CASE STUDY

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Assessment of Reservoir Sedimentation Using RS and GIS Techniques: A Case Study of Singda Dam, Manipur, India

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Abstract

Through the use of remote sensing (RS) and geographic information systems (GIS), the study sought to evaluate the reservoir sedimentation at the Singda Dam in Manipur, India. The sedimentation assessment was performed using the SWAT (Soil & Water Assessment Tool) model. In order to determine the LULC (Land Use Land Cover) of the Singda watershed between 2011 and 2020, this study also used RS and GIS methodologies. Datasets from Landsat-7 (ETM+) and Landsat-8 (OLI) were used for the chosen time period. According to the results, the proportions of the various LULC kinds in the study region between 2011 and 2020 were found to have significantly changed. The SWAT model was successfully executed, according to several outputs. Sediment yield and discharge were considered to be relevant factors for this project and are the subject of analysis. The Singda Watershed produces and discharges sediment at an average yearly rate of 2014095.53 tons and 635.92 cumecs, respectively. The coefficient of determination (R2) was found to be 0.82, or 82% for sediment loss. According to the study, this model provides satisfactory results and can be used in reservoir areas with comparable geology.

Keywords: SWAT, LULC (Land Use Land Cover), GIS (Geographic Information System), Reservoir, Sediment Yield, Coefficient of Determination.

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Introduction

A dam is a structure that blocks, directs, or slows the flow of water; it typically creates a reservoir, lake, or impoundment. It also serves as a useful barrier for the environment of flowing freshwater. More often than not, a dam refers to a reservoir.

The sedimentation rate must be periodically assessed in order to calculate a reservoir's useful life. A crucial prerequisite for efficiently allocating space for storing and managing water in a reservoir is data on the spatial pattern of sediment deposition in various reservoir zones. The theory of reservoir sedimentation has been extensively studied in several works, including Garde (1995), Morris & Fan (1998), and Jain & Singh (2003).

India's north-eastern region's land and water resources are abundant and dynamic. During the monsoon season, the area gets tremendous rain, significant flooding, and severe shortages, including a lack of drinkable water in some regions. Recurring floods, drainage congestion, soil erosion, human influence on the environment, and other fundamental issues underlie water resources, including its integrated use for drinking, irrigation, and hydropower production. Knowing the hydrological cycle and estimating the hydrological parameters are required for effective planning and economical use of the land and water resources in the area.

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Geospatial approaches are frequently used to evaluate and analyze changes in the catchment area's environment, reservoir volume or capacity, submergence zone, and silt generated within the reservoir. The largest danger to the reservoir's existence is siltation. Therefore, it is crucial to control the transport of silt from the rivers upstream. Studying the reservoir's hydrology and water balance is therefore important.

Study Area

The Singda Dam, which was constructed on the Singda River, made Singda Reservoir renowned. It is in the Senapati District of Manipur at 24.88 N and 93.80 E, about 20 km west of Imphal. The National Project Construction Corporation

Limited built the multipurpose Singda Dam project. The dam is 60.50 meters high and 497 meters in length.

The dam's primary goals are to supply agricultural amenities and drinkable water to the nearby region of Imphal. The dam's construction began in 1975 and was finished in 1995. It supplies irrigation water to a 4148-hectare (41.48-square-kilometer) project area for the nearby settlements. It provides Imphal City and Greater Imphal with pure water at a rate of roughly 7MGD.

The Singda river is a minor stream that originates close to the communities of KHARAM and WAIPHEI KHUL at around 1450 meters above sea level and travels in a south-easterly direction through KADANGBAL before joining the Nambul river close to Iroisemba. Three irrigation canals are 7.02, 3.85, and 7.04 km long from the dam to the neighboring paddy fields. The canals have 25, 20, and 15 cusecs flow rates, respectively.

Material and Methodology

The SWAT (Soil Water Assessment Tool) model is employed for the investigation. SWAT is a continuous-time model that runs at the basin scale in daily time steps. The model's goals are to forecast the timing of agricultural practices throughout the course of a year as well as the long-term effects in significant management basins (i.e., crop rotation, planting and harvest dates, irrigation, fertilizer, and pesticide application rates, and timing).

In a landscape where agriculture is the primary land use, it can be used to model the basin-scale water nutrient cycle. It might make evaluating the environmental impact of different management strategies and best management practices easier. SWAT employs a two-level disaggregation scheme; first, topographic criteria are used to identify sub-basins, then land use and soil type factors are used to further discretize the data. A Hydrologic Reaction Unit (HRU), a computational unit considered to be homogeneous in

hydrologic response to land cover change comprises areas with the same soil type and land use.

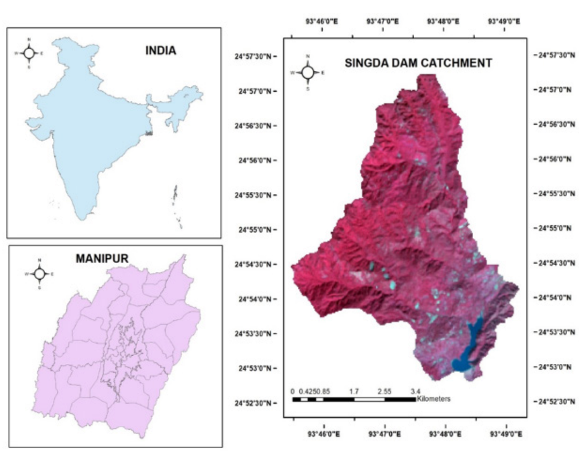

Figure 1: Study Area Map

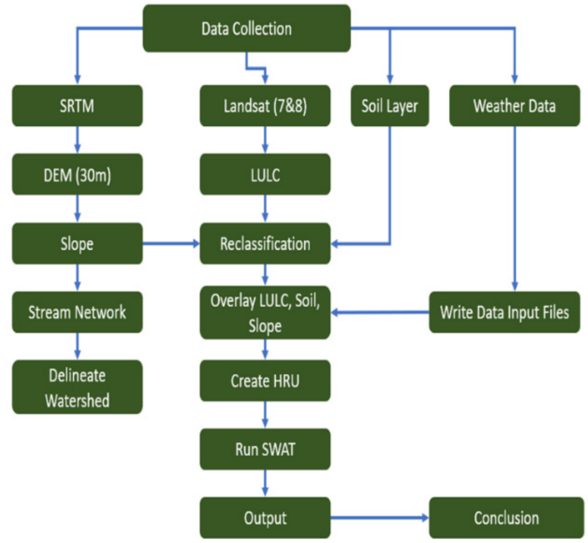

Figure 2: Methodological flow chart

Mathematical Formulation

The SWAT model calculates runoff volumes and peak flows using a master water balance technique, which is represented as follows:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

Where SW_{at} is the final soil water content on day *i* and SW_0 is the initial soil water content. Time (t) is measured in days; all other measurements are made in millimeters. The equation subtracts all water losses on day *i,* including surface runoff (Qsurf), evapotranspiration (E_a), loss to the vadose zone (Wseep), and return flow (Qgw), from the precipitation on day I (Rday) (Neitsch, Arnold et al. 2009).

The following is how runoff is calculated using the USDA Soil Conservation Service's runoff curve number (CN) approach (USDA 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (2)$$

The initial abstraction (I_a), which is a result of infiltration, interception, and surface storage, is defined as Q_{surf}, which stands for cumulative rainfall excess (runoff), Rday, which stands for rainfall depth for that day. Based on soil properties and land use classes, S is the retention parameter determined from the curve number (CN), and it can be found in a lookup table.

$$S = 25.4(\frac{100}{CN} - 10) \qquad (3)$$

During calibration, curve number plays a crucial role in determining surface runoff (Arnold, Moriasi et al. 2012). Low curve numbers represent well-drained soils from Hydrologic

Group A or B and correspond to low rates of surface runoff, whereas high curve numbers represent substantial overland flow frequently associated with developed soils.

Software Tool Used

The following tools are used:

- **Arc Map 10.2:** ESRI's Arc Map GIS software has extracted and rectified the layers needed for the SWAT model and any additional spatial derivatives.
- **Arc SWAT 2012:** For simulating different hydrological processes, including runoff, evaporation rate, sedimentation rate, etc., Arc SWAT has been interfaced with Arc Map.
- **Microsoft Excel:** For conversion of hydro-meteorological data from tabular format to GIS raster formats using station coordinate. It's also used to plot the graph.

Data

This study uses Landsat-7 enhance thematic mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) dataset of 30 meters spatial resolution multispectral imageries to generate the Land Use Land Cover map.

Data pre-processing

Correction and preparation of gathered data are needed as inputs in processing before a model may be developed. This comprises tabulating the hydro-meteorological data, production of multiple input layers, and correction of satellite remote sensing data. The Digital Elevation Model (DEM), Land Use and Land Cover (LULC), Soil layers, and conversion of hydro-meteorological data from tabular to GIS raster formats using stations Coordinate are all included in the layer.

Digital Elevation Model (DEM)

Since all topographic characteristics of the catchment and sub-catchment up to the level of HRUs are obtained from this dataset, the digital elevation model is significant data.

The properties of the channel include its depth, width, length, and slope as well as its length, area, and slope. A 30-meter spatial resolution SRTM (Shuttle Radar Topography Mission) DEM was utilized as the input dataset for this investigation and was downloaded from the USGS website.

Using DEM data, the study region is defined, and the elevation range is described as well. The study area is located from 799 m to 2283 m above mean sea level.

Generation of Land Use Land Cover

The United States Geological Survey provided the Landsat-7 (ETM+) and Landsat-8 (OLI) multispectral imagery data with a spatial resolution of 30 meters (USGS). For a decade, from 2011 to 2020 sequentially, the imagery was used for the construction of a land use and land cover layer via image classification based on maximum likelihood classification (supervised image classification). The National Remote Sensing Centre in India's classification served as the foundation for the geographic data on land use classes.

Table 1: Details of Acquired Data

Sl. No	*Data*	*Description*	*Source*
1	Landsat – 7 (ETM+) & Landsat -8 (OLI)	Multi – spectral imagery; 135-43 path- row; 30m spatial resolution	United States Geological Survey (USGS)
2	SRTM	Digital Elevation Model; 135-43 path- row; 30m spatial resolution	United States Geological Survey (USGS)
3	Hydro-meteorological Data	Precipitation Data	NASA Earth Explorer
4	Soil Data	Soil Map	National Bureau of Soil Science and Land Use Planning

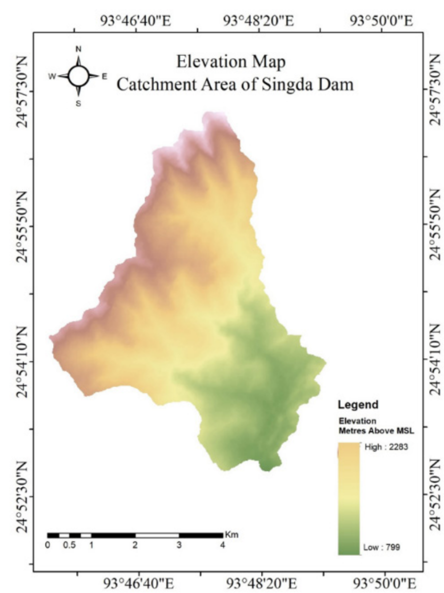

Figure 3: Elevation map catchment area of singda dam

In order to be used for picture classification, the satellite data were initially radiometrically adjusted and assembled. The image was divided into four land use classes for the purpose of change detection in the catchment area: vegetation, built-up areas, water bodies, and barren soil. The following are the LULC maps that were created for the chosen year.

Processing of soil Layer

The National Bureau of Soil Survey and Land Use Planning's Soil Map of Manipur is used to create the soil layer (ICAR). Manipur's soil map has numerous polygons corresponding to various soil types and their identification unit numbers in shapefile format. For this project, SWAT needed each polygon's features in its attribute database, including the soil series code, identification unit numbering, soil description, and other hydrological properties.

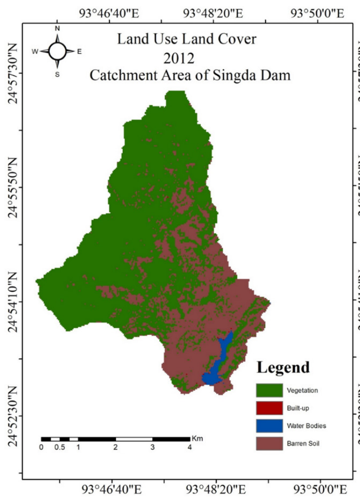

Figure 4: LULC Map of 2011

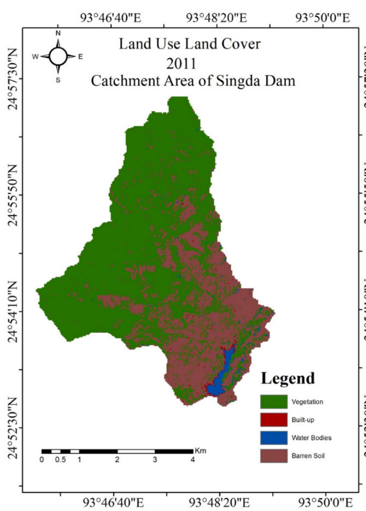

Figure 5: LULC Map of 2012

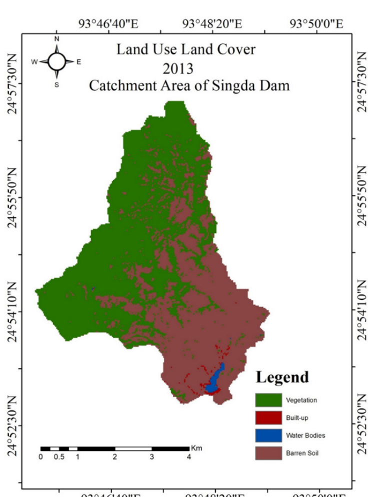

Figure 6: LULC Map of 2013

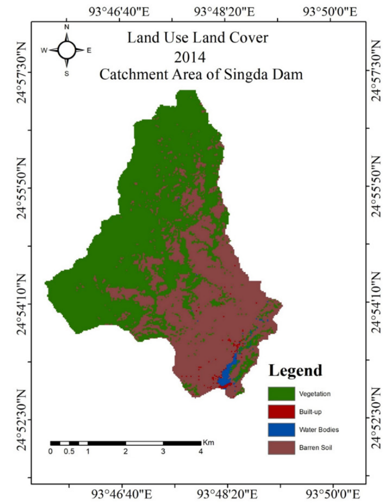

Figure 7: LULC Map of 2014

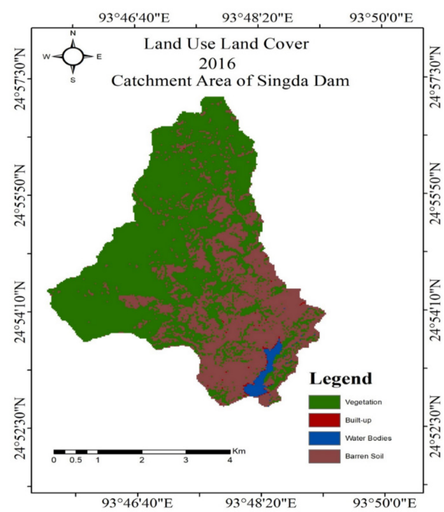

Figure 8: LULC Map of 2015

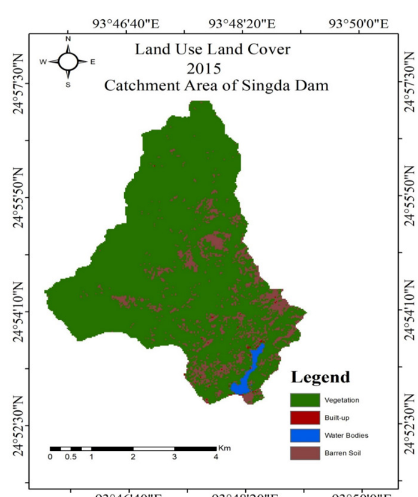

Figure 9: LULC Map of 2016

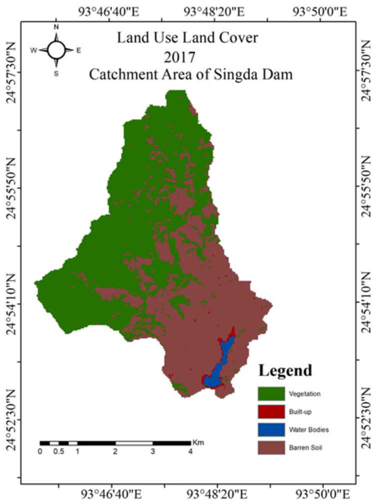

Figure 10: LULC Map of 2017

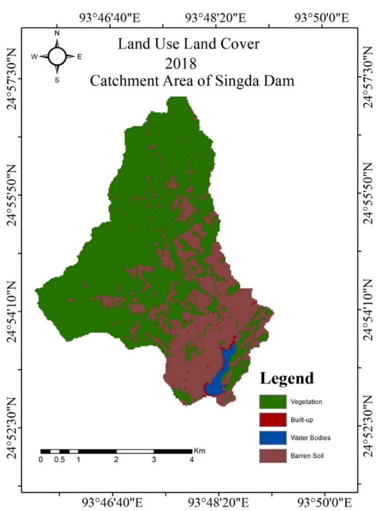

Figure 11: LULC Map of 2018

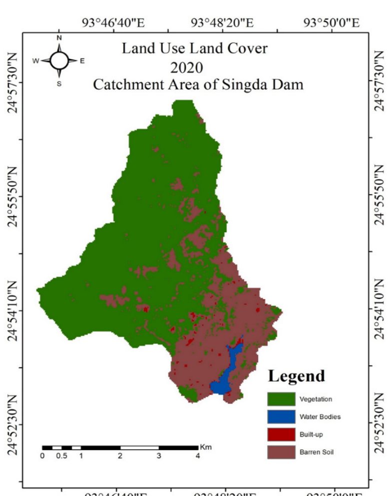

Figure 12: LULC Map of 2019

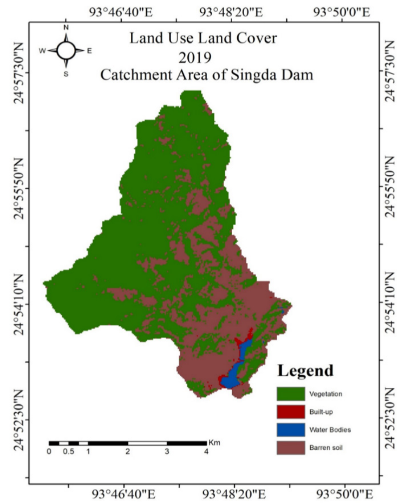

Figure 13: LULC Map of 2020

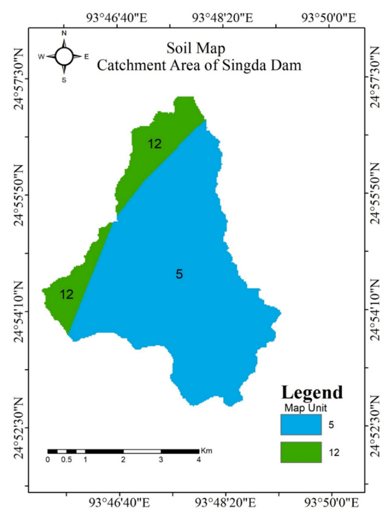

Figure 14 : Soil Map of Singda Dam

The study area's polygons are examined and divided into two soil groups. Due to the fact that SWAT is a US-based watershed model and relies on US-based input data to function, the soil input data should correspond to US soil types. But the information is based on the soil type in India. As a result, the database's accessible soil data is used to update the default SWAT user's soil. The project uses the revised "Usersoil," and the soil name is provided with the soil series codes matching the polygon identification number. The Figure 14 shows the study area's soil map. According to the mapping units, the taxonomy for various soil types was categorized as shown in Table 2.

Preparation of slope data

The slope description frame has been used with multiple slope options. It is reclassified into 5 classes, with percentages ranging from 0-3, 3-8, 8-15, 15-30, and 30 and beyond. After the slope has been reclassified, a Figure 15 is displayed below.

Table 2: Soil taxonomy

Map unit	*Series code*	*Taxonomy*
5	Ao41-2bc-5	Deep, overly drained, and fine Hillside slopes with moderately steep soils. Having a clayey surface and some erosion.
12	Bd31-2C-11	On gently to moderately sloping side slopes of hills, clayey surface with moderate to severe erosion & considerable stoniness. Deep, overly drained, clayey skeletal soil.

Processing of the hydro-meteorological data (Precipitation)

Since there aren't any data on observed precipitation, this study uses satellite-based gridded precipitation data instead. The NASA Earth data gateway is used to obtain the gridded precipitation data. Daily time-series data are collected, and using GIS techniques, they are retrieved for the research region.

The extraction is carried every year, and the Microsoft Excel spreadsheet transforms it into a tabular structure. The daily precipitation is then translated to the SWAT model's specified precipitation data format.

Results and Discussion

The SWAT model was run for the chosen year after all the necessary input layers had been prepared, and the results listed below were discovered and confirmed.

Analysis of Land Use Land Cover– Change Detection

Using Landsat multispectral imageries, the research area's LULC is generated for the chosen year. Estimated is the change in land use classes from one class to another over the passage of time.

The study determined that the catchment's overall area is 25.31 sq. km, with the vegetation class covering most of that area at a rate that varies yearly. Due to the coarse resolution, we discovered that the changing pattern of the built-up area and water bodies from the years 2011 to 2020 was quite poor.

The graph shows that the maximum vegetation cover was in the year 2015, and the lowest vegetation cover was in the year 2017. This can be a result of the monsoon activity during the research area's reported year. Additionally, it has been noted that 2015 had the least amount of barren soil, and 2017 had the highest amount.

SWAT Model Result Analysis

Various findings have been made after the SWAT model has been successfully run. Surface runoff, discharge, evapotranspiration (ET), potential evapotranspiration (PET), sediment loading, nutrient loading, groundwater output, soil moisture content, lateral flow, infiltration, etc., are a few examples of the different outputs. Sediment yield and discharge were considered to be key parameters for this

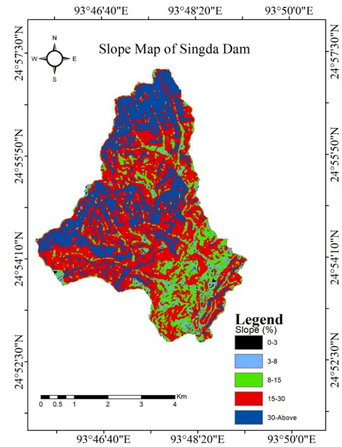

Figure 15: Slope Map of Singda Dam

Table 3: Slope class table

Sl no.	*Slope Class (%)*	*Area (Sq.km)*
1	0-3	1.01
2	3-8	6.84
3	8-15	25.16
4	15-30	71.25
5	30- Above	41.33

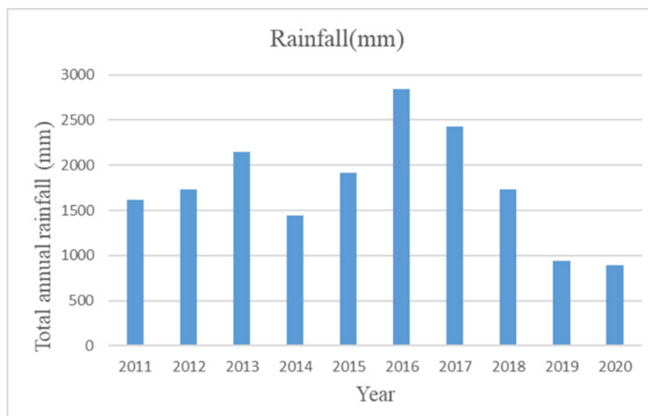

Figure 16: Total annual rainfall

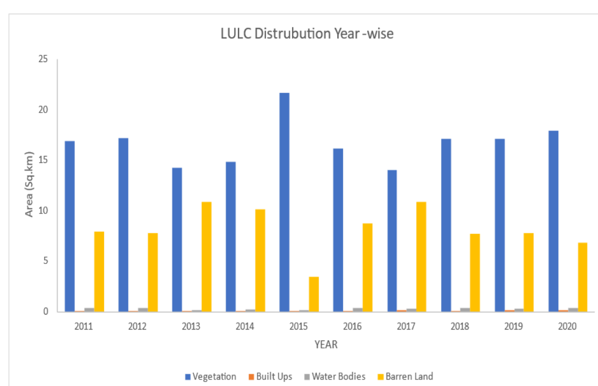

Figure 17: LULC Year-wise Distribution Chart

Table 4: LULC Year-wise Distribution Data

Class	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
	Area (Sq. Km)									
Vegetation	16.88	17.19	14.22	14.86	21.64	16.14	13.99	17.13	17.12	17.93
Built-up	0.09	0.01	0.12	0.11	0.04	0.06	0.14	0.09	0.14	0.16
Water Bodies	0.38	0.34	0.14	0.19	0.16	0.37	0.31	0.35	0.28	0.36
Barren Soil	7.96	7.77	10.83	10.51	3.47	8.74	10.87	7.74	7.77	6.86
Total Area	25.31	25.31	25.31	25.31	25.31	25.31	25.31	25.31	25.31	25.31

study and are the main subjects of analysis. Findings for this project include the ones below.

The graph displays the Singda Reservoir's yearly sediment yield. This leads to the conclusion that the maximum sediment yield occurred in 2016 and the lowest in 2020. The rate of sediment is particularly high in 2016. This can be because to deforestation that takes place to make room for human settlements and interference. Reforestation is essential.

The annual discharge of the Singda Reservoir is displayed in the graph above. The graph of annual precipitation and sedimentation yield shows that, in the studied time frame, the precipitation rate is highest in 2016, leading to the highest sedimentation yield in that year. This relationship between annual precipitation and sedimentation yield also shows that, in general, the higher the rate of precipitation, the greater the increase in sedimentation yield. Similar to the above bar charts, the years with higher rates of precipitation exhibit an increase in the sedimentation yield.

It has also been discovered that the precipitation rate directly impacts the outcomes of the LULC, with higher precipitation yielding higher sedimentation yields, which in turn result in more vegetation and less bare soil in the catchment area, as seen by the data above. This demonstrates a pattern in this research instance whereby the sedimentation yield will grow whenever the precipitation rate does, followed by an increase in the vegetation area and a decrease in bare soil.

The Sediment yield and discharge have the following correlation coefficient (R2) for the annual average sediment yield:

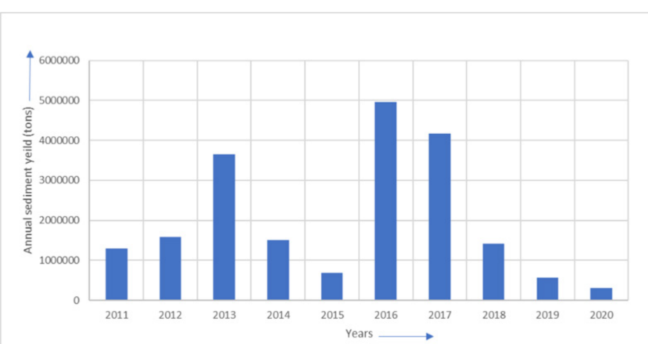

Figure 18: Annual Discharge of Singda Dam

Table 5: SWAT model result

Sl no.	*Years*	*Total Sediment Yield (tons)*	*Discharge (cumecs)*
1	2010 - 2011	1296912.696	568.8590585
2	2011 - 2012	1580056.816	593.5389754
3	2012 - 2013	3658276.224	843.1026118
4	2013 - 2014	1504057.831	457.0370791
5	2014 - 2015	686535.3835	693.8041305
6	2015 - 2016	4955146	1215.01275
7	2016 - 2017	4166622.227	985.949588
8	2017 - 2018	1417080.286	610.671036
9	2018 - 2019	561798.6071	201.9536695
10	2019 - 2020	314469.2594	189.262676

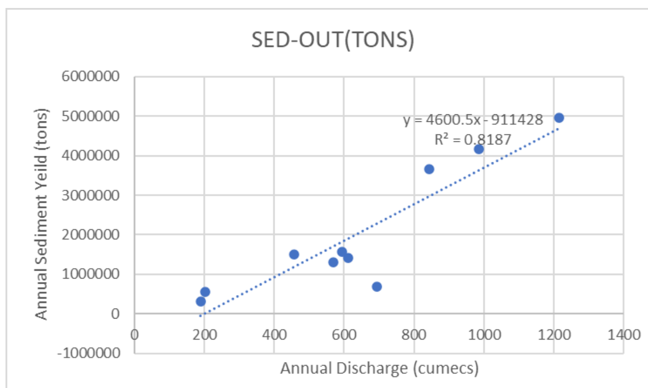

Figure 19: Co-efficient of Determination(R2)

The annual sediment yield coefficient of determination R2 between sediment yield and discharge is optimal when the R2 value is close to the upper limit, which ranges from 0 to 1. This coefficient describes the relationship between the discharge and the sediment yield. The value of 0.82, or 82%, shown in the above graph for the study's chosen area falls within the acceptable range.

Conclusion

The study mainly focuses on estimating the reservoir area's sediment yield using remotely sensed data and GIS techniques. The model used in the study produces positive results. Both observed weather data and improved land use classification were used in the model. The overall goal of this study was to evaluate the robustness of the SWAT model in estimating the reservoir's sediment yield volume. Different water balance components, such as discharge and sediment yield, are obtained and analyzed using the SWAT model of watershed hydrology. According to the findings, 2016 has the highest sediment yield of 4955146 tons/year, while 2020 has the lowest at 314469.26 tons/year.

The highest discharge is 1215.01cumecs in 2016. Rainfall and discharge are inextricably linked. As rainfall increases, so do runoff values, lateral flow, and groundwater flow, all of which contribute to the discharge from a watershed's outlets. The coefficient of determination R2 for the annual sediment yield between sediment yield and discharge is 0.82 or 82%, which is within the acceptable range.

The study concludes that a satisfactory result is achieved from this model, which can be applied in a similar reservoir area. It's known from the data collected and satellite data/imagery used that the study site is mostly hills. Land use of the study area was changed due to the anthropogenic factor, which affects the socio-economic condition of the locals and its inhabitants. Nevertheless, by incorporating additional such as data, weather, soil, etc., this could be a more improved simulation. The project's objective was to assess SWAT's performance at higher spatial-temporal resolutions rather than to generate extremely accurate findings for quick decision-making. Due to data limitations, the study relies heavily on open-source, freely available data. The spatial and temporal resolution of the data and the availability of Singda Dam data influence the accuracy of the result. As a result, validating the model's estimated result is complicated.

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