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**Comparative Evaluation of Catchment Prioritization Using SYI and RUSLE Models: A Case Study
of the Swarna Reservoir Catchment**

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Abstract

Soil erosion is a major contributor to sedimentation in many reservoirs in India. Catchment prioritization helps planners identify vulnerable areas prone to severe soil erosion and implement necessary control measures. This paper utilizes the sediment yield index (SYI) and RUSLE equations to identify critical areas of soil erosion in the Swarna reservoir catchment. It provides a means to compare subjective assessments of soil erosion severity derived from the SYI method with quantitative evaluations obtained from the RUSLE equation. Three sub-catchments were classified as having high severity, and six as having medium severity, using the SYI approach. The SYI values ranged from 1103 to 1268. The average annual sediment yield (A) for the Swarna reservoir catchment was calculated with the RUSLE equation. The soil erosivity factor R was determined using three different formulas—two suitable for Indian conditions and one for global use—based on monthly rainfall data. The severity categories for all sub-catchments were compared using the RUSLE equation and the SYI method. The RUSLE equation results closely matched the SYI method's soil erosion severity criteria, whereas other methods overestimated these categories. Overall, it is appropriate to validate the soil erosion severity criteria obtained by the SYI method with the RUSLE equation.

Keywords: Reservoir sedimentation, RS & GIS, Sediment Yield Index, RUSLE Equation, Catchment Prioritization.

1. Introduction

In a reservoir, sedimentation occurs when sediment particles are deposited as bed load and suspended load after detaching from their source (Dutta, 2016). Because soil erosion is a primary cause of sedimentation in reservoirs, studying soil erosion is crucial for estimating sediment yield and transport rates (Wagh and Manekar, 2022). Sediment yield refers to the amount of sediment discharged through a river outlet per unit catchment area per unit time (ASCE, 1992). Soil erosion can happen due to various natural and human factors, including deforestation, forest fires, unsustainable farming practices, and overgrazing by cattle. The adverse effects of soil erosion include reduced root zone effectiveness, nutrient and water imbalances, and deterioration of soil quality, leading to loss of fertile topsoil and a decrease in agricultural productivity (Pradeep et al., 2015; Noori et al., 2016). Human activities can speed up soil erosion through land use changes, deforestation, farming practices, and construction efforts (Jinren and Yingkui, 2003; Rao et al.,

2013). Reports indicate that around 85% of global soil degradation is due to soil erosion, which initially lowers soil fertility and can result in a 17% decline in crop yields, ultimately causing long-term soil deterioration (Singh and Panda, 2017). Worldwide, the total land area impacted by water erosion is about 1094 million hectares (Mha), with 751 Mha experiencing severe degradation (Lal, 2003). A consequence of soil erosion is the deposition of eroded soil into reservoirs, leading to sedimentation. Reservoir sedimentation is a complex issue influenced by many factors, such as changes in land use within catchments, hydrological variations affecting water and sediment flow, differences in sediment particle size, modifications in reservoir operations, and the reservoir's shape and size (Strand and Penibertori, 1982; Singh et al., 2023). As sediment buildup reduces the reservoir's capacity, it becomes vital to develop methods for estimating and controlling sediment inflow. Reservoir sedimentation is also a significant problem in India, where many reservoirs lose a large portion of their useful storage capacity. storage capacity due to the built-up of sediments. A report prepared by CWC, India (2015) stated that among 141 large reservoirs in India that are more than 50 years old, about one-quarter have lost at least 30% of their initial storage capacity. A study by Singh et al. (2000) has found that in India, out of 329 Mha of the country's total land area, 69 Mha of land is critically degraded and 106 Mha of land is severely eroded at an average rate of 16.4 t/ha/year soil detachment.

To determine suitable control measures for reducing sediment deposits in reservoirs, the first step should be to accurately estimate the amount of sediment and identify the critical areas within a catchment that significantly contribute to this sediment load. In India, numerous case studies are available in the literature regarding soil loss estimation from catchments. Most studies utilize GIS and remote sensing combined with the revised universal soil loss equation (RUSLE) (developed by USDA Soil and Water Conservation Service, 1993) to estimate soil erosion. Meanwhile, the sediment yield index (SYI), developed by All India Soil & Land Use Survey (AIS&LUS, 1990), is widely used in India for prioritizing catchments based on sediment loss. The research conducted by Goel et al. (2002) was among the earliest in India to demonstrate the use of digital image processing for estimating reservoir sedimentation. They employed remote sensing to derive area-elevation-capacity curves for a reservoir, which can be used to estimate capacity loss. This method was

applied to the Bargi reservoir in Madhya Pradesh, India. The potential of remote sensing in estimating reservoir sedimentation, as shown by Goel et al. (2002), encouraged many researchers in India to adopt it for various case studies. Table 1 offers an overview of some notable studies conducted on different catchments across India related to reservoir sedimentation. As shown in Table 1, RS and GIS techniques are extensively used in India to estimate reservoir sedimentation across different catchments.

RS & GIS help us to retrieve the ground data, such as soil maps, drainage maps, slope maps, and LULC maps, which can be used in conjunction with rainfall data to estimate sediment loss from a catchment. However, to quantify the sediment loss from a catchment and prioritize a catchment, RUSLE and SYI are more suitable. Javed et al., (2016) and Mishra et. al., (2021) employed an empirical model of SYI, developed by Kumar (1985), and Rao and Mahabaleshwara (1990), for estimating sediment yield for Govindsagar reservoir and Rengali reservoir, respectively. However, the parameter F (vegetative cover factor) used in their formula is highly variable, and determining it can be quite exhaustive. Dewangan and Ahmed (2020) employed RUSLE for estimating reservoir sedimentation for the Kodar river watershed, and the catchment prioritization was determined based on a minimum acceptable value for average annual sediment loss. Kumar et. al. (2021), Wagh and Manekar (2022) defined the sediment yield index as a function of delivery ratio (the percentage of eroded material that finally finds entry into the eroded stream). Jabbar and Yadav (2020) defined the SYI value as a function of the trap efficiency of a reservoir. It is apparent that there are various methods available for estimating SYI, and the suitability of the method depends on the availability of the data and the ease of procuring data.

In the present case study work, RS and GIS coupled with RUSLE have been used for estimating sediment yield from a catchment, and SYI (as a function of delivery ratio) was used for determining the priority areas for sedimentation control for the Swarna reservoir catchment in Nirmal District, Telangana. For the catchment prioritization, the larger catchment was divided into nine sub-catchments, whereas for the RUSLE equation, the catchment was divided into three sub-catchments using the Thiessen polygon method. The sediment yield index is a descriptive parameter, whereas the RUSLE equation provides a quantitative

insight into the sedimentation process from a catchment. The SYI values were therefore compared with the average annual sediment yield values to check the veracity of critical areas of sediment loss obtained from the SYI method.

In the next sections, methodology, study area details, results and discussion, and conclusion are discussed in the respective order.

Table 1: List of notable research papers related to the estimation of reservoir sedimentation using RS and GIS

S. No.	Authors	Title of the Paper	Techniques Used for	
			Estimation of Reservoir Sedimentation	Location of Case Study Area
1	Goel et al., 2002	Assessment of sediment deposition rate in Bargi Reservoir using digital image processing	Digital image processing and remotely sensed data	Bargi Reservoir, Madhya Pradesh, India
2	Jain et al., 2002	Assessment of sedimentation in Bhakra Reservoir in the western Himalayan region using remotely sensed data	Remote Sensing	Bhakra Reservoir, Himachal Pradesh, India
3	Mukherjee et al., 2007	Sedimentation study of Hirakud Reservoir through remote sensing techniques	Remote Sensing	Hirakud Reservoir, Odisha, India
4	Pandey et al., 2009	Soil erosion modelling of a Himalayan watershed using RS and GIS	Remote Sensing (RS) & Geographic Information System	Himalayan Region, India

S. No.	Authors	Title of the Paper	Techniques Used for	
			Estimation of Reservoir Sedimentation	Location of Case Study Area
			(GIS)	
5	Javed et al., 2016	Estimation of Sediment Yield of Govindsagar Catchment, Lalitpur District, (U.P.), India, Using Remote Sensing and GIS Techniques	Remote Sensing (RS) & Geographic Information System (GIS)	Govindsagar Catchment, Lalitpur, Uttar Pradesh, India
6	Mishra et al., 2021	Estimation of Sediments in Rengali Reservoir, Odisha (India) Using Remote Sensing	Remote Sensing (RS) & Geographic Information System (GIS)	Rengali Reservoir, Odisha, India
7	Dimri et al., 2022	Sediment Yield Estimation and Reservoir Sedimentation Assessment Using Geospatial Tools: A Case Study of Tehri Dam Reservoir	Remote Sensing (RS) & ArcGIS	Tehri Dam Reservoir, Uttarakhand, India
8	Singh et al., 2023	Sedimentation analysis for a reservoir using remote sensing and GIS techniques	Remote Sensing (RS) & Geographic Information System (GIS)	Samrat Ashok Sagar Reservoir, Madhya Pradesh, India

2. Study Area Description and Data Collection

The river drainage system of Telangana is mainly dominated by the basins of the Godavari River in the north and the Krishna River in the south. The development of irrigation in Telangana primarily relies on the Godavari and Krishna Rivers, along with their tributaries, reservoirs, and ponds. The total water allocated to projects in Telangana's Krishna basin is 299 TMC, while the Godavari basin has 954.23 TMC. Water from these basins is stored in reservoirs to support irrigation in dry areas, although many regions still depend on the somewhat unpredictable monsoon rainfall. The Godavari is the second-largest basin, with a total catchment area of 312812 sq. km. The Godavari and its tributaries form an inter-state river system flowing through Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, Odisha, Madhya Pradesh, Karnataka, and Puducherry. It accounts for about 23.7% of the area in the combined states of Telangana and Andhra Pradesh. Approximately 32% of the total basin area lies within the elevation zone of 500-750 meters. The overall catchment includes nine sub-basins, which are further divided into 466 watersheds. Among the major irrigation projects in Telangana is the Swarna Project, constructed across the River Swarna, a left-bank tributary of the Godavari, near Swarna village in Sarangapur Mandal, Nirmal District. The Swarna reservoir's catchment area is detailed in the thematic map in Fig. 1, and its key features are listed in Table 2. The project was started in 1959 and completed in 1978, covering a catchment area of 290 sq. km. It is located 26 km northwest of Nirmal and 246 km from Hyderabad on NH-7, with coordinates 78°14'00" E longitude and 19°14'00" N latitude, within the Pranhita sub-basin and others.

Purpose	Irrigation
Catchment Area of the Reservoir	290 sq.km
Top of Dam Level (TDL)	363.780 m
Maximum Water Level (MWL)	360.58 m
Full Reservoir Level (FRL)	360.58 m
Area at FRL	11 Sq.km
Gross Storage Capacity	2.05 MCM (1.485TMC)

2.1. Salient Features of Swarna Reservoir

The salient features of the catchment area of the Swarna Reservoir, such as temperature, rainfall, catchment characteristics, wind, and topography (Source <https://weatherspark.com/>), are described in the next sub-sections.

2.1.1.Climate

The climate of the catchment is warm, hot, and partly cloudy. The hottest months are March, April, and May having a temperature range of 37°C to 42°C. In Nirmal, the wet season is hot, oppressive, and overcast, and the dry season is sweltering and mostly clear. Over the year, the temperature typically varies from 14°C to 43°C and is rarely below 11°C or above 46°C

2.1.2.Temperature

The warmest month (with the highest average high temperature) is May (42.3°C). The month with the lowest average high temperature is December (29.4°C). The monthly variation in temperature for the region.

2.1.3.Wind

The average hourly wind speed in Nirmal varies significantly with the seasons throughout the year. The windier period lasts for four months, from May to August, with average wind speeds exceeding 8.5 miles per hour. June is the windiest month, with an average hourly wind speed of 11.0 miles per hour. The calmer season lasts for about 8.3 months, from August 29 to May 8. October is the calmest month, with an average

hourly wind speed of 5.8 miles per hour. There is notable variation in wind speed from month to month.

2.1.4.Rainfall

For estimating soil loss using the RUSL equation, PERSIANN-CCS monthly rainfall data for 19 years (2005 to 2023) for the three rain gauges located within the catchment (Fig. 2) were downloaded from the CHRIS data portal (Table 3). The latitude and longitude of the rain gauges are shown in Table 4. The monthly rainfall time series for the three rain gauges is shown in Figs. 3, 4, and 5.

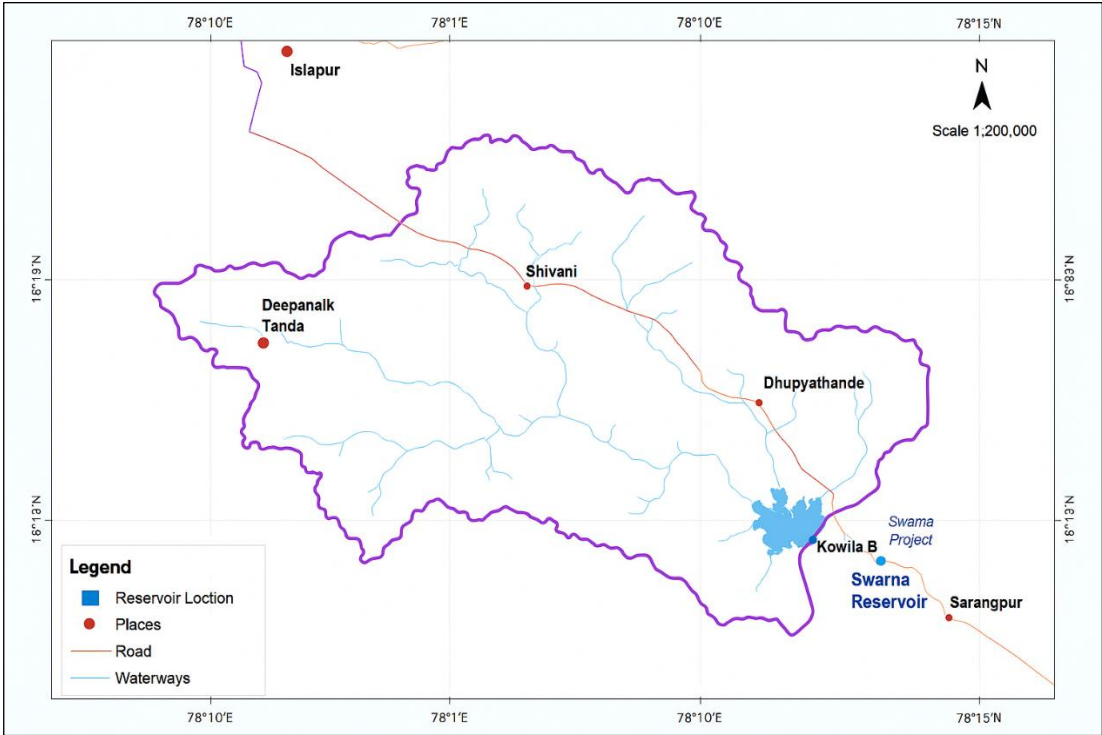


Fig. 2 Location of rain gauges in the study area catchment

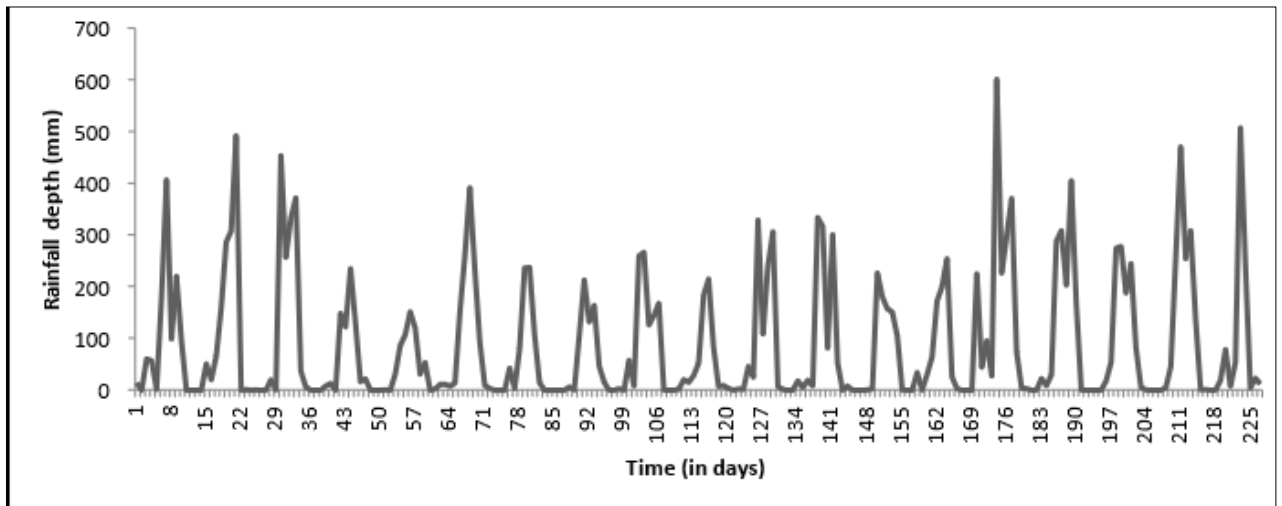


Fig. 3 Rainfall time series for rain gauge R1(Dhupyathanda) in the Swarna reservoir catchment

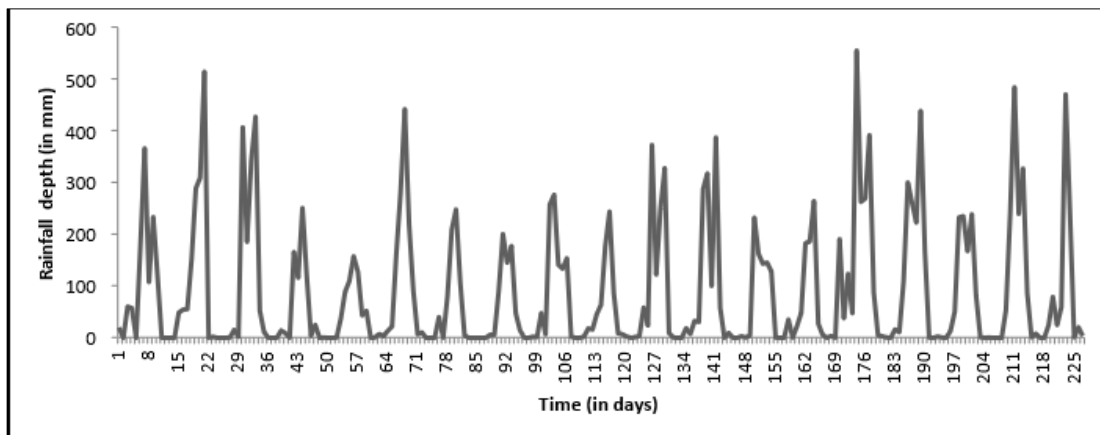


Fig. 4 Rainfall time series for rain gauge R2(Shivani) in the Swarna reservoir catchment

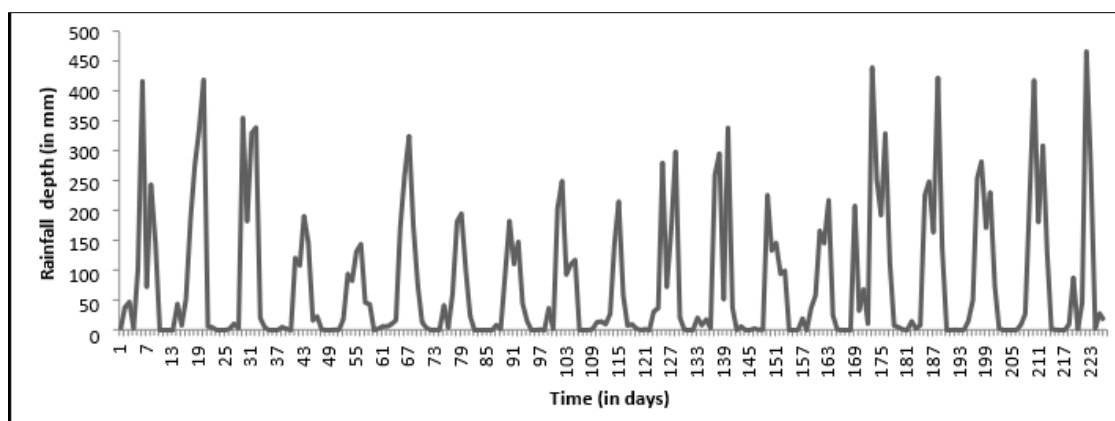


Fig. 5 Rainfall time series for rain gauge R3(Deepanaik Tanda) in the Swarna reservoir catchment

Table 3 Rain gauge stations and their location

Rain gauge ID	Rain gauge station	Latitude	Longitude	Elevation (m)
R1	Shivani	19° 20' N	78° 6' E	428.52
R2	Dhupyatanda	19° 8' N	78° 20' E	370.17
R3	Deepanaik Tanda	19° 8' N	77° 36' E	457.3

Table 4: Details of sources for thematic maps used in catchment prioritization process

S No	Type of thematic map	Source
1	Location map of the Swarna reservoir	https://www.diva-gis.org/gdata
2	Rainfall data source	https://chrsdata.eng.uci.edu/
2	Watershed map of the Swarna reservoir catchment	Global Mapper, ArcGIS
3	Soil map	WRIS web portal India https://indiawris.gov.in/wris/#/
4	Land use land cover map	Bhuvan NRSC https://bhuvan.nrsc.gov.in/home/index.php
5	Slope map	Through DEM in ArcGIS https://earthexplorer.usgs.gov/

2.1.5 Topography

The elevation of the catchment was derived from the SRTM Digital Elevation Model (DEM), and it varies from 355 to 650 m. Around 20% of the Catchment area has an elevation range of 400 m - 420 m. The highest elevation in the Catchment is 650 m, as shown in Fig.6

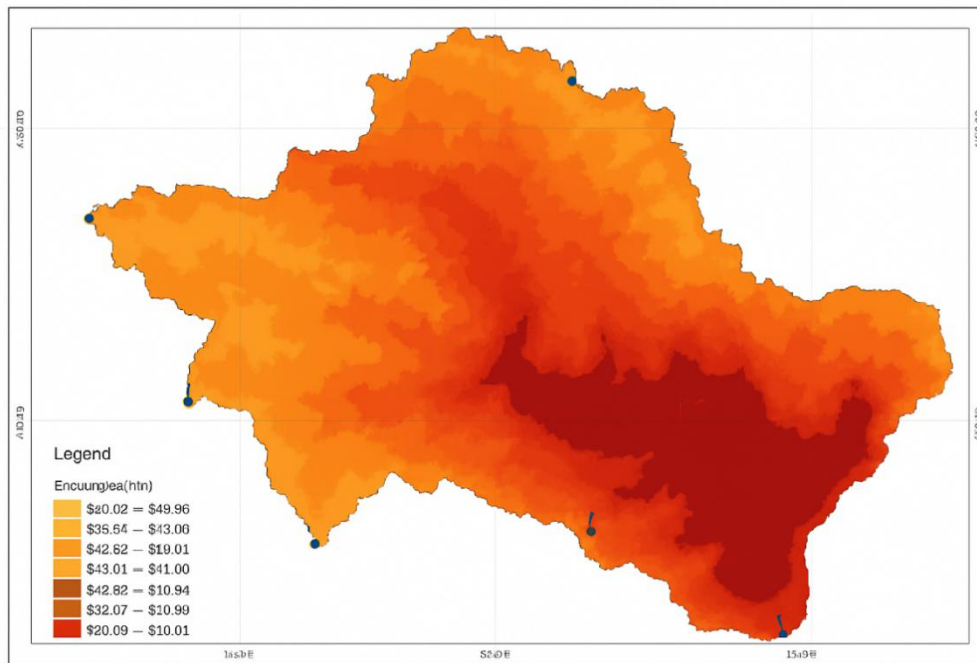


Fig. 6 Elevation Zone Map of Swarna Reservoir Catchment

2.1.6 Land Use and Land Cover

Accurate land use and land cover identification is the key to most of the planning processes. The land-use pattern has been studied using Bhuvan NRSC, 2016. The data were processed through ArcGIS and other software packages. The extracted Land Use Land Cover data was analyzed in the GIS Environment to calculate the area of each land cover type. The catchment area consists of 45.60% agriculture, 46.80% forest, and the remaining 7.6% built-up, waste lands, and water bodies. The LULC map of the study area is shown in Fig. 7, and the LULC classification data is shown in Table 5.

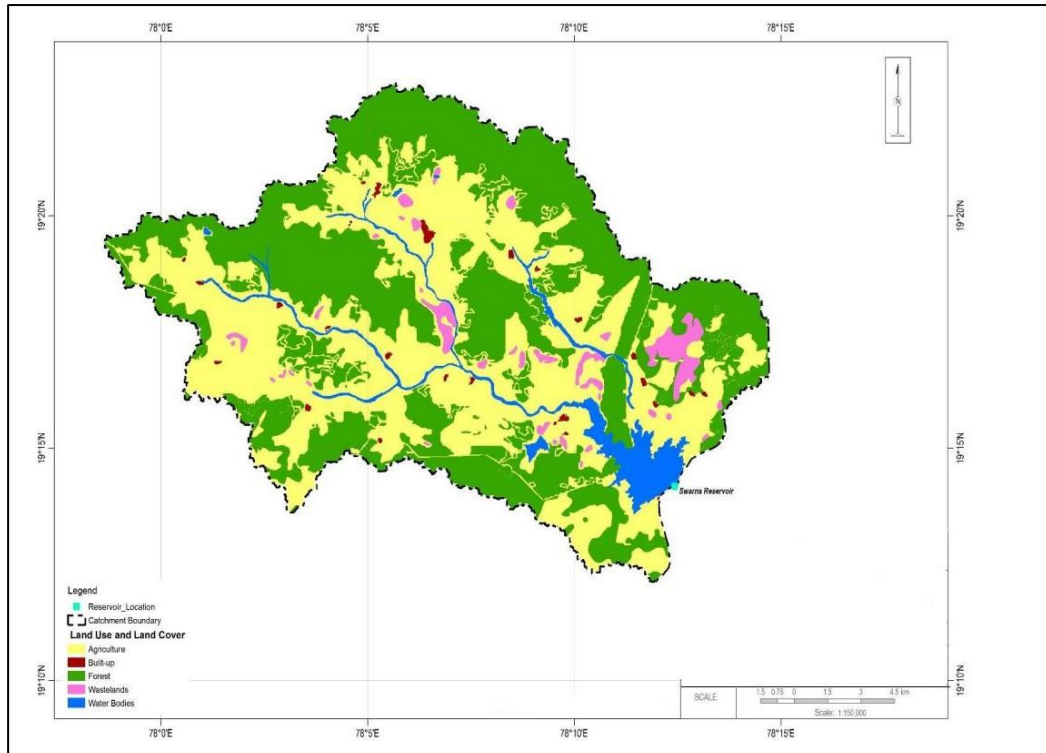


Fig. 7: Land Use and Land Cover of Swarna Reservoir Catchment

Table 5: Land Use Pattern of the Submergence and Catchment Area

Sl.No,	Description	Area (sq. km)	Value (Percentage)
1	Agriculture	135.86	45.60
2	Built up	1.39	0.50
3	Forest	139.58	46.80
4	Wastelands	7.79	2.60
5	Water Bodies	13.44	4.50
Total		298.08	100

2.1.7. Soil data

The K (soil erodibility) factor in the RUSLE equation is a function of soil intrinsic properties. The particle size distribution curve for the study area was taken from the Final Report on Swarna Reservoir Catchment

(2023). The particle size distribution curve was available for 29 sites in the catchment area. The particle sizes corresponding to D10 and D60 were considered the minimum and maximum particle sizes, respectively. Regarding the soil type distribution, the catchment area consists of 60% clay, loamy clay, sandy clay, silty clay, and sandy clay soils, and 40% of loam, silt loam, silt, and sandy loam soils. The soil map for the study area is shown in Fig. 8.

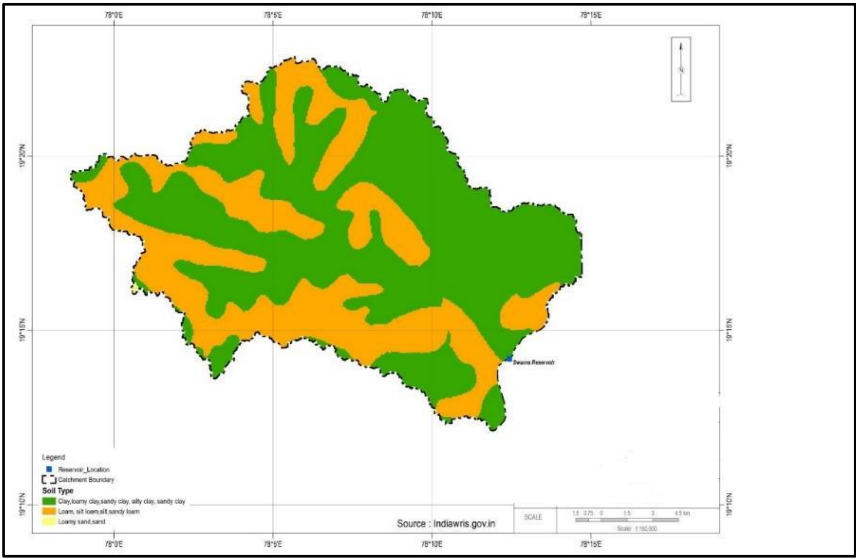


Fig. 8: Soil Map of Swarna Reservoir Catchment

2.1.8.Catchment slope

The catchment slope of the study area was determined from the SRTM DEM (Digital Elevation Model) of 30 m resolution (<https://earthexplorer.usgs.gov/>). The slope class map for the catchment is shown in Fig. 9. As can be seen from the slope map, the majority of the region has a moderate to severe slope.

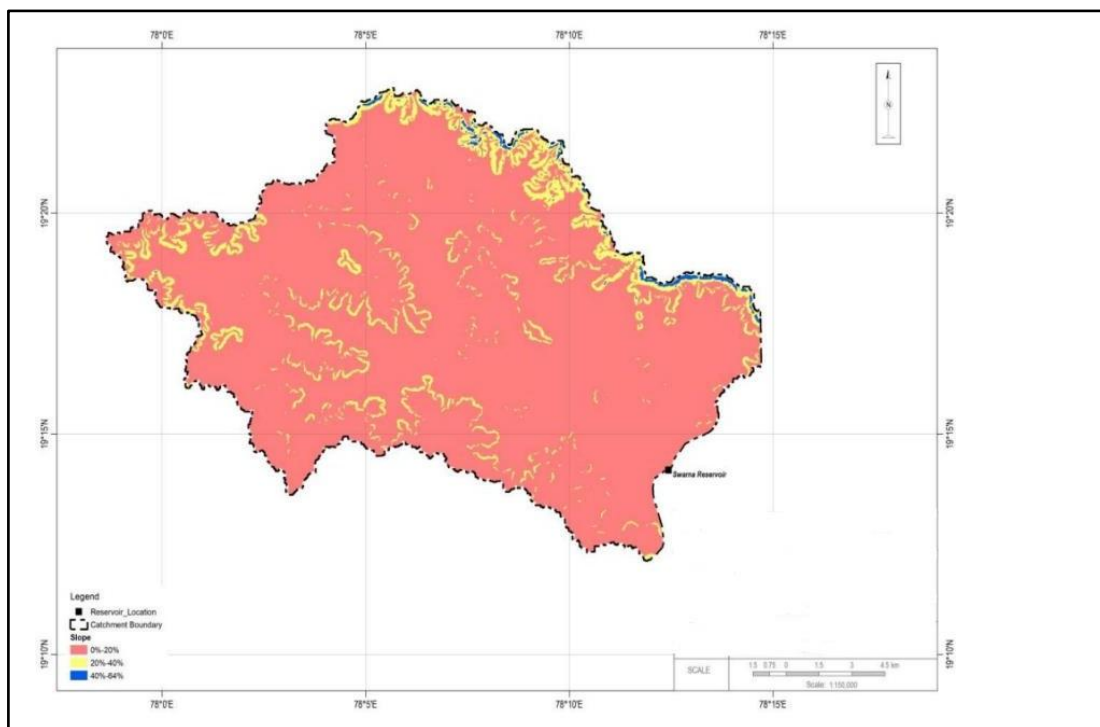


Fig. 9: Slope map of the Swarna Reservoir catchment

2.1.9.Drainage pattern

The drainage pattern is the shape that the lakes, rivers, and streams make in a specific drainage basin. Over time, the pattern left behind by stream erosion provides information about the types of rocks and geological structures in a section of the landscape subject to streams. Global Mapper and QGIS were used to create a drainage pattern using a DEM, as shown in Fig. 10. From the drainage pattern map, it can be surmised that the maximum stream order is 3.

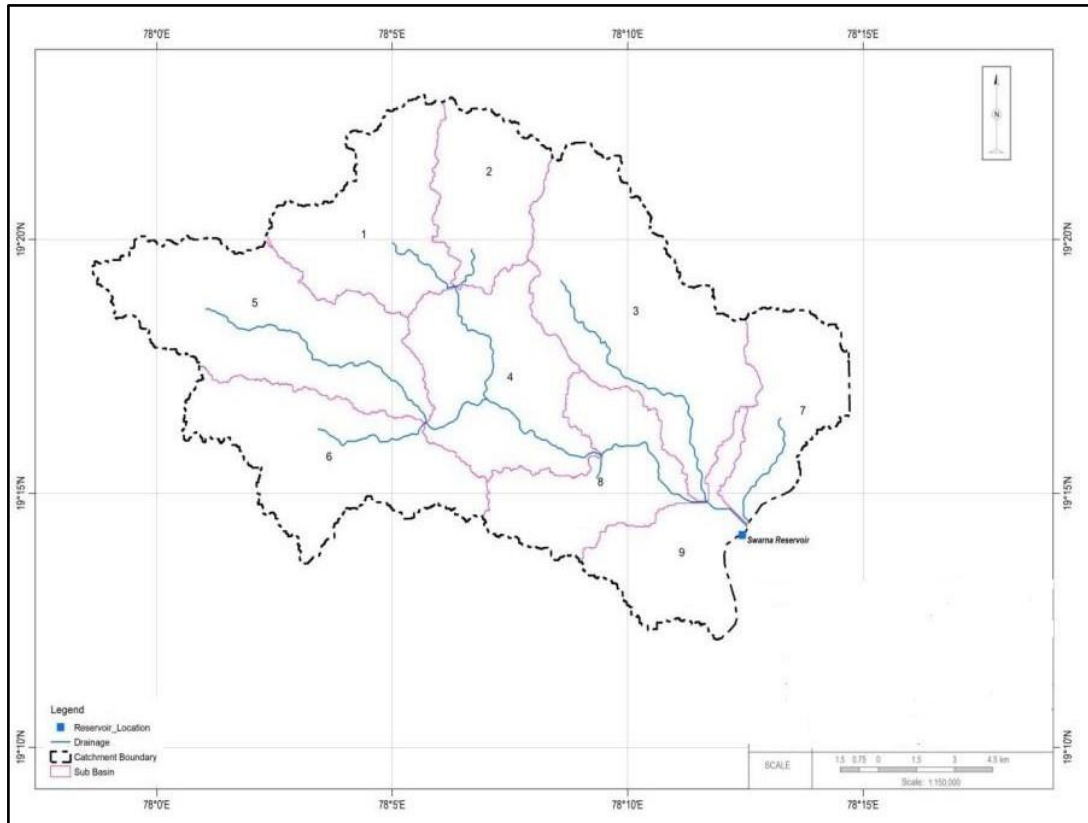


Fig. 10: Drainage map of the Swarna Reservoir catchment

3. Methodology

A detailed database of natural resources, terrain conditions, soil types in the catchment area, socio-economic status, etc., is essential for implementing a sediment control plan while considering sustainable development. Various thematic maps have been used to prepare the Catchment Area Treatment (CAT) plan. The study's requirements are outlined, and the expected outputs are finalized. The different data layers of the catchment area.

The data used for the study are as follows: Catchment Area Map, Slope Map, Soil Map, Land Use Classification Map, Drainage Map, and Current Management Practices. Table 4 shows the sources for various thematic maps used in the catchment prioritization process. In Fig. 11, the methodology flow chart is shown, illustrating the various steps involved in evaluating catchment prioritization. The methodology consists of

two parts: in the first part, the catchment prioritization is estimated for each sub-catchment using sediment yield index (SYI) values; in the second part, the RUSLE equation is used to estimate annual sediment yield from the catchment. The results obtained from both methods are compared and analyzed. A detailed description of both parts is given below.

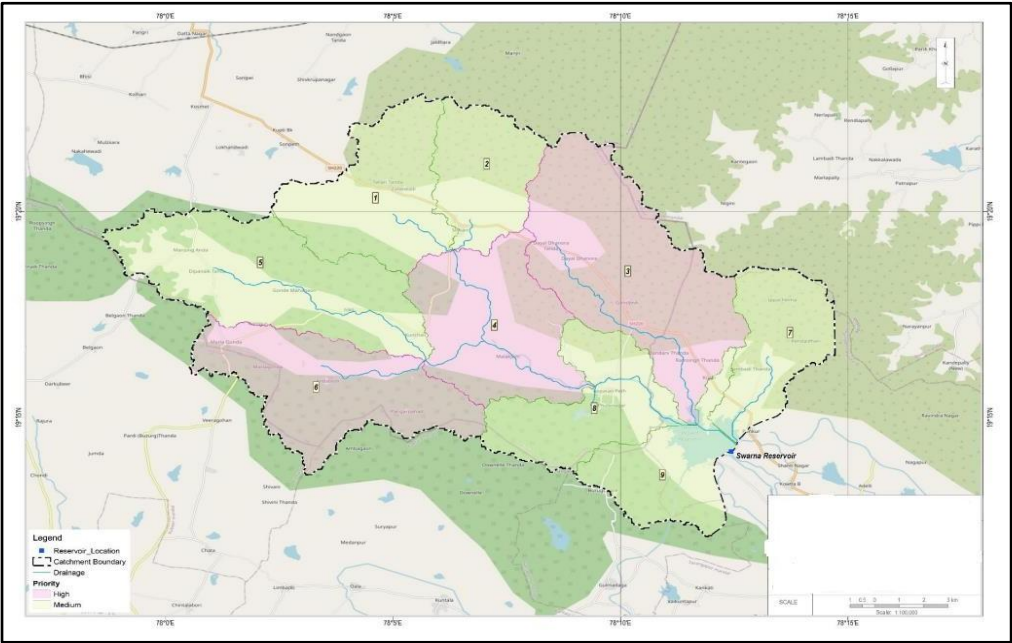


Figure 11: Sub-basin & Priority map of the Swarna Reservoir catchment

3.1 Catchment prioritization of the Swarna reservoir catchment using the sediment yield index.

In this section, the methodology for determining SYI is discussed in detail. The larger Swarna reservoir catchment was divided into nine sub-catchments using the drainage outlet delineation method. The SYI values were estimated for each sub-catchment. The overlay maps used for estimating SYI values were: LULC map, slope map, soil map, and drainage pattern map. In the study area section, a brief description of these outlay maps was presented. One of the important steps in the estimation of SYI values is estimating erosion intensity and delivery ratio. The next section describes the method for finding erosion intensity and delivery ratio for the catchment.

3.1.1 Estimating erosion intensity and delivery ratio

The determination of the erosion intensity unit is based on integrated information on soil characteristics, physiography, slope, land use/land cover, lithology, and structure. This is achieved by superimposing thematic map overlays and assigning a weight to each erosion- intensity unit. The composite map for delineating erosion intensity units was created by layering maps of soil types, slope, and land use/land cover. This composite erosion intensity map was further overlaid onto the drainage map, which included sub-watershed boundaries, resulting in the establishment of the Composite Erosion Intensity Unit (CEIU) for each individual sub- watershed. Each element of the erosion intensity unit is assigned a weightage value. The cumulative weightage values of the erosion intensity units approximate the relative erosion intensity within the watersheds. A basic factor of $K = 10$ was used to determine the cumulative weightage values. The value of 10 indicates an equilibrium condition between erosion and deposition. Any value of $K = (10 + x)$ indicates increasing erosion intensity, whereas a value of $K = (10 - x)$ indicates decreasing deposition intensity. After overlaying LULC, slope, soil, and drainage pattern maps, the resulting erosion intensity map for the Swarna reservoir catchment is shown in Fig. 12. The weightage values assigned to the three thematic layers are shown

in Table 6. The other parameter in the SYI formula, i. e., delivery ratio, indicates the percentage of eroded material that finally enters the reservoir. The delivery ratio depends on drainage characteristics (such as slope, drainage density, relief length, proximity to the active stream) and soil characteristics (texture of the eroded soil, vegetation, size of the sediments). For the present study, the delivery ratio for each sub-catchment was determined based on the nearest stream distance, which is shown in Table 7. For all the sub-catchments, the nearest stream distance lies between 0 and 2 km, and the delivery ratio is either 1 or 0.09.

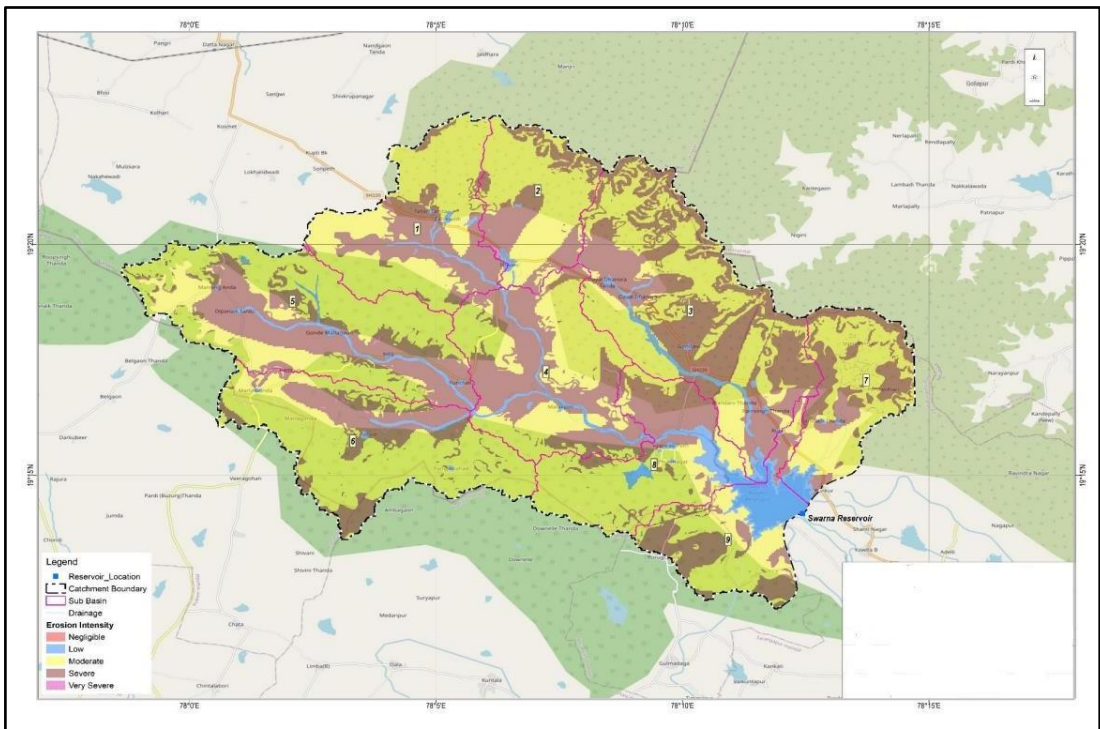


Figure 12: Erosion intensity map of the Swarna Reservoir catchment

Table 6: Weightage values of three thematic layers used in the study

S.No	Parameters/factors	Categories/Classes	Assigned weightage value
1	Soil texture	Loamy-skeletal Soil	5
		Coarse-loamy Soil	9
		Sandy Soil	5
		Loamy Soil	7
		Clayey Soil	1
		Silty Soil	3
		Fine Loamy Soil	5
2	Slope (Degree)	0-1	1
		1.1-5	3
		5.1-10	5
		10.1-20	7
		20.1-70.29	9
3	LULC	Builtup	1
		Waterbody	1
		Open forest	3
		Cropland	5
		Scrub land	5
		Fallow land	7
		Barren land	7
		Sand	9
		Gullies/Ravines	9

Table 7: Delivery ratio criteria based on the nearest stream distance

SI No.	Nearest Stream Distance (km)	Delivery Ratio
1	0 - 0.9	1
2	1.0 - 2.0	0.9
3	2.0 - 5.0	0.8
4	5.0 - 15.0	0.7
5	15.0 - 30.0	0.5

3.1.2 Prioritization of sub-watersheds and Sediment Yield Index (SYI)

The Sediment Yield Index (SYI) model, developed by AISLUS in 1994, combines factors such as erosivity, erodibility, and aerial extent to assess sedimentation. This model has been effectively utilized for the operational prioritization of smaller hydrologic units within the catchment areas.

Smaller hydrologic units within large catchments are prioritized according to their SYI values. The frequency distribution of SYI values is analyzed to determine appropriate thresholds for different priority categories. Watersheds and sub-watersheds are subsequently classified according to their SYI values. Application of the SYI model for sub-watershed prioritization requires assessment of multiple factors, including climate (total rainfall, frequency, and intensity), land characteristics (landforms, slope, and drainage), surface cover, and management practices.

The area of each of the mapping units is computed, and the SYI of individual sub-watersheds is calculated using the following equation:

$$SYI = \frac{\sum(A_i \times W_i \times D_i \times 100)}{A_w} \quad (1)$$

Where A_i is the area of the i^{th} mapping unit; W_i is the weightage value of i^{th} mapping unit; A_w is the total area of the sub-watershed; D_i is the delivery ratio. SYI values for the classification of various categories of erosion intensity rates are shown in Table 8. Sediment Yield Index (SYI) was calculated after dividing the total catchment area into nine sub-watersheds, which were then categorized into five erosion ranking classes, i.e.,

Very high, High, Medium, Low, and Very low, according to priorities. These prioritized watersheds would require treatment according to their priority ranking for soil conservation measures.

Table 8: SYI values for classification of various categories of erosion intensity rates

SI No.	Priority	SYI Range
1	Very high	>1300
2	High	1200 - 1300
3	Medium	1100 - 1200
4	Low	1000 - 1100
5	Very Low	< 1000

3.2 Estimation of annual sediment yield using RUSLE

The quantity of sediment yield from the catchment was estimated using the RUSL equation. The RUSL equation is expressed as:

$$A = RKLSCP \quad (2)$$

Where A is the mean annual soil loss ($\text{ton ha}^{-1} \text{ year}^{-1}$); R is the rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$); K is the soil erodibility factor ($\text{ton h MJ}^{-1} \text{ mm}^{-1}$); L is the slope length factor and S is the slope steepness factor (both are unitless); C is the cover and management factor (unitless); and P is the support practice factor (unitless). The procedure for estimating the value of an individual parameter in the RUSL equation is shown in the methodology chart. Three rain gauges are located in the study area catchment. The area of influence for each rain gauge was determined in QGIS using the Thiessen polygon method, and the same is shown in Fig. 5. The annual sediment yield from each Thiessen polygon was estimated by applying the RUSL equation separately for each polygon. Daily rainfall data for 19 years (2005 to 2023) for each rain gauge were downloaded from the CHRS data portal (<https://chrsdata.eng.uci.edu/>). The RUSL equation parameters were determined by following the methodology as described by Dutta (2016) and Benavidez et al. (2018).

3.2.1 Estimation of rainfall erosivity factor, R

The rainfall erosivity factor, R , represents the impact of rainfall on soil erosion. The annual R factor is a function of the mean annual EI_{30} value, the calculation of which requires detailed long-term rainfall data (preferably hourly). Since the availability of long-term hourly rainfall data is not possible for all regions, several researchers have developed methodologies to determine the value of R from annual or monthly rainfall data. One such methodology for determining R from annual rainfall data and elevation was given by Naipal et al. (2015), who developed a set of regression equations for R as a function of mean annual precipitation (P) and elevation (z) for different climatic zones. The Swarna reservoir catchment falls under the Nirmal district, which would roughly correspond to a temperate climate with warm summers. For this climate type, the rainfall erosivity factor equation, as presented by Naipal et al. (2015) is:

$$\ln R = 5.267 + 0.839 \times \ln P - 0.635 \times \ln Z \quad (3)$$

Where P is the mean annual precipitation in mm and Z is the elevation in m. The units of R are $\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$. In the context of India, Ram et al., (2004), Jain and Das (2010), and Nakil and Khire (2016) have developed simple formulas for estimating R for Indian catchments with annual rainfall data. The formula for R as given by Ram et al. (2004) is:

$$R = 81.5 + 0.38 \times P \quad (4)$$

P is the annual precipitation for areas where annual precipitation ranges between 340 and 3500 mm; units of R is $\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$. The formula for R as given by Nakil and Khire (2016) is:

$$R = 839.15 \times e^{0.0008P} \quad (5)$$

P is the annual precipitation in mm, and units for R are $\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$. The average rainfall erosivity factor for each Theissen polygon under each formula is shown in Table 9

Table 9: Annual average rainfall erosivity factor (R) under the three different formulas

Rain Gauge	Rainfall Data	Equation proposed by	R Value (MJ mm ha ⁻¹ h ⁻¹ y ⁻¹)
R1	Monthly	Ram et al, 2004 and Jain and Das, 2010	488.45
R2			492.93
R3			439.1
R1	Monthly	Naipal et al., 2015	1428.6
R2			1582.2
R3			1229.7
R1	Monthly	Nakil and Khire, 2016	2064
R2			2085.21
R3			1839.3

3.2.2. Estimation of soil erodibility factor, K

The soil erodibility factor K is affected by the intrinsic properties of a soil. K shows to what extent soil can be detached by rainfall splash and surface flow (Zhang et al., 2018; Dutta, 2016). According to Renard et al. (1996), the K factor can be determined using the following mathematical equation:

$$K = 0.0034 + 0.0405 \times \exp \left[-0.5 \left(\frac{\log d_g + 1.659}{(d_i + d_{i-1})/2} \right)^{0.7101} \right] \quad (6)$$

$$d_g = \exp(\sum f_i \ln g_i) \quad (7)$$

where d_g is the geometric mean particle size; d_i is the maximum diameter, d_{i-1} is the minimum diameter, and f_i is the corresponding mass fraction. The value for the mean particle size of the sediments in the study area was obtained from particle distribution curves (Final Report: Updation of area elevation capacity curves for Swarna Project, 2023). The minimum diameter d_{i-1} (corresponding to D10 size) of the soil particle was found to be about 0.0304 mm, and the maximum, d_i (corresponding to D60 size) of the soil particle diameter was

found to be about 0.7219 mm. The geometric mean particle size (d_g) was estimated to be around 0.376 mm. The K factor for the study area is 0.02 tonnes h MJ⁻¹ mm⁻¹.

3.2.3 Estimation of topographic factor LS

The topographic factor was determined using the mathematical equation given by Wischmeier and Smith (1978):

$$LS = \left(\frac{\lambda}{22.13} \right)^{K'} [65.41 \sin^2 \theta + 0.065] \quad (8)$$

Where λ is the field slope length, K' is the exponent factor ranging from 0.2 to 0.5, and θ is the angle of slope. The field slope length and angle of slope for the study area were estimated from the slope map and elevation map prepared in QGIS. The LS factor for the study area varied from 7.4 to 7.55.

3.2.4. Cover and management practice factor (C) and support practice factor (P)

Cover management factor, C, is the ratio of soil loss from cropped land under specified conditions to the corresponding clean tilled continuous fallow (Dutta, 2016). The C factor for many crops is not available in India. A composite C factor for each Theissen polygon was determined by using the following equation:

$$C_{comp,i} = \frac{\sum_{j=1}^k (C_{ij} \times A_{fij})}{A_i} \quad (9)$$

Where, $C_{comp,i}$ is the composite C factor value for Theissen polygon i ; C_{ij} is the cover management factor for land use j in the polygon i , and A_{fij} is the area under land use j in the polygon i ; A_i is the area of Theissen polygon i . The C factor as a function of different land use (Thapa, 2020) is shown in Table 10. P factor represents the effect of surface conditions like contouring, strip cropping, and terraces on flow paths and hydraulics. The P factor (support practice factor) values as a function of catchment slope (Kumar and Kushwaha, 2013; Thapar, 2020) are shown in Tables 10 & 11. As much of the catchment slope is about 20%, the P factor value for the entire catchment was taken as a constant value of about 0.95.

Table 10: Values of cover management factor (C) as a function of land use

Land use	C factor
Forest	0.03
Shrub land	0.03
Grassland	0.01
Cultivated area	0.21
Barren land	0.45
Water body	0.0
Snow glacier	0.0

Table 11: P factor values as a function of slope

Slope %	P factor
0 – 7	0.55
7 – 11.3	0.60
11.3 – 17.6	0.80
17.6 – 26.8	0.95
> 26.8	1.00

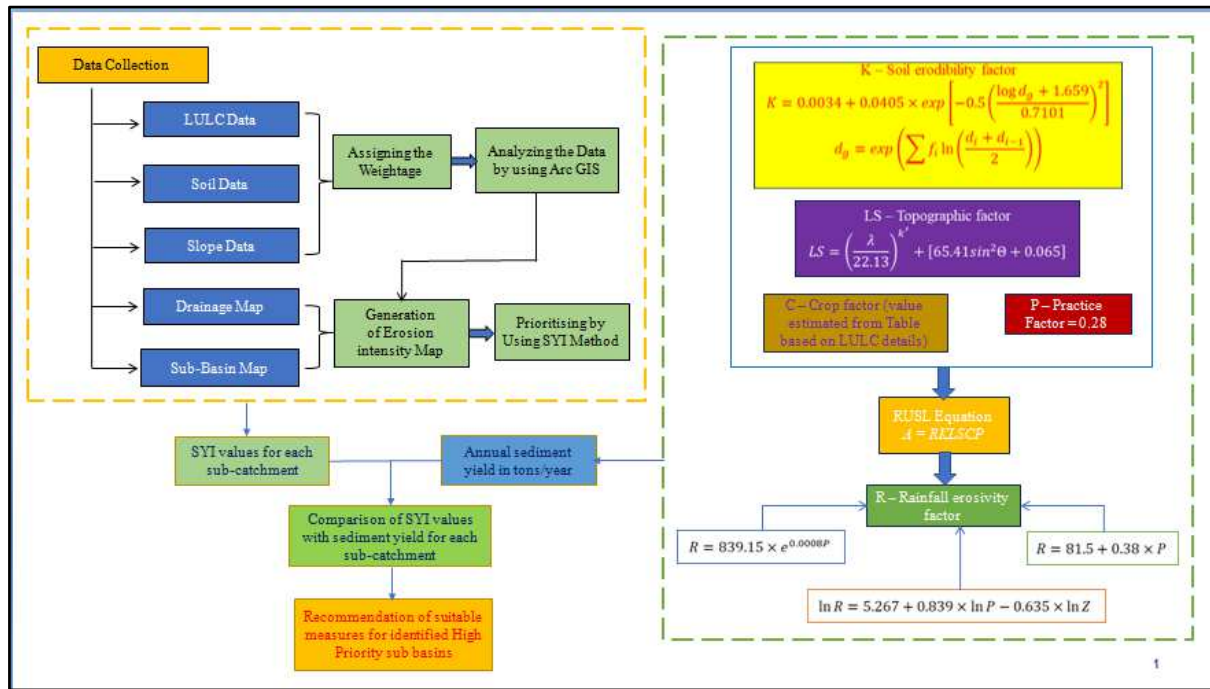


Fig. 13 Methodology flow chart describing the processes involved in performing catchment prioritization study for the Swarna reservoir catchment

4. Results & Discussion

The catchment prioritization for the Swarna reservoir was determined by comparing sediment yield index values and annual sediment yield values using the RUSLE equation. For the SYI analysis, the catchment was divided into nine sub-catchments, and the sediment yield index value was determined for each sub-catchment separately.

4.1. Analysis of thematic layers/maps of the SYI model

In the Swarna reservoir catchment, the slope ranges from 0% to 64%, and most of the area is in the 0% - 20% slope range. The slope has been categorized into three classes (Fig.9), with higher weightage values assigned to the higher slopes as they enhance erosion (Table 6). Land-use and landcover (LULC) classes directly affect sediment because of their interaction with soil and water. Five LULC classes were identified (Fig. 8 and Table 5), with agriculture & forest being the dominant classes. Weightage values were assigned to the LULC classes based on their susceptibility to soil erosion (Table 6). Gullies/ravines and barren land classes are at the highest

priority (9 value) as they have zero to little vegetation and promote erosion. Three types of soil texture have been identified as shown in Fig. 8. Higher weightage has been assigned to coarser soil, e.g., sandy soil, because it consists of granular materials and can erode quickly compared to other soil types. The weightage values for different thematic layers were assigned based on the published literature paper by Lohar et al. (2018).

4.2. Sediment yield value index by using the SYI Model

The sediment yield index value for all the sub-catchments (SC) was determined using Eqn. 1. The erosion intensity map resulting from overlay of LULC map, soil map, slope map, and drainage density map is shown in Fig. 12. It can be seen from erosion intensity map that the areas adjoining a stream fall under very severe category, whereas the areas corresponding to agriculture land use fall under severe category of erosion intensity. Much of the forest land comes under the moderate category of erosion intensity. These results are commensurate with the inferences presented in various literatures (Rawat et al., 2013; Gajbhiye et al., 2014; Naqvi et al., 2015; Yadav et al., 2015; Wagh and Manekar, 2022) regarding the influence of land use on erosion intensity.

4.3. Prioritization of the Swarna reservoir catchment

The sediment yield index values were used to prioritise 9 catchments of the Swarna reservoir, as shown in Fig. 11. The highest sediment yield index value was observed in sub-basin number 6, and accordingly, this sub-catchment has been classified under the high severity category as shown in Table 12. Being a 3rd order stream, all the sediments from different parts of the basin through the drainage systems are transported and deposited through this catchment. For the sub-catchments 1, 2, 5, 7, 8, and 9 the SYI value varies between 1103 and 1136, and hence these sub-catchments were classified under the moderate risk category (Table 12). The sediment yield index is moderate in these catchments as some of the areas belong to moderate slope and much of the land use falls under agriculture and forest lands. The sub-catchments 3 and 4 were categorized as high severity as their SYI values were found to be 1248 and 1246, respectively. These catchments are characterized by very steep slopes, and they cover agriculture and forest areas with high stream orders. The SYI values for all the sub-catchments are summarized in Table 12. Based on the SYI values, the catchment

prioritization rank for the nine sub-catchments in decreasing order of priority is: SC6 > SC3 > SC4 > SC1 > SC2 > SC5 > SC7 > SC8 > SC9.

Table 12: Sediment yield index and prioritization as per erosion intensity values

S. No	Watershed	Erosion Intensity Class	Area (Km ²)	Weightage	Weightage x Area	DR	Gross Silt (5 x 6)	SYI	Priority	Ranking
1	1	Negligible	0.0	10	0	0.9	0.0	1136	Medium	4
		Slight	0.80	11	8.80	0.9	7.92			
		Moderate	20.53	13	266.89	0.9	240.20			
		Severe	10.39	12	124.68	0.9	112.21			
		Very Severe	0.03	10	0.30	0.9	0.27			
		Total	31.75				360.6			
2	2	Negligible	0.00	10	0.00	0.9	0.00	1135	Medium	5
		Slight	0.33	11	3.63	0.9	3.27			
		Moderate	13.48	13	175.24	0.9	157.72			
		Severe	7.52	12	90.24	0.9	81.22			
		Very Severe	0.05	10	0.50	0.9	0.45			
		Total	21.38				242.6			
3	3	Negligible	0.00	10	0.00	1	0.00	1248	High	2
		Slight	2.26	11	24.86	1	24.86			
		Moderate	24.08	12	288.96	1	288.96			
		Severe	28.26	13	367.38	1	367.38			
		Very Severe	0.02	10	0.20	1	0.20			
		Total	54.62				681.4			
		Negligible	0.00	10	0.00	1	0.00			
		Slight	1.38	11	15.18	1	15.18			

4	4	Moderate	17.91	13	232.83	1	232.83	1246	High	3
		Severe	16.50	12	198.00	1	198.00			
		Very Severe	0.00	10	0.00	1	0.00			
		Total	35.79				446.0			
5	5	Negligible	0.00	10	0.00	0.9	0.00	1129	Medium	6
		Slight	1.57	11	17.27	0.9	15.54			
		Moderate	27.06	13	351.78	0.9	316.60			
		Severe	17.72	12	212.64	0.9	191.38			
		Very Severe	0.03	10	0.30	0.9	0.27			
		Total	46.38				523.8			
6	6	Negligible	0.00	10	0.00	1	0.00	1268	High	1
		Slight	0.55	11	6.05	1	6.05			
		Moderate	26.71	13	347.21	1	347.21			
		Severe	10.96	12	131.52	1	131.52			
		Very Severe	0.06	10	0.60	1	0.60			
		Total	38.28				485.4			
7	7	Negligible	0.00	10	0.00	0.9	0.00	1127	Medium	7
		Slight	1.13	11	12.43	0.9	11.19			
		Moderate	12.49	13	162.37	0.9	146.13			
		Severe	8.16	12	97.92	0.9	88.13			
		Very Severe	0.00	10	0.00	0.9	0.00			
		Total	21.78				245.5			
		Slight	2.73	11	30.03	0.9	27.03			
		Total								
		Negligible	0.0	10	0.0	0.9	0.0			
		Moderate	16.36	13	212.68	0.9	191.41			

8	8	Severe	7.59	12	91.08	0.9	81.97	1126	Medium	8
		Very Severe	0.00	10	0.00	0.9	0.00			
		Total	26.68				300.4			
9	9	Negligible	0.00	10	0.00	0.9	0.00	1103	Medium	9
		Slight	4.08	11	44.88	0.9	40.39			
		Moderate	9.65	13	125.45	0.9	112.91			
		Severe	7.68	12	92.16	0.9	82.94			
		Very Severe	0.01	10	0.10	0.9	0.09			
		Total	21.42				236.3			

4.4. Annual soil loss from the Swarna reservoir catchment using the RUSL equation

As only monthly rainfall data was available for the study area, the annual soil erosivity factor for each Thiessen polygon was determined using three different formulas that use monthly rainfall data. The equations given by Ram et al. (2005) and Nakil and Khire (2016) were developed for Indian catchments, whereas the equation given by Naipal et al., (2016) is a generalized equation for R, which can be used for estimating the rainfall erosivity factor for any region, provided monthly rainfall data for the region is available. The annual average R value for each Thiessen polygon under the three equations is shown in Table 9. The R value as calculated by Eqn. 5 was giving a very high value, when compared to the R value as calculated by Eqn. 4 (almost four times). R value calculated using Eqn. 3 was found to be between the R value determined by Eqs. 4 and 5. Within the catchment, the difference in R value found by Eqs. 4 and 5, for Thiessen polygons corresponding to the rain gauges R1 and R2, was found to be very small. For Eqn 3, the difference in R values for R1 and R2 was quite significant. This can be attributed to the fact that elevation is also included in Eqn 3. R1 is at a higher elevation when compared to R2, which may imply that elevation has a reducing effect on soil erosivity, i.e., at higher elevations, the propensity for soil erosion will be less. Rainfall has a direct bearing on soil erosivity, i.e., the higher the rainfall, the higher the R value. This is evident by comparing R

values for three polygons, in which soil erosivity for R1 and R2 is significantly higher compared to R3, and it is valid under all three soil erosivity equations.

The sub-catchment-wise annual sediment yield under three different formulas is shown in Table 13. The average annual sediment yield (in tons ha⁻¹ y⁻¹) for the entire catchment for three equations is: Naipal et al., - 352; Ram et al., - 114.75; Nakil and Khare – 484.67, respectively. The sub-catchments were categorized into severity classes based on the erosion severity category (shown in Table 14) defined by Thapar (2020). Based on this classification, the sub-catchments were categorized for annual sediment loss from low (Class I) to very severe (Class VI), as shown in Table 15. The severity classes obtained from the RUSL equation are compared with SYI values. It can be seen that the severity class for sediment erosion, when estimated using Eqn. 4 for R, is closer to the severity index as determined using SYI values. For the other methods, i.e., R

Table 13. Annual sediment yield from individual sub-catchments for R values obtained from three different equations

using Eqn. 3 and 5, the annual sediment erosion is overestimated, because of which all sub-catchments fall under ‘very high’ to ‘severe’ categories. This is very much in contrast with the severity classes as obtained by the SYI method. It can be therefore stated that for the study area under consideration, the soil erosivity factor R, as estimated using the mathematical formula given by Ram et al. (2004) and Jain and Das (2010), gives a better estimate as compared to other methods. Hence, comparing SYI values and sediment erosion values as obtained from the RUSL equation, it can be surmised that sub-catchments 3, 4, and 5 are prone to a high rate of erosion, whereas sub-catchment 6 is prone to a very high rate of erosion. Therefore, immediate sediment control measures need to be implemented for these sub-catchments. Sub-catchment 7 has a low erosion rate, hence it may not require any immediate focus for sediment control. The other sub-catchments, i.e., 1, 2, 8, and 9, fall under the medium severity category, implying that a suitable sediment control measure may be adopted for these sub-catchments in the near future.

Table 14: Erosion severity based on soil erosion rate using RUSL equation (Thapa, 2020)

Class	Rate of erosion (Mg ha ⁻¹ y ⁻¹)	Severity class
I	0 – 5	Low
II	5 – 10	Moderate
III	10 – 20	High
IV	20 – 40	Very High
V	40 – 80	Severe
VI	> 80	Very Severe

SC id	Area (km ²)	Rain gauge	K	C	LS	P	Naipal et al., (2015)			Ram et al., 2004			Nakil and Khire (2016)		
							R	A (ton ha ⁻¹ y ⁻¹)	Soil loss (tons/ y)	R	A (ton ha ⁻¹ y ⁻¹)	Soil loss (tons/ y)	R	A (ton ha ⁻¹ y ⁻¹)	Soil loss (tons/ y)
sc1	31.74	R1	0.02	0.10	7.55	0.95	1428.6	20.90	6.63	488.5	7.15	2.27	2064	30.20	9.59
sc2	21.38	R2	0.02	0.11	7.55	0.95	1582.2	25.19	5.39	492.9	7.85	1.68	2085.2	33.20	7.10
sc3-1	8.19	R1	0.02	0.07	7.49	0.95	1428.6	13.42	1.10	488.5	4.59	0.38	2064	19.39	1.59
sc3-2	46.43	R2	0.02	0.14	7.49	0.95	1582.2	32.42	15.05	492.9	10.10	4.69	2085.2	42.73	19.84
sc3								45.84	16.15		14.70	5.07		62.12	21.43
sc4-1	17.9	R1	0.02	0.08	7.55	0.95	1428.6	17.21	3.08	488.5	5.89	1.05	2064	24.87	4.45
sc4-2	17.9	R2	0.02	0.17	7.49	0.95	1582.2	39.18	7.01	492.9	12.21	2.18	2085.2	51.63	9.24
sc4								56.39	10.1		18.10	3.23		76.50	13.69
sc5-1	13.91	R1	0.02	0.10	7.49	0.95	1428.6	20.74	2.88	488.5	7.09	0.99	2064	29.96	4.17
sc5-2	32.47	R3	0.02	0.12	7.49	0.95	1229.7	21.0	6.82	439.1	7.50	2.43	1839.3	31.41	10.20
sc5								41.74	9.70		14.60	3.42		61.37	14.37
sc6-1	3.83	R1	0.02	0.17	7.49	0.95	1428.6	35.37	1.35	488.5	12.10	0.46	2064	51.11	1.96
sc6-2	1.91	R2	0.02	0.12	7.49	0.95	1582.2	26.34	0.50	492.9	8.21	0.16	2085.2	34.72	0.66
sc6-3	32.53	R3	0.02	0.11	7.55	0.95	1229.7	19.05	6.20	439.1	6.80	2.21	1839.3	28.50	9.27
sc6								80.76	8.05		27.11	2.83		114.33	11.89
sc7	21.78	R2	0.02	0.10	7.55	0.95	1582.2	22.81	4.97	492.9	7.11	1.55	2085.2	30.06	6.55
sc8	26.68	R2	0.02	0.14	7.55	0.95	1582.2	31.32	8.36	492.9	9.76	2.60	2085.2	41.28	11.01
sc9	21.42	R2	0.02	0.12	7.49	0.95	1582.2	27.02	5.79	492.9	8.42	1.80	2085.2	35.61	7.63

Table 15: Severity class for each sub-catchment

	Naipal et al. (2015)	Ram et al. (2004)	Nakil & Khire (2016)	Severity class as
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sub-catchment	A	Severity class	Severity	A	Severity class	Severity	A	Severity class	Severity	obtained by SYI values
sc1	20.9	IV	Very High	7.15	II	Moderate	30.2	IV	Very High	Medium
sc2	25.19	IV	Very High	7.85	II	Moderate	33.2	IV	Very High	Medium
sc3	45.84	V	Severe	14.7	III	High	62.12	V	Severe	High
sc4	56.39	V	Severe	18.1	III	High	76.5	V	Severe	High
sc5	41.74	IV	Very High	14.6	III	High	61.37	V	Severe	Medium
sc6	80.76	V	Severe	27.11	IV	Very High	114.33	VI	Very Severe	High
sc7	22.81	III	High	7.11	I	Moderate	30.06	IV	Very High	Medium
sc8	31.32	IV	Very High	9.76	II	Moderate	41.28	IV	Very High	Medium
sc9	27.02	IV	Very High	8.42	II	Moderate	35.61	IV	Very High	Medium

5. Conclusion

A comparative approach for catchment prioritization for the Swarna reservoir catchment, in Nirmal district, Telangana State, was presented in this work. The soil erosion severity estimated using the SYI method was compared with the soil erosion severity obtained from the RUSLE equation. The average sediment yield index value was found to be 1169, whereas the minimum and maximum values were 1103 and 1268, respectively. The SYI values corroborated the general influence of land use type on erosion intensity. For instance, sub-catchment 6, which is categorized under high severity for soil erosion, has a greater percentage of area under agriculture, whereas sub-catchment 9, which is categorized under low severity for soil erosion, has almost equal portions of land under agriculture, forest, and water bodies. It indicates that agricultural lands are more prone to erosion. This conclusion is validated by the RUSLE equation, also, wherein sub-catchment 6 has the highest sediment yield when compared to other sub-catchments. The average annual sediment yield for each

sub-catchment was determined using three different R values (two valid for Indian catchments and one applicable for global use) and monthly rainfall data. When the rainfall erosivity factor (R) as defined by Nakil and Khire (2016) and Naipal et al. (2015) was used for determining the average annual sediment yield, the resulting sediment yield was found to be very large and very much in contrast with SYI values. The annual sediment yield when R was estimated using the formula given by Ram et al., (2004) gave values matching the SYI severity classes. It can be therefore stated that for Indian catchments, the catchment prioritization as obtained by the RUSLE equation closely matches the catchment prioritization as obtained from the sediment yield index method, when the soil erosivity factor is estimated using the equation given by Ram et al. (2004).

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Statement & Declarations

- **Ethical Approval**

Ethical approval was not necessary for this study, as it did not involve human participants or the use of animal data.

- **Consent to Participate**

Not applicable, as this study did not involve any human participants.

- **Consent to Publish**

Not applicable. This study does not include any individual data requiring consent for publication.

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- **Competing Interests**

The author declares no competing interests.

- **Availability of Data and Materials**

The data utilized in this study are publicly accessible sites.