Final Draft Report

PRIORITIZATION OF SUB-CATCHMENTS OF THE SONG AND NAYAR RIVER CATCHMENTS FOR DEVELOPMENT OF RIVER REJUVENATION PLAN

Submitted to

Watershed Management Directorate,
Dehradun, Uttarakhand

Submitted by

National Institute of Hydrology,
Jal Vigyan Bhawan, Roorkee (Uttarakhand) – 247667

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STUDY TEAM

Dr. M. K. Goel	Director, NIH
Dr. Y. R. S. Rao	Scientist ‘G’ & Head, EHD, NIH
Dr. Pradeep Kumar	Scientist ‘E’ & P.I., EHD, NIH
Dr. S. S. Rawat	Scientist ‘F’, C4S, NIH
Dr. Shakti Suryavanshi	Scientist ‘C’, EHD, NIH
Dr. Shailendra K. Kumre	Scientist ‘B’, EHD, NIH
Dr. S. M. Pingale	Scientist ‘D’, HID, NIH

1. INTRODUCTION

1.1 Background

The Song and Nayar River catchments, located in Uttarakhand, India, are critical hydrological systems that play a vital role in sustaining ecological balance, supporting biodiversity, and meeting the water demands of local communities. These river systems are increasingly experiencing hydrological stress due to a combination of natural and anthropogenic factors, including climate change, land use modifications, and urban expansion. The degradation of riverine ecosystems, declining water availability, and increasing sediment loads necessitate urgent intervention to ensure sustainable water resource management and ecological restoration.

Recognizing the criticality of these issues, the Spring and River Rejuvenation Authority (SARRA) initiated a state-level program aimed at the rejuvenation of key river systems in Uttarakhand, including the Song and Nayar Rivers. As part of this initiative, the National Institute of Hydrology (NIH), Roorkee, was assigned the task of assessing and prioritizing sub-catchments within these river basins for targeted conservation and restoration efforts. The overarching objective is to enhance water security, improve ecological resilience, and ensure the long-term sustainability of riverine habitats.

Hydrological systems are highly dynamic and governed by multiple interrelated parameters such as precipitation variability, terrain characteristics, soil permeability, and land use patterns. In recent decades, the Song and Nayar catchments have witnessed significant land use and land cover (LULC) changes, including deforestation, expansion of built-up areas, and shifts in agricultural practices. These changes have directly influenced hydrological regimes, affecting surface runoff, infiltration rates, and groundwater recharge potential. Additionally, the encroachment of urban areas and increased extraction of water resources have placed further stress on these river systems, altering their natural flow regimes and impacting water quality.

To ensure effective river rejuvenation, it is essential to identify and address the key drivers of hydrological degradation. Sub-catchments that exhibit significant ecological and hydrological stress need to be prioritized for intervention through measures such as afforestation, watershed management, and sustainable land use planning. Given the growing challenges posed by climate change, there is also an urgent need to enhance the resilience of these river systems by integrating nature-based solutions and adaptive management strategies.

This study aims to contribute to the scientific understanding of the hydrological and ecological dynamics of the Song and Nayar River catchments. By assessing the underlying factors influencing streamflow variations, water availability, and ecosystem health, the findings will help inform data-driven policies for sustainable river basin management. The study will also provide actionable insights for policymakers, water resource managers, and local communities to implement effective conservation strategies, thereby ensuring the long-term preservation of these vital river systems.

The rejuvenation of the Song and Nayar Rivers is not only critical for sustaining local water resources but also for maintaining the ecological integrity of the region. A holistic approach that integrates scientific research, community participation, and policy support will be essential in achieving sustainable outcomes. Through strategic planning and evidence-based decision-making, this initiative will contribute to the broader goal of safeguarding Uttarakhand’s riverine ecosystems while promoting water security for future generations.

1.2 Objectives

a) To assess streamflow dynamics in the Song and Nayar (East and West) catchments, by analyzing the observed / estimated streamflow data to identify trends and patterns over time.
b) To assess the role of governing factors (Rainfall Pattern, Morphometry, LU/LC, Soil Types etc.) on the hydrological behaviour of the selected river catchments and their sub-catchments
c) To prioritize the sub-catchments on the basis of land use / land cover changes and morphometric characteristics and establish a framework for their prioritization considering the societal importance (population residing in the sub-basin and the JJM schemes for providing their domestic water requirements).

2. STUDY AREA

The Song River is a spring-fed river that originated from different small rivulets of the mountainous range of Dhanolti, crossing with Sahastradhara streams, flowing downward towards Doon valley basins, and finally assimilates into river Ganga. Apart from the surrounding natural beauty, the Song River of Dehradun is famous for its abundant natural sulphur springs. These springs originate from the cracks of the mountain and flow into the main stream, thus making the river water rich in sulphur content. People come here to take a dip in the mineral rich water. It is believed that sulphur bath is beneficial for various ailments, especially skin diseases. The river Song is located at 30º28' latitude and 78º8' longitude, with which peoples of Raiwala, Doiwala, Chiddarwala, and Lacchiwala are very much attached because this river is the only ultimate source of water for them travelling a total distance of approximately 107 km. It merges into river Ganga at 78°14'54'' longitude and 30°02'02'' latitude just upstream of Haridwar near Satyanarayan G&D station maintained by CWC after crossing Satyanarayana area in Figure 1. The river Suswa is an important tributary of river Song originating from the midst of the clayey depression of the Mussoorie range drains eastern part of Dehradun city and joint river Song at south-east of Doiwala. Dehradun and Doiwala are two major urban settlement situated in the catchment. Rispana and Bindal are two major drainage networks carrying municipal sewage from Dehradun and Doiwala discharges into the Song river through the Suswa river. The average annual rainfall is approximately 1451 mm, with around 1181 mm (81%) occurring during the monsoon season, making July and August the wettest months of the year.

The Nayar River, which flows fully within the Pauri Garhwal region, is the second-largest perennial spring-fed river in the state of Uttarakhand after the Ramganga River. Its two main branches, Purvi Nayar River and Pashchimi Nayar River originates in the dense Dudhatoli Reserved Forest. Purvi Nayar River is approximately 94 km long, while Pashchimi Nayar River is around 91 km long. Near Satpuli, they eventually combine to form the 20 km-long Nayar River. After joining of these two rivers with each other, the river travels to Vyas Ghat where it finally confluences with Ganga River. The Nayar River's watershed is bounded by districts of Uttarakhand, Tehri Garhwal to the north, Chamoli to the east, Almora to the south-east, Nainital to the south, and Dehradun to the west. Horn peaks, serrated canyons, hanging valleys, and waterfalls make it unique. Paithani, Thalisain, Pathisain, Pabo, and Satpuli are signifcant cities in the Nayar watershed. Its latitude and longitude boundaries are, respectively, 29°45'N to 30°15'N and 78°32'E to 79°12'E. The Nayar watershed covers an area of 1956.33 km^2, which has elevations ranging from 428 to 3102 m and receives about 1700 mm of rainfall on average annually. Also, the area’s yearly average temperature ranges from 25 °C to 30 °C. The location has a pleasant summer time climate.

The Song and Nayar River catchments, located in Uttarakhand, India, are critical hydrological systems that play a vital role in sustaining ecological balance, supporting biodiversity, and meeting the water demands of local communities. These river systems are increasingly experiencing hydrological stress due to a combination of natural and anthropogenic factors, including climate change, land use modifications, and urban expansion. The degradation of riverine ecosystems, declining water availability, and increasing sediment loads necessitate urgent intervention to ensure sustainable water resource management and ecological restoration.

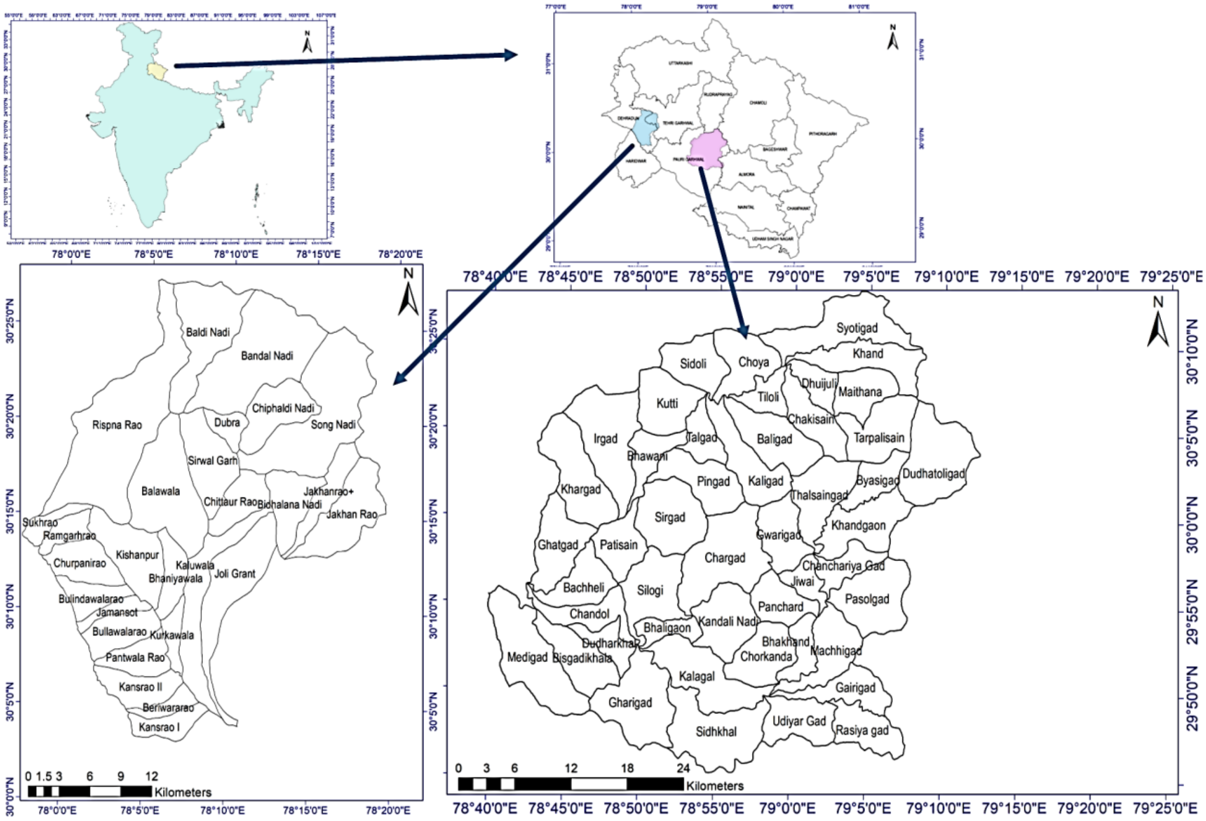


Fig. 1: Study area

3. METHODOLOGY

The methodology for identifying potential areas for watershed management involves the systematic integration of multiple thematic layers using Geographic Information System (GIS) tools. The approach consists of data collection, thematic layer preparation, weighted overlay analysis and classification of potential areas for Watershed management. The study utilizes key spatial datasets, including a Digital Elevation Model (DEM), land use/land cover (LULC) data, soil data and geological data. The methodology ensures a structured analysis to identify zones suitable for watershed management within the Song and Nayar catchment.

3.1 Data Collection

The successful delineation of potential areas for watershed management requires the integration of multiple datasets that provide insights into terrain characteristics, soil properties, geological formations, and land use changes. These datasets are essential for designing effective interventions aimed at enhancing groundwater recharge and sustainable water resource management. The key datasets utilized in the study are described in detail below.

3.1.1 Topographical Data

In this study, the FAB DEM (Fine-resolution Adaptive Blending Digital Elevation Model) dataset was used to analyze terrain characteristics. This dataset provides a high-resolution elevation model with a 30-meter spatial resolution, ensuring an accurate representation of topographical variations within the study area. The DEM was instrumental in deriving slope gradients, flow direction, drainage networks, and watershed boundaries. Since slope directly influences groundwater recharge potential, the DEM was further processed to classify the study area into different slope categories. Gentle slopes facilitate infiltration, whereas steep slopes promote surface runoff, reducing recharge potential.

3.1.2 Soil Data

Soil characteristics play a crucial role in determining infiltration rates, permeability, and water retention capacity, all of which directly affect groundwater recharge. The soil classification data was obtained from the National Remote Sensing Centre (NRSC) and sourced from the GIS server of IIT Delhi (available at http://gisserver.civil.iitd.ac.in/grbmp/downloaddataset.aspx).

3.1.3 Geological Data

Geological formations significantly influence subsurface water movement, storage capacity, and permeability. Understanding the lithological characteristics of the study area is critical for groundwater recharge planning. Geological data was obtained from the Geological Survey of India (GSI), providing detailed lithological and structural information. This dataset includes information on rock types, fractures, fault zones, and subsurface permeability.

3.1.4 Land Use and Land Cover (LULC) Data

Land use and land cover (LULC) patterns provide critical insights into surface conditions, vegetation cover, impervious surfaces, and anthropogenic influences on groundwater recharge. Changes in land use over time affect infiltration, runoff, and evapotranspiration, making it necessary to analyze historical LULC trends.

The LULC maps were generated using Landsat satellite imagery for different time periods, allowing for a time-series analysis of land use change. The datasets used for LULC classification include:

1995: Landsat 5 (30m resolution)
2005: Landsat 7 (30m resolution)
2015: Landsat 8 (30m resolution)
2023: Landsat 9 (30m resolution)

These datasets were processed using supervised classification techniques, with training samples collected for different land cover classes. The integration of LULC data with slope, soil, and geology information allowed for a more comprehensive assessment of groundwater recharge potential and the identification of priority areas for conservation and intervention.

3.2 Preprocessing

The first step in the analysis involved acquiring relevant spatial datasets, which were processed to generate thematic layers for further analysis. The DEM was obtained and used to derive the slope characteristics of the study area. Slope influences the infiltration and runoff of rainwater, thereby affecting the recharge potential. The land use/land cover dataset was collected through satellite imagery and classified into different land cover categories. The soil data was acquired and provided information on soil texture, which play a crucial role in infiltration. Additionally, geological data was incorporated to understand the subsurface lithology, as different rock formations exhibit varying degrees of porosity and permeability. The final dataset included information on priority areas for watershed management, which was useful in identifying regions where conservation efforts are required.

Before further analysis, all datasets were projected into a common coordinate reference system to ensure spatial alignment. The data preprocessing stage also involved correcting spatial inconsistencies, eliminating noise, and filling missing values where necessary.

3.3 Generation of Thematic Layers

Each dataset was processed to derive thematic layers that represent different factors affecting groundwater recharge.

3.3.1 Slope analysis

The slope map was derived from the DEM using the Slope Tool in ArcGIS. Slope influences the movement of surface water, with flatter areas allowing more infiltration and steeper slopes facilitating runoff. The slope values were categorized into five classes: flat and gentle slope areas with a gradient of 0-8 percentage were assigned high recharge potential, Rolling slopes between 8-15 percentage were given intermediate recharge potential followed by hilly and mountainous slopes between 15-40 percentage and steep mountainous slopes between 40-60 percentage were classified as low recharge zones due to increased surface runoff and greater than 60 percentage slope were considered as very low recharge zones. Figure 1 presents the slope distribution across the study areas, indicating that significant portions of the basin have moderate to steep slopes, which may limit infiltration in certain regions.

3.3.2 Land use/land cover classification

The land use/land cover map was prepared using remote sensing data and classified into different categories such as forest, agricultural land, urban settlements, water bodies, and barren land. Each land cover type influences groundwater recharge differently. Forested regions, which cover a substantial portion of the study area, promote infiltration due to dense vegetation and minimal surface runoff. Agricultural areas also contribute to recharge, though the extent varies depending on land management practices. Urbanized regions, on the other hand, have impervious surfaces such as roads and buildings that significantly reduce infiltration, leading to low recharge potential. Water bodies, though they contribute to direct recharge, are limited in spatial extent. The classified LULC maps provide a clear representation of the land use patterns within the basin, highlighting regions with varying recharge capacities.

3.3.3 Soil analysis

The soil characteristics of the study area were analyzed using a soil map, which categorized different soil types based on soil texture which plays a critical role in groundwater recharge.

3.3.4 Geology

Geological formations influence groundwater recharge by determining the storage capacity and movement of water through subsurface layers. Areas with porous rock formations, such as Tal and Balini formation, have a higher potential for recharge, whereas regions with impermeable rock layers, such as Rautgara and Chandpur formation, restrict infiltration. Understanding the geological characteristics is essential for assessing long-term groundwater availability and recharge sustainability.

3.4 Identification of Priority Watershed Management Areas

The final thematic layer incorporated into the analysis was the identification of priority areas for watershed management. These areas indicate regions where conservation measures such as check dams, afforestation, and rainwater harvesting could be implemented to enhance recharge. By integrating these priority areas, the study ensured that recharge assessments aligned with ongoing watershed conservation efforts, thereby promoting sustainable water resource management.

3.5 Weighted Overlay Analysis

The Weighted Overlay Analysis (WOA) is a GIS-based multi-criteria decision-making technique used to integrate multiple thematic layers and determine the potential areas for watershed management. The different thematic layers prepared were combined using a weighted overlay approach to generate the potential areas for prioritization for watershed management. Each layer was assigned a weight based on its relative influence on recharge. The weighting process was determined based on literature review and expert judgment, ensuring a balanced representation of factors. In this study, land use, soil, slope and geological characteristics was assigned equal weights. The thematic layers were standardized to a common scale and combined using the Weighted Overlay Tool in ArcGIS.

3.9 Classification and Visualization of Potential Areas for Watershed Management

The final potential areas for watershed management was classified into five categories: very low, low, moderate, high, and very high potential. Areas with dense forest cover, permeable and deep soils, and gentle slopes exhibited the highest recharge potential, while urbanized zones, steep slopes, and shallow depth soils were categorized as low recharge zones. The classified map was visualized using a color gradient, with darker shades representing higher recharge potential and lighter shades indicating limited recharge capacity. The resulting map provides a spatial representation of groundwater recharge suitability across the study area.

To enhance clarity and to streamline the execution of the work, the results were analyzed and presented at the micro-watershed level designated by the Watershed Management Directorate for the Song and Nayar river basins.

4. RESULTS AND DISCUSSION

4.1 Land Use and Land Cover Change Analysis

The transformation of land use and land cover (LULC) plays a significant role in shaping the hydrological and ecological landscape of river basins. Over the years, natural and anthropogenic influences have altered land use patterns, impacting the delicate balance between vegetation cover, water availability, and urban development. The Song and Nayar River Basins, vital sources of water and ecological stability in their respective regions, have witnessed distinct LULC changes over the last three decades. Understanding these shifts provides insights into how land use transitions may influence broader environmental and water resource dynamics. For this study, supervised classification using the Random Forest algorithm was employed in Google Earth Engine (GEE), leveraging its robust processing capabilities to analyze satellite imagery from multiple time periods. The classification results offer a comprehensive view of how land cover has evolved in these basins, shedding light on trends such as afforestation, urban expansion, shrinkage of water bodies, and changes in agricultural land use.

4.1.1 Land Use and Land Cover Changes in the Song River Basin (1995-2023)

The Song River Basin has undergone significant land cover modifications over the years, reflecting both natural succession and human interventions. Table 1 and Figures 2 to 5 exhibit the changes in land use and land cover categories in the Song River Basin over four time periods (1995, 2005, 2015, and 2023). The most notable trend observed is the increase in forest cover, which has expanded from 624.34 km² in 1995 to 728.93 km² in 2023. This increase suggests active afforestation efforts or natural regrowth, potentially influenced by conservation policies or changing land management practices. While forest expansion contributes to soil stabilization and enhances groundwater infiltration, its effects on water availability must be considered, as denser vegetation can lead to higher evapotranspiration rates.

Table 1: Land use / land cover changes in the Song River Basin during 1995-2023

Class/Year	1995 (Area-km^2)	2005 (Area-km^2)	2015 (Area-km^2)	2023 (Area-km^2)
Forest	624.34	660.76	660.64	728.93
Water	48.22	26.86	43.25	19.93
Shrub	103.65	73.79	44.48	10.62
Built Up	77.66	90.39	110.84	115.79
Crop	114.28	116.33	108.93	92.87

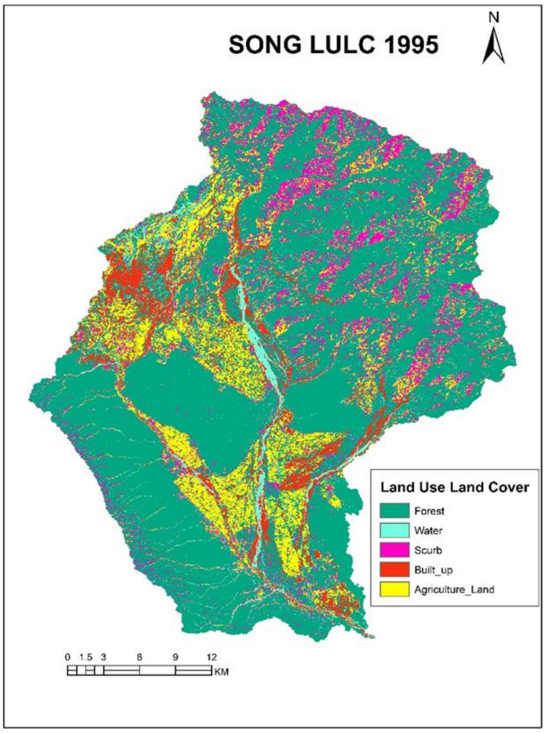


Fig. 2: Land use Land Cover for Song River Basin (1995)

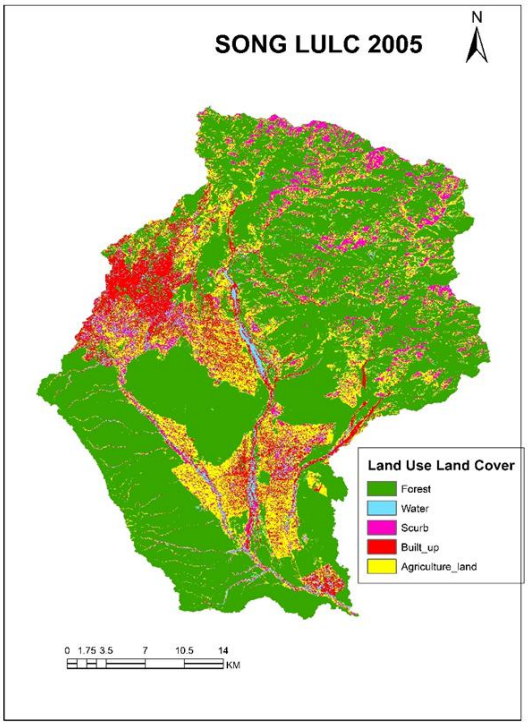


Fig. 3: Land use Land Cover for Song River Basin (2005)

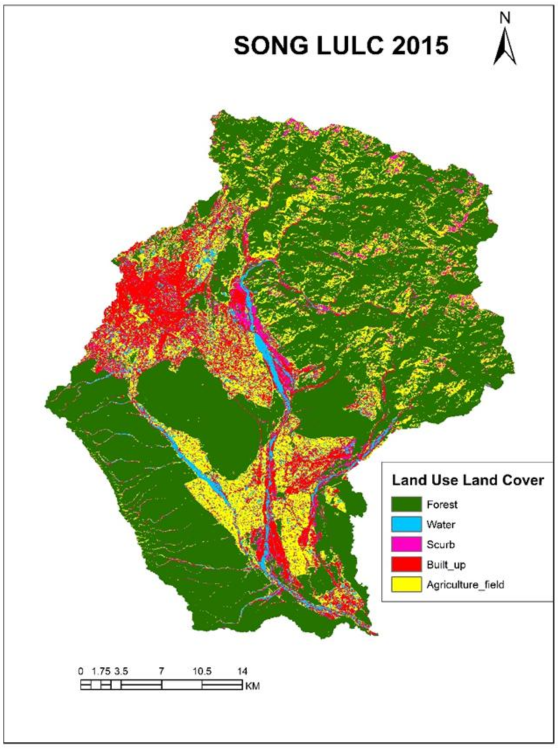


Fig. 4: Land use land cover for Song river basin (2015)

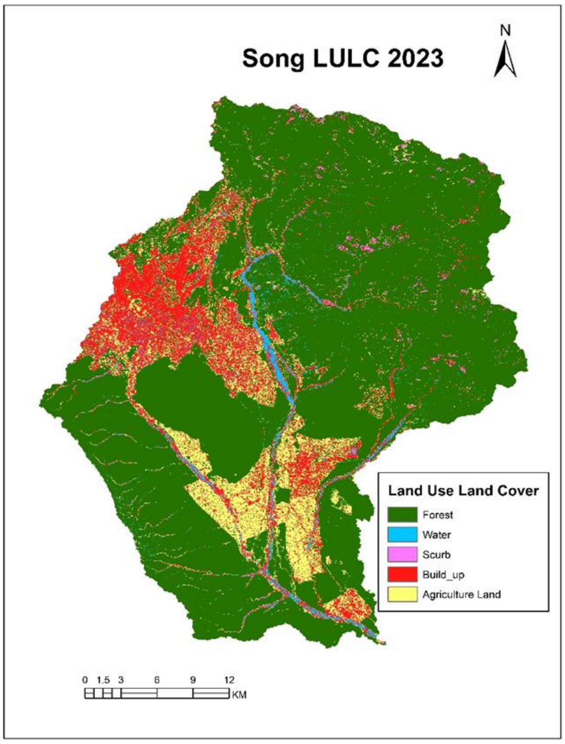


Fig. 5: Land use land cover for Song river basin (2023)

Water bodies, in contrast, have diminished significantly, with their extent reducing from 48.23 km² in 1995 to only 19.93 km² in 2023. This trend highlights a shift in surface water distribution, which could be associated with reduced baseflows, increased sedimentation, or encroachment into wetland areas. The decline in water bodies suggests possible long-term hydrological changes, where surface runoff patterns and aquifer recharge dynamics may be evolving in response to land use alterations. Shrubland cover has also seen a drastic reduction, shrinking from 103.65 km² in 1995 to merely 10.62 km² in 2023. This nearly complete loss of shrubland indicates that much of this land has transitioned into either dense forest or built-up areas. The transition from shrubland to forest suggests a gradual ecological succession, whereas the conversion to built-up areas signals ongoing urbanization. The built-up area itself has expanded, increasing from 77.66 km² in 1995 to 115.79 km² in 2023. The steady growth of urban settlements, especially in and around Dehradun, aligns with broader patterns of population increase and infrastructure development. The spread of built-up areas alters land surface permeability, influencing runoff patterns and groundwater recharge potential. A landscape once dominated by open land and agricultural fields is increasingly marked by impermeable surfaces, modifying natural hydrological processes over time. Agricultural land, on the other hand, has decreased from 114.28 km² in 1995 to 92.87 km² in 2023. This reduction suggests a gradual shift in land use priorities, where some farmland may have been converted into urban spaces, while other portions could have transitioned into forested zones. The decline in agricultural extent over time reflects changes in land management practices, possibly influenced by economic, environmental, or policy-driven factors.

The Land Use/Land Cover (LULC) Map of the Song Catchment (2023) highlights the spatial distribution of forests, shrublands, built-up areas, croplands, and water bodies. The dominance of forest cover suggests a well-vegetated landscape, but the presence of urban expansion and declining water bodies indicates increasing human interventions. The expansion of built-up areas, particularly around Dehradun, has modified natural drainage patterns, increasing surface runoff and reducing groundwater recharge potential. The reduction in agricultural land suggests a shift in land use priorities, possibly influenced by economic changes or urban sprawl.

4.1.2 Land Use and Land Cover Changes in the Nayar River Basin (1995–2023)

Table 2 and Figs. 6 to 9 exhibit the changes in land use and land cover categories in the Nayar River Basin over four time periods (1995, 2005, 2015, and 2023). Forest cover has shown a steady increase, rising from 852.72 km² in 1995 to 938.60 km² in 2023. This expansion suggests ongoing forest regeneration or afforestation efforts, reinforcing the ecological importance of forested regions in maintaining slope stability and influencing water balance. However, such trends should also be examined for their effects on local hydrology, as increased vegetation density can shift the distribution of available water resources. Water bodies in the Nayar Basin have slightly expanded, increasing from 46.03 km² in 1995 to 51.13 km² in 2023. This growth may be attributed to watershed management efforts, hydrological interventions, or natural variations in precipitation patterns. Shrubland, however, has followed a downward trajectory, reducing from 480.14 km² in 1995 to 357.95 km² in 2023.

Table 2: Land use / land cover changes in Nayar River Basin during 1995-2023

Class/Year	1995 (Area-Km^2)	2005 (Area-Km^2)	2015 (Area-Km^2)	2023 (Area-Km^2)
Forest	852.72	887.92	920.53	938.60
Waterbody	46.03	39.67	46.91	51.13
Shrub	480.14	470.09	399.24	357.95
Built-up	180.85	198.63	221.83	274.23
Crop	134.94	102.81	105.17	87.78
Wasteland	31.21	27.77	32.04	15.33

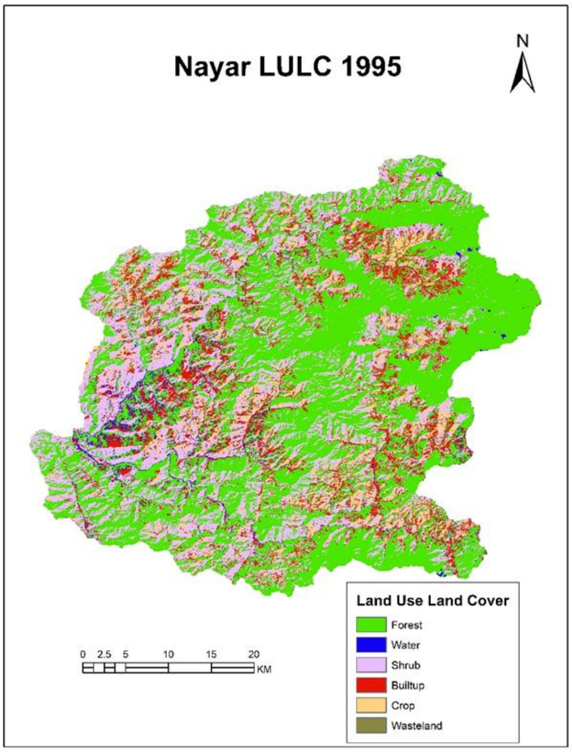


Fig. 6: Land use land cover for Nayar basin (1995)

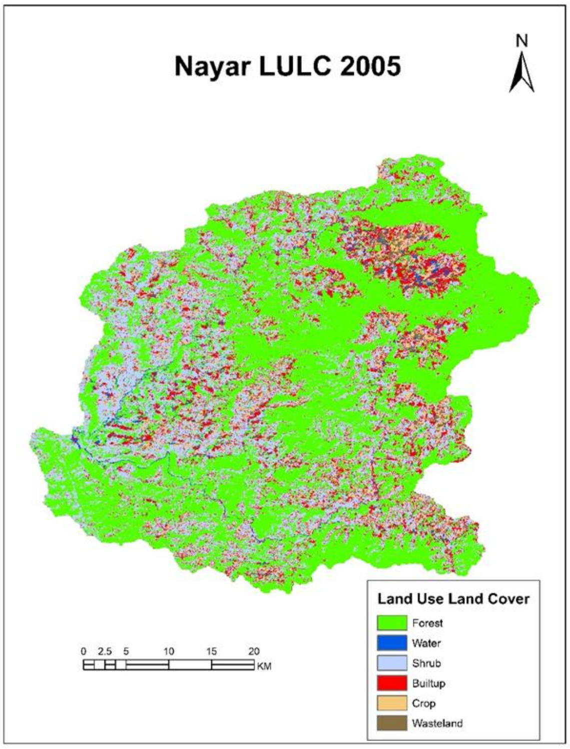
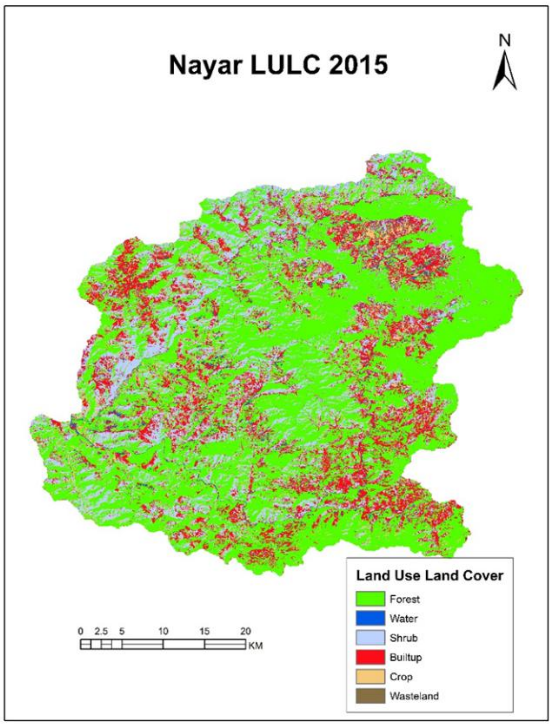


Fig. 7: Land use land cover for Nayar basin (2005)



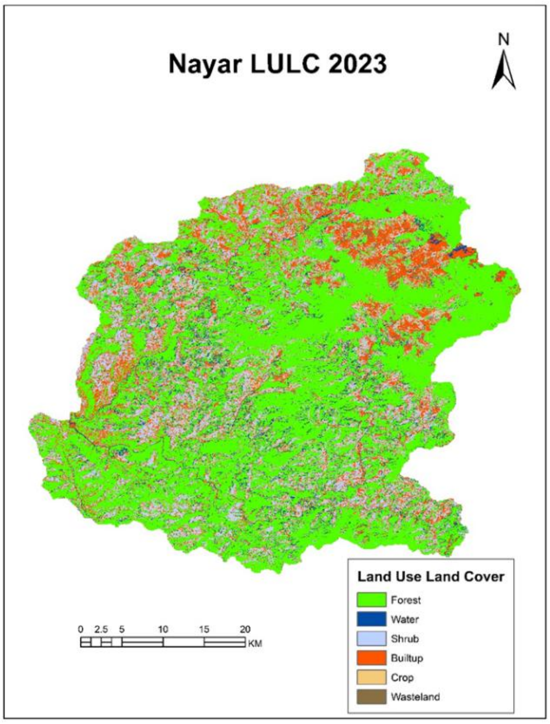


Fig. 8: Land use land cover for Nayar basin (2015)

Fig. 9: Land use land cover for Nayar basin (2023)

This reduction reflects broader land use changes, where open landscapes are being replaced by either forested regions or human settlements. The gradual loss of shrubland could indicate shifts in ecosystem composition, where vegetation dynamics are responding to both climatic factors and land management practices. Urban expansion has been pronounced in the Nayar Basin, with built-up areas increasing from 180.85 km² in 1995 to 274.23 km² in 2023. This increase underscores the ongoing transformation of the basin into a more urbanized landscape, driven by infrastructure growth and population expansion. Urbanization alters natural drainage networks, increases surface runoff, and influences local climate conditions, gradually reshaping the basin's hydrological characteristics. Agricultural land in the Nayar Basin has also experienced a decline, dropping from 134.94 km² in 1995 to 87.78 km² in 2023. This shift may suggest evolving agricultural practices or land use conversion for non-agricultural purposes. As agricultural land contracts, the spatial distribution of cultivated areas changes, influencing both groundwater extraction patterns and food production systems. One of the more notable trends in the Nayar Basin is the reduction in wasteland, which has decreased from 31.21 km² in 1995 to 15.33 km² in 2023. This decline suggests that previously unproductive land has either been repurposed for agriculture, afforestation, or urban development, reflecting broader land rehabilitation efforts or shifts in land use demand.

The patterns of LULC change observed in both river basins highlight evolving interactions between natural landscapes and human activities. The expansion of forest cover in both basins suggests an increasing focus on conservation or natural succession, but it also calls for attention to potential hydrological shifts due to changing evapotranspiration dynamics. The contrasting trends in water bodies between the two basins reflect differing hydrological conditions, where factors such as sedimentation, watershed management interventions, and climate variability play key roles in shaping surface water availability. The steady urban expansion in both basins underscores the growing influence of human settlements on the landscape. As built-up areas continue to spread, land surface permeability decreases, modifying groundwater recharge processes and increasing runoff intensity. The decline in shrubland and agricultural land in both basins signals a transition in land use priorities, where open landscapes are either forested or urbanized over time. While some of these changes align with conservation goals, others indicate shifts in land availability for cultivation, potentially influencing local livelihoods and food security.

The LULC Map of the Nayar Catchment (2023) reveals a significant proportion of forested areas, indicating the ecological importance of this basin. However, urbanization and infrastructural development are gradually encroaching into natural landscapes. The persistence of cropland in certain regions suggests ongoing agricultural dependence, though the contraction of these areas hints at possible land abandonment or conversion to other uses. The presence of water bodies, though limited, underscores the need for conservation efforts to sustain hydrological balance.

The evolving land cover patterns in the Song and Nayar River Basins reflect a complex interplay of ecological processes, human interventions, and environmental factors. These transformations not only reshape the physical landscape but also influence long-term water resource sustainability, necessitating an integrated approach to land and water management that considers both conservation objectives and human development needs.

4.2 Slope Analysis

4.2.1 Slope analysis of Song Catchment

The Slope Map of the Song Catchment illustrates the varying topographical gradients across the basin (Fig. 10). The Song Catchment exhibits a mix of steep slopes in the upper reaches and gentler slopes in the downstream areas. The slope ranges between 0 to 85 percentage. The upper hilly regions experience rapid runoff, leading to low groundwater recharge potential but high susceptibility to erosion and landslides. The gentler slopes in the lower basin facilitate infiltration, supporting groundwater recharge and agricultural activities.

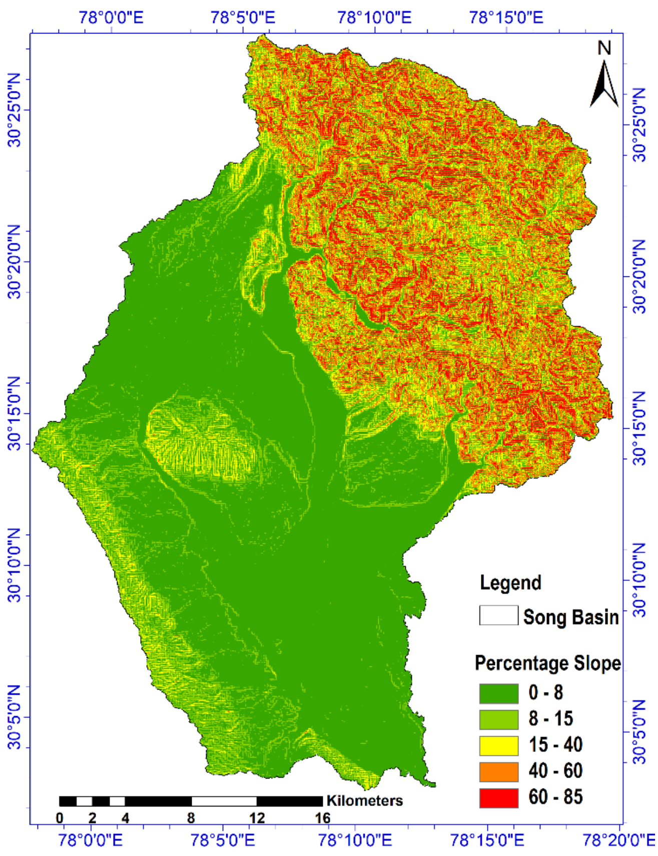


Fig. 10: Slope Map of the Song Catchment

4.2.2 Slope Analysis of Nayar Catchment

The Slope Map of the Nayar Catchment shows a topography characterized by steep gradients in the mountainous terrain and moderate slopes in the middle and lower reaches (Fig. 11). The slope varies between 0-89 percentage. The presence of rugged terrain in the upstream areas results in high runoff rates and low infiltration, necessitating soil conservation measures to prevent degradation. Downstream, the moderate slopes offer better recharge potential, making them more suitable for agricultural expansion and water retention projects.

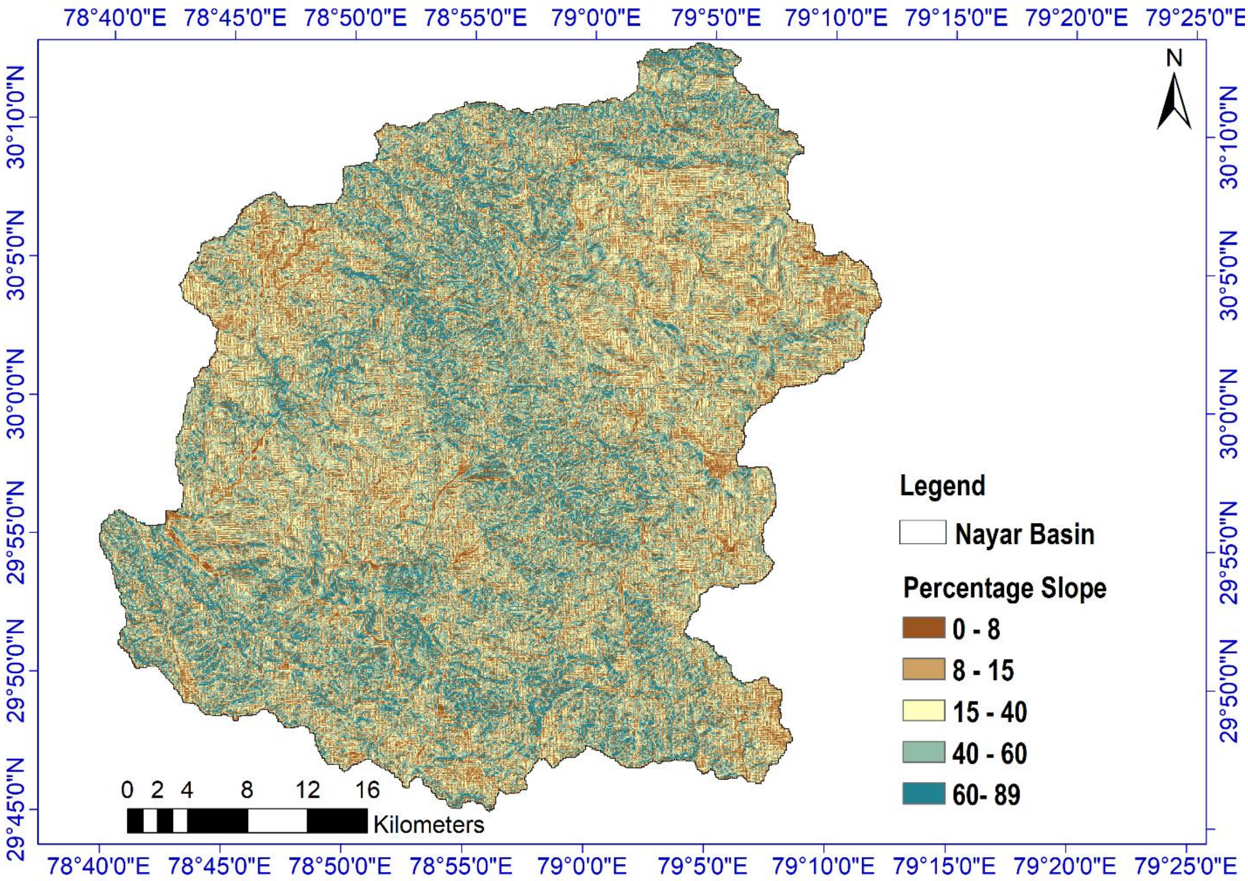


Fig. 11: Slope Map of the Nayar Catchment

4.3 Soil Characteristics

4.3.1 Soil Characteristics of song Catchment

The soil map of the Song Catchment categorizes the basin based on soil texture (Fig. 12). The presence of deep Silty loam and loamy soils in certain areas indicates high infiltration rates, making them suitable for groundwater recharge. Conversely, some loamy soil with shallow layers in other sections exhibit low permeability, leading to surface water accumulation and increased runoff. The distribution of alluvial soils in the floodplain areas suggests fertile lands favorable for agriculture, though these regions might also be susceptible to seasonal flooding and erosion.

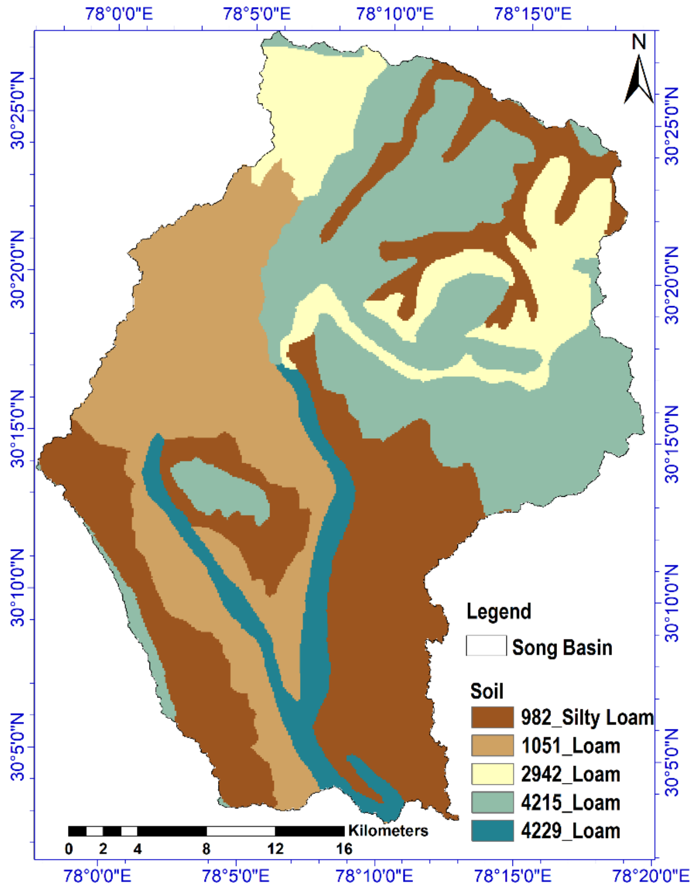


Fig. 12: Soil Map of the Song Catchment

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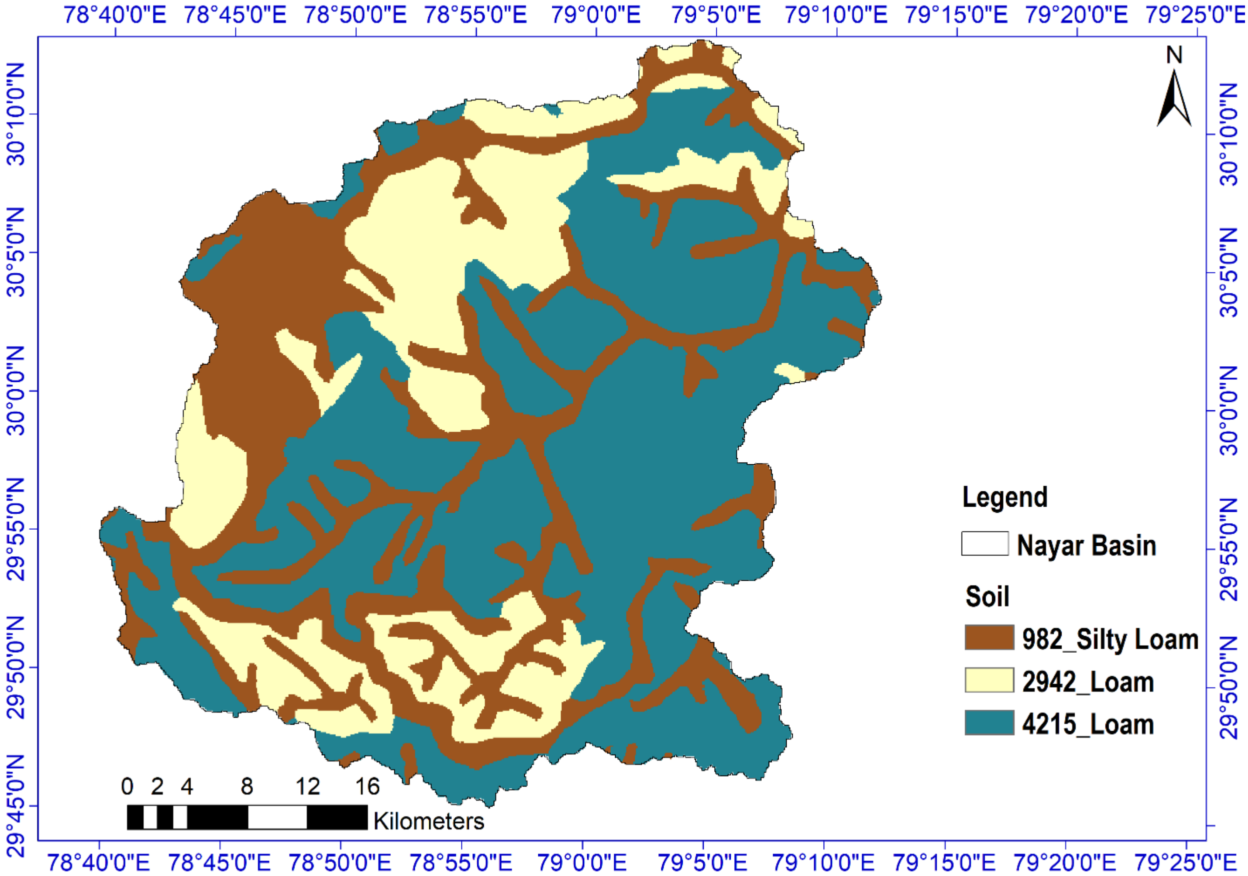

Fig. 13: Soil Map of the Nayar Catchment

4.4 Geology

4.4.1 Geology of song Catchment

The Geology Map of the Song Catchment provides valuable insights into the lithological formations and structural geology that influence groundwater storage and movement (Fig. 14). The catchment area is divided into Shivalik group Doon gravel, Naghat-Berinag formation, Blaini Formation, Krol Formation, Saryu-Gumalikhat-Munsiyari formation, Tal formation, Chandpur formation, Nathuakhan Betalghat, Bhatwari, Bansi subathu and Chakrata formation. The Blaini Formation, Shivalik group Doon gravel and Tal formation have a higher potential for water storage followed by

Krol, Chakrata Formation, Bansi subathu, Nathuakhan Betalghat, Chandpur, Saryu-Gumalikhat-Munsiyari formation.

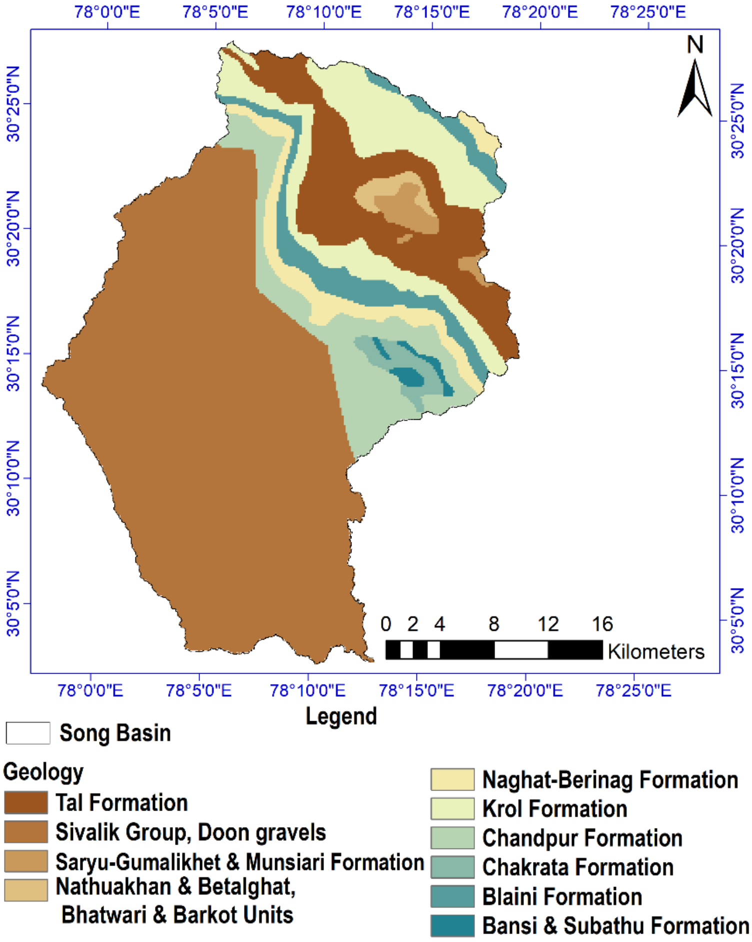

Fig. 14: Geology map of the Song Catchment

4.4.2 Geology of Nayar Catchment

The Geology Map of the Song Catchment provides valuable insights into the lithological formations and structural geology that influence groundwater storage and movement (Fig. 15). The catchment area is divided into Chandpur, Saryu-Gumalikhat-Munsiyari, Rautgara, Deoban, Nathuakhan Betalghat, Naghat-Berinag, Chakrata, Tal, Blaini and Krol formation. The Deoban, Tal, Blaini and Krol formations have a higher potential for water storage followed by Naghat-Berinag, Chakrata, Nathuakhan Betalghat, Rautgara, Chandpur and Saryu-Gumalikhat-Munsiyari formation.

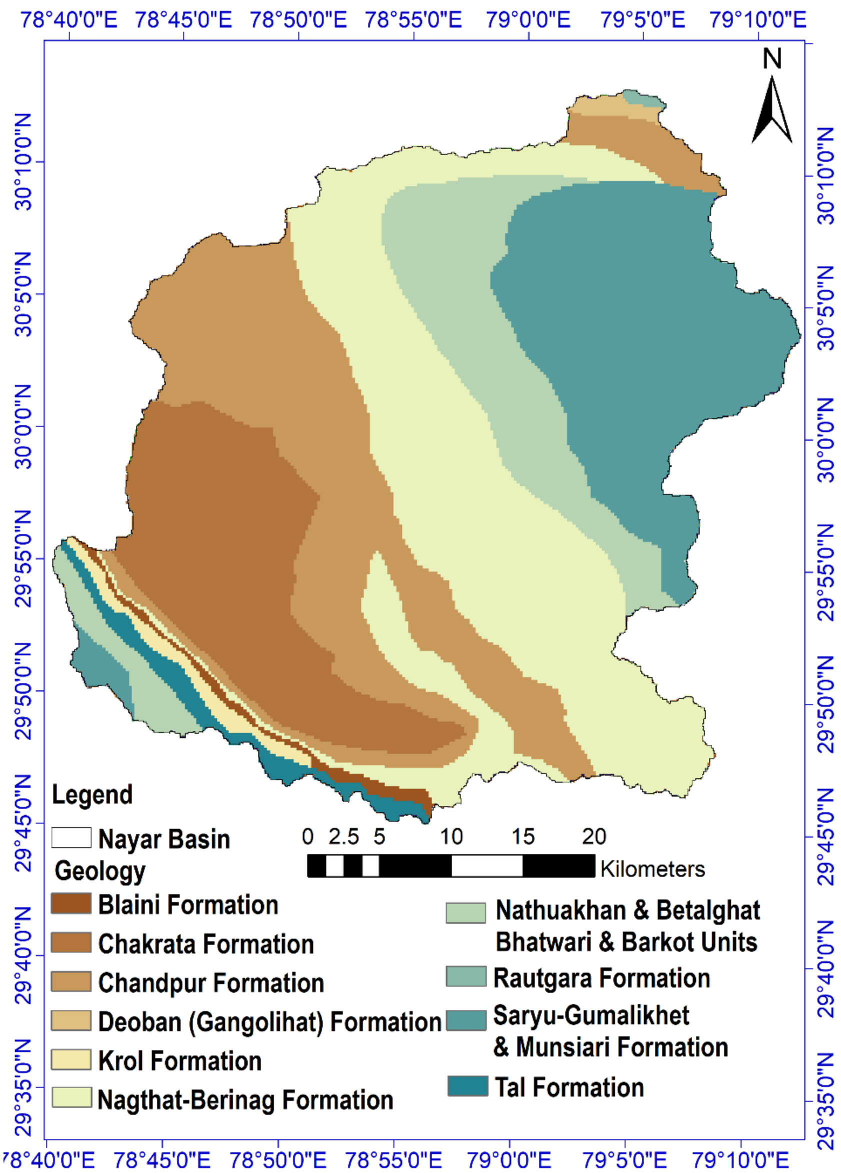

Fig. 15: Geology map of the Nayar Catchment

4.5 Priority Areas for Watershed Management

4.5.1 Priority areas of Song Catchment for watershed management

The identification of potential areas for priority watershed management in the Song Catchment highlights the need for targeted conservation interventions to mitigate environmental degradation and restore hydrological balance. Given the catchment's ecological importance and its role in sustaining regional water availability, the Watershed Management Directorate of Uttarakhand has delineated the catchment into 29 microwatersheds: Balawala, Baldi Nadi, Bandal Nadi, Beriwararao, Bhaniyawala, Bidhalana Nadi, Bulindawalarao, Bullawalarao, Chiphaldi Nadi, Chittaur Rao, Churpanirao, Dubra, Golapani Rao, Jakhan Rao 1, Jakhan Rao 2, Jaman Sot, Joli Grant, Kaluwala, Kansrao 1, Kansrao 2, Kisanpur, Kurkawala, Pantwala Rao, Ramgarh Rao, Rispana Rao, Satyanarayan, Sirwalgarh, Song Nadi, and Sukh Rao. These microwatersheds serve as distinct hydrological units for prioritization based on various watershed management criteria. Fig. 16 and Table 3 exhibited the rank of different subwatershed based on the priority for watershed management within the Song catchment. The findings indicate that about 64.85% of the Song Catchment falls under the high-priority category. About 24.57% of the catchment is classified as medium-priority and the remaining about 10.57% falls under the low-priority category.

This watershed prioritization framework provides a scientific basis for implementing nature-based solutions and sustainable land management practices to enhance water security, improve ecological resilience, and mitigate flood risks within the Song Catchment. By addressing these priority areas through well-planned conservation strategies, the long-term sustainability of the watershed can be ensured, contributing to improved water availability and ecosystem health in the region.

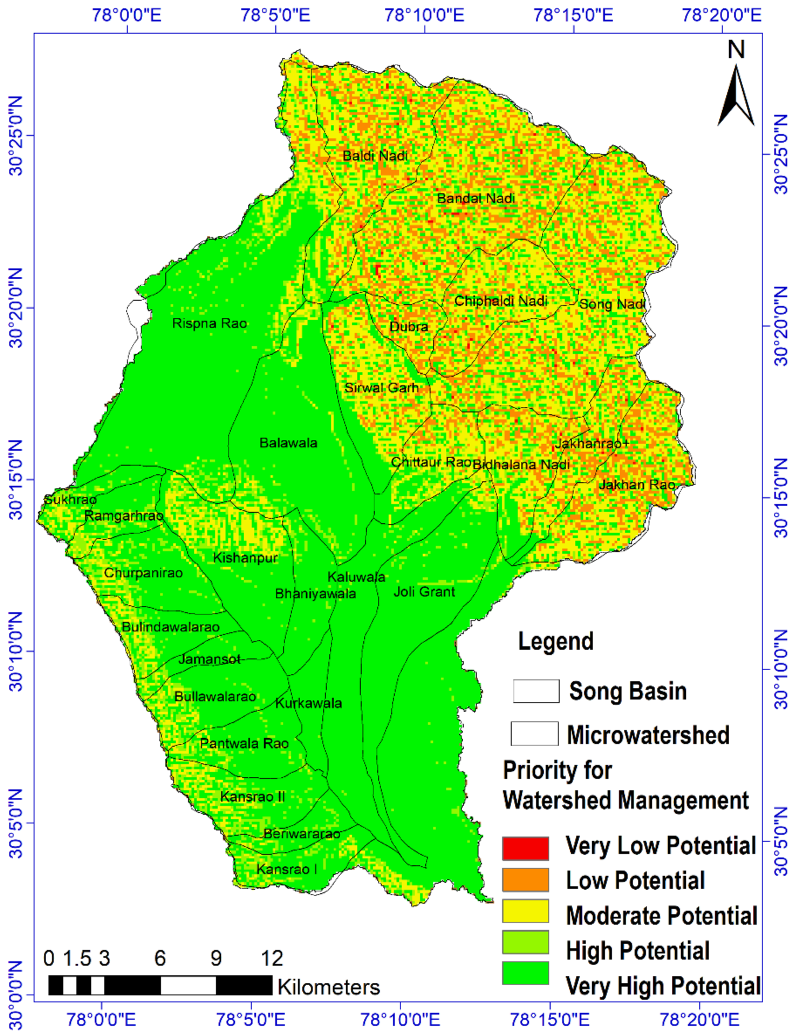

Fig. 16: Potential areas of subwatersheds for watershed management in the Song catchment

Table 3: Priority ranking of subwatersheds for watershed management in the Song catchment

High Priority			Medium Priority			Least Priority		
Microwatershed	Area km^2	Rank	Microwatershed	Area km^2	Rank	Microwatershed	Area km^2	Rank
Rispana Rao	117.54	1	Jakhan Rao 1	39.53	11	Kansrao 1	14.61	21
Song Nadi	86.33	2	Churpanirao	24.19	12	Jakhan Rao 2	19.83	22
Balawala	63.88	3	Chiphaldi Nadi	30.29	13	Ramgarh Rao	11.46	23
Golapani Rao	59.18	4	Bullawalarao	22.45	14	Kurkawala	9.66	24
Bandal Nadi	83.75	5	Kansrao 2	22.23	15	Sukh Rao	9.38	25
Joli Grant	48.56	6	Bidhalana Nadi	25.59	16	Satyanarayan	9.12	26

Kaluwala	40.45	7	Pantwala Rao	19.19	17	Beriwararao	9.02	27
Kisanpur	37.29	8	Chittaur Rao	20.61	18	Jaman Sot	8.48	28
Baldi Nadi	50.98	9	Bhaniyawala	16.51	19	Dubra	10.04	29
Sirwalgarh	35.25	10	Bulindawalarao	15.55	20			

4.5.2 Priority Areas of Nayar Catchment for Watershed Management

The identification of potential areas for priority watershed management in the Nayar Catchment underscores the need for urgent conservation measures to restore hydrological balance and ensure long-term water sustainability. In alignment with the recommendations of the Watershed Management Directorate, Uttarakhand, the Nayar Catchment has been systematically delineated into 47 microwatersheds: Chargad, Medigad, Irgad, Sidhkhal, Dudhatoligad, Gharigad, Khargad, Syotigad, Kalagal, Pasolgad, Sirgad, Silogi, Khandgaon, Tarpalisain, Khand, Thalsaingad, Kaligad, Baligad, Kandali Nadi, Machhigad, Bisgadikhala, Pingad, Ghatgad, Chorkanda, Udiyargad, Kutti, Chakisain, Bachheli, Gwarigad, Rasiya Gad, Sidoli, Gairigad, Patisain, Chandol, Panchard, Choya, Maithana, Byasigad, Chanchariya Gad, Bhawani, Dudharkhal, Talgad, Bhakhand, Bhaligaon, Jiwai, Dhuijuli, and Tiloli. These microwatersheds represent distinct hydrological units, each requiring specific interventions based on their priority ranking for watershed management. Fig. 17 and Table 4 exhibited the rank of different subwatershed based on the priority for watershed management within the Nayar catchment. The assessment revealed that approximately 48.78% of the Nayar Catchment falls within the high-priority category. Around 32.43% of the catchment is classified as medium priority and the remaining 18.79% of the catchment is categorized as low priority.

The watershed prioritization framework serves as a strategic guideline for implementing targeted conservation measures in the Nayar Catchment. By integrating nature-based solutions and sustainable land management practices, the resilience of the watershed can be enhanced, ensuring improved water availability, reduced sedimentation, and better adaptation to climatic variations. Addressing these priority areas with well-planned interventions will contribute to the long-term sustainability of the catchment, benefiting both ecological and socio-economic systems within the region.

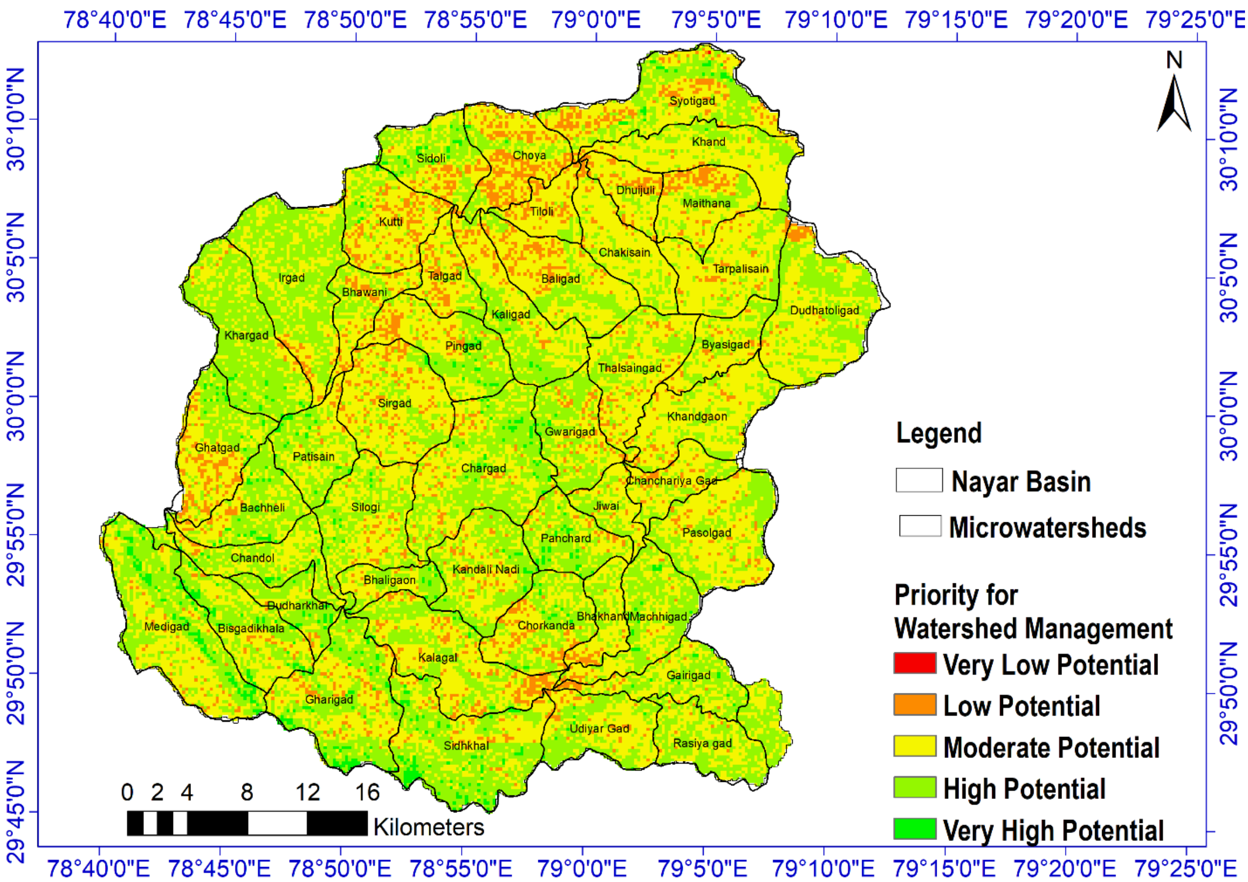

Fig. 17: Potential areas for priority for watershed management in Nayar Catchment

Table 4: Priority ranking of micro-watersheds for watershed management in the Nayar catchment

High Priority			Medium Priority			Least Priority		
Microwatershed	Area (km^2)	Rank	Microwatershed	Area km^2	Rank	Microwatershed	Area km^2	Rank
Chargad	67.88	1	Kaligad	39.78	17	Patisain	27.81	33
Medigad	65.73	2	Baligad	42.56	18	Chandol	26.63	34
Irgad	61.44	3	Kandali Nadi	39.19	19	Panchard	25.91	35
Sidhkhal	62.11	4	Machhigad	35.73	20	Choya	34.34	36
Dudhatoligad	56.25	5	Bisgadikhala	35.82	21	Maithana	27.81	37
Gharigad	57.39	6	Pingad	37.21	22	Byasigad	21.66	38
Khargad	52.33	7	Ghatgad	38.47	23	Chanchariya Gad	19.97	39
Syotigad	53.56	8	Chorkanda	35.23	24	Bhawani	20.82	40
Kalagal	52.25	9	Udiyargad	32.78	25	Dudharkhal	16.69	41
Pasolgad	47.49	10	Kutti	36.15	26	Talgad	19.43	42
Sirgad	48.46	11	Chakisain	30.38	27	Bhakhand	16.9	43
Silogi	42.73	12	Bachheli	30.21	28	Bhaligaon	14.62	44
Khandgaon	42.26	13	Gwarigad	31.1	29	Jiwai	14.62	45
Tarpalisain	41.72	14	Rasiya gad	28.7	30	Dhuijuli	16.35	46
Khand	38.51	15	Sidoli	30.59	31	Tiloli	16.35	47
Thalsaingad	40.49	16	Gairigad	28.27	32			

By focusing conservation efforts on identified priority areas, resource allocation can be optimized to achieve maximum environmental and hydrological benefits. The integration of soil conservation, afforestation, and water retention strategies will enhance ecosystem resilience, mitigate flood risks, and improve groundwater sustainability.

5. CONCLUDING REMARKS

The prioritization of microwatersheds of Song and Nayar river catchments has been carried out considering the four important factors viz. LULC, soil type, slope and geology. Subsequently, the respective maps pertaining to LULC, soil type, slope and geology have been prepared for both the catchments. For finalizing the priority equal weightages (1 to 5) have been given to all four factors and the combined priority at different points of the basin has been worked out. To transfer the results on the micro-watershed level for practical implementation of watershed management works, these spatial priorities have been overlaid on the micro-watershed maps of both the basins and the highest priority micro-watersheds in the Song and Nayar Basins have been finally recommended as follows:

Table 5: Highest priority micro-watersheds in Song River catchment

Micro-watersheds	Area (km^2)	Priority Rank
Rispana Rao	117.54	1
Song Nadi	86.33	2
Balawala	63.88	3
Golapani Rao	59.18	4
Bandal Nadi	83.75	5
Joli Grant	48.56	6
Kaluwala	40.45	7
Kisanpur	37.29	8
Baldi Nadi	50.98	9
Sirwalgarh	35.25	10

Table 6: Highest priority micro-watersheds in Nayar River catchment

Micro-watersheds	Area (km^2)	Priority Rank
Chargad	67.88	1
Medigad	65.73	2
Irgad	61.44	3
Sidhkhal	62.11	4
Dudhatoligad	56.25	5
Gharigad	57.39	6
Khargad	52.33	7
Syotigad	53.56	8
Kalagal	52.25	9
Pasolgad	47.49	10
Sirgad	48.46	11
Silogi	42.73	12
Khandgaon	42.26	13
Tarpalisain	41.72	14
Khand	38.51	15
Thalsaingad	40.49	16