An Efficient Watershed Prioritization Technique Based on Slit Production Prediction Using Remote Sensing Data

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Abstract

Prioritization of watersheds based on soil erosion has evolved to turn out to be an integral part of watershed administration so as to preserve the invaluable resource of Mother Nature. Land administration, land use, slope, soil, and climate are the most significant elements contributing to soil erosion. Due to watershed heterogeneity, these parameters exhibit spatial variation. Consequently, the watershed is typically divided into small regions, demonstrating uniformity. Throughout this analysis, the watershed is divided into numerous smaller ones, and the remote sensing technology revolution was employed as a source of data to get accurate and current information about soil and land use. Topographic maps were used to determine the slope details. The slope, soil, and land-use were employed in an uncomplicated mathematical formulation to estimate the silt production of each smaller watershed; the smaller watersheds were divided into four distinct groups according to statistics. Examining the benefits due to the usage of remote sensing imagery, it is concluded that 2–5 m data sources are inexpensive. It is also advised to use the same imagery for sediment yield prediction as well as watershed management tasks.

Keywords: **Geographic Information Systems (GIS), run-off, remote sensing, watershed, soil erosion Sediment yield.**

1. Introduction

Runoff and precipitation are two predominant factors that cause soil erosion, which is the most significant contributor to issues related to the degradation of land and a crucial part of land administration. Due to the passage of rainfall, eroding soil in the condition of silt goes downstream. Sediment yield is indeed the silt load coursing out of a drainage basin or catchment.

Land use, specifically vegetation, the intensity of rainfall, the slope and the soil, are the primary factors determining sediment yield [1]. For this valuable resource, watersheds have indeed been assigned as preservation planning units [2, 4]. Water, soil, land use, and the connections between high and low land are all taken into account during watershed management [9]. Predicting sediment output is important for several reasons, including water and soil conservation, studying reservoir sedimentation, and other similar topics. The soil erosion rate inside a watershed can be put into context by knowing the origins of sediment yield within that basin [3]. Priority areas within a watershed are pinpointed so that corrective actions can be taken to reduce soil erosion. This is done by dividing the entire watershed into smaller sections (called grids or cells) with similar features in terms of soil erosion-causing causes.

This matrix or grid based strategy has been utilized in numerous investigations to identify zones which are prone to erosion in the catchment area [5]. Micro-watersheds are the tiniest elements in the pecking order and represent an alternative method of subdividing the watershed into considerably smaller portions. In lieu of a matrix or grid, smaller watersheds are utilized for silt production estimation and subsequent prioritization [10].

Satellite-based Remote Sensing photos now allow for the collection of current data on a watershed's land use and soils, which can be used to pinpoint the most at-risk locations for soil erosion [7]. Improved spatial resolution in satellite imaging during the past two decades has been a major boon to gathering detailed, microscopic information. With this context in mind, this work set out to prove that medium-resolution satellite pictures (5–10m) may be used to extract useful information on land use and soils, which could then be used to calculate the Soil Yield Index (SYI) and prioritize smaller watersheds within a larger watershed. This will show land managers which areas are prime micro-watershed research areas.

2. The Study Area

In this investigation, we considered the watershed (Kamala) of a modest watercourse lagoon in the Balasore district of the Indian state of Orissa, which is roughly 7700 hectares in size and for which we were able to fetch data on soils and land use up to date thanks to the proliferation of satellite imagery using remote sensing technology. For the purposes of watershed delineation, the point where the tributary joins the river Sona, which flows north, is considered to be the watershed's outlet. The watershed is delimited by the coordinates 210°24′00″ to 210°36′00″ north and 860°32′35″ to 860°32′45″ east. The watershed stretches for around 16 kilometers. There are two distinct ends to the watershed's topography. The watershed is largely level in the north but has some high hills and valleys in the south. The long, rectangular form of the basin causes the peak flow to be stretched out. Annual precipitation averages 1732 mm, with 80 percent falling between June and September.

3. Software tools and digital materials used

1. 6 m resolution panchromatic data from May 1996 IRS 1C, May 1996 (row no. 57, path no. 107).
2. 23 m resolution multispectral data from the IRS 1C from February 1997 (path no. 106, row no. 57).
3. scale 1:50000 topographical maps from Survey of India, 1972 with the following numbers: 73K/10,11,14,15
4. Image processing software EASI/PACE (PCI Geomatica) along with data analyzing geospatial tools ARC/INFO GIS which is especially capable of analyzing the soil maps of the scale 1:250,000.

4. Methodology

4.1. Fusion of multiple images and geo-referencing of remote sensing images

The 6 m spatial resolution panchromatic image of the IRS was assisted by control points derived from a topographic scale of 1:50000 in order to geo-reference them. The IRS 1C rendered multispectral image with a 23m resolution relative to the panchromatic image was geo-referenced. The two data sets, which were already geo-referenced, were then combined or merged to create a fused image, which is actually a hybrid form resulting from merging. The merged digital image was at a resolution of 6m. This image now has both the color characteristics of a multispectral image and the high resolution benefits of a panchromatic image, making it superior for visual understanding.

4.2. Micro-watershed and Watershed delineations

Typically, a dividing ridge between two river system or drainage system with an area of between 10,000 and 25,000 acres necessitate a formal administration. This large ridge is then divided into several micro-watersheds with sizes between 500 and 1,000 km² [6].

4.3. Information extraction regarding land cover and land use

The mapping of land use and land cover was done utilizing the fused image produced at earlier stage. Using visual interpretation, the following land cover and land use classes can be identified: settlement spread (L7), roads (L6), open/dense forests (L2), canals (L5), water bodies (L4), degraded forests (L3), and agricultural (L1). For this purpose, enough ground data was used and Table I includes distribution on land cover and land use.

	Classes of land use							
Micro-water sheds Nos	L1	L2	L3	L4	L5	L6	L7	Area of micro-watershed
1	276.2	141.3	-	6.9	-	7	93.3	524.5
2	327.8	191.1	-	3.8	-	6.6	44.2	573.6
3	546.4	206.6	-	6.8	-	8	84.3	852.1
4	364.8	348.4	-	7.3	-	11.1	90.1	821.6
5	487.4	181.7	-	8	-	10.7	109.8	797.6
6	440.1	-	-	16.6	-	9.4	102.5	568.7
7	595.7	-	45.2	4.6	4	21.1	56.7	728.1
8	408.5	-	81.9	2.5	-	60.3	26.3	525.5

Table 1: Distribution of land cover and land use

4.4. Soil resource mapping

The Government of India typically publishes soil maps at a scale of 1:250,000 through its unit called All India Soil and Land Use Survey, for regions of the nation. When planning watersheds with smaller areal extents, the data at the above scale is out of scope and insufficient. Therefore, using the image processing technique called fusing or merging and another technique for interpreting data from visual images, the soil resources have been compiled. When compiling the classes of soil, the current land cover map was also consulted. The fused image was overlaid with the digitized soil classes from the map. Taking its homogeneity into account and comparing it to the geomorphology, the boundaries of the classes were adjusted. When interpreting the results, some ground samples were used. There are five different types of soil in the area, and Tables 2 and 3 provide their taxonomic names, descriptions, and statistics for each category.

4.5. Making of a slope map

The contours of maps of topographic scale at 1:50,000 with 10 m intervals were used to create the area's slope map. Using accepted methods, the area's slope was divided into seven categories as follows [6]:

0-1% : nearly level
1-3% : very gently sloping
3-5% : gently sloping
5-10% : moderately sloping
10-15%: strongly sloping
15-35%: moderately steep to steep sloping
>35% : very steep sloping

Taxonomic name	Description
aericochraqualfs	Fine, extremely dense, loamy, and poorly drained soils with the formation of alluvium on to flat plains withsubject to low erosion.
typicustorthents	Slightly steeping denuded mounts of granitic lands; there are average slope, well-exhausted, coarse soils with fine surfaces and with significant erosion.
udichaplustalfs	Almost level, fine, well-drained with a fine surface; average.
typicustocrepts	Deep, fully draned with a fine surface that are found at rippling or modestly drooping hillsides in gneissic gneiss landscapes

Table 2: Taxonomic names and soil class characterizations

Micro-water sheds↓Soil types→	I	II	III	IV	V	Total area in hectares
MW1	361.5	-	162.6	0.4	-	524.5
MW2	312.8	-	207.5	53.3	-	573.6
MW3	486.5	-	375.3	-	-	852.1
MW4	329.5	-	154.9	116.8	-	821.6
MW5	635.3	-	18.6	7.3	-	797.6
MW6	550	-	-	-	-	568.7
MW7	501.6	-	-	-	226.5	728.1
MW8	263	64.7	-	197.8	-	525.5
MW9	97.9	198.3	126	-	235	657.2
MW10	87.5	418	-	-	317.8	823.3
MW11	-	607.9	-	-	245.8	853.7
Area under soil types in hectares	3625.6	1289	1410.5	375.6	1025.1	7725.8

Table 3: Soil statistics

Table 4 contains the related statistics of chosen study area. The combined false-color image of the Plate I, shown in figure 1, which maps the watershed, land use, soil and slope is used for making of a slope map the contours of the existing maps at the topographic scale of 1:50,000 with 10 m intervals were used to create the area's slope map.

Micro-water Sheds↓ Slope level→	1	2	3	4	5	6	7	Area in hectares
MW1	524.4	-	-	-	-	-	-	524.5
MW2	417.5	156	-	-	-	-	-	573.6
MW3	236.2	615.9	-	-	-	-	-	852.1
MW4	479.2	342.6	-	-	-	-	-	821.6
MW5	538.7	258.8	-	-	-	-	-	797.6
MW6	481.5	87.1	-	-	-	-	-	568.7
MW7	375.9	331.8	-	-	20.4	-	-	728.1
MW8	311	143.7	-	3.1	18.5	47.9	1.3	525.5
MW9	0.2	468.9	-	58.7	16	100.7	12.6	657.2
MW10	27.1	328.3	-	82.4	60.8	296.9	28.1	823.3
MW11	-	183.1	9.8	185.3	159.9	282.1	33.4	853.7
Area in hectares	3391.7	2916.2	9.8	329.5	275.6	727.6	75.4	7725.8

Table 4: Statistics of slopes

4.6. Estimation of Silt Yield Index

In the present study, prioritization has been achieved using the Silt Production Index (SYI), which was actually presented by the agricultural ministry of India in 1991 as shown in Eq. 1.

$$SYI = \frac{(\text{Weightage x Delivery ratio x } 100)}{\text{Area of the micro-watershed}} \quad \ldots \text{Eq. 1}$$

The weighting of the sediment yield depends on the administration techniques, land use, soil, slope, physiographic and climate. The ration of delivery is the percentage of the soil detached from an area that makes it to the sump region via drainage flow.

The slope and land use maps that were created are utilized as a key input to calculate the ratio of delivery and potentiality of erosion (weightage). Here is a fundamental model [8] based on the aforementioned theory and practices as shown in Eq. 2.

$$SYI = \frac{\sum_{j=1}^{n1}\left[\left(\sum_{l=1}^{n2}\left(\sum_{k=1}^{n3} AL_k \times L_k\right)\times SW_l\right)W_j \times D_j \times 100\right]\times F_i}{M}$$

… Eq. 2

In the above equation,

n3 – Number of land use class in a unit of slope mapping.

n2 – Number of slope mapping in a unit of under soil mapping.

n1 – Number of soil mapping in a micro-watershed.

F_i – Proposition factor of size of micro-watershed number *i*.

D_j – Delivery ratio of soil mapping unit number.

M – Area of a micro-watershed.

SW1 – Weighted factor for a unit of slope mapping.

W_j – Weightage of soil mapping unit number *j*.

L_k – Type factor for land use number *k*.

AL_k – Land use number k in slope unit number *i* and soil unit number *j*.

SYI – Slit Yield Index for micro-watershed number *i*.

The above prototype has been employed to independently compute the Slit Yield Index for every smaller watershed. For micro-watersheds eleven through one, the SYI values are 52, 158, 440, 247, 413, 535, 753, 1028, 1022, 795, and 609, respectively. Finally, the silt yield index was used to grade smaller watersheds on a four-point scale, and they were in the lower, average, above average, and higher categories. The extremely higher degree of vulnerability of degradation necessitates a higher conservation priority. The calculated silt yield indices were classified using statistical modeling, and the following two values were considered for classification: standard deviation (σ) and mean (μ). Finally, the classifications were made as follows:

Index values below (μ - σ): Priority A
Index values between (μ) and (μ - σ): Priority B
Index values between (μ) and (μ + σ): Priority C
Index values above (μ + σ): Priority D

The classifications with other details are shown in table 5.

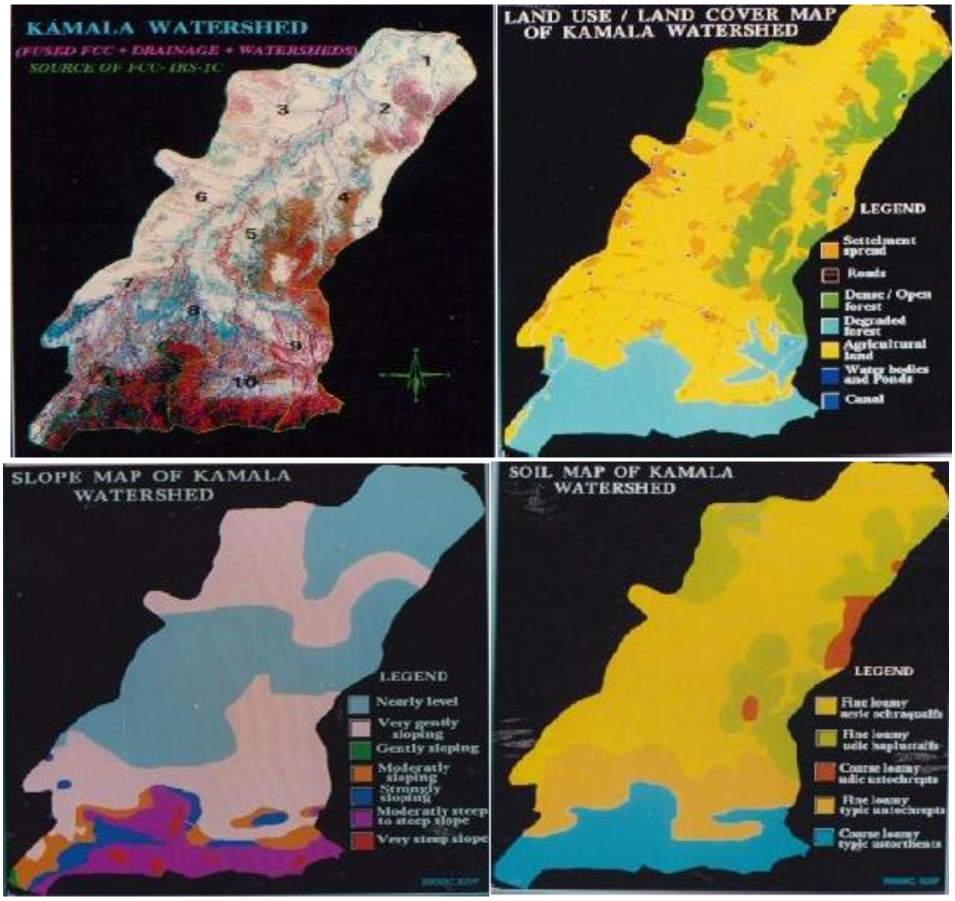

Figure 1: Plate I

Micro-watershed	1	2	3	4	5	6	7	8	9	10	11
Area in hectares	525	574	852.1	821.6	798	568.7	728.1	525.6	657.2	823.3	853.7
Dominant land use class		Agri	Agri	Agri and dense forests	Agri	Agri	Agri	Agri	degraded forests, Agri	degraded forests, Agri	degraded forest
Dominant Soil Group	A	A, C	A, C	A	A	A	A	A, C	B, D	B, D	B
Dominant slope	A	A	B	B	A	A	A, B	A	B	B, D	D
Computed SYI	609	795	1022	1028	753	535	413	247	440	158	52
Prioritization	Above average	Above average	Higher	Higher	Above average	average	average	average	average	lower	Lower

Table 5: Micro-watershed Prioritization

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5. Conclusion

The soil, land cover and land use data retrieved after the fusion process two different images were judged to be more current and plenty as far as quantity and quality of information is concerned than the previous maps. In fact, it can be anticipated that this information will suffice the needs of administration of watershed. The Silt Yield Index were calculated using soil and land use data retrieved from fusion images and slope information availed from existing topographical image maps and the micro-watersheds were brought into a four-point scale grading system. The 6 m (panchromatic) and 23 m (multispectral) medium resolution remote sensing pictures were determined to be appropriate after fusion process in terms of quantity and quality of information, currency and accuracy. The computation of and analysis on SYI suggests that the size of micro-watersheds can be reduced to 200-100 hectares in order administer the watersheds effectively. Also, it can be concluded that using stereoscopic satellite images with a spatial resolution of 1 m, instead of 6 m panchromatic images, n the fusion process can further enhance the quantity and quality of information, surprisingly, which includes the slope data. It may be noted that slope data was availed existing topographical maps in the present study.

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