.7	36.7	39	40.5	43.7	47	50	50	50	50	50
62.5	at 41.7	39.7	42.5	44.5	46	48.5	50.5	53.7	57.5	62.5	63	63	63	63
75		46.2	49.7	52.7	55	57.5	60.2	63.7	67.5	73.7	75	75	75	75
87.5		50	56.7	60.2	63.7	66	69.7	73.7	77.7	84.5	88	88	88	88
100		at 80.7	63.7	67.7	72	74.2	78.7	83	87.7	95	100	100	100	100
112.5			70.5	75	80.2	82.5	87.2	92.7	98	105	111	112	112	112
125			75	81.5	87.7	90.5	95.7	102	108	115	121	125	125	125
137.5			at 122	88.7	95.2	98.7	104	111	118	126	132	137	137	137
150				95.2	102	106	112	120	127	136	143	150	150	150
162.5				100	109	113	120	128	135	145	153	160	162	162
175				at 160	115	120	127	135	143	154	164	170	175	175
187.5					121	126	134	142	151	161	170	179	185	187
200					125	133	140	148	158	168	178	188	196	200
225					at 197	144	151	160	171	182				
250						150	161	170	183	194				
275						at 240	171	181	194	205				
300							175	190	203	215				
325							at 287	198	213	224				
350								200	220	232				
375								at 331	225	240				
400									at 372	247				
425										250				
									at	412				
450	25	50	75	100	125	150	175	200	225	250				

Table 10.2: Correction factor for effective rainfall

Effective storage	20	25	37.5	50	62.5	75	100	125	150	175	200
Storage factor	0.73	0.77	0.86	0.93	0.97	1.00	1.02	1.04	1.06	1.07	1.08

10.1.3 Irrigation water requirement

The net irrigation water requirement for each of the crop during the various stages of the crop growth on a ten-daily basis has been arrived at by deducting the effective rainfall from the evapotranspiration requirements of the respective crop as given in Eqn. 10.1.

$$NIR = C_{use} - Eff_{rain} \qquad \text{....... (10.1)}$$

where, NIR = net irrigation requirement, C_{use} = consumptive use requirements, Eff_{rain} = effective rainfall

The gross irrigation requirement is derived by dividing the net irrigation requirement by the field channel efficiency and conveyance losses. The field channel efficiency is considered as 0.70 whereas the conveyance losses are taken as 0.80. The gross irrigation requirement is computed by Eqn. 10.2 given as,

$$GIR = \frac{NIR}{\eta_f * \xi_c} \qquad \text{....... (10.2)}$$

where, GIR = gross irrigation requirement, η_f = field channel efficiency, ξ_c = conveyance losses

10.2 Analysis & Results

10.2.1 Crop evapotranspiration

The evapotranspiration from cropped areas have been computed by the Penman-Monteith equation and have been worked out on a ten-daily basis generally considering four growth stages of the crop namely, initial stage, development stage, growth stage and the final stage. The total crop evapotranspiration is arrived at by summing up the ten-daily crop evapotranspiration over the entire crop period. The village-wise crop evapotranspiration is then added to get the total crop evapotranspiration for the study area for a particular crop. The reference evapotranspiration ET_o has been evaluated and is given in Table 10.3.

Table 10.3: Climate and reference crop ET_o data

Month	Maximum temperature (deg.C)	Minimum temperature (deg.C)	Humidity (%)	Wind speed (km/d)	Sunshine (Hours)	Solar radiation (MJ/m2/d)	ET_o (mm/d)
January	24.4	11.4	44.5	81.6	7.9	15.4	2.7
February	27.1	13.5	39.5	105.6	8.6	18.3	3.73
March	32.7	18.5	25	105.6	8.7	20.8	4.91
April	38	23.4	21	100.8	9	22.9	5.84
May	40.8	26.2	42.5	146.4	8.8	23.2	6.99
June	37.7	25.5	65	156	6.4	19.6	5.69
July	30.6	23.4	84	153.6	4.5	16.7	3.88
August	28.7	22.6	81.5	124.8	4.6	16.4	3.65
September	30.6	22.2	72	108	6.2	17.7	4.02
October	32	20.2	48.5	64.8	8.1	18.3	3.75
November	28.9	16.2	37.5	67.2	8.4	16.4	2.99
December	25.4	12.6	33	48	7.8	14.6	2.18

10.2.2 Effective rainfall

The effective rainfall for the watershed has been worked out on the basis of USDA-SCS method using Table 10.1 & Table 10.2.

10.2.3 Irrigation water requirement

The net irrigation water requirement for each crop during the various stages of the crop growth on a ten-daily basis has been arrived at by using Eqn. 10.1. The requirement is then worked out village-wise and summed up to get the total net irrigation water requirement during the various stages of the crop growth. The computations for the irrigation water requirement of Jowar crop is given in Table 10.4.

Table 10.4: Irrigation water requirement for Jowar (cu. m)

Mon	Stage	Crop Coeff.	Et_o	Et_{crop}	Effective rainfall	NIR	NIR all villages (cu. m)
(deca day)			(mm/ day)	(mm/dec aday)	(mm/decaday)	(mm/deca day)	
I-Jul	Initial	0.40	3.88	15.52	15.52	0.00	0.0
II-Jul	Initial	0.40	3.88	15.52	15.52	0.00	0.0
III-Jul	Develop	0.48	3.88	18.62	18.62	0.00	0.0
I-Aug	Develop	0.64	3.65	23.36	23.36	0.00	0.0
II-Aug	Develop	0.81	3.65	29.57	29.57	0.00	0.0
III-Aug	Develop	0.97	3.65	35.41	35.41	0.00	0.0
I-Sep	Growth	1.05	4.02	42.21	20.84	21.37	4666.9
II-Sep	Growth	1.05	4.02	42.21	20.84	21.37	4666.9
III-Sep	Growth	1.05	4.02	42.21	20.84	21.37	4666.9
I-Oct	Late	0.96	3.75	36.00	0.00	36.00	7863.0
II-Oct	Late	0.78	3.75	29.25	0.00	29.25	6388.7
III-Oct	Late	0.5	3.75	18.75	0.00	18.75	4095.3
Total							32348

The net irrigation water requirement for each crop in the kharrif and rabi season have been computed village-wise and summed up to arrive at the net irrigation requirement for the watershed on a ten-daily basis. The gross irrigation requirement is computed by Eqn. 10.2. The crop-wise irrigation water requirement during kharrif and rabi seasons is given in Table 10.5.

Table 10.5: Irrigation water requirement of crops grown in Tumri watershed

Kharrif crops				Rabi crops			
S. N	Name of the crop	NIR (MCM)	GIR (MCM)	S. N	Name of the crop	NIR (MCM)	GIR (MCM)
1	Paddy	0.158	0.282	1	Wheat	1.292	2.308
2	Jowar	0.032	0.058	2	Black gram	0.053	0.094
3	Bajra	0.000	0.000	3	Matar	0.038	0.068
4	Macca	0.018	0.032	4	Chana	0.802	1.433
5	Kodon	0.102	0.183	5	Alsi	0.018	0.033
6	Kutki	0.007	0.013	6	Potato	0.013	0.022
7	Arher	0.074	0.133	7	Rajgir	0.079	0.141
8	Udad	0.008	0.015	8	Masur	0.528	0.944
9	Til	0.037	0.066	9	Tevda	0.030	0.054
10	Ramtil	0.022	0.039	10	Onion	0.006	0.010
11	Sava	0.008	0.015	11	Garlic	0.006	0.010
12	Parsa	0.005	0.008	12	Groundnut	0.058	0.104
13	Moong	0.000	0.000	13	Arher	0.266	0.475
14	Soyabean	0.120	0.214	14	Others	0.013	0.022
Total		*0.592*	*1.056*	Total		*3.147*	*5.619*

The gross irrigation requirement on a ten-daily basis in the watershed during the kharrif and rabi crops is given in Table 10.6. The gross irrigation requirement during the kharrif and rabi season is 1.056 and 5.619 MCM respectively. The water storage structures may be planned keeping in view these gross irrigation water requirements in order to sustain the present cropping practices. However depending on the feasibility of the construction of additional water storage structures and based on the land capability classification, alternative land use plan may be developed depending on the assured availability of the water for bringing more areas under irrigated agriculture.

Table 10.6: Gross irrigation requirement for kharrif and rabi crops

Kharrif season requirements			Rabi season requirements		
Month/ (Decaday)	NIR	GIR	Month/ (Decaday)	NIR	GIR
II-Jun	0.043	0.076	III-Oct	0.003	0.006
III-Jun	0.044	0.078	I-Nov	0.136	0.243
I-Jul	0.000	0.000	II-Nov	0.142	0.253
II-Jul	0.000	0.000	III-Nov	0.142	0.254
III-Jul	0.000	0.000	I-Dec	0.202	0.360
I-Aug	0.000	0.000	II-Dec	0.204	0.364
II- Aug	0.000	0.000	III-Dec	0.220	0.393
III- Aug	0.000	0.000	I-Jan	0.283	0.505
I-Sep	0.112	0.201	II-Jan	0.292	0.522
II- Sep	0.086	0.154	III-Jan	0.292	0.521
III- Sep	0.071	0.127	I-Feb	0.349	0.624
I-Oct	0.152	0.271	II-Feb	0.207	0.370
II-Oct	0.046	0.083	III-Feb	0.198	0.354
III-Oct	0.037	0.067	I-Mar	0.317	0.567
Total	0.591	1.056	II-Mar	0.160	0.285
			Total	3.147	5.619

11.0 WATERSHED MODELING

Runoff is one of the most important hydrologic variable used in most of the water resources applications and the relation between the precipitation and runoff is very complex, influenced by various storm and basin characteristics. Runoff processes operating at any particular location varies from time to time. Large variations in hydrologic characteristics occur over small, apparently homogeneous areas to such an extent that all the runoff processes, namely, overland flow, saturated overland flow and through flow may occur during a single storm event. The contributing areas in the basin may vary in extent in different seasons and during the progress of a storm. The type of runoff process and the location of the source areas, whether close to the outlet and adjacent to the stream channels or on ridges remote from the stream channels, have a considerable influence on the resulting hydrograph.

The time interval used in the measurement of the variables affects the derivation of any relationship, although with continuously recorded rainfall and stream discharge, this constraint is removed. Hence, relating a flood peak to a heavy storm requires continuous records, but determining water yield from a catchment can be accomplished satisfactorily using relationships between the totals of monthly or annual rainfall and runoff. Also reliable prediction of quantity and rate of runoff from land surface into streams and rivers is difficult for ungauged watersheds. However, this information is needed in dealing with many watershed development and management problems. The satellite data can be interpreted to derive thematic information on land use, soil, vegetation, drainage, etc which, combined with conventionally measured climatic parameters (precipitation, temperature etc) and topographic parameters height, contour, slope, provide the necessary inputs to the rainfall-runoff models.

11.1 Methodology

11.1.1 SCS curve number model

The Soil Conservation Service model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs. The USDA Soil Conservation Service Curve Number (SCS-CN) model is used in the study for estimating the direct runoff values at the gauged Nala sub-watershed and ungauged Tumri watershed (i.e. the complete watershed). SCS-CN model is a widely and commonly used model for water resources management and planning. It is simple and can be applied to urban and sub-urban areas as well as on agricultural watersheds.

In this method the runoff depth (effective rainfall) is a function of total rainfall depth and curve number, usually represented by curve number (CN), which is an index that represents the watershed runoff potential for a given Antecedent Moisture Condition (AMC) The SCS-CN runoff curve number, is a quantitative descriptor of the land use/land-cover/soil characteristics of the watershed. For the establishment of CN of a basin, information on hydrologic soil group, hydrologic condition, treatment or practices and land use/land-cover are utilized. The curve number varies in the range of 1 to 100, and is a function of AMC and catchment properties producing runoff namely, hydrologic soil type, land use and treatment practices and ground surface condition.

In the SCS-CN model, if the actual runoff is referred as Q and potential runoff (total rainfall) as P, with $P \geq Q$, then the actual retention is $P-Q$; and potential retention S, will always follow the relation, $S \geq (P-Q)$. The model is based on the assumption of proportionality between retention and runoff in the following form,

$$\left(\frac{P-Q}{S}\right)=\left(\frac{Q}{P}\right) \qquad ....(11.1)$$

which, states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. This assumption underscores the conceptual basis of the SCS-CN model. P, Q and S are expressed in the same units.

For practical application, Eqn. 11.1 is improved by reducing the potential runoff by an amount equal to the initial abstraction. The initial abstraction consists mainly of interception, infiltration and surface storage, all of which occur before the runoff begins.

The modified equation can be expressed in the following form of Eqn. 11.2 given as,

$$\left(\frac{P-I_a-Q}{S}\right)=\left(\frac{Q}{P-I_a}\right) \qquad ....(11.2)$$

where, I_a = initial abstraction

Solving for Q from Eqn. 11.2, we have

$$Q=\frac{(P-I_a)^2}{(P-I_a+S)} \qquad ....(11.3)$$

which is subject to the limitation that $P \geq I_a$

To simplify the Eqn. 11.3, the initial abstraction is related to potential retention. Some researchers have developed the following relationship between initial abstraction and potential maximum retention for Indian conditions.

(a) For black cotton soil regions (AMC-I) and for all other regions

$$I_a = 0.30S \qquad \text{....(11.4)}$$

Therefore Eqn. 11.4 reduces to

$$Q = \frac{(P - 0.30S)^2}{(P + 0.70S)} \qquad \text{....(11.5)}$$

(b) For black cotton soil regions (AMC-II and AMC-III) :

$$I_a = 0.10S \qquad \text{....(11.6)}$$

Therefore Eqn. 11.6 reduces to

$$Q = \frac{(P - 0.10S)^2}{(P + 0.90S)} \qquad \text{....(11.7)}$$

Since potential maximum retention varies widely, it is expressed in terms of CN by Eqn. 11.8 as,

$$S = \left(\frac{25400}{CN}\right) - 254 \qquad \text{....(11.8)}$$

where, CN = runoff curve number (dimensionless), S = surface retention in mm

The runoff CN varies with the specific combination of hydrologic soil cover complexes, hydrologic soil group, land use and treatment practices, hydrologic surface condition and antecedent moisture condition. All these have direct bearing on the amount of runoff produced by a watershed. For a watershed, the CN for the varying land uses within the watershed is determined and the composite curve number (CCN) which is the weighted average is estimated using Eqn. 11.9 given as,

$$CCN = \frac{\sum_{i=1}^{n} CN_i A_i}{\sum_{i=1}^{n} A_i} \qquad ....(11.9)$$

where, CN_i = curve number for a the i^{th} land use, A_i = area under the i^{th} land use, n = total number of land use classes.

11.2 Analysis & Results

The analysis carried out in establishing the curve number for the Nala sub-watershed and Tumri watershed and subsequent estimation of surface runoff from these basins is explained in the following steps.

11.2.1 Preparation of soil map

With the help of the soil information of the basin and referring the National Atlas of India, Calcutta, on the soil regions and geology etc. soils are classified as per the soil conservation service soil classification system. This information is then transferred on to the base map for preparation of the soil map both for the Nala sub-watershed and Tumri watershed. The soil map of the study area is already given as Fig. 8.1.

11.2.2 Preparation of landuse map

IRS 1D LISS-III merged with geo-referenced Pan satellite data was used for identifying the land use classes in the Nala sub-watershed and Tumri watershed. The land use map have prepared for both the Nala sub-watershed and Tumri watershed. The following five land use classes have been found in these basins, namely, forests, agriculture land, barren/fallow lands, scrubs and water bodies. The map showing the land use classification for Tumri watershed is already given as Fig. 7.2. The land use details for Nala sub-watershed and Tumri watershed are given in Table 11.1 and Table 11.2 respectively.

Table 11.1: Land use pattern in Tumri watershed

S. No.	Prevailing land use	Area under the land use(ha)
1.	Dense forest	587.98
2.	Open forest	521.90
3.	Barren land	706.14
4.	Agriculture	540.15
5.	Built up	27.93
6.	Water bodies	7.23

Table 11.2: Land use pattern in Nala watershed

S. No.	Prevailing land use	Area under the land use(ha)
1.	Dense forest	68.46
2.	Open forest	6.73
3.	Barren land	113.61
4.	Agriculture	79.2

11.2.3 Determination of curve number

For establishment of the runoff curve number, the information on hydrologic soil group, hydrologic condition, land treatment or practices and land use/ land cover are acquired from field surveys, soil map and the land use map of the watersheds. The runoff curve number for each of the land use classes were found from standard tables given by USDA-SCS, depending on the hydrologic condition, soil group and 5-day AMC. The AMC state is determined based on the previous 5-day antecedent moisture condition in the watershed as given by Table 11.3.

Table 11.3: Criteria for the AMC condition

S. No.	AMC Condition	Total preceding 5-day rainfall	
		Dormant season	Growing season
1.	I	Less than 12.7 mm	Less than 35.56 mm
2.	II	12.7 mm to 27.94 mm	35.56 mm to 53.34 mm
3.	III	More than 27.94 mm	More than 53.34 mm

The curve number determined for different land use classes using the USDA-SCS standard tables is for the average condition AMC-II. The corresponding curve numbers for AMC-I and AMC-III condition is determined using Table 11.4.

Table 11.4: Curve number for dry (AMC-I) and wet (AMC-III) conditions

S.No.	CN for AMC-II	Corresponding CN for		S.No.	CN for AMC-II	Corresponding CN for	
		AMC-I	AMC-III			AMC-I	AMC-III
1.	100	100	100	11.	50	27	65
2.	95	87	99	12.	40	23	60
3.	90	78	98	13.	35	19	55
4.	85	70	97	14.	30	15	50
5.	80	63	94	15.	25	12	45
6.	75	57	91	16.	20	9	39
7.	70	51	87	17.	15	7	33
8.	65	45	83	18.	10	4	26
9.	60	35	79	19.	5	2	17
10.	55	31	75	20.	0	0	0

The composite curve number (CCN) for the Nala sub-watershed and Tumri watershed is then computed using Eqn. 11.9. The corresponding CCN for the AMC-I and AMC-III condition have also been determined for both Nala sub-watershed and Tumri watershed are given in Table 11.5 and Table 11.6 respectively.

Table 11.5: Composite curve number for Tumri watershed

S. N.	Land use	Curve Number (CN)	Area (ha)	Weighted area
1.	Dense forest	77	587.98	45274.76
2.	Open forest	82	521.90	42795.8
3.	Barren land	85	706.14	60021.9
4.	Agriculture	88	540.15	47533.2
5.	Built up	91	27.93	2541.63
6.	Water bodies	100	7.23	723.00
CCN			**83.17**	

Table 11.6: Composite curve number for Nala watershed

S. N.	Land use	Curve Number (CN)	Area (ha)	Weighted area
1.	Dense forest	77	68.46	5271.42
2.	Open forest	82	6.73	551.86
3.	Barren land	85	113.61	9656.85
4.	Agriculture	88	79.2	6969.60
CCN			**83.77**	

11.2.4 Estimation of sub-watershed runoff

The SCS Curve Number model is used in the computation of runoff of Nala sub-watershed, using the composite curve number and daily rainfall for the sub-basin. The rainfall and stream flow is being monitored on a continuous basis on the Nala tributary on a bridge site near Tumri village. Using the sub-watershed composite curve number, potential maximum retention, S and the daily rainfall 'P', the sub-watershed direct runoff depth is computed, which is subsequently converted into discharge units (cumecs) after multiplying and dividing by the sub-basin area and time constants respectively. The base flow is then added to the direct surface runoff to arrive at the total surface runoff from the gauged Nala sub-watershed. The hydrographs of the calculated and observed surface runoff were than plotted, to ascertain the accuracy with which the flows are estimated. The graph showing comparison of calculated and observed daily runoff for Nala sub-watershed for the monsoon period (June to Oct.) for the year 2006-07, 2007-08 & 2008-09 is presented in Fig. 11.1, Fig. 11.2 and Fig. 11.3 respectively.

The model efficiency has been computed using the Nash-Sutcliffe goodness of fit given by Eqn. 11.10 as,

$$\eta = 1.0 - \frac{\sum_{j=1}^{m}(Q_{obs} - Q_{com})^2}{\sum_{j=1}^{m}(Q_{obs} - \bar{Q})^2} \qquad \text{..... (11.10)}$$

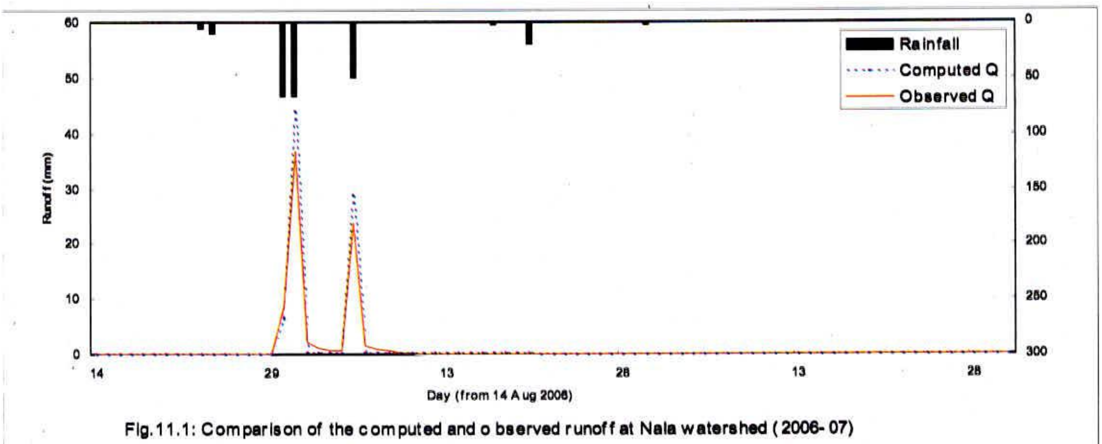


Fig.11.1: Comparison of the computed and observed runoff at Nala watershed (2006-07)

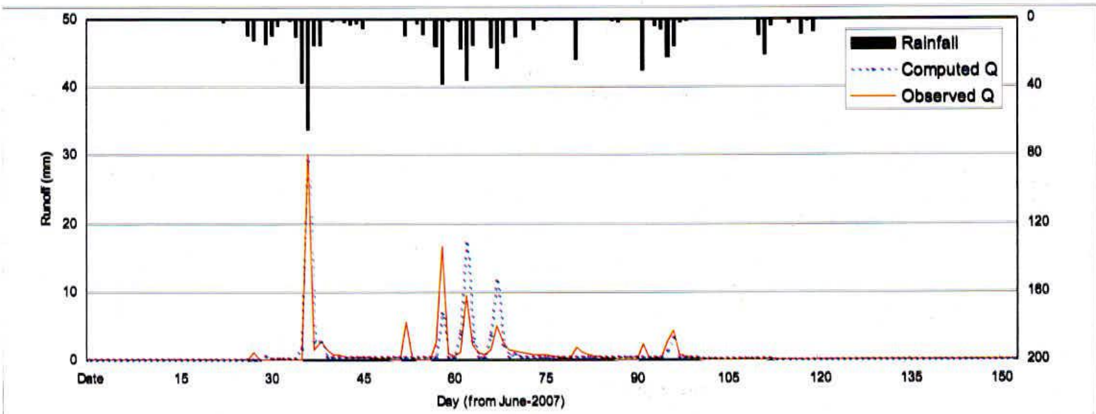


Fig.11.2 : Comparison of the computed and observed runoff at Nala watershed (2007-08)

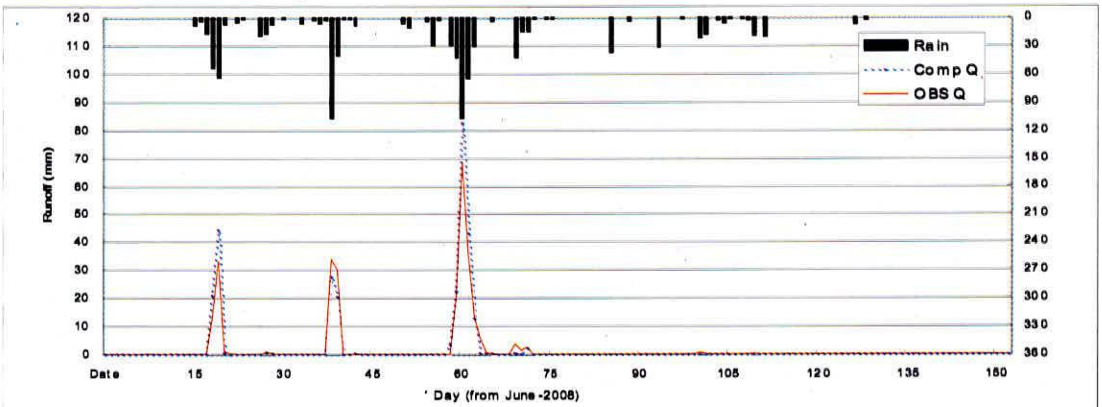


Fig. 11.3: Comparison of the computed and observed runoff at Tumri Nala (2008-09)

where, η = model efficiency, Q_{obs} = daily observed surface runoff, Q_{com} = daily computed surface runoff, $\bar{Q}$ = mean observed surface runoff, j = number of days in the simulation run. The root mean squared error is computed using the Eqn. 11.11 given by,

$$RMSE = \frac{1}{m}\sqrt{\sum_{j=1}^{m}(Q_{obs} - Q_{com})^2} \qquad \text{..... (11.11)}$$

The percentage difference in volume between the observed and computed seasonal surface runoff is computed by Eqn. 11.12 given by

$$D_{vol} = 100\frac{\left(\sum_{j=1}^{m} Q_{obs} - \sum_{j=1}^{m} Q_{com}\right)}{\left(\sum_{j=1}^{m} Q_{obs}\right)} \qquad \text{..... (11.12)}$$

The monthly and seasonal streamflow for Nala sub-watershed for 2007-08 & 2008-09 have also been compared and given in Table 11.7 and Table 11.8 respectively.

Table 11.7: Comparison of observed and computed streamflow for Nala sub-watershed (2007-08)

S. No.	Month	Computed runoff (mm)	Observed runoff (mm)	Efficiency (%)	RMSE	Difference in volume (%)
1.	June	0.49	1.04	80.04	0.19	-5.07
2.	July	50.08	65.58			
3.	August	48.70	38.14			
4.	September	8.93	9.21			
5.	October	0.00	0.00			
Total		108.2	113.97			

It can be observed from these graphs that the SCS-CN model is able to simulate the flows adequately in the Nala watershed for all the years of 2006-07, 2007-08 & 2008-09. The overall model efficiency during the calibration run for 2007-08 is 80.04% with a root mean square error of 0.19 and difference in total volume between the observed and

Table 11.8: Comparison of observed and computed stream flow for Nala sub-watershed (2008-09)

S. No.	Month	Computed runoff (mm)	Observed runoff (mm)	Efficiency (%)	RMSE	Difference in volume (%)
1.	June	66.57	47.63	93.27	0.29	6.50
2.	July	157.01	152.72			
3.	August	60.16	63.46			
4.	September	0.00	2.60			
5.	October	0.00	0.00			
Total		283.74	266.41			

computed surface runoff of -5.07%. Similarly the model efficiency during 2008-09 is 93.27% with a root mean square error of 0.29 and difference in total volume between the observed and computed surface runoff of 6.50%.

11.2.5 Estimation of surface runoff at Tumri watershed

Before the computation of the runoff from the Tumri watershed, the time of concentration needs to be calculated. The time of concentration is calculated using the Kirpich's formula, where the inputs are the main stream river length and mean slope of the main stream as given by Eqn. 11.13.

$$T_c = 0.0195 L^{0.77} S^{-0.385} \quad \text{.... (11.13)}$$

The time of concentration for the Tumri watershed is 2.39 hours and as the time of concentration is less than 24 hours there is no effect of time-lag from any portion of the watershed. The watershed direct runoff at the outlet of Tumri watershed is estimated using the daily rainfall and the CCN for the Tumri watershed. As the land use pattern and the composite curve number for the Nala sub-watershed and Tumri watershed are similar, it is assumed that the runoff generating mechanisms are more or less similar for both catchments. Therefore the base flow for the Tumri watershed was computed on a proportional basis based on the catchment areas of the watershed and sub-watershed and added to the direct surface runoff to arrive at the stream flow at the watershed outlet. The monthly and seasonal totals of stream flow for Tumri watershed have been computed for 2007-08 and 2008-09 and given in Table 11.9.

Table 11.9: Monthly and seasonal computed streamflow for Tumri watershed

S. No.	Month	Computed runoff (MCM)	
		2007-08	2008-09
1.	June	0.010	1.609
2.	July	1.155	3.794
3.	August	1.118	1.824
4.	September	0.204	0.000
5.	October	0.000	0.000
Total		2.490	7.227

The total surface runoff from the Tumri watershed (full watershed) is 2.49 MCM only in 2007-08 owing to the severe drought in the entire Bundelkhand region. The rainfall for the year 2006-07 was near normal rainfall and the surface runoff component estimated was 8.05 MCM. Similarly the surface runoff during 2008-09 has been computed to be 7.23 MCM which is a good rainfall year. So planning for drinking water and irrigation has to be done accordingly, to cater to these demands even during the drought years.

12.0 WATERSHED PRIORITISATION

Soil and water conservation are key issues in watershed management and for demarcating the priority watersheds so as to ensure an optimum and sustainable development through scientific planning, the watershed requires an appraisal of its agro-ecological characteristics, its limitation and potential for resources development. A watershed can be divided in to a number of sub-watersheds to determine the limitation and potential of smaller areas in the watershed. A priority sub-watershed delineation survey carried out in the watershed helps to identify the significant variation of natural resources and limitations. Watersheds have assumed importance for preserving the ecological balance between natural resource development and conservation, particularly in the fragile and heterogeneous erosion-susceptible hilly ecosystem. Decisions related to watershed management require scientific knowledge of resource information, slopes, expected sediment yield and priority class of watersheds for conservation planning. Comprehensive land development procedures attract special attention that enable soil and water conservation, better and productive land use and optimum and effective use of available natural resources.

Soil being one of the potential resources of a watershed demands proper conservation and management and it could only be possible if its degree of degradation is assessed properly. Soil conservation strategies are to be planned according to the severity of the extent of the soil erosion problem. The severity of erosion can be evaluated by the priority delineation of the watershed considering many factors, the important few among them being the annual erosional soil loss and morphometric analysis. The prioritization of watershed helps in taking up soil conservation measures on the priority basis.

12.1 Methodology

The prioritization of sub-watersheds is an essential element in planning and management of watersheds and before taking up any watershed management program, first issue to be addressed pertains to which area of the watershed should be treated first and by adopting prioritization, the planners and mangers may be able to identify the stressed areas of watershed which require immediate attention. The prioritization approach for Tumri watershed, envisages the sub-division of the watershed into 19 small sub-watersheds (SW-1 to SW-19) and thereafter estimation of soil loss using sediment yield model, soil loss using USLE approach, drainage density and average slope for each of the sub-watershed. On the basis of each parameter in these above four groups, a priority ranking has been assigned and an average priority for each sub-watershed has been determined. All 19 sub-watersheds boundary have been stored separately and using ILWIS 3.0 soil loss, average slope and sediment yield for each of the sub-watersheds have been computed.

12.1.1 Sediment yield

A number of sediment yield models, both empirical and conceptual are commonly used to address wide ranging soil and water management problems. Most conservation planning for erosion control, however, uses empirical models to estimate average annual soil loss. Investigation into such empirical relationships reveal that most of these models require input parameters in terms of spatial information of land use, vegetation cover, soils, slopes, drainage density, conservation practices, runoff and rainfall intensity. A simple empirical model, useful for Indian condition, quoted in literature (Kumar, 1985, Rao & Mahabaleswara, 1990) has been used for analysis wherein, the sediment yield can be expressed as given by Eqn. 12.1,

$$V_s = 1.067x10^6 p^{1.384} A^{1.292} D_d^{0.392} S^{0.129} F^{2.51} \qquad \ldots.(12.1)$$

where, V_s = sediment yield (Mm^{3}x10^3/yr), p = annual precipitation (cm), A = sub-watershed area (km^2), D_d = drainage density (km/sq. km), S = average slope, F = vegetative cover factor which is expressed by Eqn. 12.2 as,

$$F = \frac{0.21F_1 + 0.2F_2 + 0.6F_3 + 0.8F_4 + F_5}{\sum_{i=1}^{5} F_i} \qquad \ldots.(12.2)$$

where, F_1 = area under reserved and protected forest, F_2 = unclassified forest area, F_3 = cultivated area, F_4 = grass & pasture land, F_3 = wasteland

The above equation indicates that all the parameters except precipitation are essentially mapping inputs, which can be derived conveniently from drainage map and topographic contour map whereas the land use can be derived from digital analysis of satellite data. As the model is empirical, it incorporates those parameters which essentially contribute to the sediment yield process to produce more realistic estimation of erosion rates for conservation planning process.

12.1.2 Soil loss using USLE

The Universal Soil Loss Equation (USLE), has been used to determine the soil loss from the sub-watersheds. The USLE equation and the estimation of soil loss have been explained in detail in Chapter 9 and the soil loss from Tumri watershed has been determined by multiplication of thematic maps of R, K, L, S, C and P. All sub-watershed maps were converted to raster maps. All these raster maps and the soil loss map have the same geo-reference so that they can be manipulated and overlaid one over the other. Using ILWIS 3.0, the soil loss map for each of sub-watershed have been determined and using histogram of that map, the average soil loss from sub-watersheds have been computed separately.

12.1.3 Average slope

The slope is an important topographical factor responsible for degradation of watershed as steep slopes causes more soil erosion resulting in development of gullied lands and loss of fertility and moisture holding capacity of soils. For generation of slope map, the contour map and point elevation map of Tumri watershed have been used and using ILWIS 3.0, the slope map for the region is generated. The slope map of each of sub-watershed has been generated and using statistics of these maps, the average soil loss from sub-watersheds have been computed separately.

12.1.4 Drainage density

The drainage system shows the geomorphologic status of the region and the drainage density of any watershed being high, is indicative of the fact that more water may go downstream as direct surface runoff unless appropriate measures are adopted. Also there may be more soil erosion because of entry of eroded soil in the drainage, very soon after detachment. So for the management and planning of watersheds, these areas should be treated on priority basis and both soil and water conservation measures are required. For determination of drainage density of sub-watersheds, the drainage map of each sub-watershed has been prepared separately and using histogram, the total length of drainage obtained. The drainage density of sub-watershed may be estimated using area of that watershed in the Eqn. 12.3 given as,

$$D_d = \frac{\sum_{i=1}^{n} Li}{A} \qquad \text{....(12.3)}$$

where, D_d = drainage density (km/km2), Li = length of i^{th} segment of drainage, n = number of segments, A = catchment area of sub-watershed

12.2 Analysis & Results

The Tumri watershed is a highly degraded watershed which requires urgent consideration for watershed management and conservation measures. The topography of the watershed which is highly undulating creates high intensity erosive runoff. The minimal depth of soil is a major limitation in the watershed. About one-third area of the watershed is under barren land use subjective of the severe crunch of soil, water and other resources for sustainable development. It is therefore very important to identify the vulnerable areas in the watershed so that the conservation measures can be taken in those areas or sub-watersheds on urgent basis. For prioritization of watershed for conservation measures, the Tumri watershed has been divided in to 19 sub-watersheds (SW-1 to SW-19) ranging from 39.86 hectare to 286.49 hectare. The different sub-watersheds of Tumri watershed has been presented in Fig. 12.1.

12.2.1 Sediment yield

The sediment yield from the sub-watersheds of the Tumri watershed has been computed using Eqn. 12.1 & Eqn. 12.2. In this empirical equation, average rainfall, slope, drainage density and land use have been used as inputs. The average rainfall and land use have been estimated in USLE computation, while average slope and drainage density for all sub-watersheds have been computed using USLE model and by Eqn. 12.3 respectively. The computation of sediment yield from different sub-watersheds has been presented in Table 12.1. The sediment yield in sub-watersheds ranges from 0.30 ha-m/100 sq. km/yr (SW-14) to 7.51 ha-m/100 sq. km/yr (SW-16).

12.2.2 Estimation of soil loss

The details of the USLE model, estimation of parameters and values of parameters for Tumri watershed have been given in Chapter 9. The soil loss in Tumri watershed has been determined in ILWIS 3.0 software and using *iff* statement, the soil loss maps of all sub-watersheds have been generated separately. The histogram of soil

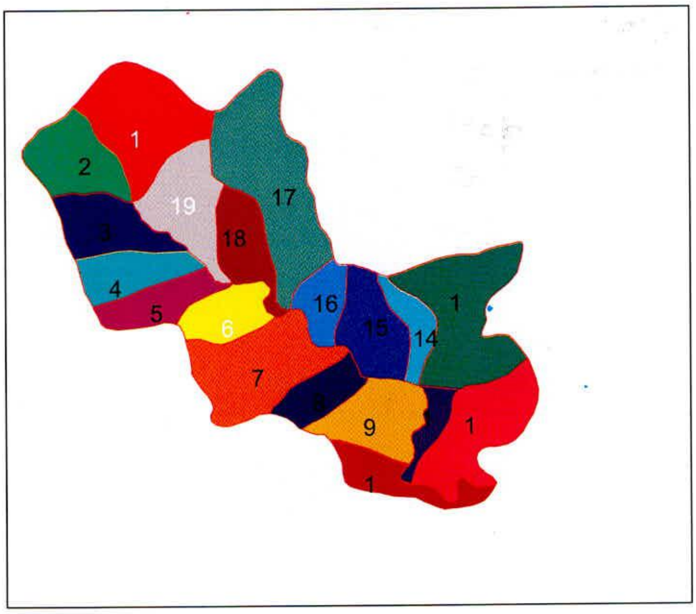


Fig 12.1: Representation of sub-watersheds

loss map of each sub-watershed has been used to estimate the soil loss from that sub-watershed. The average soil loss from sub-watersheds and their priority has been given in Table 12.2. Priority ranking of sub-watersheds considering soil loss indicates that SW-18 has maximum soil loss in order of 26.14 t/ha/yr and this sub-watershed should be considered on priority for soil conservation, if soil loss is only criteria for selection of priority areas. Similarly, SW-13 can be considered as last priority watershed with soil loss of 2.13 t/ha/yr only.

12.2.3 Average slope

The contour map of Tumri watershed and surrounding region has been digitized from the Survey of India toposheets. The point elevation has also been marked in a separate point map. Using ILWIS 3.0, the slope on each pixels of the watershed has been determined. The slope maps for sub-watersheds have been obtained using *iff* statement. The average slope for a sub-watershed has been computed using the information from histogram of the slope map of that sub-watershed. The average slope and priority of watersheds according to slope criteria is presented in Table 12.2. The average slope in

Table 12.1: Computation of sediment yield from various sub-watersheds

Watershed	Annual Rair P (cm)	Area A (sq. km)	Drainage density Dd (km/sq. km)	Average slope S	Protected forest F1 (sq. km)	Open forest F2 (sq. km)	Cultivated Area F3 (sq. km)	Grass & Pasture F4 (sq. km)	Waste land F5 (sq. km)	Vegetation Cover factor F	Sediment yield Vs (M cum/year)
Tumri	123.46	23.91	3.84	0.10	5.88	5.22	5.40	0.00	7.41	0.54	13710.46
SW-1	123.46	2.10	7.14	0.12	0.92	0.66	0.43	0.00	0.10	0.32	215.82
SW-2	123.46	1.27	5.97	0.14	0.62	0.35	0.25	0.00	0.06	0.32	103.84
SW-3	123.46	1.13	5.00	0.09	0.21	0.11	0.51	0.00	0.30	0.59	367.24
SW-4	123.46	0.93	3.74	0.05	0.00	0.16	0.40	0.00	0.36	0.68	335.44
SW-5	123.46	0.84	4.07	0.07	0.02	0.39	0.13	0.00	0.31	0.56	189.92
SW-6	123.46	0.84	3.74	0.04	0.05	0.06	0.22	0.00	0.50	0.79	413.61
SW-7	123.46	2.01	8.91	0.10	0.62	0.19	0.40	0.00	0.81	0.60	1028.59
SW-8	123.46	0.71	3.41	0.10	0.11	0.13	0.04	0.00	0.43	0.71	277.47
SW-9	123.46	1.25	5.21	0.07	0.34	0.01	0.27	0.00	0.62	0.69	605.11
SW-10	123.46	0.83	3.96	0.08	0.20	0.20	0.35	0.00	0.07	0.44	106.46
SW-11	123.46	1.69	8.51	0.10	0.51	0.72	0.46	0.00	0.00	0.31	154.72
SW-12	123.46	0.40	2.19	0.08	0.16	0.10	0.15	0.00	0.00	0.35	18.77
SW-13	123.46	2.29	8.56	0.12	0.89	1.40	0.00	0.00	0.00	0.20	81.36
SW-14	123.46	0.53	2.62	0.11	0.11	0.36	0.02	0.00	0.04	0.27	15.56
SW-15	123.46	1.17	6.06	0.09	0.11	0.26	0.09	0.00	0.72	0.72	682.95
SW-16	123.46	0.65	3.65	0.06	0.00	0.00	0.08	0.00	0.57	0.95	485.41
SW-17	123.46	2.88	1.10	0.10	0.66	0.06	0.91	0.00	1.25	0.67	950.23
SW-18	123.46	0.99	3.66	0.07	0.04	0.00	0.26	0.00	0.70	0.87	693.36
SW-19	123.46	1.42	4.77	0.10	0.32	0.07	0.45	0.00	0.58	0.65	634.69

the sub-watersheds ranges between 4.41 degree (SW-6) and 13.51 degree (SW-2). The average slope of Tumri watershed is about 9.5 degree and soil conservation measures are essentially required in the watershed.

12.2.4 Drainage density

The drainage density plays an important role in the selection of priority sub-watersheds. Total length of drainage has been computed from histogram of drainage map of each sub-watershed and Eqn. 12.3 used to estimate the drainage density. The analysis of drainage density indicates that there is not much variation in drainage densities in sub-watersheds and it varies between 3.34 km/km^2 (SW-1) and 5.65 km/km^2 (SW-16).

12.2.5 Priority assessment

All the 19 sub-watersheds have been arranged in the decreasing order of each priority class and priority one has been given for sub-watershed having maximum amount of that criteria. On the basis of each criterion, priority rankings from 1 to 19 for sub-watersheds have been assigned. The first priority rank indicates the most risk involved and requires immediate attention. In case of sediment yield, the WS-16 is having the maximum sediment yield as 7.51 ha-m/100 sq. km/yr and has been allotted priority ranking 1 and WS-14 is having the minimum sediment yield as 0.30 ha-m/100 sq. km/yr and given priority ranking 19. Similarly, the priority ranking has been given for soil loss, slope and drainage density. After determining the priorities in all criteria, the average priority for all sub-watersheds have been estimated and the computation of priority assessment has been presented in Table 12.2.

From the analysis, it is observed that the average priority in sub-watersheds ranges from 5.0 to 14.0 and SW-15 has the top most priority because of 5.82 ha-m/100 sq km/year sediment yield, 21.7 t/ha/yr soil loss, 8.88 degree average slope and drainage density of 5.16 km/km^2. Similarly, WS-13 is the lowest ranked in the priority table with sediment yield of 0.35 ha-m/100 sq km/year, 2.13 t/ha/yr soil loss, 12.40 degree average slope and density of 3.74 km/km^2. The priority classes for all sub-watersheds have also been assigned to determine the treatment areas in different priority classes. All these sub-

Table 12.2: Priority ranking for sub-watersheds

Watershed No.	Area	Sediment yield	Soil loss	Slope %	Drainage density	Priority ranking				Average Priority	Priority ranking
	hect	Hect-m/100 sq.km./year	(t/hect/yr)		km./sq.km						
		PC-1	PC-2	PC-3	PC-4	PC-1	PC-2	PC-3	PC-4		
WS-1	214.07	1.03	5.34	12.23	3.34	14	17	3	19	13.00	**17**
WS-2	126.96	0.82	5.74	13.51	4.70	16	16	1	9	8.67	**10**
Ws-3	113.06	3.25	14.75	8.79	4.42	11	10	11	12	11.00	**13**
Ws-4	92.95	3.61	12.06	4.56	4.03	9	12	18	14	14.67	**18**
Ws-5	84.00	2.26	9.47	6.50	4.84	12	13	16	7	12.00	**16**
WS-6	83.58	4.95	14.96	4.41	4.47	5	9	19	10	12.67	**12**
WS-7	200.66	5.13	13.23	9.77	4.44	4	11	8	11	10.00	**4**
WS-8	70.46	3.94	22.08	10.12	4.84	8	2	6	6	4.67	**2**
WS-9	124.79	4.85	20.33	7.39	4.18	6	5	14	13	10.67	**6**
WS-10	82.61	1.28	15.92	7.69	4.79	13	8	13	8	9.67	**11**
WS-11	169.00	0.92	7.44	10.31	5.03	15	15	5	4	8.00	**7**
WS-12	39.86	0.47	8.74	8.41	5.49	17	14	12	2	9.33	**14**
WS-13	229.15	0.35	2.13	12.40	3.74	18	19	2	17	12.67	**19**
WS-14	52.68	0.30	5.04	10.67	4.98	19	18	4	5	9.00	**15**
WS-15	117.35	5.82	21.7	8.88	5.16	3	3	10	3	5.33	**1**
WS-16	64.61	7.51	20.43	5.52	5.65	1	4	17	1	7.33	**3**
WS-17	286.49	3.30	17.92	9.74	3.83	10	6	9	15	10.00	**9**
WS-18	96.95	7.01	26.14	7.27	3.77	2	1	15	16	10.67	**5**
WS-19	141.78	4.46	16.05	10.10	3.36	7	7	7	18	10.67	**8**

watersheds have been divided in four classes ranging from low, moderate, high and very high priority classes and sub-watersheds having average priority up to 6 have been considered as very high priority sub-watersheds, more than 6 and less than 10 considered as high priority sub-watersheds, more than 10 and less than 12 considered as moderate priority sub-watersheds and sub-watersheds having priority more than 12 considered as low priority sub-watersheds. The area under different priority classes has been depicted in Table 12.3. From the analysis, it has been observed that about 985 ha, which is nearly 40% comes under high and very high priority classes.

Table 12.3: Area under various priority classes of sub-watersheds

S. No.	Priority class	WS-No.	Average priority	Priority ranking	Area (ha)	Total area
1.	V. High	15	4.75	1	117.35	252.42
2.	V. High	8	5.5	2	70.46	
3.	V. High	16	5.75	3	64.61	
4.	High	7	8.5	4	200.66	733.18
5.	High	18	8.5	5	96.95	
6.	High	9	9.5	6	124.79	
7.	High	11	9.75	7	169.00	
8.	High	19	9.75	8	141.78	
9.	Moderate	17	10.00	9	286.49	785.23
10.	Moderate	2	10.50	10	126.96	
11.	Moderate	10	10.50	11	82.61	
12.	Moderate	6	10.75	12	83.58	
13.	Moderate	3	11.00	13	113.06	
14.	Moderate	12	11.25	14	39.86	
15.	Moderate	14	11.50	15	52.68	
16.	Low	5	12.00	16	84.00	620.18
17.	Low	1	13.25	17	214.07	
18.	Low	4	13.25	18	92.95	
19.	Low	13	14.00	19	229.15	

13.0 GIUH BASED RUNOFF MODELLING

The hydrological response of a watershed is dependent on its geology, soil characteristics, topography, vegetation and climate. A part of the precipitation occurring over any part of surface of the earth flows over it through streams as surface runoff and some portion enters the earth's surface in the form of sub-surface water and joins the river after sometime or percolates down to join the ground water. This apportioning of precipitation in surface runoff, sub-surface flow or contribution to ground water is dependent upon surface of a basin and is reflected in the indices that are described by geomorphology of the basin such as its linear, aerial and relief aspects.

The development of relationships between the geomorphologic characteristics and the hydrological variables serve as useful tool to determine the hydrological response of the basin. It attains greater importance particularly in case of ungauged basins, where lack of data poses problems in optimal planning for water resources development activities. Geomorphologic characteristics have been used in various fields such as hydrology, flood management planning, terrain evolution, energy resources and other engineering project.

13.1 Unit Hydrograph (UH)

In the category of conceptual model, the unit hydrograph theory was first proposed by Sherman in 1932 and is defined as the hydrograph of direct surface runoff resulting from unit effective rainfall, which is uniformly distributed over the basin at a uniform rate during a unit time. The unit hydrograph is expressed by U(d, t), where the U(d, t) is an ordinate of direct runoff at any interval of t resulting from 1 cm of rainfall uniformly distributed in the catchment in *d*-hour duration.

13.2 Instantaneous Unit Hydrograph (IUH)

If the duration of the rainfall excess becomes infinitesimally small, the resulting unit hydrograph is called the instantaneous unit hydrograph (IUH), and is expressed by U(0, t), or simply U(t). The major advantage of the IUH in comparison with a unit hydrograph is that IUH is independent of the duration of the rainfall excess, resulting thereby in an elimination of one variable in the hydrograph analysis. Moreover, the use of the IUH is better suited for the needs of theoretical investigations on the rainfall-runoff relationship in drainage basins.

13.3 Geomorphological Instantaneous Unit Hydrograph (GIUH)

The basis of the development of geomorphological instantaneous unit hydrograph (GIUH) is that when a unit rainfall occurs in the basin instantaneously, its arrival and intensity at outlet is mainly affected by the underlying natural order in the morphology of the catchment and the hydraulic characteristics of the channel. One advantage of the GIUH approach is the potential of deriving the UH using only the information obtained from topographic maps or remote sensing, possibly linked with Geographical Information System (GIS) and Digital Elevation Model (DEM). Hence, in case of ungauged catchment, geomorphological based model can be used to estimate the hydrologic response of a catchment.

Snyder (1938), analyzed a large number of hydrograph from drainage basins in Appalachian mountainous region in United States and developed the relationships, wherein, he related the time lag of unit hydrograph (t_p) with the product of length of main channel (L_{ca}) and length of the stream from a point on the stream nearest to the centroid of the catchment to the outlet. Clark (1945) developed IUH model by assuming that the outflow hydrograph for any storm is characterized by the translation and storage effect of separable basin sub-areas. Rodriguez and Valdes (1979) first introduced the GIUH in which the runoff ordinates are interpreted in the framework of travel time distribution using geomorphological characteristics of the basin. The structure of the hydrologic response is found to be intimately linked to the geomorphologic parameters of a basin. The geomorphologic parameters have also been found to have very good relationship with the parameters representing IUH. A new approach of rainfall-runoff modeling has been developed at the National Institute of Hydrology (NIH, 1993) in which geomorphological parameters have been used with conceptual modeling of IUH. In this study, the methodology developed by NIH has been applied for Nala sub-watershed up to Tumri village and Tumri watershed.

13.4 Methodology

In the approach developed by NIH, the IUH of Clark model is developed using geomorphological characteristics of the watershed. The geomorphological parameters of Nala sub-watershed and Tumri watershed have been evaluated. The digital elevation model have been developed which is used as input for the model. A computer program has been developed for the computation of ordinates of IUH and DSRO. The brief methodology for the development of GIUH is being presented here.

13.4.1 Development of time area diagram

The time area diagram is used as an input to the Clark based GIUH model. For preparation of time area diagram, digital elevation model for the region has been generated using the contour lines. The time of travel have been calculated by Eqn. 13.1 given as,

$$t = \frac{kL}{\sqrt{S}} \qquad \text{.... (13.1)}$$

where, t = time of travel, L = length of stream, S = slope of the stream, K = proportionality constant. The initial estimate of time of travel can be obtained by Kirpich's formula, as given by Eqn. 13.2 as,

$$T_c = 0.0195 L^{0.77} S^{-0.385} \qquad \text{.... (13.2)}$$

where, T_c = time of concentration in min, L = length of main stream in meters, S = mean slope of the main stream.

Using the length of mainstream and mean slope of the basin, the time of concentration is calculated. The value of k in the Eqn. 13.1 may be obtained by putting the values of T_c, L and S. After computing the constant k, the time of travel for different points in the basin can be estimated using Eqn. 13.1. All the values of time of travel in the watershed are estimated and the interpolation technique of ILWIS 3.0 has been used to obtain the isochronal map. Using the isochronal map, the contributing area at any time interval has been found out. Similarly, a relationship is also developed between the ratio of contributing time to time of concentration (T/T_c) and contributing area to total area of the basin (A/A_c) and this relationship is used as an input in the Clark based GIUH model.

13.4.2 Excess rainfall estimation

The rainfall amount which produces surface runoff is termed as rainfall excess. For any rainfall-runoff modeling, the initial step is to estimate rainfall excess by separating the hydrological abstractions from the rainfall hyetograph. Although a number of methods are available for the separation of abstractions, the ϕ-index method has been used.

13.4.3 Geomorphology based Clark model

Clark model based on GIUH assumes that the rainfall excess first undergoes pure translation and then attenuation. The translation is achieved by a travel time-area histogram and the attenuation by routing the results of the above through a linear reservoir at the outlet of the catchment. The storage of the linear reservoir assumed at the outlet of the catchment can be described by Eqn. 13.3,

$$S = RQ \qquad \text{.... (13.3)}$$

where, R = storage time constant, Q = outflow.

The Clark model uses the Muskingum equation for routing the inflows at various times. The outflow (Q_2) for Muskingum method is given by Eqn. 13.4 as,

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1 \qquad \text{.... (13.4)}$$

For Clark model,

$$C_0 = \frac{0.5\Delta t_c}{R + 0.5\Delta t_c}, \qquad \text{.... (13.5)}$$

$$C_1 = \frac{0.5\Delta t_c}{R + 0.5\Delta t_c}, \qquad \text{.... (13.6)}$$

$$C_2 = \frac{R - 0.5\Delta t_c}{R + 0.5\Delta t_c}, \qquad \text{.... (13.7)}$$

where, I_1 and I_2 are the inflows at time t_1 and t_2, Q_1 and Q_2 are outflows at time t_1 and t_2

$$\Delta t_c = t_1 - t_2 \qquad \text{.... (13.8)}$$

Here, it can be seen that C_1 and C_2 are same, and since the inflows are derived from the histogram $I_1 = I_2$ for each time interval, the Eqn. 13.4 will reduce to Eqn. 13.9 as,

$$Q_2 = 2C_1I_1 + C_2Q_1 \quad \text{.... (13.9)}$$

The Eqn. 13.9 may written in more general form as,

$$u_i = CI_i + (1-C)u_{i-1} \quad \text{.... (13.10)}$$

where, u_i = i^{th} ordinate of IUH, C = routing coefficient, $C = \frac{\Delta t}{R + 0.5\Delta t}$, Δt = time interval in hours, I_i = i^{th} ordinate of time area diagram

Rodriguez–Iturbe and Valdes (1979) gave two equations for computation of peak flow and time to peak using geomorphological coefficients as given in Eqn. 13.11 and Eqn. 13.12,

$$q_p = \frac{1.31R_L^{0.49}V}{L_\Omega} \quad \text{....(13.11)}$$

$$t_p = 0.44\left(\frac{L_\Omega}{V}\right)\left(\frac{R_B}{R_A}\right)^{0.55}(R_L)^{-0.38} \quad \text{.... (13.12)}$$

where, t_p = time to peak in hours, L_Ω = length of the highest order stream in km, q_p = peak flow in units of inverse hours, V = expected peak velocity in m/sec, R_B = bifurcation ratio, R_L = length ratio, R_A = area ratio

By multiplying q_p and t_p, we get Eqn. 13.13 given as,

$$q_p * t_p = 0.5764\left(\frac{R_B}{R_A}\right)^{0.55}(R_L)^{0.05} \quad \text{.... (13.13)}$$

The term given in Eqn. 13.12 is not dependent on storm characteristics but only a function of catchment characteristics.

13.4.4 Relationship between excess rainfall and peak velocity

In the GIUH based Clark model, the expected peak velocity is used as an input. This dynamic parameter at any given moment during the storm may be considered as constant through out the basin (Rodriguez et al, 1979). The velocity at peak runoff is used for the derivation of GIUH. A relationship between intensity of excess rainfall and peak velocity has been developed for the watershed and sub-watershed. Two different approaches are available for gauged and ungauged catchments.

13.4.4.1 Gauged catchment

This approach is used when the discharges and corresponding velocities at different depths are available at the outlet of the watershed. The discharge (Q) and velocity (V) at any depth may be considered as equilibrium discharge (Q_e) and equilibrium velocity respectively. The intensity of excess rainfall i, is calculated by Eqn. 13.14 given as,

$$i = \frac{Q_e}{0.2778A} \quad \text{.... (13.14)}$$

Using different pairs of V and i, a relationship can be developed in the form of $V=ai^b$.

13.4.4.2 Ungauged catchment

In case of ungauged catchment, the geometric properties of gauging section, bed slope and Manning's roughness coefficient should be known with adequate degree of accuracy. At different depths, the cross sectional area, wetted perimeter and hydraulic mean depth is estimated. The velocities and corresponding discharges are computed using Manning's equation and cross sectional areas. Graphs are plotted between depth v/s area of cross section and depth v/s discharge. Equilibrium discharge may be calculated for an intensity of rainfall i, given by Eqn. 13.15 as,

$$Q_e = 0.2778iA \quad \text{.... (13.15)}$$

where, A = catchment area in km^2, Q_e = equilibrium discharge in cumecs.

The depth corresponding to that intensity may be calculated by the relationship between depth v/s discharge. For this depth, the cross sectional area is calculated using the relationship of depth v/s area of cross section. Using the equilibrium discharge and cross sectional area, velocity at an intensity of rainfall is computed. Similarly, velocity have been calculated for various intensities and a relationship between intensity of rainfall and equilibrium velocity in the form of $V=ai^b$ developed.

13.4.5 Application of new approach in Clark Model

A new approach has been developed in National Institute of Hydrology, Roorkee in the year 1993, in which the parameters of the Clark model are computed using geomorphological characteristics of the basin. Using the relationship developed between

V and I earlier, the peak velocity may be estimated for the highest rainfall intensity of a storm. The peak discharge (Q_{pg}) of IUH may be calculated with the help of Eqn. 13.11 where the inputs are length ratio and length of highest order stream. The time of concentration is calculated using Eqn. 13.16,

$$T_c = \frac{0.2778L}{V} \qquad \text{.... (13.16)}$$

Two trial values of storage coefficients R_1 and R_2 are assumed and ordinates of two instantaneous unit hydrographs computed at very small time interval (0.1 or 0.05 hrs) using Eqn. 13.10. The peak of both the computed instantaneous unit hydrographs may be found out as Q_{pc1} and Q_{pc2}. The objective functions (FCN_1 and FCN_2) is worked out using Eqn. 13.17 and Eqn, 13.18,

$$FCN_1 = (Q_{pg} - Q_{pc1})^2 \qquad \text{.... (13.17)}$$

$$FCN_2 = (Q_{pg} - Q_{pc2})^2 \qquad \text{.... (13.18)}$$

The first derivative FPN of the objective function FCN with respect to storage coefficient R is calculated by Eqn. 13.19 as,

$$FPN = \frac{(FCN_1 - FCN_2)}{(R_1 - R_2)} \qquad \text{.... (13.19)}$$

The increment (ΔR) and next trial value of storage coefficient (R_{new}) is computed by equations of Newton-Raphson method given as,

$$\Delta R = \frac{FCN_1}{FPN} \qquad \text{.... (13.20)}$$

$$R_{new} = R_1 + \Delta R \qquad \text{.... (13.21)}$$

Again the ordinates of two IUH's may be computed considering $R_1 = R_2$ and $R_2 = R_{new}$ and FCN1, FCN2, FPN, ΔR and R_{new} may be calculated using the same procedure till any one of the following conditions satisfy.

$$FCN_2 = 0.000001 \qquad \text{.... (13.22)}$$

$$\frac{ABS(\Delta R)}{R_1} = 0.001 \qquad \text{....(13.23)}$$

Number of trials exceeds 1000

With the help of final value of storage coefficient (R_2), time area diagram and time of concentration, the ordinates of IUH have been computed for a particular storm. The ordinates of a D-hour unit hydrograph (U_i) can be obtained for IUH using Eqn. 13.24 given as,

$$U_i = \frac{1}{n}\left[0.5\left(u_{i-n} + u_i\right) + u_{i-n+1} + ------- + u_{i-1}\right] \quad \text{.... (13.24)}$$

This unit hydrograph have been used to estimate the direct surface hydrograph for this particular storm. The performance of the model has been evaluated using spatial correlation coefficient (SC), integral square error (ISE), relative mean absolute error (RMAE), relative mean square error (RMSE) and relative error in peak (REP). The equations used for computation of SC, ISE, RMAE, RMSE and REP are given as,

$$SC = \frac{2\sum_{t=1}^{n} Q_o(t)Q_c(t) - \sum_{t=1}^{n}\left[Q_c(t)\right]^2}{\sum_{t=1}^{n} Q_o(t)} \quad \text{.... (13.25)}$$

$$ISE = \frac{\left[\sum_{t=1}^{n}\left\{Q_o(t) - Q_c(t)\right\}^2\right]^{0.5}}{\sum_{t=1}^{n} Q_o(t)} \quad \text{.... (13.26)}$$

$$RMA = \frac{\frac{1}{n}\sum_{t=1}^{n}\left[Q_o(t) - Q_c(t)\right]}{Q_{op}} \quad \text{....(13.27)}$$

$$RMSE = \frac{\left[\sum_{t=1}^{n}\left\{Q_o(t) - Q_c(t)\right\}^2\right]^{0.5}}{n} \quad \text{....(13.28)}$$

$$REP = \frac{Q_{op} - Q_{cp}}{Q_{op}} \quad \text{.... (13.29)}$$

where, $Q_o(t)$ = observed discharge at time t, $Q_c(t)$ = computed discharge at time t, Q_{op} = observed peak discharge at time t, Q_{cp} = computed peak discharge at time t, n = number of observations.

13.5 Analysis & Results

It has been observed that the runoff measurements in Madhya Pradesh are limited only on big rivers. Hence, it is very important to develop some other methods, which may use basin characteristics and other easily available ancillary information for rainfall-runoff modeling. The geomorphological characteristics based Clark model may be used to determine the peak flow for design of small hydraulic structures such as barrage, weirs, bridges etc.

13.5.1 Time area diagram

The time area diagram, which is used as an input in the Clark model, has been prepared for the Nala sub-watershed and the Tumri watershed using ILWIS 3.0. The time area diagrams and graphical representation of relationship between T/T_c and A/A_c of Nala sub-watershed and Tumri watershed have been given in Fig. 13.1 and Fig. 13.2 respectively. The following best-fit equations have been obtained from the time area diagram for the Nala sub-watershed as well as Tumri watershed,

For Nala sub-watershed

$$\frac{T}{T_c} = 0.072\left(\frac{A}{A_c}\right)^3 + 0.322\left(\frac{A}{A_c}\right)^2 + 0.617\left(\frac{A}{A_c}\right) \qquad ....(13.30)$$

For Tumri watershed

$$\frac{T}{T_c} = 0.189\left(\frac{A}{A_c}\right)^3 + 0.295\left(\frac{A}{A_c}\right)^2 + 0.531\left(\frac{A}{A_c}\right) \qquad .... (13.31)$$

13.5.2 Relationship between rainfall intensity and peak velocity

The gauging of few flood events in the Nala sub-watershed has been carried out and a relationship between rainfall intensity *(I)* and equilibrium velocity *(V)* has been developed. The graphical representation of rainfall intensity and equilibrium velocity for Nala sub-watershed has been presented in Fig. 13.3. The relationship between I (mm/hr) and V (m/sec) is given as Eqn. 13.32. The same V and i relationship has been used for application of model in Tumri watershed.

$$V = 0.865 i^{0.565} \qquad .... (13.32)$$

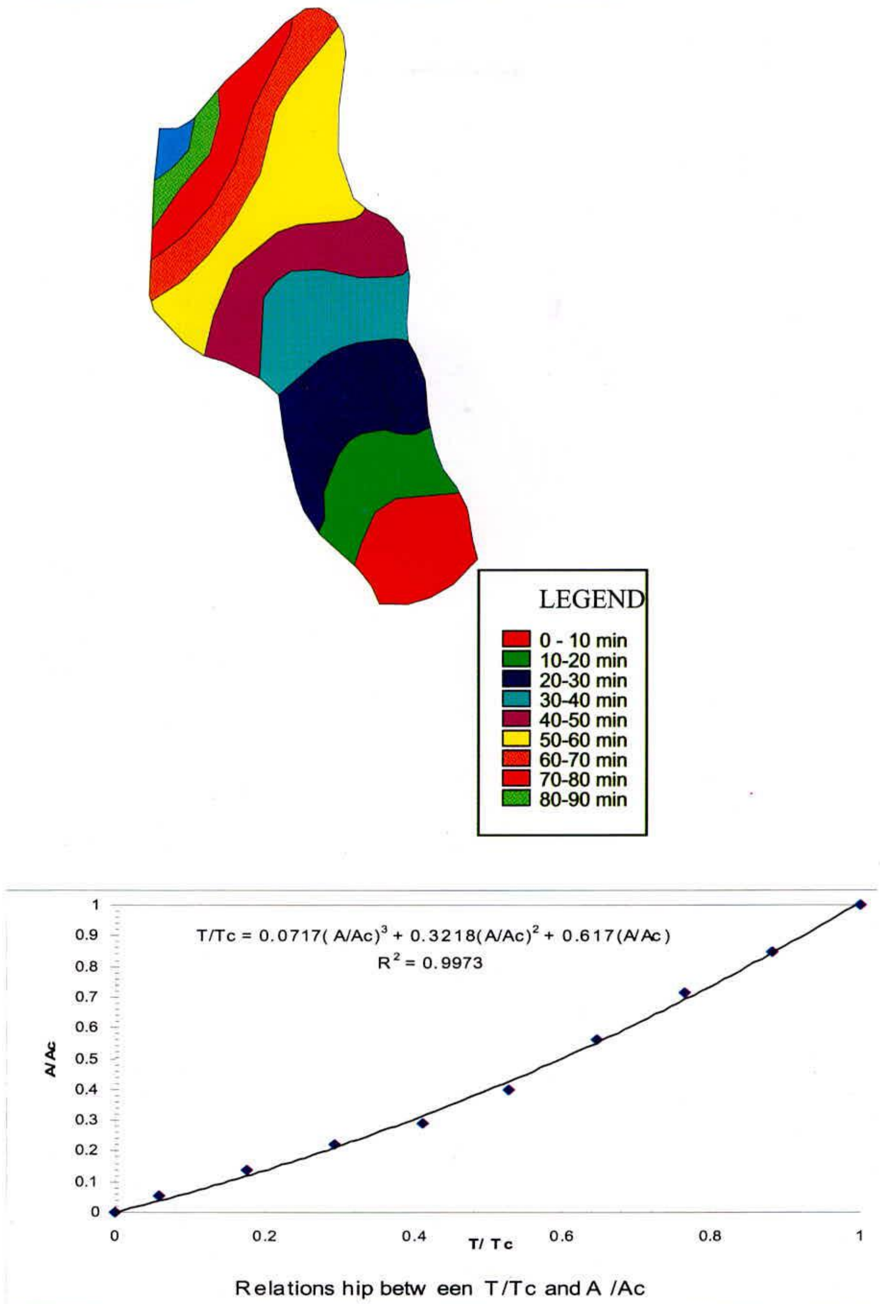


Fig. 13.1: Time area diagram and relationship between T/T_c and A/A_c for Nala sub-watershed

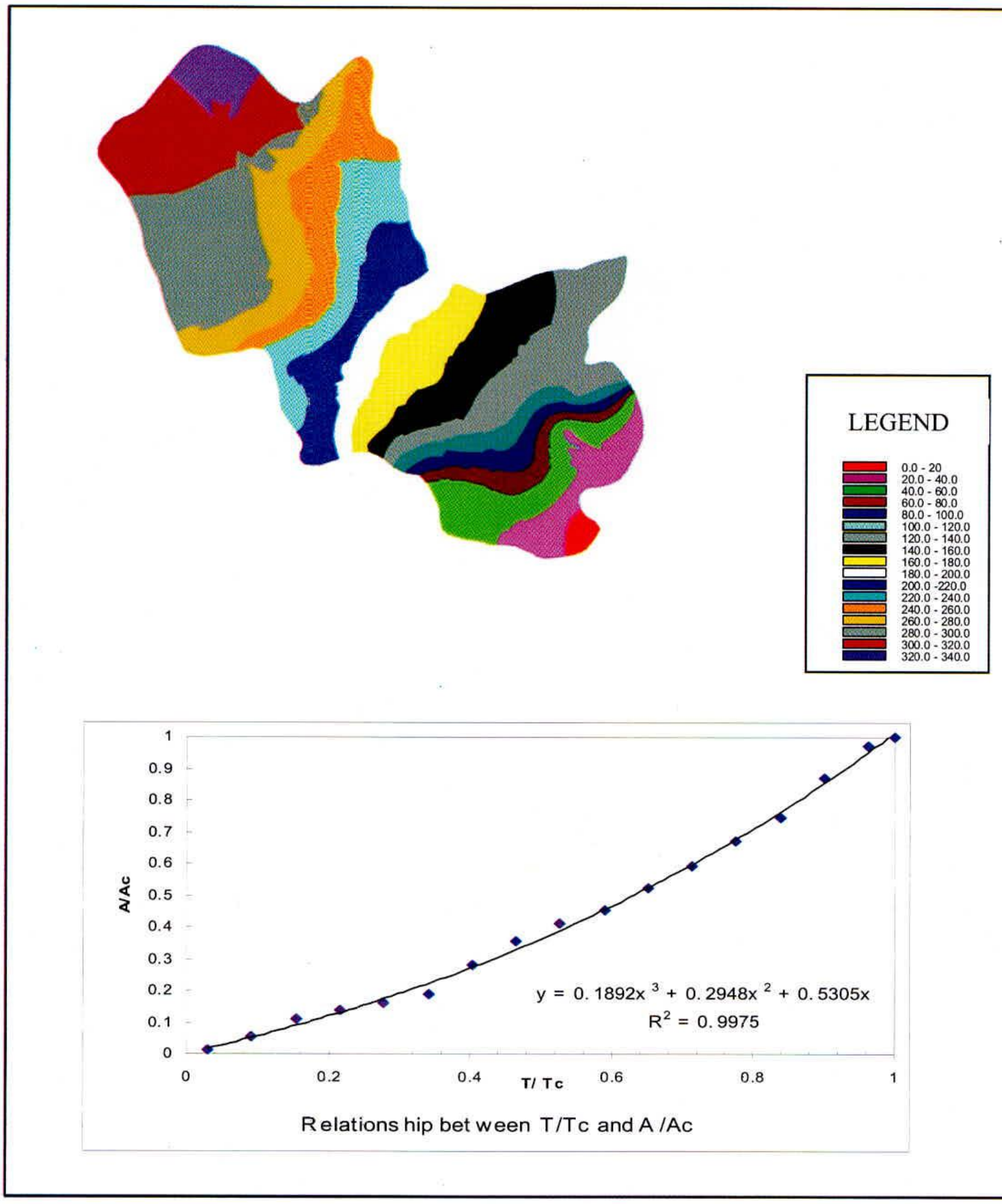


Fig. 13.2: Time area diagram and relationship between T/T_c and A/A_c for Tumri watershed

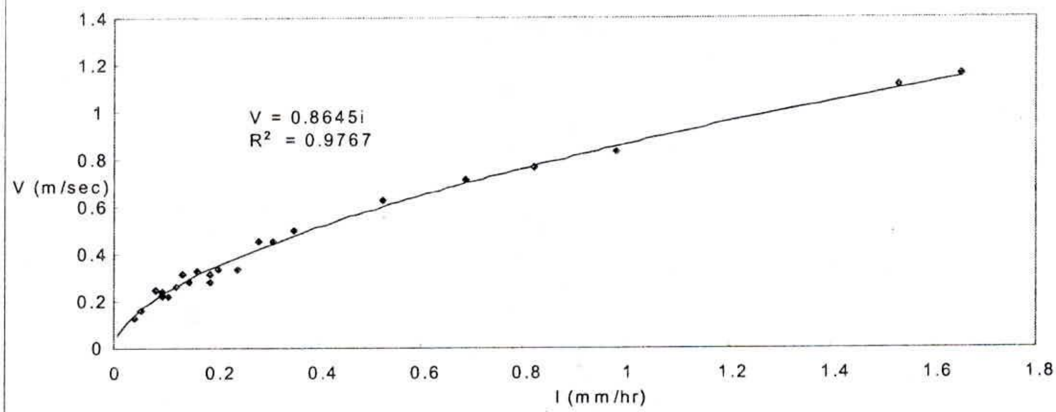


Fig. 13.3: Relationship between Eq. Rain (I) & Velocity (V) for Nala sub-watershed

13.5.3 Application of GIUH based Clark model

For development of the GIUH based Clark model, a program in FORTRAN has been developed using the methodology given above. Fifteen storm events spread over 2006-07 and 2007-08 and twelve storms spread over 2008-09 have been selected for analysis, using the rainfall records from SRRG and observed runoff data The analyses of runoff hydrographs of Nala sub-watershed and Tumri watershed is discussed below.

13.5.3.1 Nala sub-watershed

Using the rainfall records from SRRG, the rainfall intensity for the selected storms have computed where the runoff data for Nala sub-watershed were recorded and the parameters and ordinates of IUH have been determined. The time of concentration (T_c), storage coefficient (R), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) for all the storms in Nala sub-watershed have been given in Table 13.1. With the help of ordinates of IUH, the ordinates of UH, DSRO and flood ordinates for all these storms have been computed. For comparison, the observed and computed runoff ordinates have been plotted on same graph for few storms. A graphical representation of comparison of computed and observed runoff for few events have been presented in Fig. 13.4 to Fig. 13.7. The performance of the GIUH model has been evaluated with the help of spatial correlation coefficient (SC), integral square error (ISE), relative mean absolute error (RMAE), relative mean square error (RMSE), and

Table 13.1: Parameters of GIUH based Clark model for Nala sub-watershed

S.N	Date	i	V	Q_{pg}	T_{pg}	Q_{pc}	T_{pc}	R	T_c
1.	30-Aug-06 A	9.00	3.11	38.29	16.02	38.30	16.0	0.088	15.0
2.	30-Aug-06 B	5.00	2.23	27.48	21.00	27.48	21.0	0.096	20.9
3.	31-Aug-06	13.0	3.83	47.14	13.02	47.14	13.0	0.071	12.2
4.	05-Sep-06	21.00	5.02	61.80	10.02	61.81	10.0	0.050	9.3
5.	07-Jul-07 A	12.00	3.66	45.06	13.02	45.06	13.0	0.063	12.8
6.	07-Jul-07 B	40.00	7.22	88.95	7.02	88.94	7.0	0.040	6.5
7.	23-Jul-07	9.00	3.11	38.29	16.02	38.30	16.0	0.088	15.0
8.	28-Jul-07	13.00	3.83	47.14	13.02	47.14	13.0	0.071	12.2
9.	29-Jul-07	20.00	4.88	60.13	10.02	60.13	10.0	0.052	9.6
10.	01-Aug-07	8.00	2.91	35.81	16.98	35.84	17.0	0.092	16.0
11.	03-Aug-07	8.00	2.91	35.81	16.98	35.84	17.0	0.092	16.0
12.	07-Aug-07	4.00	1.97	24.22	24.00	24.23	24.0	0.110	23.8
13.	31-Aug-07	7.00	2.70	33.23	18.00	33.24	18.0	0.092	17.3
14.	04-Sep-07	6.25	2.53	31.17	19.02	31.17	19.0	0.095	18.5
15.	05-Sep-07	15.00	4.15	51.11	12.00	51.11	12.0	0.066	11.3
16.	20-Jun-08	4.00	1.97	24.22	24.00	24.23	24.0	0.11	23.8
17.	27-Jun-08	7.00	2.70	33.20	18.78	33.23	18.0	0.09	17.3
18.	28-Jun-08	20.00	4.88	60.15	10.39	60.13	10.0	0.05	9.5
19.	9-Jul-08	28.00	5.90	72.73	8.59	72.71	8.0	0.04	7.9
20.	27-Jul-08	12.00	3.66	45.04	13.85	45.06	13.0	0.06	12.8
21.	29-Jul-08	16.00	4.30	53.00	11.79	53.01	11.0	0.05	10.9
22.	31-Jul-08	64.00	9.42	115.9	5.38	115.95	5.0	0.02	4.8
23.	1-Aug-08	64.00	9.42	115.9	5.38	115.95	5.0	0.02	4.8
24.	3-Aug-08	24.00	5.41	66.63	9.37	66.65	9.0	0.05	8.6
25.	9-Aug-08	24.00	5.41	66.63	9.37	66.65	9.0	0.05	8.6
26.	10-Sep-08	24.00	5.41	66.63	9.37	66.65	9.0	0.05	8.6
27.	11-Aug-08	16.00	4.30	53.00	11.79	53.01	11.0	0.05	10.9

i: Peak rainfall intensity in mm/hr; V: Peak velocity in m/sec; Q_{pg}:Peak discharge in cumecs; T_{pg}: Time to peak of IUH in min; Q_{pc}: Computed peak of IUH with Clark model in cumecs; T_{pc}: Computed time to peak of IUH with Clark model in min; R: Storage coefficient in hrs^{-1};T_c: Time of concentration in min

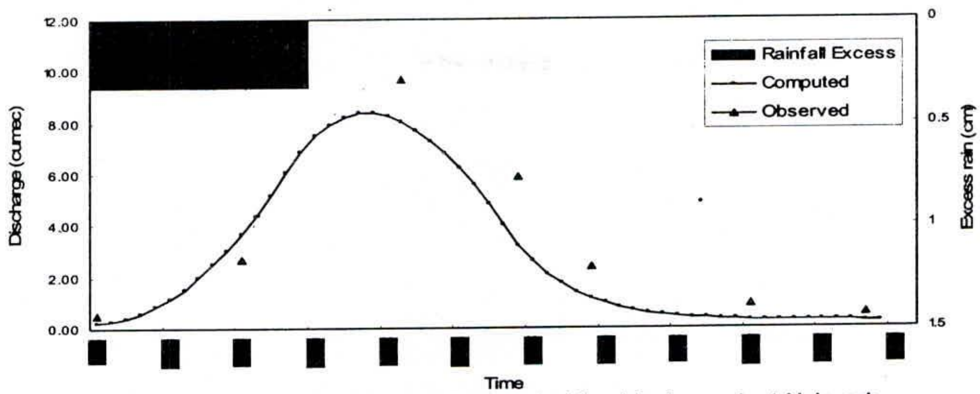


Fig. 13.4: Comparison of observed and computed flood hydrograph at Nala sub-watershed (31.08.2006)

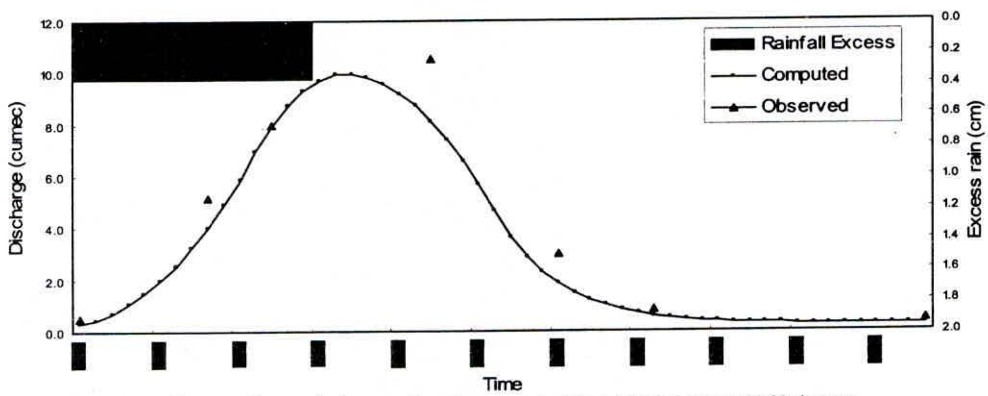


Fig. 13.5 : Comparison of observed and computed flood hydrograph in Nala sub-watershed (05.09.2007)

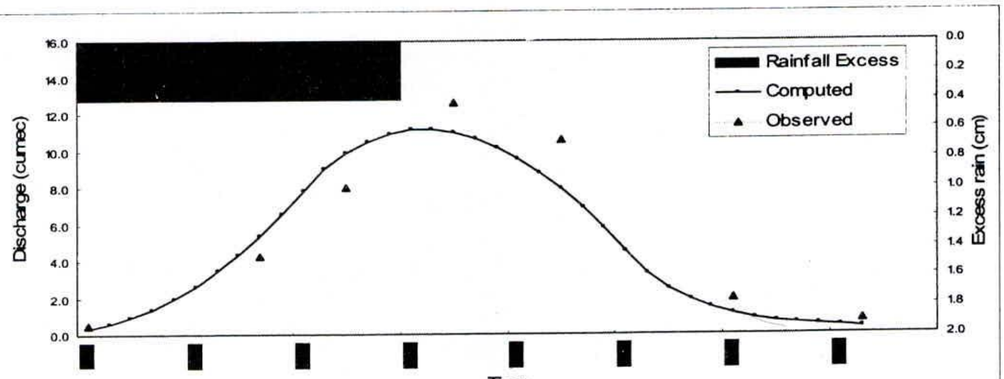


Fig. 13.6 : Comparison of observed and computed flood hydrograph in Nala sub-watershed (11.08.2008)

relative error in peak (REP) and given in Table 13.2. The RMSE varies between 0.11 and 1.83 for the gauged Nala sub-watershed.

Table 13.2: Performance evaluation of GIUH model in Nala sub-watershed

S.N.	Date	SC	ISE	RMAE	RMSE	REP
1.	30-Aug-06 A	0.95	0.11	0.09	0.28	0.23
2.	30-Aug-06 B	0.95	0.10	0.09	0.14	0.22
3.	31-Aug-06	0.81	0.16	0.11	0.51	0.17
4.	05-Sep-06	0.93	0.15	0.11	0.99	0.19
5.	07-Jul-07 A	0.96	0.11	0.08	0.32	0.18
6.	07-Jul-07 B	0.95	0.13	0.09	0.49	0.13
7.	23-Jul-07	0.84	0.12	0.11	0.38	0.24
8.	28-Jul-07	0.93	0.14	0.09	0.49	0.13
9.	29-Jul-07	0.96	0.07	0.09	0.64	0.16
10.	01-Aug-07	0.97	0.09	0.08	0.22	0.15
11.	03-Aug-07	0.98	0.08	0.05	0.19	0.07
12.	07-Aug-07	0.93	0.13	0.12	0.14	0.05
13.	31-Aug-07	0.98	0.05	0.04	0.11	0.03
14.	04-Sep-07	0.89	0.06	0.06	0.11	-0.09
15.	05-Sep-07	0.96	0.10	0.07	0.42	0.23
16.	20-Jun-08	0.97	0.08	0.07	0.08	0.16
17.	27-Jun-08	0.90	0.19	0.10	0.39	0.34
18.	28-Jun-08	0.98	0.07	0.06	0.42	0.09
19.	9-Jul-08	0.99	0.05	0.06	0.52	0.09
20.	27-Jul-08	0.97	0.09	0.08	0.29	0.09
21.	29-Jul-08	0.97	0.09	0.08	0.44	0.05
22.	1-Aug-08	0.97	0.09	0.08	1.83	-0.06
23.	3-Aug-08	0.97	0.10	0.08	0.74	-0.10
24.	9-Aug-08	0.94	0.12	0.10	0.92	0.03
25.	11-Aug-08	0.96	0.10	0.10	0.56	0.13
26.	2-Sep-08	0.95	0.13	0.09	1.04	-0.16
27.	10-Sep-08	0.98	0.07	0.08	0.54	-0.06

Using the outputs from model runs for the selected storms in Nala sub-watershed, relationships have been developed for parameters of GIUH (R and T_c) with equilibrium velocity (V). The graphical representations of variation of R and T_c with equilibrium velocity (V) have been given in Fig. 13.7 and Fig. 13.8.

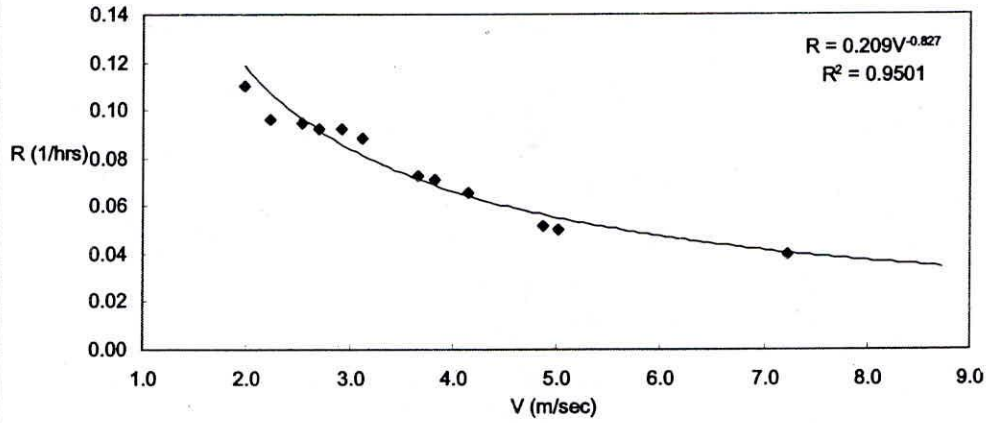


Fig 13.7: Relationship between V and R for Nala sub-watershed

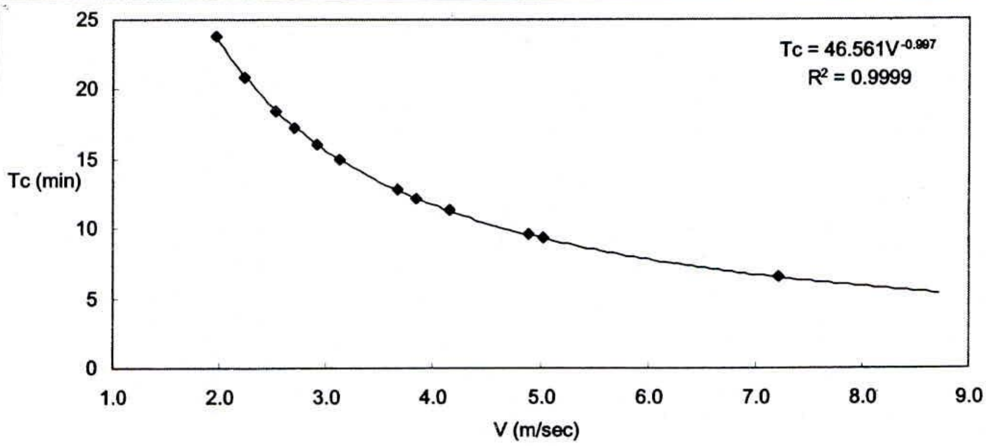


Fig. 13.8: Relationship between V and T_c for Nala sub-watershed

The following relationships between equilibrium velocity (V, m/sec) with storage coefficient (R, hrs^{-1}) and time of concentration (T_c, min) can be used for application of GIUH model for Nala sub-watershed without optimizing the model parameters.

$$R = 0.209V^{-0.827} \quad \text{.... (13.33)}$$

$$T_c = 46.561V^{-0.997} \quad \text{.... (13.34)}$$

It is well established in GIUH model, the ratio of R and (R+ T_c) remains constant for a catchment. For the Nala sub-watershed this ratio has been estimated as 0.006.

13.5.3.2 Tumri watershed

The GIUH model has been applied for same events using geomorphological characteristics of Tumri watershed. The time of concentration (T_c), storage coefficient (R), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) of all the storms in Tumri watershed have been given in Table 13.3.

Table 13.3: Parameters of GIUH based Clark model for Tumri watershed

S.N	Date	i	V	Q_{pg}	T_{pg}	Q_{pc}	T_{pc}	R	T_c
1.	30-Aug-06 A	9.00	3.11	23.45	64.8	23.40	65.0	2.70	61.7
2.	30-Aug-06 B	5.00	2.23	16.80	89.9	16.79	90.0	3.72	85.9
3	31-Aug-06	13.00	3.83	28.76	51.0	28.75	53.0	2.06	50.1
4	05-Sep-06	21.00	5.02	37.69	39.0	37.70	39.0	1.58	38.2
5.	07-Jul-07 A	12.00	3.66	27.48	53.0	27.27	54.0	2.13	52.4
6.	07-Jul-07 B	40.00	7.22	54.20	27.0	54.19	27.0	1.09	26.6
7.	23-Jul-07	9.00	3.11	23.45	64.8	23.40	65.0	2.70	61.7
8.	28-Jul-07	13.00	3.83	28.76	51.0	28.75	51.0	2.06	50.1
9.	29-Jul-07	20.00	4.88	36.66	40.0	36.67	40.0	1.62	39.3
10.	01-Aug-07	8.00	2.91	21.90	69.6	21.89	70.0	2.93	65.4
11.	03-Aug-07	8.00	2.91	21.90	69.6	21.89	70.0	2.93	65.4
12.	07-Aug-07	4.00	1.97	14.61	99.6	14.84	100.0	4.06	97.2
13.	31-Aug-07	7.00	2.70	20.30	74.9	20.31	75.0	3.12	70.8
14.	04-Sep-07	6.25	2.53	19.05	80.0	19.04	80.0	3.33	75.7
15.	05-Sep-07	15.00	4.15	31.17	47.0	31.17	47.0	1.89	46.2
16.	20-Jun-08	4.00	1.97	14.61	99.6	14.84	100.0	4.06	97.2
17.	28-Jun-08	20.00	4.88	36.66	40.0	36.67	40.0	1.62	39.3
18.	9-Jul-08	28.00	5.90	44.32	39.9	44.32	40.0	1.48	32.5
19.	27-Jul-08	12.00	3.66	27.48	53.0	27.27	54.0	2.13	52.4

20.	29-Jul-08	16.00	4.30	32.54	44.8	32.33	45.0	1.80	44.6
21.	3-Aug-08	24.00	5.41	40.51	34.4	40.63	35.0	1.77	35.5
22.	9-Aug-08	24.00	5.41	40.51	34.4	40.63	35.0	1.77	35.5
23.	11-Aug-08	16.00	4.30	32.54	44.8	32.33	45.0	1.80	44.6
24.	25-Aug-08	48.00	8.00	59.78	25.8	60.09	25.0	1.03	23.9
25.	2-Sep-08	40.00	7.22	54.20	27.0	54.19	27.0	1.09	26.6
26.	10-Sep-08	24.00	5.41	40.51	34.4	40.63	35.0	1.77	35.5

With the help of ordinates of IUH, the ordinates of UH, DSRO and flood ordinates for all these storms have been computed. A graphical representation of excess rainfall hyetograph and computed runoff for few storms has been presented in Fig 13.9 to Fig. 13.11.

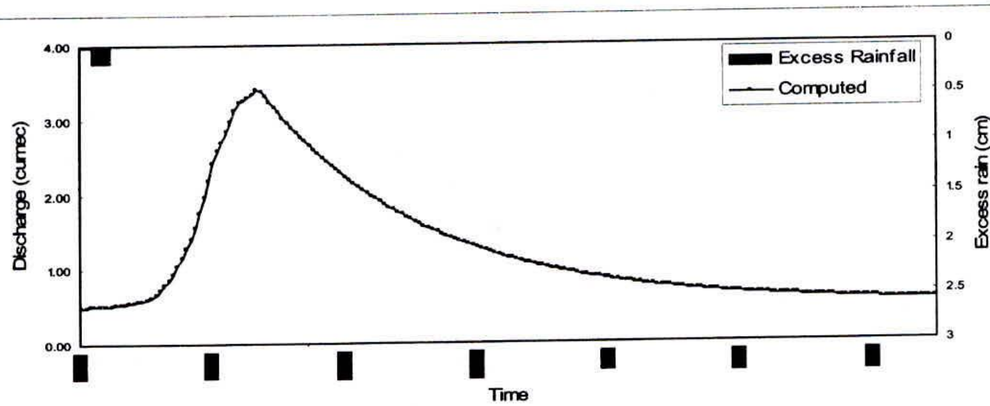


Fig. 13.9: Computed flood hydrograph for Tumri watershed (31.08.2007)

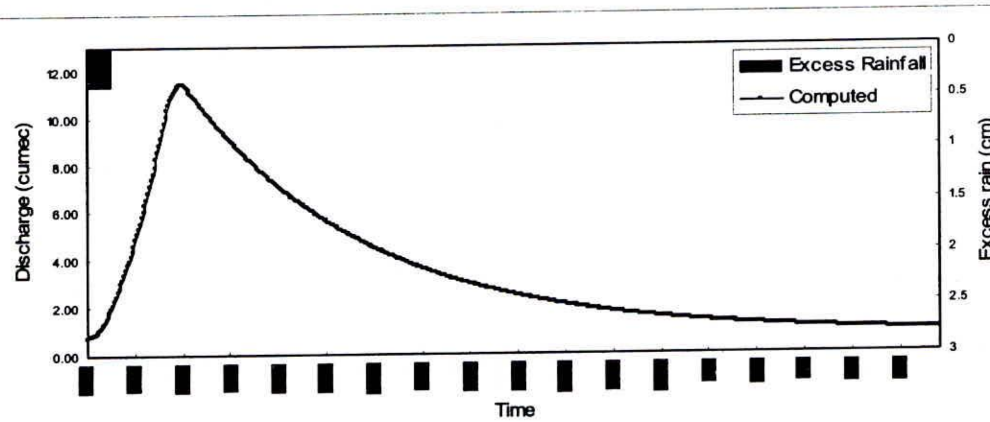


Fig. 13.10: Computed flood hydrograph for Tumri watershed (05.09.2007)

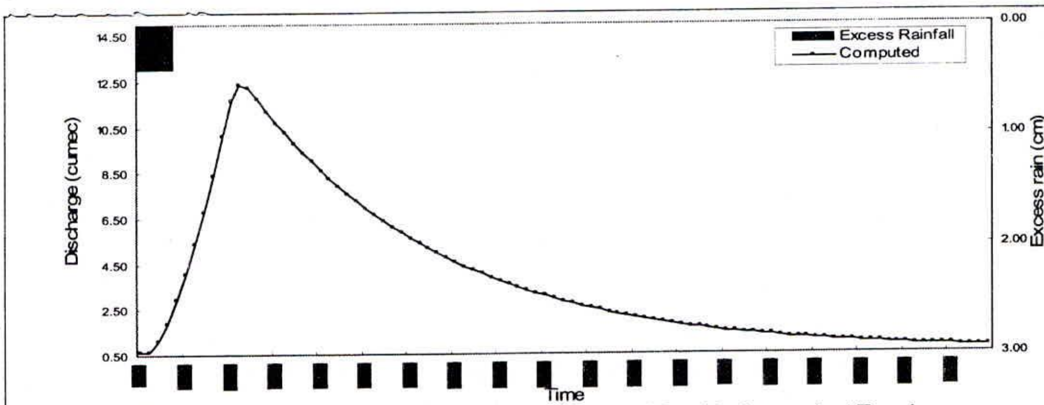


Fig. 13.11 : Comparison of observed and computed flood hydrograph at Tumri watershed (11.08.2008)

The equilibrium velocity (V) and storage coefficient (R) from Tumri watershed have been presented in Fig 13.12. Similarly, the relationship between equilibrium velocity (V) and time of concentration (T_c) has been given in Fig. 13.13.

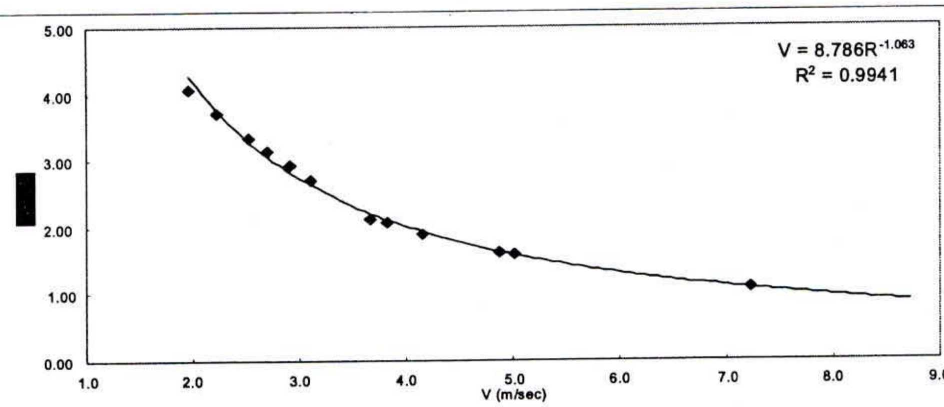


Fig. 13.12: Relationship between V and R for Tumri watershed

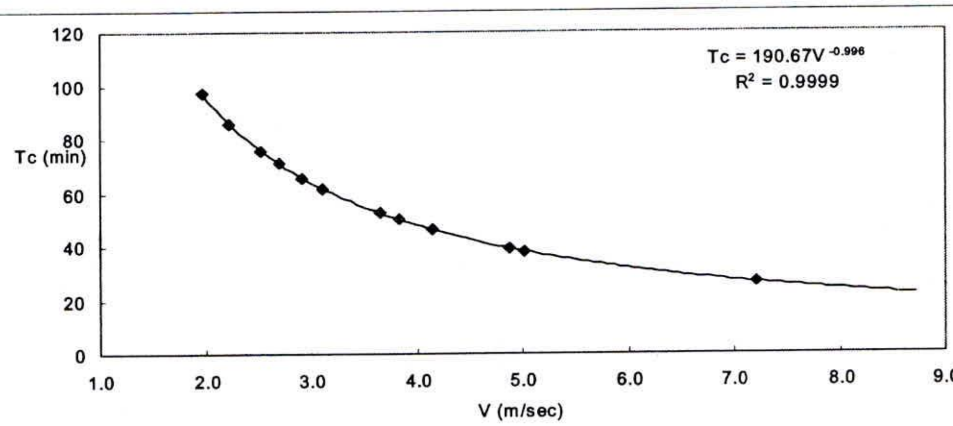


Fig. 13.13: Relationship between V and T_c for Tumri watershed

The following equations can be used for computation of parameters of GIUH model for Tumri watershed.

$$R = 7.786V^{-1.063} \quad \text{.... (13.35)}$$

$$T_c = 190.67V^{-0.996} \quad \text{.... (13.36)}$$

The value of the ratio of R and ($R+T_c$) for Tumri watershed has been estimated as 0.041.

14.0 SITES FOR SURFACE WATER STORAGE STRUCTURES

Water resources play a vital role in the economic upliftment of society and constitute one of the most crucial life support system for ensuring quality of the life and preservation of environment. In order to meet the growing demands of an ever-expanding population, available natural resources are being exploited at an increasing rate, due to which the abundant water resource has become scarce. The available water resources in ponds, tanks, and streams have drastically reduced because of silting and ground water table declined due to excess pumping for agriculture and domestic use.

Tumri watershed being located in the upstream reaches of river Sonar has many limitations including rugged topography with flat topped hills at many places in the watershed. In such watersheds the topography does not permit the construction of big projects to meet the demands of the local villagers. Here it is more feasible to construct and maintain small water storage structures for water use at local level, preferably on the second and third order streams instead of going for large projects which may require huge investment and may cause environmental imbalances. The site selection for construction of water resources structures is a very important exercise for sufficient impoundment and providing adequate water to farmers in the command area.

14.1 Decision Rules

The sites have been selected on the basis of the decision rules developed as per the requirements of the project along with the socio-economic data of the area and economic status of the landholders surrounding to the proposed tanks. The following decision rules have been considered for finalization of water storage sites.

- There should be a common drainage point or stream for the whole catchment area so that the entire runoff water from the catchment area may be stored in a storage structure.
- Submergence of dense forestlands and agricultural lands should be minimal.
- Sufficient agricultural land downstream so that the stored water may be utilized for irrigation purposes.
- Non-agricultural land should be available surrounding the storage structure for taking up the development of agro-forestry/horticulture/pastures in the degraded lands.
- The catchment area must be large enough to fill up the complete storage capacity created for the normal rainfall. Therefore sufficient inflows from the river should be available at the selected site and as such the storage structure should be located on a second or third order stream.
- The length of the structure should be minimum and the height of the dam should be within 4 to 6 meters, so that the construction cost is reasonable.
- The topography of the selected site should be such that the water spread area is less for minimal evaporation losses from the reservoir.
- The average depth in the reservoir should be such that sufficient water depth remains during summer season even after the loss of water due to evaporation and seepage.
- Sites are selected such that they are well distributed so as to cope with the demands of the various users in the entire watershed area.

14.2 Methodology

The thematic maps including base map, drainage network, geology, contours, digital elevation model, road network and land use have been used for the analysis. The narrow valleys in second and third order streams have been identified at the first stage on DEM of the study area. All these maps have been overlaid in GIS environment and considering the decision rules ten potential sites were identified based on the topography best suited for the location of a storage structure. The sites have been selected such that there is minimum submergence of agricultural and forest lands and sufficient agricultural lands are available downstream for irrigation and ample waste lands are available for development of agroforestry and grazing lands.

The bund length has been drawn over the second and third order stream and the catchment boundary for each site has been delineated by superimposing the drainage map over DEM. The DEM for each of the selected sites have been separately abstracted. Analysis of the DEM for each site was carried out to fix the height and length of the bund along with the actual field visits. The sites have also been chosen such that the length of structure is minimum for a given storage capacity and the capacity of water storage structure is maximum with narrow spread area and small bund. The water spread area and the corresponding storage capacity for each of the sites has been estimated. Another site on the main river Tumri has been identified for construction of a big irrigation project for creating downstream irrigation potential in the Sonar river basin.

Extensive visits were undertaken to the exact site locations to assess the actual site conditions and to decide whether the proposed site confirms to the decision rules on ground. Socio-economic status of the beneficiary villagers, land holdings and land use of the surrounding area are also considered while finalizing the sites. Seven sites were finalized for construction of small storage structures and one site was identified for construction of a bigger project. A separate map containing the catchment area of the selected sites have been prepared. The height of the bund was decided on the basis of the decision rules so as to get maximum storage capacity with less submergence and such that water remains at the end of summer season after considering the evaporation and seepage losses. Also assessment of the volume of water generated as runoff from the catchment area of the structure, considering the normal annual rainfall of the study area was carried out so as to confirm that the storage capacity created gets duly filled up. The water spread area and the storage capacity of each of the selected structures corresponding to the finalized bund height has been estimated. The land use classes falling under the submergence area for each of the proposed site have been abstracted from the land use map. Considering the length of bund, height of dam, water spread, depth of pondage, storage capacity created and downstream potential for irrigation priority has been assigned to the selected sites.

14.3 Analysis & Results

Site selection for suitable storage structures in the Tumri watershed have been done by carrying out extensive field visit at each of the proposed sites and discussion with local authorities and villagers. Keeping in view the points mentioned in the criterion for site selection, the possible sites were visited. About ten sites were visited in the entire watershed and finally seven sites having small storage capacities and one site for a big project were selected for further analysis. The water spread area and capacity of the storage tank at 0.5 m elevation intervals have been calculated using ILWIS 3.0. It is worth mentioning that the elevation-area-capacity curve pertains to the existing condition at each sites, however the capacity will further increase due to digging of earth for construction of bunds. A separate map containing the location, catchment area and water spread of the selected sites have been prepared and given in Fig. 14.1 while the map of the selected site for bigger project is given in Fig. 14.2.

14.3.1 Site 1

The Site 1 is situated near Patha Khurd village, where sufficient agricultural land is available downstream for irrigation. Also barren lands are available in the vicinity of the project for pasture and agro-forestry development. The height of the bund has been kept at 4.5 m. with the maximum water level at 531.0 m. above mean sea level (m.s.l). The water spread area is 11.117 hectare whereas the storage capacity created is 0.219 MCM. The catchment area of 77.95 hectares will be able to generate sufficient runoff to fill up the storage capacity created under this project considering the normal rainfall. The average depth of pondage is 1.957 m which will be useful for irrigation in kharrif and rabi season. This project is located on a third order stream. The elevation-area and elevation-capacity curves for the Site 1 have been given in Fig. 14.3 (a) & Fig. 14.3 (b) respectively.

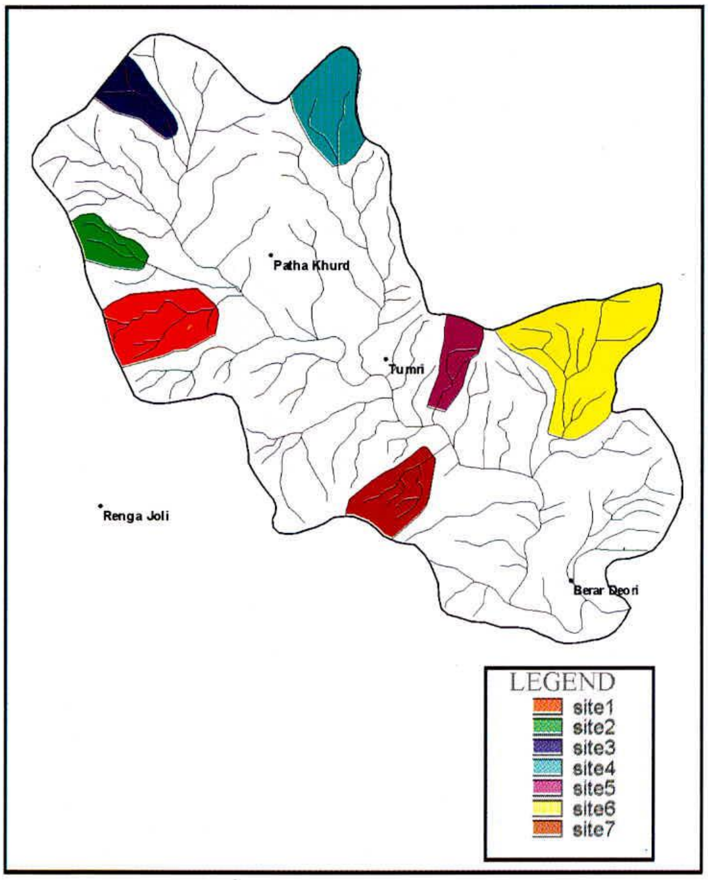


Fig. 14.1: Map showing location and catchment of storage sites

14.3.2 Site 2

The height of bund for the structure at Site 2 is kept at 3.0 m with the maximum water level at 539.5 m. The project is located on a second order stream with a water spread area of 6.499 hectare and storage capacity of 0.083 MCM. The catchment area of 30.56 hectares will be able to generate sufficient runoff to fill up the created storage capacity. The average depth of pondage is 1.274 m which seems to be less and may get dried up in summer season. However the water may be sufficient for irrigation in the kharrif season and the rabi crops can be irrigated with the combined use of surface and ground water. The elevation-area and elevation-capacity curves for the Site 2 have been given in Fig. 14.4 (a) & Fig. 14.4 (b) respectively.

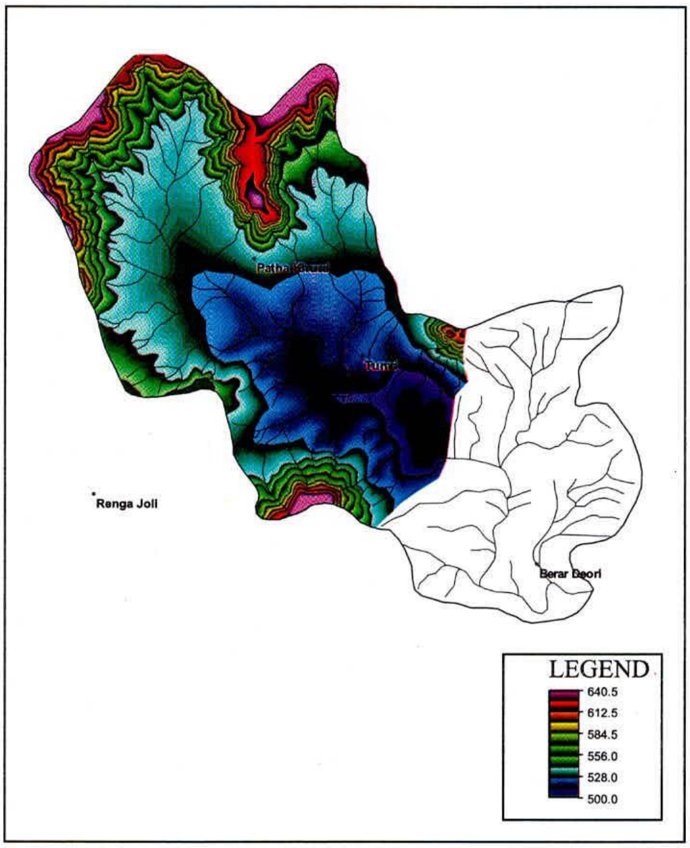


Fig. 14.2: Map showing the location, catchment and DEM of big project

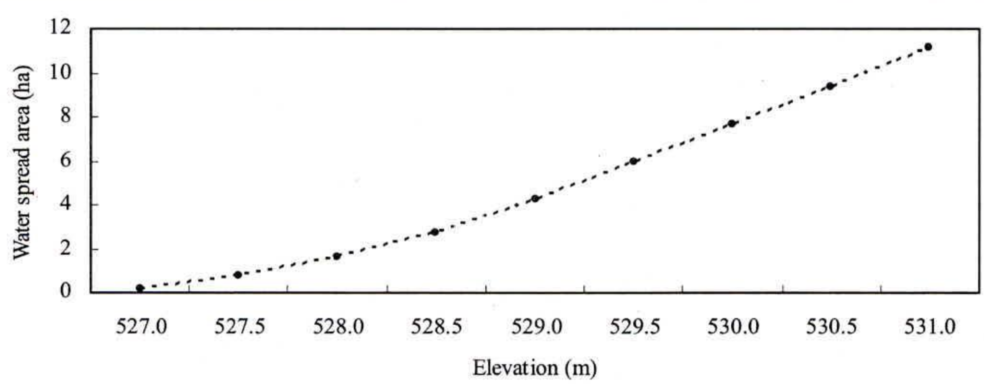


Fig. 14.3 (a): Elevation-area curve of Site-1

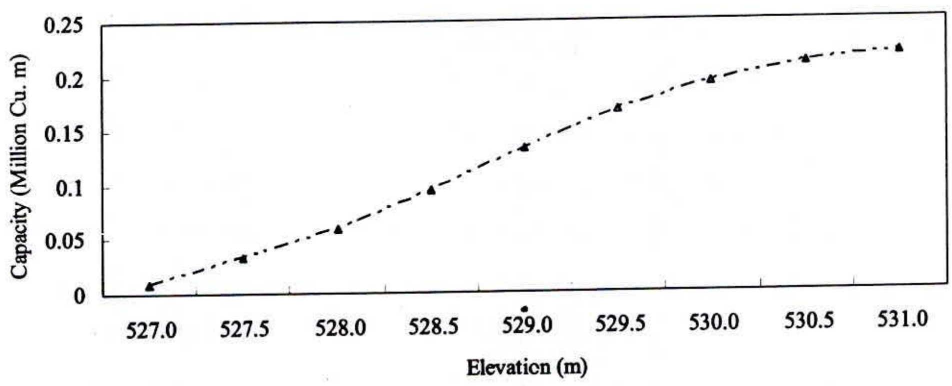


Fig. 14.3 (b): Elevation-capacity curve of Site-1

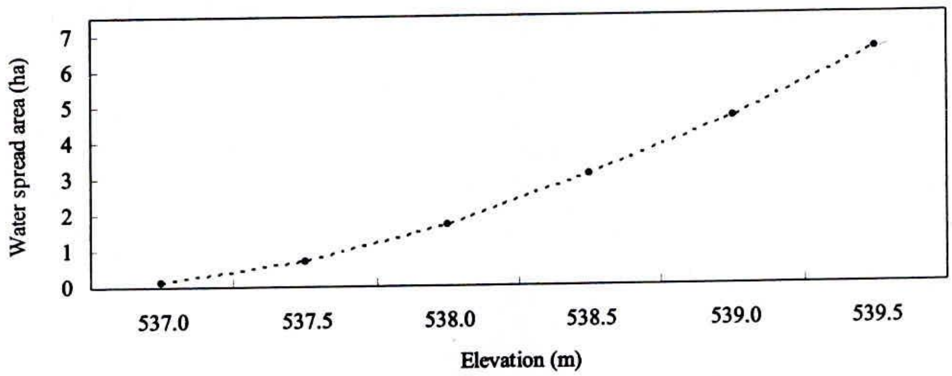


Fig. 14.4 (a): Elevation-area curve of Site-2

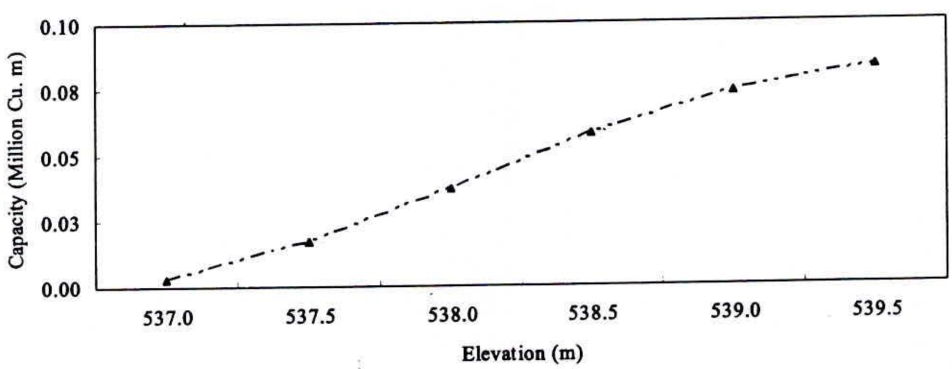


Fig. 14.4 (b): Elevation-capacity curve of Site-2

14.3.3 Site 3

The Site 3 is located at the uppermost reaches of the watershed and irrigation water is very much essential for the agricultural areas located in its vicinity. Moreover owing to the topography and geology, the ground water potential is minimal and wells get dry at the initial stages of the rabi season. This site has therefore been identified considering these factors. The water from this project can be suitably utilized for irrigating the abundant agricultural areas lying downstream of the project. The height of bund is kept at 4.0 m with the maximum water level at 542.5 m with a catchment area of 37.19 hectares. The water spread area is 4.460 hectare whereas the storage capacity created is 0.125 MCM. The average depth of pondage is 2.812 m. which will be able to meet the various demands including the evaporation and seepage losses. The elevation-area and elevation-capacity curves for the Site 3 have been given in Fig. 14.5 (a) & Fig. 14.5 (b) respectively.

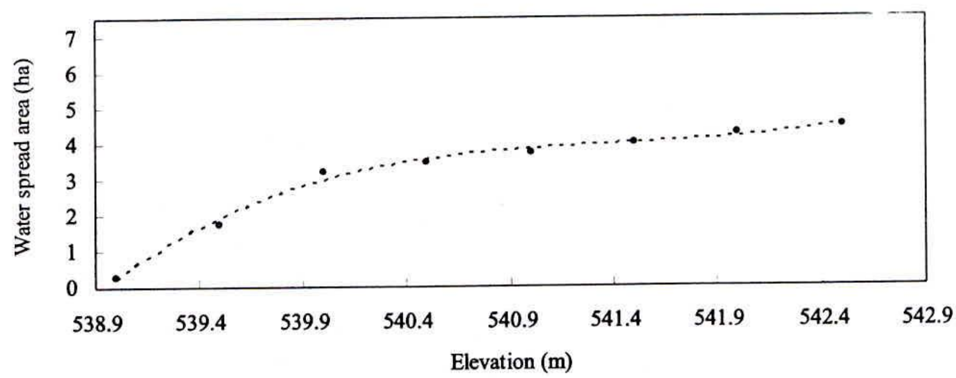


Fig. 14.5 (a): Elevation-area curve of Site-3

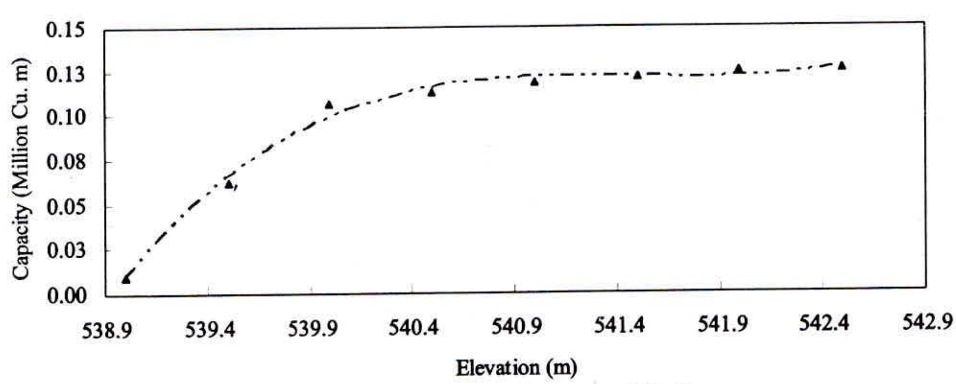


Fig. 14.5 (b): Elevation-capacity curve of Site-3

14.3.4 Site 4

The Site 4 is located at the beginning of the agricultural area which extend upto Tumri village. The topography is favorable as the water spread area is quite less but the storage capacity created is also less. The site is located on the second order stream with a catchment area of 70.79 hectares. The height of bund for the structure at Site-4 is kept at 6.0 m with the maximum water level at 545.5 m. The water spread area is 3.496 hectare whereas the storage capacity created is 0.102 MCM. The average depth of pondage is 2.913 m. which will be able to meet the various demands including the evaporation and seepage losses. The elevation-area and elevation-capacity curves for the Site 4 have been given in Fig. 14.6 (a) & Fig. 14.6 (b) respectively.

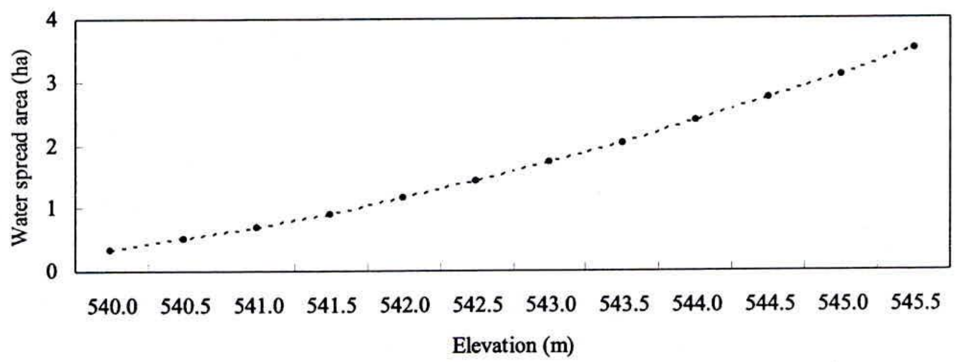


Fig. 14.6 (a): Elevation-area curve of Site-4

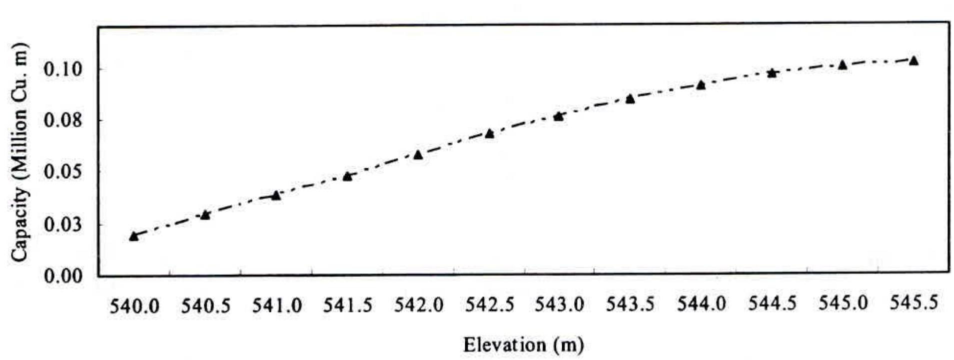


Fig. 14.6 (b): Elevation-capacity curve of Site-4

14.3.5 Site 5

The Site 5 is located on the downstream side of Tumri village and is almost centrally located. The proposed site is on a second order stream with a catchment area of 34.19 hectares and bund height of 5.50 m with the maximum water level at 505 m above m.s.l. The water spread area is 3.598 hectare with a storage capacity of 0.105 MCM and average depth of pondage of 2.909 m. which will be able to meet the agricultural demand. The site is located on the barren lands and abundant barren lands are available in its vicinity for development of agroforestry and grazing lands.. The elevation-area and elevation-capacity curves for the Site-5 have been given in Fig. 14.7 (a) & Fig. 14.7 (b) respectively.

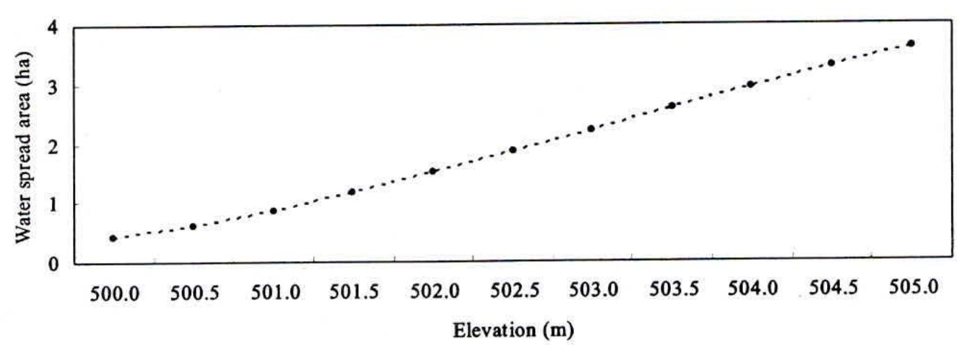


Fig. 14.7 (a): Elevation-area curve of Site-5

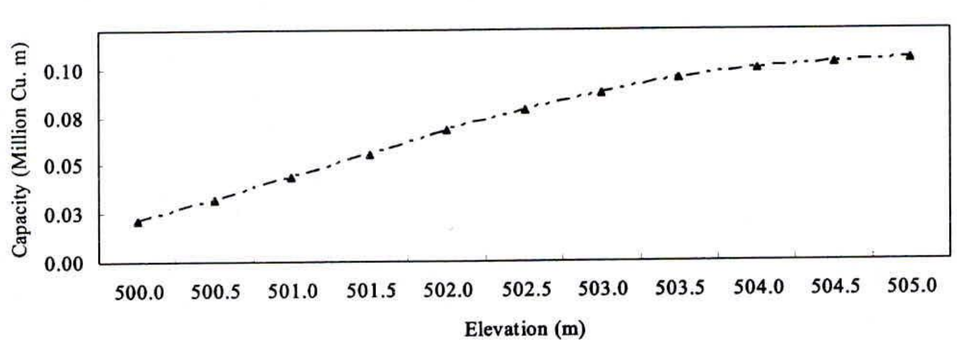


Fig. 14.7 (b): Elevation-capacity curve of Site-5

14.3.6 Site-6

The Site 6 is a comparatively bigger site having a catchment area of 154.97 hectare and is located near village Berar Deori. This catchment of this site is located in open forests. Considerable lands are available further downstream for agriculture where the water from the storage structure can be used for effectively for irrigation. This project will be very much useful to the farmers of the area who have migrated to other villages due to the recurrent problems of droughts. The selected site is on a third order stream with an area of submergence of 8.725 hectares and storage capacity of 0.447 MCM. The height of the bund is kept as 6.5 m and the average depth of pondage is 5.124 m. and the ample storage capacity created will be able to meet the demands for agriculture. The elevation-area and elevation-capacity curves for the Site 6 have been given in Fig.14.8 (a) & Fig. 14.8 (b) respectively.

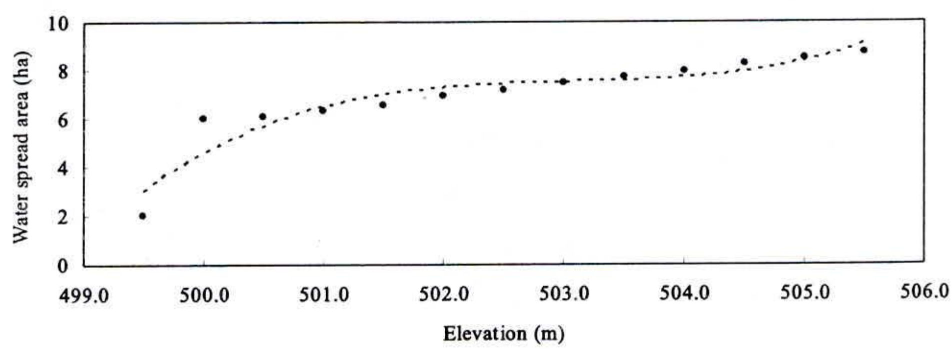


Fig. 14.8 (a): Elevation-area curve of Site-6

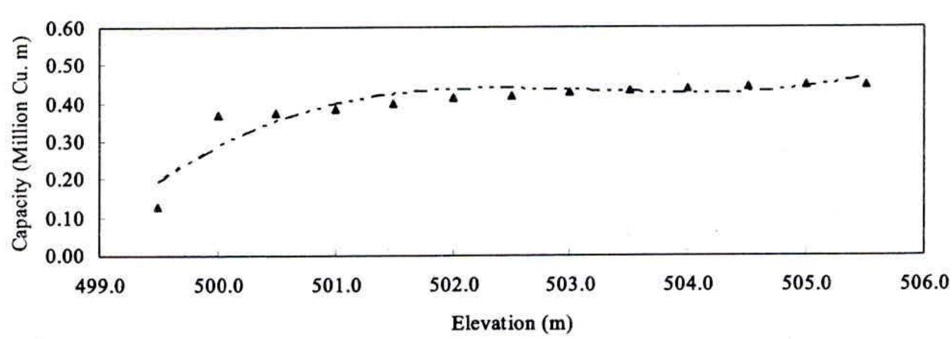


Fig. 14.8 (b): Elevation-capacity curve of Site-6

14.3.7 Site 7

The Site 7 is again located on a third order stream with a catchment area of 53.79 hectares which lies completely on barren lands. The height of the bund is 7.0 m. and the water spread area and the storage capacity created is 4.075 hectares and 0.141 MCM respectively. The average depth of pondage is 3.466 m. and water will remain in the project even during summers. The project can be utilized to cater to the water requirements for developing agro-forestry and grazing lands in the watershed. The elevation-area and elevation-capacity curves for Site 7 have been given in Fig. 14.9 (a) & Fig. 14.9 (b) respectively.

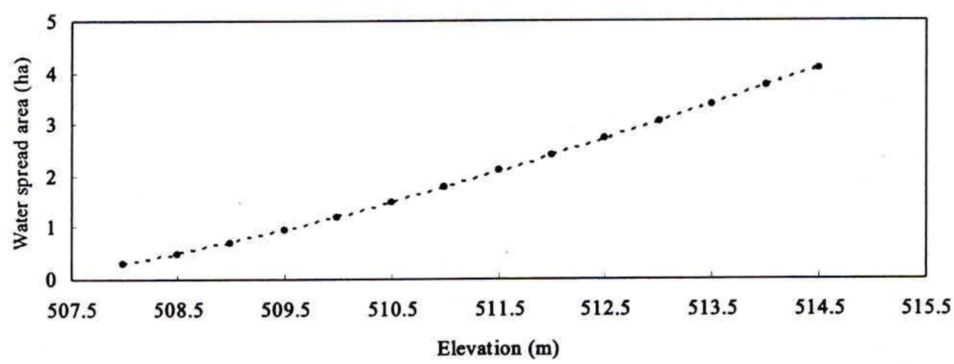


Fig. 14.9 (a): Elevation-area curve of Site-7

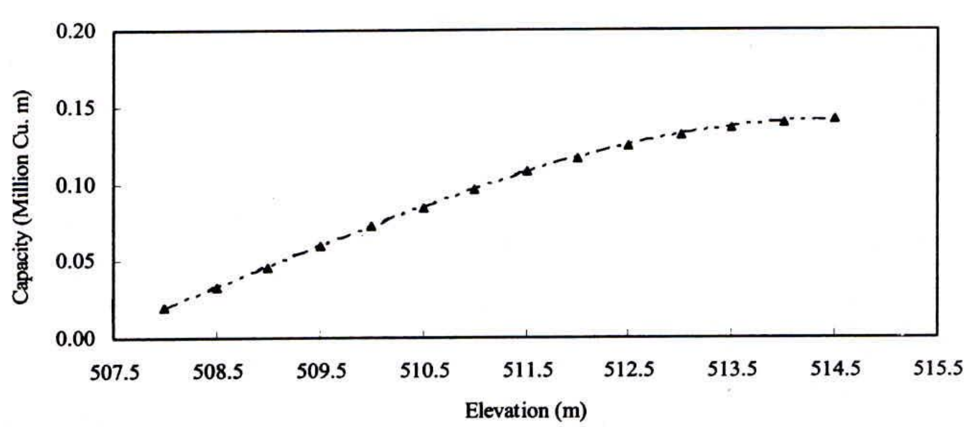


Fig. 14.9 (b): Elevation-capacity curve of Site-7

14.3.8 Big project site

Another site has been identified on the main river Tumri for possible construction of a big irrigation project creating downstream irrigation potential in the Sonar river basin. The topography seems favorable with the river running in deep gorge surrounded by steep hills on both the banks. The height of the bund is 14.5 m. whereas the water spread area and the storage capacity is 75.85 hectare and 6.396 MCM respectively. The average depth of pondage is 8.44 m. and the land use falling under submergence include barren lands (52.57 ha), agricultural (12.89 ha) and open forests (10.40 ha). The elevation-area and elevation-capacity curves for the big project site have been given in Fig. 14.10 (a) & Fig. 14.10 (b) respectively. The general details including the height of dam, maximum water level, water spread area, catchment areas and average pondage depth of all the sites has been given in Table 14.1.

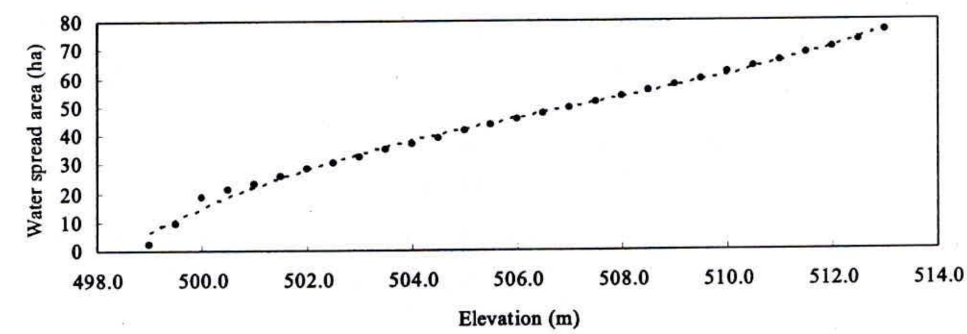


Fig. 14.10 (a): Elevation-area curve of site for big project

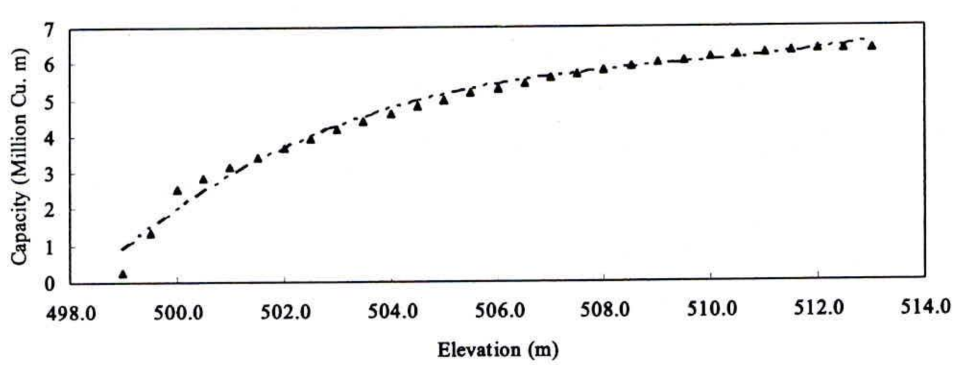


Fig 14.10 (b): Elevation-capacity curve of site for big project

Table 14.1: Salient features of the proposed storage structures

Site no.	Catchment area	Height of bund	Maximum water level	Area of Submer-gence	Storage capacity	Runoff from catchment	Average pondage depth
	(hectare)	(m)	(m)	(hectare)	(MCM)	(MCM)	(m)
Site-1	77.95	4.5	531.0	11.177	0.219	0.273	1.957
Site-2	30.56	3.0	539.5	6.499	0.083	0.107	1.274
Site-3	37.19	4.0	542.5	4.460	0.125	0.130	2.812
Site-4	70.79	6.0	545.5	3.496	0.102	0.248	2.913
Site-5	34.19	5.5	505.0	3.598	0.105	0.120	2.909
Site-6	154.97	6.5	514.5	8.725	0.447	0.542	5.124
Site-7	53.79	7.0	513.0	4.075	0.141	0.188	3.466

The priority of the selected sites has been assessed on the basis of pondage depth, ratio of submergence area to catchment area and ratio of storage to catchment area. The average pondage depth suggests whether water will remain in the tank after taking care of the evaporation losses. The tank with the highest average pondage depth has been given the highest priority and vice-versa. The ratio of submergence area to the catchment area gives and indication of the percentage of the catchment area that will come under submergence. The tank having the lowest submergence to catchment area ratio has been accorded the highest priority. The ratio of storage volume created to the catchment area gives an indication of the type of topography of the selected site. The site with the highest storage volume to catchment area is assigned the highest priority. The priorities for each category range from 1 to 7, one being for the highest priority site and vice-versa. The individual priorities of each of the three classes have been summed up to arrive at a total sum of priority values. Then the sites are ranked according to the priority as arrived at by these three deciding factors. The Site 6 is having the highest priority whereas Site 2 has been accorded the lowest priority. The recommended sites in the order of priority and the criteria used for deciding the priorities are presented in Table 14.2.

Table 14.2: Priorities of the selected sites for construction of small storage structures

Site no.	Priority criteria			Weights				Priority of selected sites
	Ratio of Submer & C. Area (%)	Ratio of storage & C. Area (%)	Pondage depth (m)	Subme-rgence / C. Area	Storage / C. Area	Pondage depth	Sum	
Site 1	14.34	0.28	1.957	6	4	5	15	6
Site 2	21.27	0.27	1.274	7	5	7	19	**7**
Site 3	11.99	0.34	2.812	5	1	2	8	2
Site 4	4.94	0.14	2.913	1	7	6	14	5
Site 5	10.52	0.31	2.909	4	2	3	9	3
Site 6	5.63	0.29	5.124	2	3	1	6	**1**
Site 7	7.58	0.26	3.466	3	6	4	13	4

15.0 SELECTION OF ZONES FOR ARTIFICIAL RECHARGE

The ground water scenario in India, which receives a substantial amount of rainfall, is not very encouraging primarily due to imbalance between exploitation and recharge to ground water. More and more areas in the country are getting converted to dark zones due to overexploitation of water. The Tumri watershed also experiences more than 5 to 6 m water table fluctuation which is increasing progressively. Tumri watershed inspite of experiencing good rainfall but being situated on basaltic formation faces severe water shortages during summer seasons and lack of water conservation and artificial recharge measures which has led to an alarming decline of ground water table in the region.

The artificial recharge is the process by which the ground water is augmented at a rate much higher than those under natural condition of replenishment to restore supplies from aquifers depleted due to excessive ground water development. De-saturated aquifer offer good scope in which source water if available, can be stored using artificial recharge techniques. The main advantages of artificial recharge include enhancement of the sustainable yields of wells and hand pumps in areas where over-development has depleted the aquifer, raising the water table of the region, relatively smaller structures required as compared to surface storage structures, negligible losses as compared to surface storage, no adverse effect like inundation of large surface areas and subsequent loss of cropped lands, no displacement of local population, utilization of surplus rain water. The techniques of artificial recharge can be broadly divided in following categories namely, direct surface techniques, direct sub-surface techniques, combined surface and sub-surface techniques and indirect techniques.

15.1 Direct Surface Techniques

These methods are suitable where large area of basin is available with unconfined aquifers. The rate of infiltration depends on the nature of top soil. The presence of solid suspension in water used for recharge clogs the soil pores leading to reduction in infiltration rate and ultimately the recharge rate. The various direct surface techniques of ground water recharge include flooding,. basins or percolation tanks, stream augmentation, ditch and furrow method and over irrigation.

15.1.1 Flooding

The method of flooding is suitable for relatively flat topography. The water is spread as a thin sheet. Higher rate of vertical infiltration is obtained on areas with undisturbed vegetation and sandy soil covering.

15.1.2 Basins or percolation tanks

This is the most common method for artificial recharge in which water is impounded in series of basins or percolation tanks. The size of basin depends on the topography of the area and flatter areas will have larger basins. This method is applicable in alluvial areas as well as hard rock formations and the efficiency is more in highly fractured and weathered hard rock formations.

15.1.3 Stream augmentation

Seepage from natural streams or rivers is one of the most important sources of recharge of ground water reservoir. When total water available in a river exceeds the rate of infiltration, the excess is lost as runoff and this runoff can be arrested by constructing check bunds or widening of stream beds, thereby enabling larger area of spread for the water for increasing the infiltration. The water stored in these structures is mostly confined to stream course and a series of such check dams may be constructed to harness maximum runoff.

15.1.4 Ditch and furrow method

In areas with irregular topography, shallow, flat bottomed and closely spaced ditches or furrow provides maximum water contact area for recharge from stream or canal. Generally, lateral ditch pattern, dendritic ditch pattern and contour patterns of ditch and furrows are commonly used and the structure lies below the surface and recharges ground water directly.

15.1.5 Over irrigation

In this method, irrigation fields are used as recharging zones and excessive irrigation water is applied on the field. The excessive water drained into the ground and improves the water table of the region.

15.2 Direct Sub-surface Techniques

In this method the recharge structure lies below the surface and recharges ground water directly. The important direct sub-surface techniques include injection wells or recharge wells, recharge pits and shafts, dug well and borehole recharge, borehole flooding, natural opening and cavity fill.

15.2.1 Injection wells or recharge wells

Water is pumped in the injection well for recharge whereas water flows under gravity in recharge wells. This technique is suitable for augmenting the ground water storage of deeper aquifers by pumping-in treated surface water and is comparatively costlier and requires specialized techniques to protect the well from clogging.

15.2.2 Recharge pits and shafts

In areas where an impervious layer is encountered at shallow depths, pits and shafts are suitable artificial recharge structures. Silt free source water can be put into recharge shaft directly through pipes and in the areas where source for recharge water is having silt, the shaft/pit should be filled with boulder, coarse sand from bottom to have an inverted filter or the source water should be passed through a separate filter chamber before it enters the shaft/pit.

15.2.3 Dug well and borehole recharge

In alluvial as well as in hard rock areas, thousands of dug wells have gone dry due to considerable decline of water levels. These dug wells can be used as recharge structures where the storm water and other surplus water from canals can be diverted to directly recharge the dry aquifer. Similarly, the household and irrigation boreholes can be used to recharge deeper aquifers by transferring additional water from roof top and canal water.

15.2.4 Natural opening, cavity filling

It is field specific method, in which some natural opening or cavity in the earth crust due to erosion process is suitably used for recharging the sub-surface aquifers.

15.3 Combined Surface and Sub-surface Technique

In this technique, both surface and sub-surface methods of recharge have been used simultaneously to augment the ground water storage. Basin or percolation tanks with pit shafts or wells are the most common example of combined surface and sub-surface techniques. Injection wells are drilled in the water spread area of percolation tank or basin, so that the deeper aquifer can be supplemented through these injection wells or recharge wells.

15.4 Indirect Techniques

In the indirect techniques, the effect of other activities in the basin increases the water table in the region and effective yield from aquifer is increased. The main indirect techniques for artificial recharge include induced recharge from surface water sources and aquifer modification.

15.4.1 Induced recharge from surface water sources

It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface water such as perennial streams, unlined canals or lakes. The heavy pumping lowers the ground water level and cone of depression is created. Lowering of water levels induces the surface water to replenish the ground water.

15.4.2 Aquifer modification

This method involves the change of hydraulic properties of aquifer by external means. The fractures and faults in the confined aquifer can be modified by blasting or hydro-fracturing.

15.5 Methodology

The basic requirement for developing any artificial recharge scheme includes availability of non-committed surplus monsoon runoff and identification of suitable hydro-geological sites for creating sub-surface reservoirs through cost effective artificial recharge techniques. The availability of rain water can be studied by the analysis of rainfall pattern, number of rainy days, frequencies, variation of rainfall and availability of direct surface runoff (DSRO). The analysis of surface runoff by SCS-CN method and dependable water availability implies that there is ample scope for development of artificial recharge in the watershed.

The techniques for artificial recharge may be site-specific and suitability may vary from region to region depending upon the geology, geomorphology, ground water table fluctuation, rainfall, and soil characteristics. The GIS approach has been used to identify areas suitable for artificial recharge wherein various thematic maps have been generated in ILWIS 3.0. Decision rules have been framed on the basis of topography, geology, land use, soil type, soil depth, and ground water table fluctuation and all these maps have been integrated to obtain a map depicting zones suitable for artificial recharge. The various thematic maps used for identification of artificial recharge zones include geomorphology, water table fluctuation, drainage density, infiltration capacity, slope, soil depth, soil type and land use maps.

15.5.1 Geomorphology map

The geomorphology and geology of the watershed are important factors for selection of areas and methods for artificial recharge. The sub-surface geological formations may be considered as "warehouse" for storing water that come from sources located on earth surface. The water is held in the decomposed and weathered mantle in hard rock areas, where groundwater storage and circulation takes place due to predominantly control of morphology. The groundwater occurs extensively in the lower areas of valley whereas the groundwater storage is poor in the areas located in hill slopes and along drainage divide. Besides, suitable lithological condition, favorable geological structures and geomorphological units are also important factors whose dimensions and shape allow retention of substantial volume of water in porous and permeable formations of hard rock areas.

15.5.2 Watertable fluctuation map

The water table fluctuation plays an important role in selection of sites for artificial recharge. The pre-monsoon and post-monsoon ground water levels in and around the watershed have been used and the water table fluctuation calculated as the difference between the post-monsoon levels to pre-monsoon levels. The average of these differences has been used for preparation of the ground water table fluctuation map using the Krigging interpolation technique. The slicing operation was used to designate the watershed in the in various fluctuation classes.

15.5.3 Drainage density map

For developing the drainage density map, the entire watershed has been divided in to grids of 30"x30" (850m x 850m approximately). The length of drainage in each of these grids has been determined and drainage density for each grid has been put in the centre of grid and a point map prepared. The ordinary Krigging operation has been performed to get drainage density map and slicing operation performed to divide the whole watershed in different drainage density classes ranging from 0.0 to 1.0 km/km^2, 1.0 to 2.0 km/km^2, 2.0 to 3.0 km/km^2, 4.0 to 5.0 km/km^2, more than 5.0 km/km^2.

15.5.4 Infiltration capacity map

The infiltration and soil-water movement are the most important hydrological processes in the artificial recharge, since they determine the rates and amounts of runoff generated in the stream. If the rate of infiltration of the soil is low, it will not permit the entry of water into the aquifers and most of the rain water may go waste as surface runoff. For obtaining this map, the infiltration capacities have been obtained on fourteen test sites using double-ring infiltrometer tests, considering various soil types and land uses in the watershed. The infiltration rates have been plotted and Krigging operation performed to obtain the infiltration capacity map. The slicing operation was used to determine the spatial variation of infiltration capacities of 0.0 to 1.0 cm/hr, 1.0 to 2.0 cm/hr, 2.0 to 3.0 cm/hr, 4.0 to 5.0 cm/hr and more than 5.0 cm/hr.

15.5.5 Slope map

The topography plays very important role in the groundwater occurrence, storage and movement in the hard rocks region. The contour map and point elevation map have been prepared and contour interpolation technique used to get digital elevation map (DEM) of the area. The watershed has been divided into two classes namely slope less than 5% and slope more than 5% with the help of slicing operation.

15.5.6 Soil depth map

For preparing the soil depth map of the study area, detailed soil profiles have been collected at 14 stations in the watershed. The soil depth for each of the test sites have been determined and Krigging interpolation performed to obtain the soil depth map. The slicing operation has been used to divide the whole area in to different soil depth classes of 0.0 to 20.0 cm, 20.0 to 40.0 cm, 40.0 to 60.0 cm and more than 60.0 cm.

15.5.7 Soil type map

The soils in the Tumri watershed are mainly clayey loam, loamy sand and sandy gravel type. The clayey loam type of soil found in the river beds are suitable for agriculture purposes, while the gravely sand type of soil found predominantly in barren areas.

15.5.8 Landuse map

The land use map of the study area has been prepared using digital image analysis technique for identification of land uses in the watershed. Six land use classes could be classified in the sub-basin based on the ground truth survey and digital classification. The land use classes include agriculture, barren, open forest, dense forests, water bodies and built up areas.

15.5.9 Identification of recharge areas

The selection of recharge area and method of recharge are important aspects of any recharge scheme. The recharge area should be selected in such a way so that the additional runoff gets retained and infiltrates. The soil conservation measures of contour farming, contour bunding, grassed waterways, and terracing have been planned in agriculture land use of different land capabilities. These measures will also recharge the ground water aquifer, and therefore agriculture lands have not been considered for the selection artificial recharge areas. Similarly, in case of forest lands, the environmental clearance is required for implementation of recharge schemes and this may also submerge the forests in water spread. The large barren area is available in Tumri watershed which can be considered for selection of artificial recharge zones. The suitable sites in the forest areas have been identified in hilly nallahs where small check bunds can be constructed. The following important criterions have been fixed for identification of artificial recharge sites

- Land use should be barren,
- Slope should be less than 5 %,
- Drainage density should be less than 5 km/sq.km.
- Buried pediments, pediments and alluvial plains
- Sandy gravel and loamy soil
- Infiltration capacity should be more 2 cm/hr
- Ground water fluctuation should be more than 5 m.

15.6 Analysis & Results

For identification of the most suitable, suitable and unsuitable zones for artificial recharge in Tumri watershed, different thematic maps explained in the methodology have been prepared in ILWIS 3.0, GIS software. All these maps are overlaid and considering the above criteria, suitable areas for ground water recharge have been selected.

15.6.1 Geomorphology map

The geomorphology map has been prepared from satellite data and field investigation of the watershed. The geomorphology of the watershed consists of hills, pediments, buried pediments and alluvial plains. The geomorphology map of the watershed has been presented in Fig 15.1. The distribution of different geomorphological classes has been given in Table 15.1. From the analysis, it has been observed that about one third area of the watershed is hilly with high slope and limited soil depth.

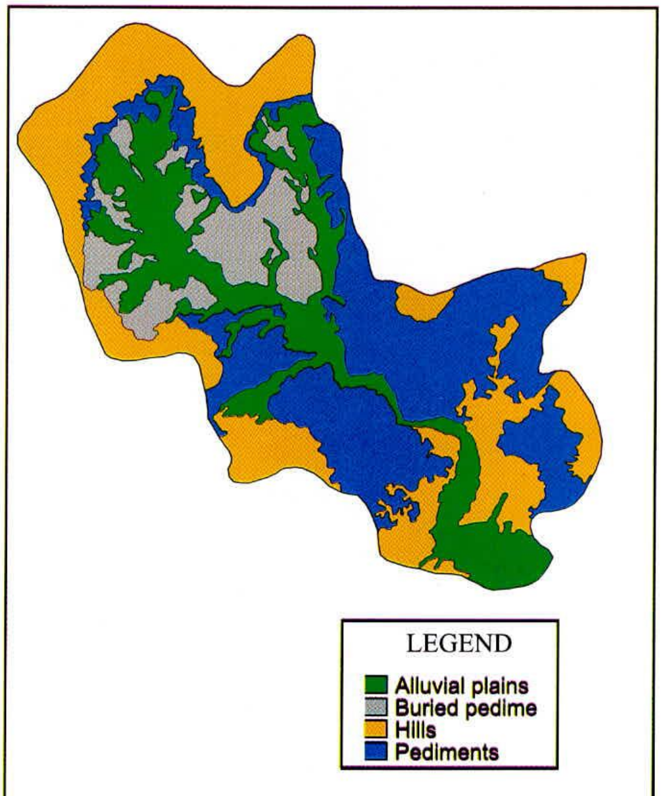


Fig. 15.1: Geomorphology map of Tumri watershed

Table 15.1: Distribution of geomorphologic classes in Tumri watershed

S.N.	Geomorphological class	Area (ha)	Percentage
1.	Hills	763.05	31.91
2.	Pediments	853.23	35.69
3.	Burried pediments	221.87	9.28
4.	Alluvial plains	552.82	23.12

15.6.2 Water table fluctuation map

The water table fluctuation map has been prepared using average difference in water table in post-monsoon and pre-monsoon and presented in Fig 15.2. It has been observed that the average fluctuation of ground water table in the watershed is more than 5 m which is an essential condition for artificial recharge site selection. The distribution in different ranges of ground water table fluctuation has been given in Table 15.2.

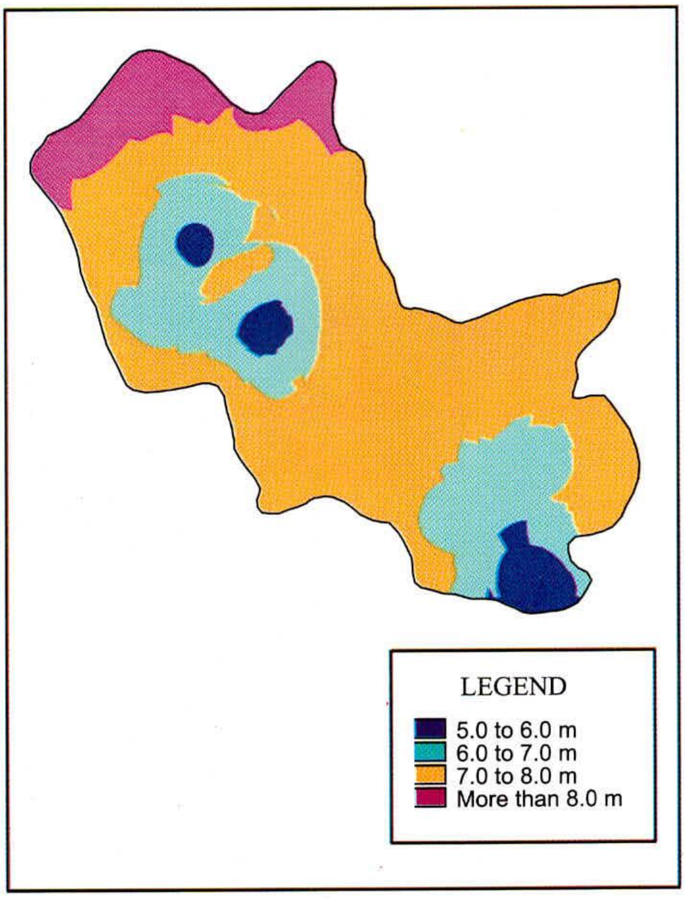


Fig.15.2: Ground water table fluctuation map

Table 15.2: Ground water fluctuation classes in Tumri watershed

S.N.	Water table fluctuation (m)	Area (ha)	Percentage
1.	5.0 m to 6.0 m	117.93	4.93
2.	6.0 m to 7.0 m	560.64	23.25
3.	7.0 m to 8.0 m	1475.75	61.7
4.	More than 8.0 m	236.67	9.90

15.6.3 Drainage density map

The drainage density map of the watershed has been prepared by determining the length of river falling in blocks of 30"x30". The drainage density value of each block has been put in the centre of that block as a point map and then raster map has been obtained by Krigging and slicing operation. The drainage density map of the study area has been presented in Fig. 9.3 and distribution has been given in Table 9.3.

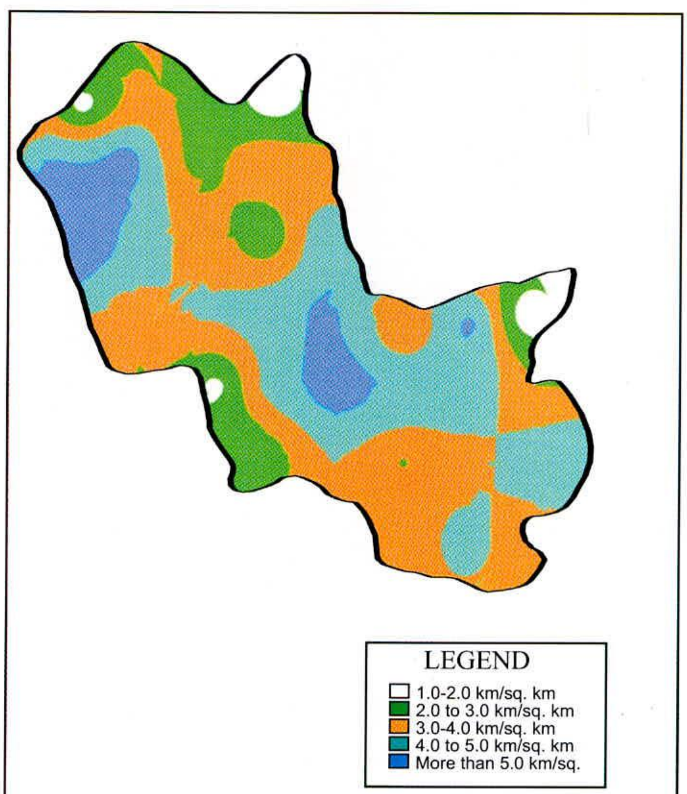


Fig. 15.3: Drainage density map

Table 15.3: Drainage density classes in Tumri watershed

S.N.	Drainage density	Area (ha)	Percentage
1.	1.0 km/km^2 to 2.0 km/k^2	85.11	3.56
2.	2.0 km/km^2 to 3.0 km/k^2	330.39	13.82
3.	3.0 km/km^2 to 4.0 km/k^2	987.89	41.32
4.	4.0 km/km^2 to 5.0 km/k^2	775.71	32.44
5.	More than 5.0 km/k^2	211.90	8.86

15.6.4 Infiltration capacity map

The infiltration capacity map of the watershed has been given in Fig 15.4 and infiltration capacity classes in the Tumri watershed is given in Table 15.4.

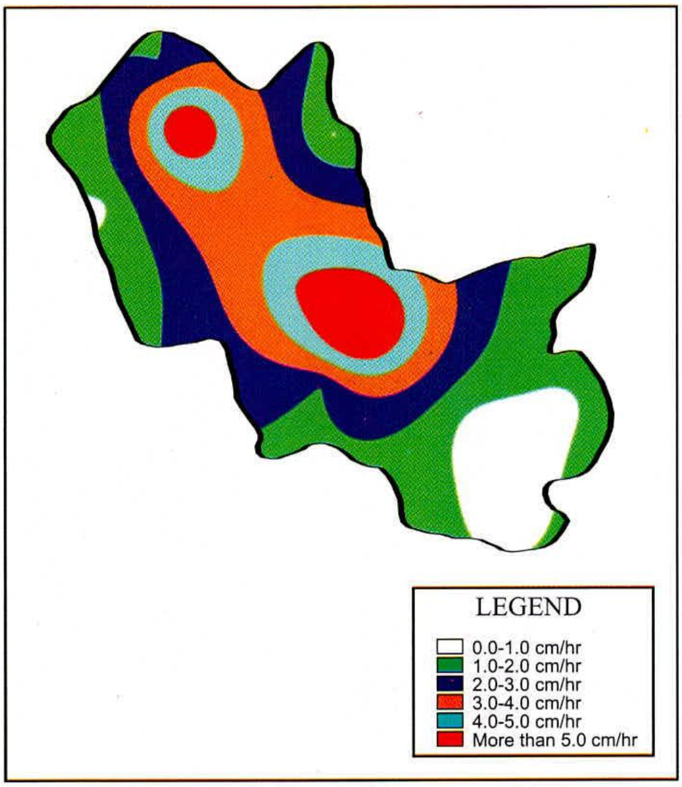


Fig. 15.4: Infiltration capacity map

Table 15.4: Distribution of infiltration capacity in Tumri watershed

S.N.	Infiltration capacity	Area (ha)	Percentage
1.	0.0 cm/hr to 1.0 cm/hr	265.55	10.73
2.	1.0 cm/hr to 2.0 cm/hr	702.59	29.38
3.	2.0 cm/hr to 3.0 cm/hr	551.64	23.07
4.	3.0 cm/hr to 4.0 cm/hr	473.37	19.80
5.	4.0 cm/hr to 5.0 cm/hr	244.84	10.24
6.	More than 5.0 cm/hr	162.01	6.78

15.6.5 Slope map

The watershed has been divided in to two classes namely, slope less than 5% and slope more than 5%. The slope map of the watershed is presented in Fig 15.5 and slope classes in Tumri watershed have been given in Table 15.5.

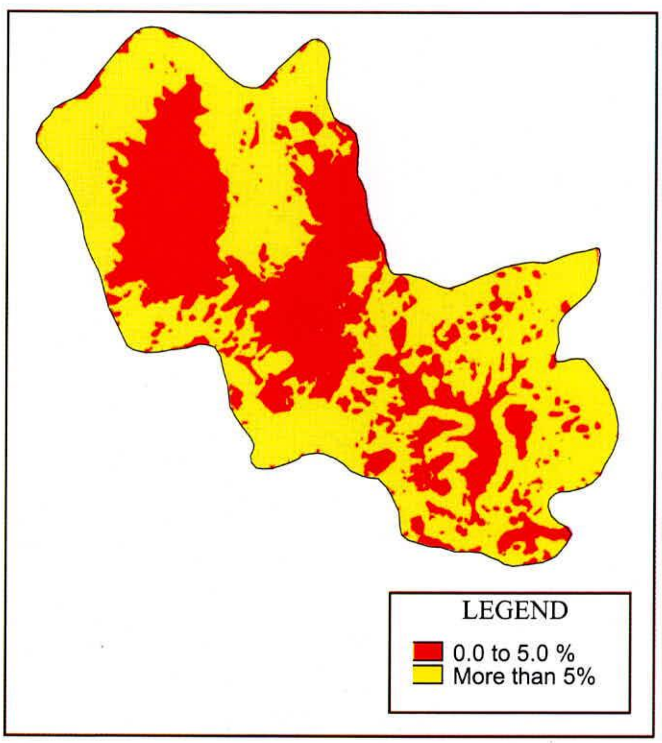


Fig. 15.5: Slope map of Tumri watershed

Table 15.5: Distribution of slope classes in Tumri watershed

S.N.	Slope	Area (hect)	Percentage
1.	Less than 5 %	917.04	38.35
2.	More than 5%	1473.96	61.65

From the analysis, it may be concluded that more than 60% area in Tumri watershed is having slope more than 5% and not considered suitable for artificial recharge. In the forested areas with slope more than 5%, a series of small check dams may be considered.

15.6.6 Soil depth map

The soil depth map of Tumri watershed has been given in Fig 15.6 and soil depth classes in Tumri watershed is given in Table 15.6.

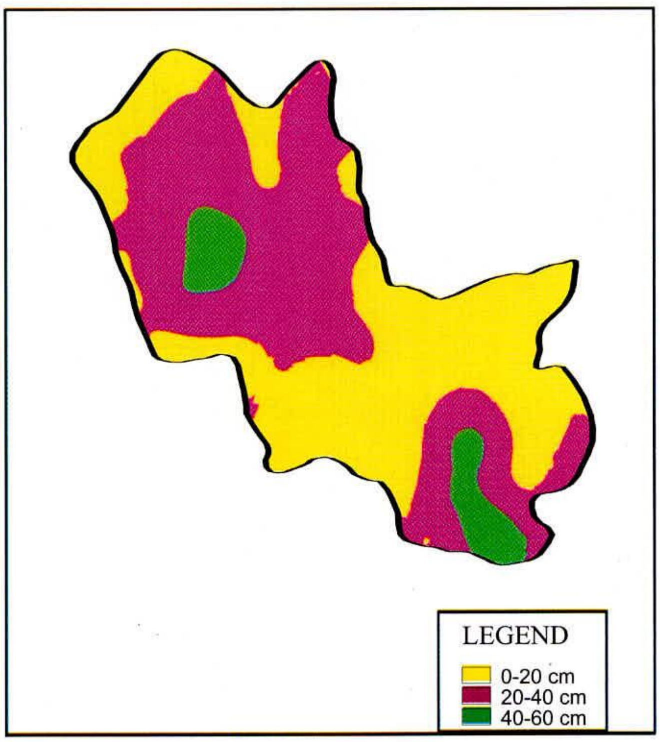


Fig.15.6: Soil depth map of Tumri watershed

Table 15.6: Soil depth classes in Tumri watershed

S.N.	Soil depth	Area (ha)	Percentage
1.	0.0 cm to 20.0 cm	1069.69	45.87
2.	20.0 to cm 40.0 cm	1124.91	47.05
3.	40.0 to cm 60.0 cm	169.40	7.08

15.6.7 Soil type map

The soils in the Tumri watershed are mainly clayey loam, loamy sand and sandy gravel type. The soil type map of the watershed has already been given in Fig. 8.1 in Chapter 8 and the distribution of the various soil types is given in Table 15.7. From the analysis, it may be observed that about 46% area of watershed having loamy sand soil type.

Table 15.7: Soils types in Tumri watershed

S. N.	Soil type	Area (hectare)	Percentage
1.	Clayey loam	349.61	14.62
2.	Loamy sand	1097.12	45.89
3.	Sandy gravel	944.27	39.49

15.6.8 Landuse map

The land use map of the study area has been prepared using digital image analysis technique of satellite data. The land use classes include agriculture, barren, open forest, dense forests, water bodies and built up areas. The land use map has already been presented as Fig. 7.2 in Chapter 7 and distribution of the various land use classes is also given in Table 7.8 in Chapter 7.

15.6.9 Zones for artificial recharge

The maps explained above have been prepared in ILWIS 3.0 with the same geo-reference and all these maps crossed and considering the criteria given in the methodology, a map for artificial recharge zones has been prepared. The watershed has been divided into most-suitable, suitable and unsuitable classes. The map showing suitable recharge areas has been given in Fig. 15.7 and distribution of areas under various recharge classes in Table 15.8.

Table 15.8: Suitable zones for artificial recharge in Tumri watershed

S.N.	Suitability	Area (hectare)	Percentage
1.	Most suitable	33.08	1.38
2.	Suitable	288.65	12.07
3.	Not suitable	2034.11	85.07
4.	Water bodies	7.23	0.30
5.	Built up areas	27.93	1.17

From the analysis, it may be concluded that about 14% area of the watershed is suitable for artificial recharge. It consists of barren areas in the watershed and therefore measures of artificial recharge structures can be implemented without any clearance and loss of productive land. Apart from these zones, the contour farming, contour bunding, farm ponds, kundas and other measures can be taken in agricultural lands. These measures may be helpful for controlling soil erosion and provide more time for rain water to augment the ground water table. Also, nallah bunds, and check dams are useful in hilly streams of forested areas. These structures will reduce the velocity of flowing water and give time for water to infiltrate in deep aquifers. The location of these check dams have been marked in the map which will be useful for the implementing agencies. These check dams or nallah bandhan should be constructed of locally available materials such as brushes, boulders, and earth.

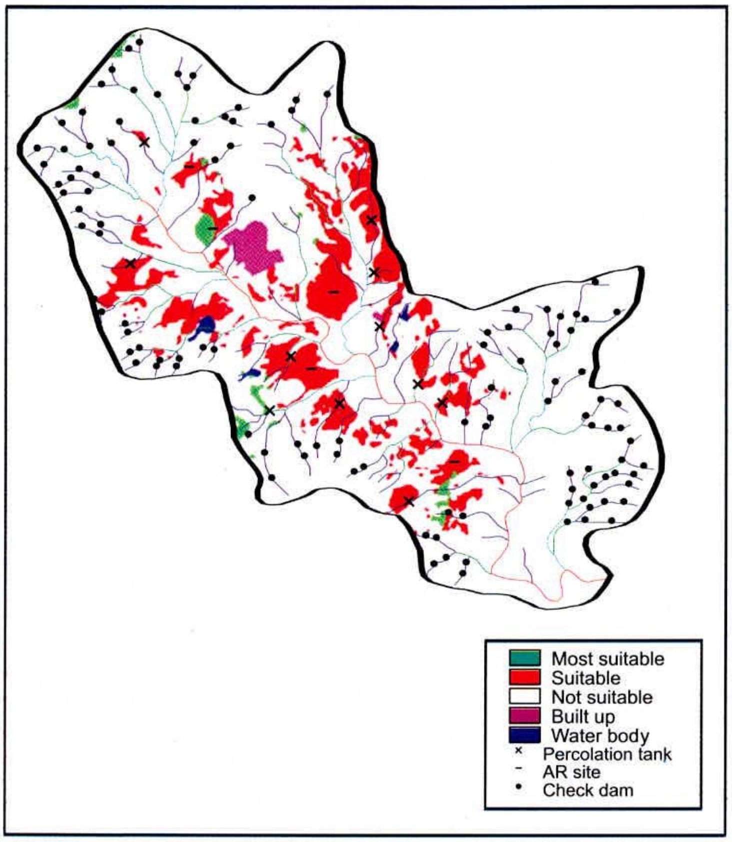


Fig.15.7: Artificial recharge zones and sites for check dams

16.0 SUGGESTED LANDUSE PLAN AND MANAGEMENT STRATEGIES

Soil is an important medium which acts as a filter, cleaning air and water and also receives organic wastes and recycles the nutrients back to plants and holds and breaks down some toxic wastes.. Soil erosion affects farming in detrimental ways. Gravity pulls constantly at soil, nudging it downhill, causing soil slips, cracks, creep and slumps. The most damaging effect of rainfall is its impact with which water droplets hit the soil, causing dislodging and the flow of water causes sheet-wash, rills, surface gullies, tunnels and scours the rivers banks. Measures of soil conservation taken up to prevent soil erosion are vital for the sustenance of livelihood of the human population.

A watershed cannot be developed through just water conservation but soil conservation is also necessary alongwith it. Both soil and water are conserved while arresting the soil running off with water. The topsoil of about 5-6 cm is the most fertile layer and water is retained in the layer below the topsoil. Farmers till the land before the monsoon to make the topsoil loose for sowing and if the field does not have proper bunds, this loose soil get carried away easily alongwith the rainwater and settles in nallahs, rivulets, rivers and dams which ultimately lower the storage capacity of dams. Therefore, it is very important that the speed at which rainwater flows should be impeded to prevent dislodging and transport of topsoil. This is the basic principle of watershed development through soil and water conservation techniques.

The three important principles generally considered in the control of erosion include, usage of land in accordance with its capability, protection of the surface of soil by surface cover and controlling the runoff before it develops into an erosive force. There are always strong links between measures for soil conservation and measures for water conservation. Reduction of surface runoff by structures or by changes in land management will also help to reduce soil erosion. Similarly, reducing soil erosion will generally increase the infiltration and help in water conservation. The development of an alternative land use plan is the first step in the planning process after the assessment of the various controlling and limiting factors in the watershed. Subsequently the management strategies can be devised according to the suggested land use plan and prevailing conditions in the watershed, to improve the overall health of the watershed and its inhabitants.

16.1 Suggested Landuse Plan

For development of proposed land use plan for Tumri watershed, the land capability classification of the watershed has been used as a guiding principle. The land capability classification suggests the best possible use according to the limitation of a particular piece of land. The population of the villages, cattle, local conditions, proposed sites for water storage structures, present status of forest and availability of barren land have been considered in devising the suggested land use plan. The suggested land use plan has been prepared in such a manner that the watershed becomes self-sufficient in terms of fuel, fodder and food requirements. The following points have been considered while deciding the suggested land use plan for the watershed:

- Land capability classification may be the basis for deciding the land uses.
- All the demands in the watershed should be met within the watershed.
- Agricultural area in the watershed may be increased to make watershed self-sufficient in major crop production.
- Area of dense forest may be increased by converting the open forest into dense forest.
- As a majority of the local population in the watershed depends on diary products from cattle, pasture land may be developed in the watershed to produce sufficient fodder for cattle.
- Improvement of the economy of tribes of the watershed by development of agroforestry.
- Conservation of soil and water in watershed by improved land use and corrective measures.

The suggested land use plan for the watershed has been presented in Fig. 16.1 and area falling under each land use class has been given in Table 16.1. The area under the water bodies have increased from 7.23 ha to 49.25 ha taking into consideration the water spread areas of the proposed storage structures in the watershed. The storage structures apart from providing the irrigation water may also be used for fish farming which will boost the income of the local populace. The area under dense forests is proposed to be increased from 587.98 ha to 1096.94 ha as the open forests can be converted into dense forests by additional planting of tree saplings of teak and other existing plant varieties. Proper conservation measures are needed for agricultural area in the watershed which can been increased from the current 540.15 ha to 610.51 ha as additional areas can be brought under agriculture, near the command areas of the proposed storage structures. The additional water stored in these storage structures will be used for taking up cultivation of crops extensively in both seasons, which is not the present case due to lack of irrigation water. The surface water available in these storage structures will to some extent remove the complete dependency on the ground water resources for irrigation. The barren areas can mostly be brought under agroforestry and grazing lands, which will improve the local economy and provide the requisite fodder for the livestock in the villages which are otherwise starving due to lack of pastures in the watershed. The area within the watershed which can be brought under agroforestry and

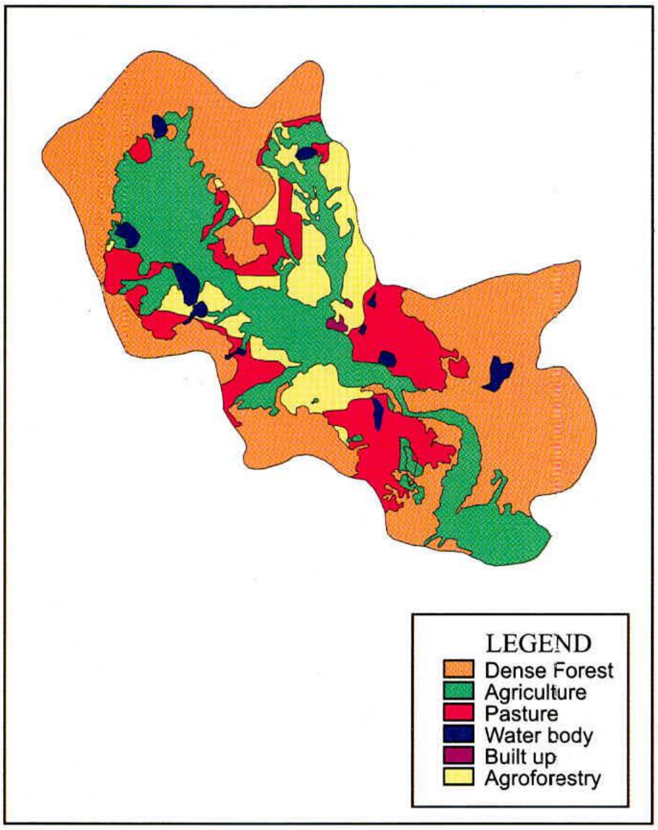


Fig.16.1: Suggested landuse plan for Tumri watershed

Table 16.1: Comparison of present and suggested land use plan

S.N.	Land use	Present land use (ha)	Suggested land use (ha)
1.	Agriculture	540.15	610.51
2.	Open forest	521.90	Nil
3.	Barren	706.14	Nil
4.	Dense forest	587.98	1096.94
5.	Pasture	Nil	328.19
6.	Agro forestry	Nil	278.17
7.	Built up	27.93	27.93
8.	Water bodies	7.23	49.25

pastures is 278.17 ha and 328.19 ha respectively. The suggested land use plan apart from improving the overall health of the watershed, will improve the living conditions of the local population, which is otherwise very poor and completely dependent on local quarries for livelihood. The proposed land use plan will conserve the precious land and water resources in the watershed along with the improvement of the biodiversity of the forests.

16.2 Soil Conservation Measures

A well-designed and maintained soil conservation system helps sustain productivity while providing clean water to the watershed. The soil conservation measures can be classified into five broad groups as, agronomic measures, mechanical measures, vegetative measures, biological measures and chemical measures.

16.2.1 Agronomic measures

Crops and vegetables which adequately cover the ground surface and have extensive root system reduce soil erosion. The plant canopy protects the soil from the adverse effect of rainfall and the grasses and legumes produce dense sod which helps in reducing soil erosion and the vegetation provides organic matter to soil. The various agronomic measures for controlling soil erosion include crop rotation, strip cropping, and contour farming, cultivation of dense plants and grasses, mulching, use of organic manure, controlled grazing and good tillage.

16.2.1.1 Crop rotation

Crop rotation is the planned sequence of growing various crops and is necessary for checking erosion and maintaining the soil productivity. A good rotation should include densely planted small-grain crops and spreading legume crop. Also a deep rooted crop should succeed a shallow rooted one so that nutrients and moisture could be tapped from different depths of soil.

16.2.1.2 Strip Cropping

It consists of growing erosion-permitting crops (jowar, bajra, maize) in alternate strips with erosion-checking close growing crops (grasses, pulses). Strip cropping employs several good farming practices including crop rotation, contour cultivation, proper tillage, stubbles mulching, and cover cropping and is a very effective means for controlling soil erosion, especially in gently slopping lands.

16.2.1.3 Contour farming

It is often recommended to plough the fields across the slope along the contour. The furrows so formed are miniature bunds which lie in the path of water flow and across it. It includes formation of contour strips along with contour bunds and contour hedges.

16.2.1.4 Cultivation of dense plant and grasses

Sod forming crop such as lucern (medicago sativa L), Egyptian cloveror, Berseem (Trifolium alexandrinum), ground nut (Arachis hypogea L), sannhemp (Crotolaria juncea), grasses, cover the surface of the land and their roots bind the soil particles to form soil aggregates, thus preventing soil erosion.

16.2.1.5 Cultivation of proper crops

Cultivation of row crops in sloppy lands generally leads to soil erosion. Cereals and fodder crops can be broadcasted in sloppy lands and plants remain haphazardly in field which creates obstacle to movement of water resulting in more infiltration and reducing soil erosion. Mixed and intercropping (cowpea-vigna catjang, with cotton-gossipum sp., maize-zea mays with soyabean- glycine max) checks the soil erosion and avoids the risks of the crop failure.

16.2.1.6 Mulching

Mulches of different kinds such leaves, straws, paper, and stubbles minimize evaporation and increase the absorption of moisture and protect the surface of the land against the beating action of rain drops. Later on they decay to form humus which improves the physical condition of soil. Natural mulching also helps in the infiltration of water and the reduction of evaporation.

16.2.1.7 Organic manure

The use of organic manure for agriculture improves the soil structure. The crumb and granular structure of the soil increases the infiltration and permeability in the soil and conserve the soil water thereby reducing the soil erosion.

16.2.1.8 Good tillage

Tillage is the mechanical manipulation of soil by different kinds of implements and may consist of several types of soil manipulation such as ploughing, harrowing, and cultivation. Tillage makes the soil loose and friable which helps in retention of water.

16.2.2 Mechanical measures

Mechanical measures of soil conservation include various engineering techniques and structures with the objective of division of long slopes into a series of shorter ones in order to reduce the velocity of runoff water and retention of water for long period so as to allow maximum water to be absorbed and held in the soil so that less water flows down the slope at non-erosive velocity. The important mechanical soil conservation measures include contour bunding, terracing, contour trenching, diversion drains, grassed waterways, and temporary check dams.

16.2.2.1 Contour bunding

Contour bunding consists of building earthen embankment at intervals across the slope and along the contour line of the field on fields where the slope is not very steep and the soil is fairly permeable. A series of such bunds divide the area into strips and act as barrier to the flow of water, as a result of which the amount and velocity of runoff are reduced, resulting in reduced soil erosion.

16.2.2.2 Terracing

A terrace is an embankment of earth constructed across the slope to reduces the length of the hill-side slope, thereby reducing sheet and rill erosion and prevents formation of gullies. The different types of terraces include, bench terracing, channel terrace, narrow based terrace, and broad based ridge terrace

16.2.2.3 Contour trenching

Contour trenches are ditches dug along a hillside in such a way that they follow a contour and run perpendicular to the flow of water. The soil excavated from the trenches is deposited on the lower edge of the trenches where permanent vegetation is planted to stabilize the soil. These trenches reduce surface water flow velocity, act as trap for the water and soil, minimize soil erosion and prevent pollutants from draining into water bodies.

16.2.2.4 Diversion drains

Diversion drains are trenches with an earthen wall on the downhill side that are laid at a grade of 0.5 to 1% on the slope to divert flows to a stable drainage path (rock surface, riprap spill path, stabilized gully, or grassed waterway). They are used to divert the excess erosive runoff from the protected area safely to the outlet.

16.2.2.5 Grassed waterways

Grassed waterways play an important role in prevention of gully erosion and also intercept pollutants leaving the field. Since the waterways are a flow way for excess runoff, nutrient and pesticide applications within their boundaries must be carefully managed to avoid movement of pollutants directly to surface water.

16.2.2.6 Temporary check dams

Temporary check dams are constructed across small channels to control gully erosion and it reduces the velocity of flowing water and trap small amounts of sediment. Check dams can be constructed of either stone or logs.

16.2.3 Biological Measures

The underlying principle here is that soil erodes only if it is bare and exposed to the 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 the falling raindrops is dissipated when they hit the vegetation. It also slows down the movement of water across the surface and allows it to infiltrate into the soil, becoming available to the roots of plants or percolating down to the water table. A great range of biological conservation measures have been developed and used.

In the case of grazing land, this can simply amount to ensuring that the land is never overgrazed and that sufficient cover is always retained to protect the soil. For cropped 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. Relay cropping can be used where different crops are planted in a rotation but the farmer does not wait until one crop is harvested before the next crop is planted. The seedlings of maize may be planted in narrow strips running through a wheat crop. The maize is planted out a few weeks before the wheat is harvested so that, when the wheat crop is harvested, the maize plants are already big enough to provide a partial cover to the soil.

16.2.3.1 Agroforestry/Farm forestry

Agroforestry practices encompass an entire spectrum of land use systems in which woody perennials are deliberately combined with agricultural crops and animals in some spatial or temporal arrangement. The positive effects of trees 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 structure, 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.

16.2.3.2 Grazing management

The various methods 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 compartments with the aim to give rest to a 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 lands for regeneration.

16.2.3.3 Afforestation

Afforestation is the growing of forests where there were no forests earlier like abandoned cropland, pastureland, or grasslands, due to adverse factors such as unstable soil or aridity. In various arid, tropical and sensitive areas, once the forest cover is destroyed, the land quickly dries out and becomes inhospitable to new tree growth. Other critical factors include overgrazing by livestock and over-harvesting of forest resources.

16.2.3.4 Reforestation

Reforestation is the re-establishment of the forest either naturally or artificially after its removal, or planting more trees. Reforestation is carried out on land where trees have been recently removed due to harvesting or natural disasters such as a fire, landslide, flooding, or volcanic eruption.

16.2.4 Chemical measures

The chemical measures are also used to enhance nutrient level of the soil. The proposed land use plan of the watershed envisages an increase in cropped area which will certainly require more chemical inputs in the form of manure and fertilizers besides plant protection measures like herbicide, insecticide and pesticides.

16.3 Water Conservation Measures

Most of the land under the cultivation in Tumri watershed is under rainfed conditions and productivity in such areas can be stabilized and improved by water conservation and harvesting measures to control the in-situ moisture content. As the watershed is subjected to high variability in rainfall, the frequent dry spells even within the monsoon period may cause fluctuation in crop production. It is therefore practical to develop integrated water conservation and harvesting structures to mitigate droughts as they also harvest the runoff water and store and recycle it for stabilization of agricultural ponds.

Rainwater harvesting is collecting the runoff in order to store it for later use and includes land based systems with man-made landscape features to channel and concentrate rainwater in either storage basins or planted areas. Water harvesting constituents include collection and harvesting of excess rainfall, efficient storage of harvested water, water application, lifting and conveyance, and utilization of applied water for maximum benefits.

16.3.1 Water conservation on agricultural lands

The techniques for water conservation in agricultural lands require creation of localized surface storage structures. Surface, sub-surface and ground water resources should be maximally exploited and used conjunctively. Various methods like border irrigation, furrow irrigation, corrugated irrigation, broad bed and furrow system, contour bunds, ridging and tied ridging, small storage structures, farm ponds, nallah bunding and off-stream storage can be adopted.

16.3.1.1 Border irrigation

A thin sheet of water advances along a narrow strip between ridge lines and water infiltrates into the soil as the sheet advances forward. Border irrigation is adopted where precise land leveling is possible and sufficient irrigation water is available. Border irrigation is recommended for mild slopes and close growing crops like wheat, bajra, and row crops like jowar, maize and cotton.

16.3.1.2 Furrow irrigation

Irrigation water is applied in furrows between rows of crops and water gets soaked into the root zone of the crop. The spacing of the furrows generally depends on the spacing of the crop rows and ranges form 0.60 to 1.20 m and may be laid across the slope or along the contours, to prevent erosion on steeper slopes. This method is suitable for row crops like maize, jowar, sugarcane, orchards and vegetables.

16.3.1.3 Corrugated irrigation

This is an extension of furrow irrigation method for heavy soils, small streams and close growing crops. Corrugation are closely spaced shallow furrows where the moisture is obtained both by capillary action and gravity and spacing of the corrugated furrows vary between 40 cm in sandy soils to 60 cm in black cotton soils. Crops are planted on both sides of the ridges and is generally found suitable for potatoes and turmeric crops.

16.3.1.4 Broad bed and furrow system

This system consists of broad beds about 1 m wide separated by sunken furrows about 0.50 m wide. The system is effective in slopes along the furrow in heavy, black clayey soils. Two to five rows of crops can be grown on the broad bed and works efficiently on deep black soils in areas with dependable rainfall of more than 800 mm.

16.3.1.5 Ridging and tied ridging

This method is also called as furrow blocking or basin listing and involves preparation of ridges and furrows and then damning the furrows with small mounds or ties, which increases the surface storage and is generally associated with mechanized farming and sprinkler irrigation. Tied ridges are better suited to drier conditions as compared to high rainfall areas.

16.3.1.6 Inundation techniques

In the inundation system, low earth bunds are built to retain the runoff during monsoon. The soil should have sufficient depth and moisture-retention capacity to store enough moisture for kharrif and rabi crops. The water released from one bund may be collected in the next bund down the slope. The main winter crop is planted as soon as the flooded land has dried out sufficiently and a subsidiary rice crop may be sown in the standing water in the next bund down the slope.

16.3.1.7 Small storage structures

The small storage structures help in maintaining moisture for long duration and are a key component in the integrated watershed development plan. The various uses include intercepting runoff and moderating peak flow, improving the absorption of available rainwater, enhancing groundwater recharge, reducing silt and sediment flow, providing irrigation potential to farmers, and much required life saving irrigation during stress periods at times of dry spells.

16.3.1.8 Farm ponds

Farm ponds can be impounding ponds or excavation ponds and provide water supply for irrigation, livestock, and drinking. Impounding ponds hold a large amount of water above the original ground surface, and are usually built in areas where the land slopes are gentle to moderately steep and a dam is constructed across a depression to fill the surface runoff in the pond. Excavated ponds have a large portion of the water stored below the original ground level and are constructed where the slopes are relatively flat and the pond is filled up by surface water and ground water.

16.3.1.9 Nallah bunding

Soil bunds of suitable dimensions are constructed across the nallahs or gullies to hold the runoff water which then creates flooding of upstream areas. An integrated nallah bunding helps in water harvesting, moisture control, and ground water recharge. The number of bunds depends on the slope of the stream, and quantity of runoff and is to be treated with nallah lining and gully control measures and gabion structures and boulder checks to curtail the runoff.

16.3.1.10 Off-stream storage

Off-stream storage structures are constructed away from the stream site as it may not be feasible in certain situations to construct storage structures on the stream. The stream is diverted to fill the off-stream storage structure and is generally used for drinking water needs.

16.3.2 Water harvesting for trees and shrubs

As trees and shrubs are an important part of the ecosystem, water harvesting is necessary for their survival. Biotic pressures have led to creation of degraded forests and depletion of forests completely in some parts of Tumri watershed. Micro-catchments can be developed for runoff farming and water can be retained by contour furrows and trees planted in rows. Micro-basins are also used by creating a small basin for planting a tree or planting of saplings in the centre of the contour trenches. Saplings can even be planted close to the storage structures, where the survival rate is better due to the moisture being available from the seepage and ground water build up in the surrounding areas.

16.4 Area Specific Soil & Water Conservation Measures

16.4.1 Agricultural lands

The agricultural lands in Tumri watershed which has an extent of 540.13 hectares at present is highly degraded as no soil conservation measures are being practiced. For preparation of soil conservation plan, the land capability classification of the watershed has been carried out and explained in detail in Chapter 2. According to the land capability classification, the land suitable for agriculture in the watershed have been classified into six land capability classes namely IIe, IIes, IIIe, IIIes, IVe, and IVes. The land not suitable for agriculture include classes Ve, VIe, VIes, VIIe and VIIes which can be developed for pastures, agroforestry and forests.

Agriculture is a challenging issue in Tumri watershed as crops are grown under various constraints of limited soil and water resources. The rainfall pattern is quite unpredictable and owing to the high rates of evaporation and evapotranspiration, the water requirements for irrigation are higher. A judicious management of the available water resources including rain water, surface water, and ground water is necessary. The choice of crops and cropping systems has greater relevance in such semi-arid degraded watersheds. The lands under Class-II are generally good cultivable land on almost level plains and on gentle slopes and have slight limitations of soil depth, texture, drainage or erosion that reduce the choice of plants. In Tumri watershed these areas are under agricultural land use with productive soil and generally located on the banks of rivers and their tributaries. The area under the Class-IIe is 178.9 ha whereas 153.5 ha are falling under the Class-IIes. The Class-IIe land consists of good soils on gentle slope and is subjected to water and wind erosion. Cultivation can be carried out normally with precaution against soil erosion by adopting soil conservation measures. Generally the IIes type of land class faces soil depth limitation along with soil erosion by water and wind. Cultivation can be carried out with selected crops suited for soil depth limitations.

Conservation management practices such as stubble retention and crop rotations are suggested to avoid soil degradation, including fertility and structural decline. Soils under these classes are suggested for cultivation of wheat, barley and cotton and moderately suitable for maize and tomato and slightly suitable for beans. Crop rotation needs to be practiced in Tumri watershed where generally mono-cropping practices are followed due to which soil becomes unbalanced and pests and diseases can increase. Nutrients that have been leached to deeper layers and that are no longer available in the upper soil layers can be recycled by the crops in rotation. The use of various cover crops, namely multi-purpose crops, like nitrogen-fixing crops, soil-porosity-restoring crops and pest-repellent crops can be used for crop rotation. The nitrogen-fixing legume crops in crop rotation can substitute the use of nitrogen based fertilizers. Pearl millet crop can be grown in Tumri watershed as it is very suited as a rainfed monsoon crop during kharif (June-July to September-November). The crop rotation that can be considered is pearl millet-sorghum and pearl millet-groundnut or pearl millet-groundnut-sorghum whereas on red soils, pearl millet-ragi rotation may be practiced. The dryland rotation may also include small grain-millet-fallow, moong-millet and millet-sorghum-wheat for irrigated lands. Other crop rotations that can be considered for the Tumri watershed include soyabean-maize in kharrif followed by wheat in rabi or soyabean-wheat, shorghum-wheat, maize-wheat, soyabean-shorghum-wheat cropping system. Also new drought tolerant species of crops should be encouraged in this drought prone watershed.

Intercropping systems and mixed cropping systems can also be formulated for the watershed as it may prove to be more sustainable as they result in lower runoff and soil losses compared to the sole crops. Intercropping of maize with legumes like soyabean and arhar can be practiced as the grain as well as the straw yields both increases when compared to standalone maize crop. Intercropping of wheat and mustard can be practiced in uplands whereas intercropping of wheat and potatoes can be practiced near to river banks and on field where irrigation is available. The intercropping with leguminous crops reduces the bulk density and increases the moisture retention capacity of the soil apart from higher available nitrogen and phosphorous content in the soil.

Treatment should be initiated to offset soil limitation and to conserve irrigation water. The agronomic measures suggested to arrest the erosion include contour farming, strip cropping, mixed cropping, conservation tillage, stubble mulching, and use of fertilizers and manure. Strategic crop rotations are suggested to maintain specific proportions of groundcover across catchments and tillage practices should be reduced. Contour bunding and tied ridging can be adopted for water conservation. Small storage structures and farm ponds can be created to conserve water and use it later for irrigation during the various stages of crop growth.

The lands under this class III are moderately good cultivable land on moderate slopes with limitations of moderate erosion, soil salinity and soil structure and are inferior compared to Class-IIe and Class-IIes. Other limitations include very low permeability of the sub-soil, shallow soil depth up to the bed-rock and low moisture-holding capacity. In the watershed, the area under Class-IIIe with agricultural land use is 219 ha whereas area under Class-IIIes is 452.9 ha. The Class-IIIe type of lands has good soil on moderate slopes subject to water erosion and cultivation can be allowed with precaution against permanent land damages. The Class-IIIes type of agricultural lands has erosion problems coupled with problems of moderate soil depth and gravel. In this land class, cultivation can be practiced with careful selection of crops adapted to soil depth limitations. These areas have varying suitability for different crops and are unsuitable for growing vegetable crops as productivity is much dependent on the soil fertility. The recommendation is to cultivate with precaution and need simple management practices. Both agronomic measures as well as mechanical measures are to be adopted for soil conservation in such types of lands. The agronomic measures suggested for conservation of soil from these lands include contour farming, strip cropping, mixed cropping, conservation tillage, crop rotation and use of fertilizers whereas the mechanical measures include contour bunding and grassed waterways. Small storage structures and farm ponds can be created for water harvesting in such type of agricultural lands.

Conservation agriculture can be practiced, which is a concept for resource-saving agricultural crop production and is based on enhancing natural biological processes above and below the ground by initiating interventions such as reducing mechanical soil tillage to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin at an optimum level and in a way such that it does not disrupt the biological processes. The excessive tillage of agricultural soils results in short term increases in fertility, but degrades the soils in the medium term. Structural degradation, loss of organic matter, erosion and falling biodiversity are all the disadvantages of tillage. The crop residues remain on the soil surface in a land not tilled for many years, and produce a layer of mulch which protects the soil from the physical impact of rain and wind, stabilizes the soil moisture and temperature in the surface layers, becomes a habitat for a number of organisms which macerate the mulch, and mix it with the soil and decompose it so that it becomes humus and contributes to the physical stabilization of the soil structure helping in creation of soil organic matter and thus the soil regeneration. The conservation farming practices including direct seeding, stubble retention and stubble incorporation is suggested. Also these lands are recommended for limited and less intensive rotational cropping. It is also suggested to use graded banks or permanent vegetation cover to prevent runoff damage in case conservation farming practices are not used.

The land Class-IVe and Class-IVes are also suited for occasional or limited cultivation with relatively maximum limitations as compared to Class-II and Class-III types. They are generally unsuitable for growing variety of crops because of shallow depth, erosion and excessive drainage and are suited for selected crops only and pastures. The Class-IVe type of land is moderately steep and subject to serious water erosion. Occasional cultivation in rotation with hay or pasture protected by permanent cover crops can be practiced here with intensive erosion control when in cultivation. Class-IVes type of land is subjected to erosion along with limitations for soil depth due to shallowness, gravels and stones. Very limited cultivation can be practiced here. Such soils are not economical to cultivate as they need intensive soil conservation and management practices. Therefore both agronomic as well as enhanced mechanical measures need to be implemented to arrest the soil erosion and promote beneficial agricultural production. Irrigation water is necessarily required for providing supplemental irrigation during stress periods. The agronomic measures suggested for conservation of soil on these lands include contour farming, strip cropping, mixed cropping, conservation tillage, provision of vegetal cover of shallow root plants, sprinkler and drip irrigation and use of fertilizers. The choice of proper crops and plants with dense cover along with the use of organic manure is very important for the maintenance of adequate ground cover and top soil organic matter level. As such options for suitable occasional fodder cropping or semi-intensive grazing can also be looked into. The mechanical measures which can be effectively employed include broad based terracing, diversion drain, drop outlet and grassed waterways.

16.4.2 Grazing lands

Soils in Class-V are not suitable for raising cultivated crops, but are suitable for perennial vegetation including permanent pastures or forestry, with few or no limitation. Such land is unsuitable for arable use but capable for dryland development. In Tumri watershed no area is specifically demarcated exclusively for livestock fodder and as such pastures and grasslands are not available for grazing. Generally uncontrolled grazing is carried out on natural pastures which come up during the monsoon season on the wastelands and degraded lands. The land under Class-Ve in Tumri watershed is in 45.4 ha. This land is very well suited for grazing and is located on steep slopes with limitation of soil depth subject to erosion, if cover is depleted. The major objective to develop the degraded lands is to provide a palatable vegetation cover on these lands and regeneration of the degraded vegetation cover. Mechanical measures are essentially required to control soil erosion from steep slopes. Grazing lands are suggested near the villages so that the livestock is benefited from the pastures available throughout the year. This will also prevent the cattle from grazing inside the forests thereby enhancing the overall health and vigor of the forests.

The measures for sustainable development of pastures in the Tumri watershed include initial protection from grazing of newly improved grasslands, live-hedge fencing, planting of multipurpose leguminous species of top feed value, reseeding with high yielding grass species like C. Ciliaris, C. Setigerus, D. Annulatum, P. Antidotale and Lasiurus Sindicus. Also grazing management practices should be adopted to maintain the ground cover by controlled grazing including deferred-grazing, rotational-grazing and deferred-rotational-grazing, so that sufficient fodder is available for the cattle throughout the year, since the economy of villagers in the watershed is dependent mainly on diary farming. The diversion drains, check dams, contour trenching, contour furrows, drainage ditches and grassed waterways are the mechanical measures suggested for soil conservation. Basic moisture conservation techniques like contour bunding and inter-row water harvesting system will lead to increases in herbage yield. Silvipasture systems on degraded grazing lands is also suggested which will help in enhanced biomass in the watershed.

16.4.3 Agroforestry lands and forests

These classes having limitations of very severe erosion hazard, very severe effect of past erosion, stoniness, shallow rooting zone, low moisture holding capacity, and are not suitable for cultivation but well suited for pasture and forest development. The area under Class-VIe and Class-VIes are 271 ha and 77.5 ha respectively. The Class-VIe has been suggested for development of pastures and agroforestry, while forest can be considered for the Class-VIes. These lands are found mainly on steep slopes where erosion is considerable and grazing management and logging is necessary to maintain sufficient residue and litter for soil and moisture conservation. It is very important to maintain adequate groundcover and as such, low to moderate grazing should be practiced. During summer season fire protection measures must be adopted in these areas. The intensive mechanical measures are suggested which include contour trenches, gully plugging, diversion drains, grassed waterways, dugout farm ponds, and temporary check dams. The location of temporary check dams has been suggested in Chapter 15. The brush wood dams and stone check dams are most suited in the watershed as construction materials required are abundantly available locally. The raising of commercial grasses should be adopted in pasture land while Jatropha, Amla and orange plantations should be encouraged under agroforestry. These plantations may be beneficial for improving the socio-economic status of the residents in the watershed apart from soil and water conservation. The forest management practices including raising additional shrubs and grasses should be considered in forest under Class-VIes. Top priority should be accorded to the open forests under Class-VIes and reforestation including teak plantation and local tree species like shisham can be planted to convert these areas into dense forests.

A small portion of watershed also falls under Class-VIIe and Class-VIIes. The areas under these classes are 16.8 ha and 26.1 ha respectively. These areas are the most degraded portions of the watershed and found on very steep slope with rocky outcrop and subject to severe erosion. Carefully managed forest and planned logging are necessary to maintain enough plant litter for soil and moisture conservation and fire protection is also essentially required in these areas. These areas of Tumri watershed have been suggested for development of good forest cover with intensive mechanical and biological conservation measures. Retention of perennial vegetation and revegetation of cleared areas is suggested. The vegetation clearing practice should be strictly prohibited in such type of lands. The mechanical conservation measures include construction of check dams, gulley plugging, diversion drains, and grassed waterways. An extensive afforestation program is essentially required in these areas and grazing may be strictly restricted to prevent further damage of top soil. Micro-basin techniques and continuous trenches can be made for water harvesting in such areas.

17.0 REVISED IRRIGATION WATER REQUIREMENTS

The area under agriculture in the suggested land use plan is 610.5 ha with an increase of 70.4 ha from the present agricultural area of 540.2 ha. Moreover, the irrigation requirements for the crops under the additional agricultural area can be met from the proposed storage structures suggested in the watershed. The agricultural area cropped on an average during normal monsoons in kharrif season is about 358.8 ha which is proposed to be increased to 610.5 ha under the suggested land use plan. Similarly the area under rabi crops will also increase from the present 540.2 ha to 610.5 ha as per the suggested land use plan.

The net irrigation water requirement for each of the crops during the various stages of the crop growth on a ten-daily basis has been computed for the increased agricultural area as per the suggested land use plan. The net irrigation water requirement for each crop in the kharrif and rabi season have been computed village-wise and added to compute the net irrigation requirement on a ten-daily basis during the crop growth period. The gross irrigation requirement is computed after considering the field channel efficiency and conveyance losses. The comparison of the crop-wise irrigation water requirement as per the existing and suggested land use plan for the various crops grown during kharrif season is given in Table 17.1 whereas the comparison of the crop-wise irrigation water requirement as per the existing and suggested land use plan during rabi season is given in Table 17.2.

The net irrigation water requirement for the suggested cropped area has increased from the present 0.59 MCM to 1.00 MCM whereas the gross requirements have increased from 1.06 to 1.79 MCM in kharrif season. Similarly, net irrigation water

Table 17.1: Comparison of irrigation water requirement of kharrif crops

Kharrif crops					
		NIR (MCM)		GIR (MCM)	
S. N	Name of the crop	Existing landuse	Suggested landuse	Existing landuse	Suggested landuse
1	Paddy	0.158	0.271	0.282	0.485
2	Jowar	0.032	0.046	0.058	0.083
3	Bajra	0.000	0.000	0.000	0.000
4	Macca	0.018	0.031	0.032	0.055
5	Kodon	0.102	0.174	0.183	0.311
6	Kutki	0.007	0.012	0.013	0.021
7	Arher	0.074	0.126	0.133	0.223
8	Udad	0.008	0.014	0.015	0.026
9	Til	0.037	0.063	0.066	0.113
10	Ramtil	0.022	0.037	0.039	0.066
11	Sava	0.008	0.014	0.015	0.025
12	Parsa	0.005	0.008	0.008	0.014
13	Moong	0.000	0.000	0.000	0.001
14	Soyabean	0.120	0.204	0.214	0.363
Total		*0.592*	*1.001*	*1.056*	*1.788*

requirement for the suggested cropped area has increased from the present 3.15 MCM to 3.66 MCM whereas the gross requirements have increased from 5.62 to 6.53 MCM in rabi season. The increase in water requirement is substantial in kharrif season, as more area is proposed to be brought under agriculture in kharrif season from present 358.8 ha to 610.5 ha by encouraging farmers to cultivate crops in both seasons, which is otherwise not the case, as at present much of the cultivable land is left idle for the single wheat crop in rabi season. The additional water requirement can be met by the water conserved in the watershed by adopting the site specific soil and water conservation measures, the water stored in the existing and proposed storage structures and the sustainable and judicious use of available ground water potential in the watershed.

Table 17.2: Comparison of irrigation water requirement of rabi crops

Rabi crops					
		NIR (MCM)		GIR (MCM)	
S. N	Name of the crop	Existing land use	Suggested land use	Existing land use	Suggested land use
1	Wheat	1.292	1.449	2.308	2.588
2	Black gram	0.053	0.059	0.094	0.106
3	Matar	0.038	0.043	0.068	0.077
4	Chana	0.802	0.907	1.433	1.619
5	Alsi	0.018	0.021	0.033	0.037
6	Potato	0.013	0.014	0.022	0.025
7	Rajgir	0.079	0.089	0.141	0.159
8	Masur	0.528	0.597	0.944	1.067
9	Tevda	0.030	0.034	0.054	0.061
10	Onion	0.006	0.006	0.010	0.011
11	Garlic	0.006	0.007	0.010	0.012
12	Arher	0.058	0.359	0.104	0.641
13	Others	0.266	0.014	0.475	0.025
14	Groundnut	0.013	0.058	0.022	0.104
Total		*3.147*	*3.658*	*5.619*	*6.533*

The comparison of the gross irrigation requirement for the present land use and suggested land use on a ten-daily basis in the watershed during the kharrif and rabi season is given in Table 17.3 & Table 17.4 respectively. Depending on these ten-daily irrigation water requirements, an irrigation scheduling plan may be developed for the agricultural activities under the suggested land use plan, so that crops can be grown in the watershed without experiencing stress during periods of dry spells for achieving optimum crop yield. During low rainfall years, crop varieties that consume less water can be adopted instead of completely abandoning the cultivation activities during such periods. The existing and proposed water storage structures are well distributed within the watershed and will cater to the water needs for the agricultural activities alongwith the development of agroforestry and pastures.

Table 17.3: Comparison of ten-daily requirements for kharrif crops

Kharrif crops					
S. N	Month/ (Decaday)	NIR (MCM)		GIR (MCM)	
		Existing land use	Suggested land use	Existing land use	Suggested land use
1	II-Jun	0.043	0.073	0.076	0.131
2	III-Jun	0.044	0.075	0.078	0.134
3	I-Jul	0.000	0.000	0.000	0.000
4	II-Jul	0.000	0.000	0.000	0.000
5	III-Jul	0.000	0.000	0.000	0.000
6	I-Aug	0.000	0.000	0.000	0.000
7	II- Aug	0.000	0.000	0.000	0.000
8	III- Aug	0.000	0.000	0.000	0.000
9	I-Sep	0.112	0.191	0.201	0.340
10	II- Sep	0.086	0.146	0.154	0.260
11	III- Sep	0.071	0.120	0.127	0.215
12	I-Oct	0.152	0.257	0.271	0.459
13	II-Oct	0.046	0.077	0.083	0.137
14	III-Oct	0.037	0.063	0.067	0.112
Total		*0.592*	*1.001*	*1.056*	*1.788*

Table 17.4: Comparison of ten-daily requirements for rabi crops

Rabi crops					
S. N	Month/ (Decaday)	NIR (MCM)		GIR (MCM)	
		Existing Land use	Suggested landuse	Existing landuse	Suggested landuse
1	III-Oct	0.003	0.003	0.006	0.006
2	I-Nov	0.136	0.162	0.243	0.289
3	II-Nov	0.142	0.168	0.253	0.300
4	III-Nov	0.142	0.169	0.254	0.301
5	I-Dec	0.202	0.233	0.360	0.417
6	II-Dec	0.204	0.236	0.364	0.421

7	III-Dec	0.220	0.254	0.393	0.453
8	I-Jan	0.283	0.326	0.505	0.582
9	II-Jan	0.292	0.337	0.522	0.601
10	III-Jan	0.292	0.336	0.521	0.601
11	I-Feb	0.349	0.403	0.624	0.720
12	II-Feb	0.207	0.242	0.370	0.433
13	III-Feb	0.198	0.232	0.354	0.414
14	I-Mar	0.317	0.369	0.567	0.658
15	II-Mar	0.160	0.188	0.285	0.336
Total		*3.147*	*3.658*	*5.619*	*6.533*

18.0 IMPACT ASSESSMENT OF CONSERVATION MEASURES

18.1 Impact of Conservation Measures on Runoff

The suggested land use plan envisages changes in the present land use wherein some of the land use types including dense forests, and agricultural land uses have increased whereas new land uses like pastures and agroforestry have been suggested instead of degraded barren lands. Moreover conservation measures have been suggested based on the land capability classes. The effect of the changes in land uses and conservation practices introduced will lead to the change in the curve number of the individual land use type and subsequent change in the composite curve number for the watershed. The comparison of the present land use and the suggested land use along with their respective curve numbers is given in Table 18.1.

The composite curve number as per the present land use pattern of the watershed is 83.17 whereas the composite curve number reduces to 74.59 if the suggested land use plan is considered and proposed conservation measures adopted. This implies that the lesser quantity of the rainfall will go as stream flow from the watershed i.e. implicitly more water will be retained inside the watershed as soil moisture and ground water. The SCS-CN has been applied for the estimation of daily and seasonal runoff for both, the present land use pattern as well as the suggested land use pattern.

Table 18.1: Composite curve number for suggested land use plan

S.N.	Land use	Present land use		Suggested land use	
		Area (ha)	CN	Area (ha)	CN
1.	Agriculture	540.15	88	610.51	82
2.	Open forest	521.90	82	Nil	--
3.	Barren	706.14	85	Nil	--
4.	Dense forest	587.98	77	1096.94	70
5.	Pasture	Nil	--	328.19	74
6.	Agro forestry	Nil	--	278.17	71
7.	Built up	27.93	91	27.93	91
8.	Water bodies	7.23	100	49.25	100
	Composite curve number		83.17		74.59

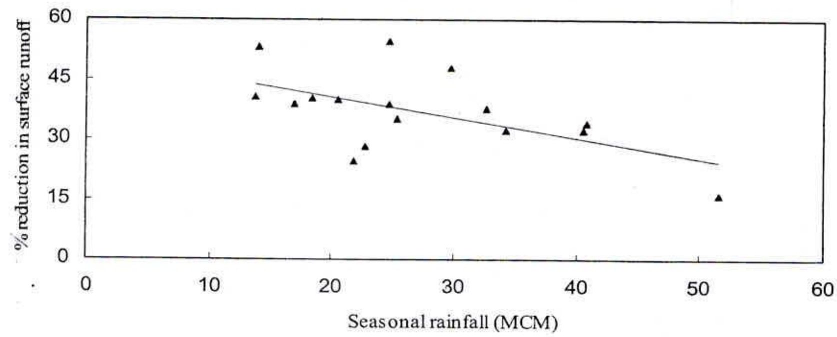
The comparison of seasonal runoff under is presented in Table 18.2.

Table 18.2: Impact of suggested land use on seasonal runoff

S.N.	Year	Rainfall (MCM)	Surface runoff (MCM)		% difference
			Present land use	Suggested land use	
1.	1993-94	34.29	11.77	7.99	32.03
2.	1994-95	40.87	16.21	10.69	34.05
3.	1995-96	13.99	2.06	0.97	52.91
4.	1996-97	18.31	4.41	2.63	40.14
5.	1997-98	24.74	4.74	2.15	54.64
6.	1998-99	21.76	8.20	6.20	24.39
7.	1999-00	40.55	15.41	10.44	32.25
8.	2000-01	20.42	5.20	3.13	40.00
9.	2001-02	25.33	5.76	3.73	35.24
10.	2002-03	16.95	5.54	3.40	38.81
11.	2003-04	29.80	7.05	3.66	48.09
12.	2004-05	32.59	10.36	6.47	37.64
13.	2005-06	51.57	31.87	26.75	16.10
14.	2006-07	24.70	6.57	4.01	38.96
15.	2007-08	13.76	2.49	1.47	40.56
16.	2008-09	22.67	7.23	5.18	28.35

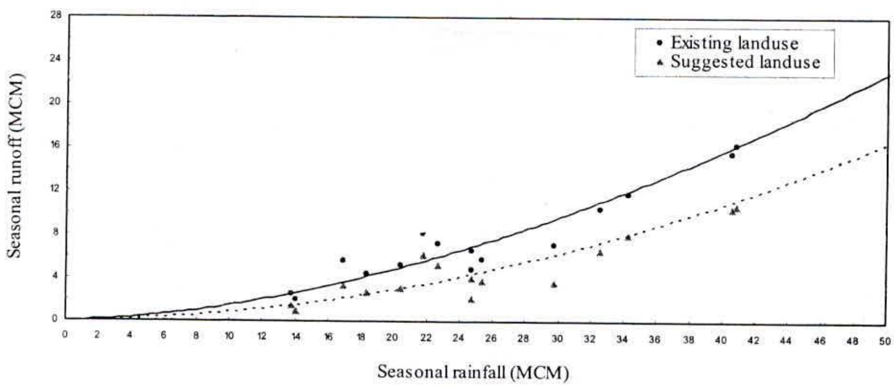
The percentage difference in the computed runoff between the present land use and suggested land use varies between 16.1% and 54.6%. The analysis indicates that the conservation measures will improve the infiltration of water into the ground substantially, and the infiltration enhancement is more predominant during low rainfall years as can be seen from Fig. 18.1. This will be very beneficial to the Tumri watershed as it experiences frequent low rainfall patterns.

Fig. 18.1: Reduction in runoff due to suggested land use plan



A graph has been plotted between the rainfall and computed runoff under the present as well as suggested land use and trend lines fitted as given in Fig. 18.2. This curve depicts the difference in quantity of surface runoff being generated by the watershed in its virgin state as well as after the implementation of conservation measures and suggested land use plan. The graph clearly depicts that for the seasonal rainfall up to 1.20 MCM, negligible surface runoff is being generated from the watershed under the prevailing land use whereas if the suggested land use and conservation measures are adopted then for a minimum seasonal rainfall of up to 2.50 MCM negligible surface runoff is generated from the watershed. This implies that more water can be conserved in the watershed if the suggested land use plan and conservation measures are adopted. The graph can also be effectively used to estimate the surface runoff generated from the watershed for planning of water resources development projects downstream.

Fig. 18.2: Comparison of direct runoff between existing and suggested management plan



The runoff generated from few storms one each in 2006, 2007 and 2008 are given in Fig. 18.3. to Fig. 18.5. The conservation measures and the suggested land use will reduce the peak runoff as well as the overall hydrograph characteristics considerably. The peaks, runoff volume and percentage reduction in volume for few storms have been presented in Table 18.3. It can be observed that the reduction in peak runoff for the three storms considered varies between 15.9% and 40.8% whereas the percentage difference in runoff volume varies between 21.9% and 31.9%.

Fig. 18.3 Comparison of computed runoff between present and suggested land use for Aug 28 to Sep 01, 2006

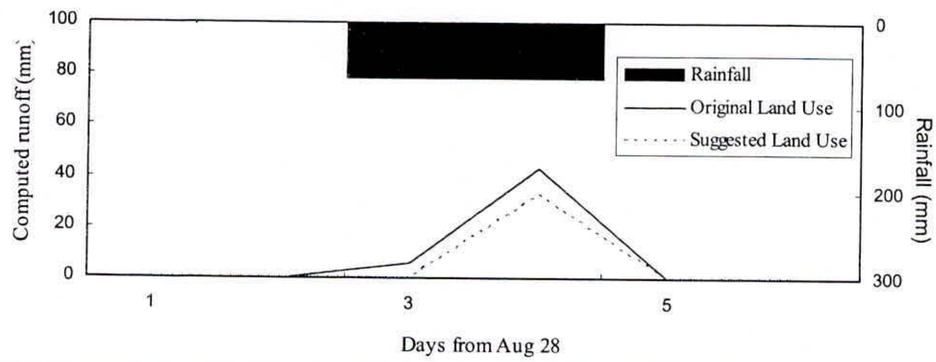


Fig. 18.4 :Comparison of computed runoff between present and suggested land use for storm of July 03 - 10, 2007

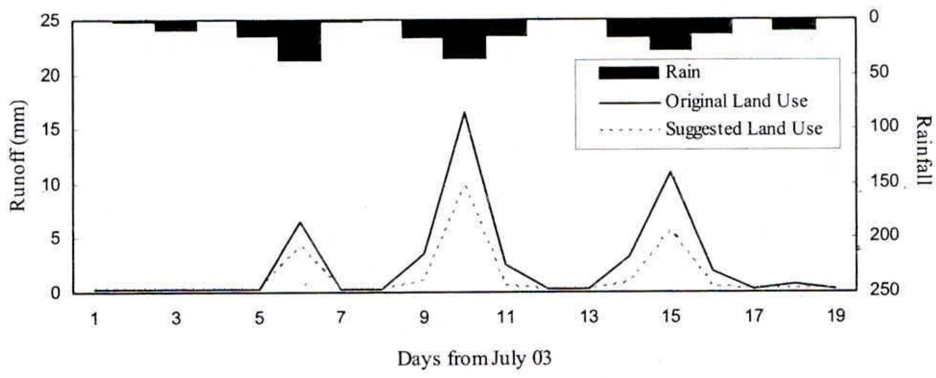


Fig: 18.5 Comparison of computed runoff between present and suggested land use for for storm of July 28 - Aug 07, 2008

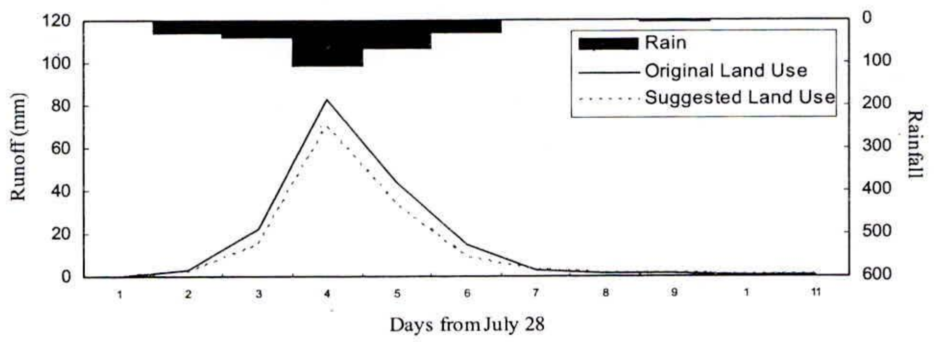


Table 18.3: Comparison of peak runoff and runoff volumes for few storms

S.N.	Storm	Peak runoff (cumecs)			Runoff volume (MCM)		
		Existing	Suggested	% reduction	Existing	Suggested	% reduction
1.	Aug 28 to Sep 01, 2006	11.94	9.00	24.62	1.87	1.28	31.95
2.	July 3 to 10, 2007	4.57	2.71	40.76	1.18	0.63	22.92
3.	July 28 to Aug 07, 2008	23.06	19.38	15.95	4.20	3.28	21.94

18.2 Impact of Conservation Measures on Soil Erosion

The suggested land use plan has been developed on the basis of the land capability and appropriate changes in land use have been incorporated in the plan. Also soil conservation measures like agronomic measures including crop rotation, strip cropping, contour farming, cultivation of dense plants and grasses, cultivation of proper crops, mulching, organic manure, controlled grazing and good tillage have been suggested along with the various mechanical measures like contour bunding, terracing, contour trenching, diversion drains, grassed waterways and temporary check dams. Also biological measures including agroforestry/farm forestry, grazing management, afforestation and reforestation have been suggested depending on the present land use and extent of erosion. There is a considerable change in the land use pattern and subsequent modification of C-factor and P-factor due to conservation measures, as can be seen from Table 18.4.

Table 18.4: C-factor and P- factor values for suggested land use plan

S.N.	Land use	Present land use			Suggested land use		
		Area (ha)	C-factor	P-factor	Area (ha)	C-factor	P-factor
1.	Agriculture	540.15	0.42	1.00	610.51	0.23	0.50
2.	Open forest	521.90	0.09	1.00	Nil	--	--
3.	Barren	706.14	1.00	1.00	Nil	--	--
4.	Dense forest	587.98	0.14	0.80	1096.94	0.008	0.70
5.	Pasture	Nil	--	--	328.19	0.030	0.45
6.	Agro forestry	Nil	--	--	278.17	0.050	0.60
7.	Built up	27.93	0.024	1.00	27.93	0.024	1.00
8.	Water bodies	7.23	0.009	1.00	49.25	0.009	1.00

The effect of these changes on the soil erosion can be assessed by soil erosion modeling using Universal Soil Loss Equation. The comparison of the expected soil loss from various types of land uses in the watershed as per the present land use pattern and the suggested land use plan with proposed conservation measures are given in Table 18.5. The agricultural land in the suggested land use plan has been increased from

540.2 ha to 610.2 ha which is about 13% increase, but the suggested conservation measures

Table 18.5: Comparison of soil erosion for present and suggested land use plan

S. N.	Land use	Present land use (ha)	Erosion (t/ha/yr)	Suggested land use (ha)	Erosion (t/ha/yr)
1.	Agriculture	540.15	14.78	610.51	3.54
2.	Open forest	521.90	3.68	Nil	--
3.	Barren	706.14	34.56	Nil	--
4.	Dense forest	587.98	0.97	1096.94	0.43
5.	Pasture	Nil	--	328.19	0.46
6.	Agro forestry	Nil	--	278.17	0.99
7.	Built up	27.93	1.30	27.93	1.30
8.	Water bodies	7.23	0.22	49.25	0.22

will decrease the average rate of erosion from 14.78 to 3.54 t/ha/yr, which is about 76% reduction in soil erosion. This reduction in erosion from agriculture land will help in the build up of nutrients, moisture and soil depth thereby leading to increased productivity of crops.

The major emphasis in the proposed land use plan is on conversion of open forests and some parts of suitable barren lands into dense forests. If the suggested land use plan is adopted in Tumri watershed, the dense forests can be enhanced from 597.9 ha to 1096.9 ha, which is about 86% increase in the forested area. The suggested conservation practices in the forested lands will reduce the erosion from 0.97 t/ha/yr to 0.43 t/ha/yr, which is about 56% reduction in soil erosion. Presently erosion is taking place at a maximum rate from the barren areas in the watershed at the rate of 34.56 t/ha/yr. The barren lands are proposed to be converted into pastures and agroforestry land uses, which will subsequently reduce the rate of erosion to 0.46t/ha/yr and 0.99 t/ha/yr respectively, with the adoption of proper soil conservation measures. The average rate of soil erosion from the watershed can be reduced significantly from the current 14.60 t/ha/yr to 1.33 t/ha/yr, if the suggested land use plan is implemented for the watershed along with the recommended soil conservation measures. The soil loss that is expected from the suggested land use has been divided into four classes and the distribution of the expected erosion pattern is given in Table 18.6.

Table 18.6: Distribution of areas under various erosion classes

S. No.	Erosion class	Area (hectare)	% of area
1.	Less than 0.50 t/ha/yr	1173.30	49.07
2.	0.50 to 2.0 t/ha/yr	765.26	32.01
3.	2.0 to 5.0 t/ha/yr	343.22	14.35
4.	More than 5.0 t/ha/yr	109.21	4.57

From the analysis it has been observed that expected soil erosion in 49%t area of the watershed can be brought in the range less than 0.50 t/ha/yr, whereas merely 4.57% of the area will be subject to erosion rates more than 5.0 t/ha/yr, if the proposed conservation measures and suggested land use change plan is implemented. The soil erosion map for the suggested land use plan is given in Fig. 18.6.

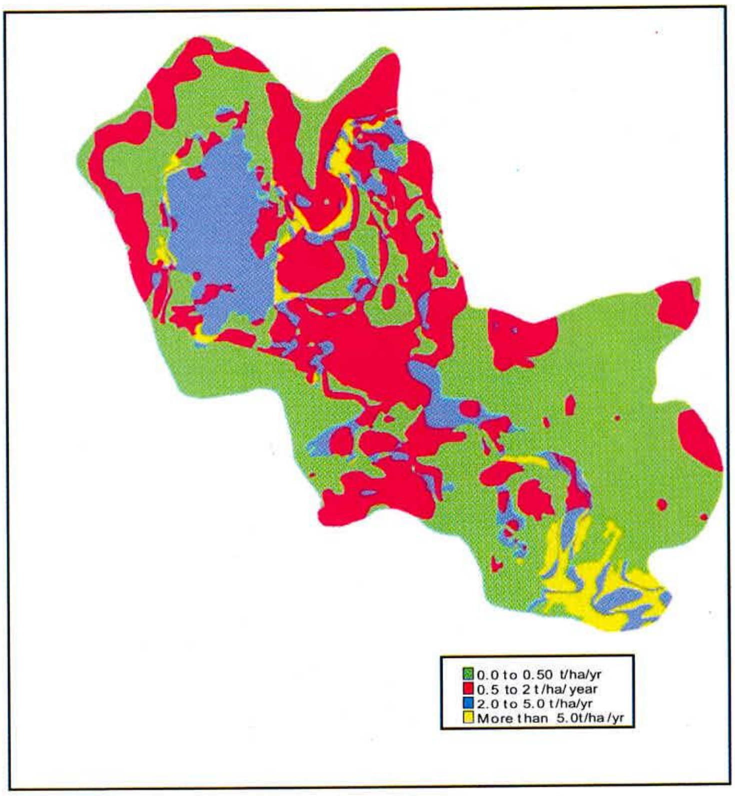


Fig. 18.6: Soil erosion map for the suggested land use plan

19.0 CONCLUSIONS

The Tumri watershed is a highly degraded watershed characterized by undulating land forms, limitation of soil depth, wide spread erosion and uncontrolled removal of forests. The years 1995-96, 1996-97, 2000-01, 2002-03 and 2007-08 are drought years as revealed from the seasonal rainfall departure analysis. Since the probability of occurrence of the 75% of the normal seasonal rainfall is 69.4%, being less than 80%, the watershed can be considered to be drought prone. Based on the infiltration tests conducted at fourteen test sites on varying land use and soil types, Horton's model and Kostiakov's model have been developed, which will be useful in modeling studies.

The detailed water budgeting study gives an insight into the various important components of the hydrological cycle. The study reveals that rainfall is the major inflow component whereas surface runoff is the major outflow component. About 8.05 MCM of water flows down the stream untapped in a normal rainfall year and as such the surface water potential is good and should be tapped at various locations in the watershed for creating additional agricultural areas. The unaccounted water which indicates the accuracy in estimation of the water budget components is -1.557 MCM and 3.290 MCM in monsoon and non-monsoon season respectively and seems to be on the higher side in non-monsoon season, which may be due to the outflow into the confined aquifer due to the highly fissured geology of the region, not being quantified.

The annual expected soil loss from the watershed was estimated to be 34912.7 tonnes in the present land use pattern and is comparable with Khosla's method which estimates the soil loss as 33340 tonnes/year. The estimated soil loss can be reduced by 70% if half of the barren lands are converted to pastures and the remaining barren lands converted to forests. The gross irrigation water requirement under present land use pattern during kharrif and rabi season is 1.056 and 5.169 MCM respectively, which may be met by tapping the surface water resources judiciously. SCS curve number model can be used effectively to model the rainfall runoff process in the watershed. The model is able to simulate the flows with an efficiency of 80% and 93% and RMSE of 0.19 and 0.20 in 2007-08 & 2008-09 respectively, which is encouraging. The difference in volume between the observed and computed seasonal surface runoff is only -5.07% and 6.05% in 2007-08 & 2008-09 respectively, which substantiates that the model can be used effectively to estimate the surface runoff in the study area on the basis of minimum inputs of daily rainfall, and curve number, which has already been established for the watershed.

The sub-watershed SW-15 has been identified as the top most priority watershed and SW-13 may be considered as the least priority watershed for taking up soil and water conservation works. The sub-watersheds SW-8, SW-9, SW-11, SW-15, SW-16, SW-18 and SW-19 have been identified as very-high and high priority watersheds having a total geographical area of about 1000 hectare. These high and very-high priority watersheds should be treated without delay and suitable soil and water conservation measures as suggested should be initiated here. GIUH based Clark model has been applied on gauged Nala sub-watershed and at the outlet of the ungauged Tumri watershed and is capable of simulating the non-linear response to various storm events. The flood hydrograph have been developed and the RMSE between the observed and computed storm events varies between 0.11 and 1.83 for the Nala sub-watershed.

The major problem being faced in the Tumri watershed is lack of water for drinking and irrigation. Seven sites have been selected for construction of storage sites which will be useful in the development of agricultural lands, pastures and agroforestry on barren lands. The construction of storage structures at the selected sites will alleviate the water scarcity prevalent in the watershed. These structures can also be used as water harvesting structures which will ultimately helpful for water conservation in the watershed. The watershed has been divided in the most suitable, suitable and unsuitable recharge zones. From the analysis, it may be concluded that about 13% area of Tumri watershed is suitable for artificial recharge and can be used effectively to recharge the ground water and increase the groundwater levels considerably. The creation of storage structures and artificial recharge measures will enhance the agricultural productivity and coverage of land by bio-mass.

The implementation of suggested land use plan which has been prepared after considering the land capability classes and water availability, will to a great extent improve the overall health and biodiversity of the watershed. The proposed soil and water conservation measures for the suggested land use pattern and various land capability classes will alleviate the current problems of acute soil erosion and lack of water availability in the watershed. The SCS-CN model application indicates that more water will be retained inside the watershed due to the modification of the curve number as a result of the suggested land use plan and proposed soil and water conservation measures. The reduction in seasonal runoff varies between 16.1% and 54.6% for varying ranges of rainfall experienced in the watershed, if the suggested land use management plan is adopted. This will enhance the infiltration of water into the ground which will be very beneficial for the drought prone Tumri watershed. The analysis of daily rainfall and runoff from the present and suggested land use pattern indicates that the conservation measures and the suggested land use plan can reduce the peak runoff and the reduction in peak runoff for few storms considered varies between 15.9% and 40.8%, whereas the percentage difference in runoff volume varies between 21.9% and 31.9%. The reduction in peak runoff will considerably reduce the soil erosion and occurrence of recurrent floods in the watershed. The average rate of soil erosion from agricultural land is expected to decrease from present 14.78 t/ha/yr to 3.54 t/ha/yr, which will help in the accumulation of nutrients, moisture and soil depth, thereby leading to increased productivity of crops. The average rate of soil erosion from the watershed can be reduced significantly from the present rate of 14.60 t/ha/yr to 1.33 t/ha/yr if the suggested land use plan is adopted for the watershed along with the recommended soil conservation measures.

To enable local people in the watershed to prevent, arrest and reverse degradation of life support systems like land and water, it is important to manage the forest lands, non-forest wastelands, crop lands and water in an integrated approach. Another important aspect to be taken care of is that, structures constructed under the watershed management projects should not be abandoned after the initial enthusiasm, as lack of maintenance would ultimately turn back the watershed into its earlier state arresting the increase in agricultural production and growth of other natural resources. Also mechanisms should also be evolved to look after the common lands by engaging responsible local inhabitants. The constant monitoring and evaluation in terms of changes in ground water levels, afforestation, biomass coverage, and reduction in soil loss is essential alongwith the impact assessment analysis. A massive programme of training and capacity building also needs to be initiated. The conceived watershed management plan can be effectively implemented so as to increase agricultural production while arresting ecological degradation in rainfed and resource poor Tumri watershed. It would, at the same time, also help to improve the level of living of the poor by providing more sustainable exploitation of available resources. The watershed can be developed as a model watershed based on the suggested recommendations given in the comprehensive management plan, so that other degraded and neglected watersheds in the Bundelkhand region can be developed scientifically to fully utilize the resources in a judicious and sustainable manner.

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