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Research article

Soil and Water Conservation Prioritization Using Geospatial Technology – a Case Study of Part of Subarnarekha Basin, Jharkhand, India

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Abstract: Changing patterns of land use and land cover have exploited the natural resources. Soil, water and forests are degraded, both quantitatively and qualitatively. Deforestation in recent years has led to changes in the environment and more of soil erosion and loss of potable water. In order to conserve and sustainably use soil and water, a watershed management approach is necessary. It helps in restoring water by increasing the infiltration and reducing the erosion of soil. Such measures should be propagated in rainfall deficit areas. The present study has attempted to study the upper watershed part of Subarnarekha basin in Jharkhand state of India. Remote sensing satellite data (Landsat 8 OLI/TIRS 2013) was used for delineation of the land use/land cover and vegetation index maps. Several thematic layers like slope, drainage and rainfall were integrated to achieve a priority area map using spatial multicriteria decision making. It delineated high medium and low priority areas within the watershed for soil and water conservation. The high priority area was 16.63% of the total study area. Further, the causes were analysed and conservation measures proposed.

Keywords: watershed; soil and water conservation; geospatial; spatial multicriteria decision making; Subarnarekha

1. Introduction

The present scenario is witnessing the environmental changes leading to global climate change which is mainly human-induced. The main factors are deforestation, erratic changes in land use and land cover, agriculture development and increasing urbanization [1]. Climate change and intensive human activities are not only deteriorating the land cover but are also responsible for altering the river systems throughout the world [2,3]. The relationship between anthropogenic pressure and environmental degradation were studied by several researchers such as soil fertility decline [4], deforestation [5], soil and water resources degradation [6] and plant biomass production [7]. Much of our river basins have also been affected due to the developmental activities. The impact on hydrological characters of a river basin is mainly because of the anthropogenic factors like dam construction, Lee and bridge construction, sand-gravel mining, ground water withdrawals and industrialization [8,9].

The changes and variations in the natural resources should be monitored both at regional and local scale. The future of mankind is dependent on planned development and simultaneously not exploiting the natural resources like soil and water. They play a major role in governing the livelihood [10]. India, which is agriculture dominated country having large rural population, the drawbacks and constraints, which hinder the sustainable usage of resources was due to the unavailability of large spatial databases and inadequate monitoring techniques. The increase in the unplanned urban expansions, industries, agriculture expansion and destruction of forests has contributed to the soil erosion [11]. Conservation of soil and water at watershed level is a crucial step towards sustainable management.

Watershed is an ideal unit for planning and management of land and water resources [12]. It is capable of sustaining livelihood for the population living within the boundary apart from supplying drinking water and recreation [13]. Watershed condition changes over time due to natural processes and anthropogenic influences. The development of a watershed ensures that natural resources like land, water, plants, animals and humans are protected, conserved, adequately utilized and further possibility of their sustainability is guaranteed. The management of watershed aims to bring out a balance in the ecosystem where natural resources are on one side and all living beings including humans on the other side. The association between natural resources like land use, water and soil and the connection between uplands and downstream areas is better reflected while managing the watershed [14,15]. Land use/land cover change has influence on hydrological setup and sediment yield in the river basin [16].

Satellite remote sensing and Geographic Information System GIS) are ideal tools capable of identifying, locating and mapping various land forms or land units [17] as well as monitor and manage the natural resources [18]. The availability of data at various resolutions makes it feasible to monitor changes at different scales and time periods. Further, incorporating various thematic layers in GIS domain, it is possible to model and achieve delineating priority areas for conservation, management and planning. Thus, GIS supports decision making analysis. Problems arising from erosion and sedimentation can be solved when modeling for prioritizing watersheds is executed and evaluated [19]. On the basis of erosivity and sediment yield index values, suitability map with high, medium and low priority areas for soil and water conservation were clubbed [20]. Javed et al., analysed in Kanera watershed of Guna district of Madhya Pradesh, had used satellite data of (IRS LISS II and LISS III) to prioritize sub watersheds based on morphometric and land use analysis [21].

It is important to delineate the priority areas for soil and water conservation within a watershed because then only suitable measures in terms of technology and management can be employed. Watershed prioritization is useful for soil conservationist and planners. Watershed prioritization and productivity analysis was done by Martin and Saha, in Son River watershed in Dehradun district of Uttarakhand utilizing remote sensing and GIS [22]. Study conducted by Verma and Udaybhaskara; integrated Watershed Erosion Response Model (WERM) and Universal Soil Loss Equation (USLE) model with GIS to estimate erosion assessment parameters [23]. Watershed prioritization using satellite remote sensing of (IRS P6) and GIS by using WERM [24] in Vedganga basin, India; Panwar and Singh studied in Takoli Watershed of District Tehri (Uttarakhand) [25] and Pawar-Patil and Mali in Himalayan terrain on similar model [26].

The present study is in a part of state Jharkhand and West Bengal. A large population of the state consists of tribals who dwell in rural areas. Agriculture and other allied occupations are the main source of livelihood. Knowledge gap in agriculture and water sectors coupled with lack of awareness of government schemes has hampered the development of water bodies in the area which would provide long term benefit for sustainable agriculture and farming. Attempts have been made by many researchers to study some watersheds using geospatial technology. A few examples are Dutta et al., used TRMM data to predict potential risk of soil erosion in Sanjal watershed of Jharkhand [27]. A correlation between spatial patterns of potential soil erosion and slope in the watershed was established. A merged product from CARTOSAT-1 and LIS-4 Sensor was used by Prakash et al., to study the Bandu Watershed, located in Eastern India, in the Paschimi Singhbhum District in the state of Jharkhand [28]. The erosion prone areas were mapped which are essential for soil conservation and watershed management. Das and Guchait estimated the average annual soil loss of the Kharkai watershed, Jharkhand, India using the RUSLE Model [29].

The objectives of the present study are (1) to utilize the geospatial technology towards visualizing the spatial dimension of land, climate and topographical data and to reveal the trends and their interrelationships. (2) To identify the priority areas within the watershed for soil and water conservation. (3) The priority area maps were further validated using the satellite data (Landsat-8 TIRS) derived summer temperature (9th May 2015) data.

2. The Study Area

The study was carried out in upper part of Subarnarekha basin of Jharkhand state of India given in the figure1. It is situated in the northeast part of our country, India with a total area of 29,196sq km. The Subarnarekha River which covers an area of 12831.12 km^2 flows through the state of Jharkhand. The Subarnarekha basin covers the states of Jharkhand, Odisha and the parts of West Bengal. The watershed for the analysis falls in the districts of Ranchi, Ramgarh, Khunti, Seraiekela Kharsawan of Jharkhand and Pureliya district of West Bengal lying between latitudes 22° 47' 59'' N to 23° 33' 01'' N and longitudes 85° 8' 51'' E to 86° 14' 34'' E. (Figure 1). The Subarnarekha basin is surrounded by the Chota Nagpur plateau in the north and the west, by Baitarani basin in the south, in the south east by the Bay of Bengal and the Kasai valley of Kangsabati river on the east (Kumar and Joshi, 2016). The starting point of it is near Piskanagri village in Ranchi district, Jharkhand. It traverses a distance of 395 Km before falling into Bay of Bengal. The principle tributaries joining from right are Kanchi, Karkari, Kharkai Raru and Garru, left tributary is Dulang. (www.india-wris.nrsc.gov.in).

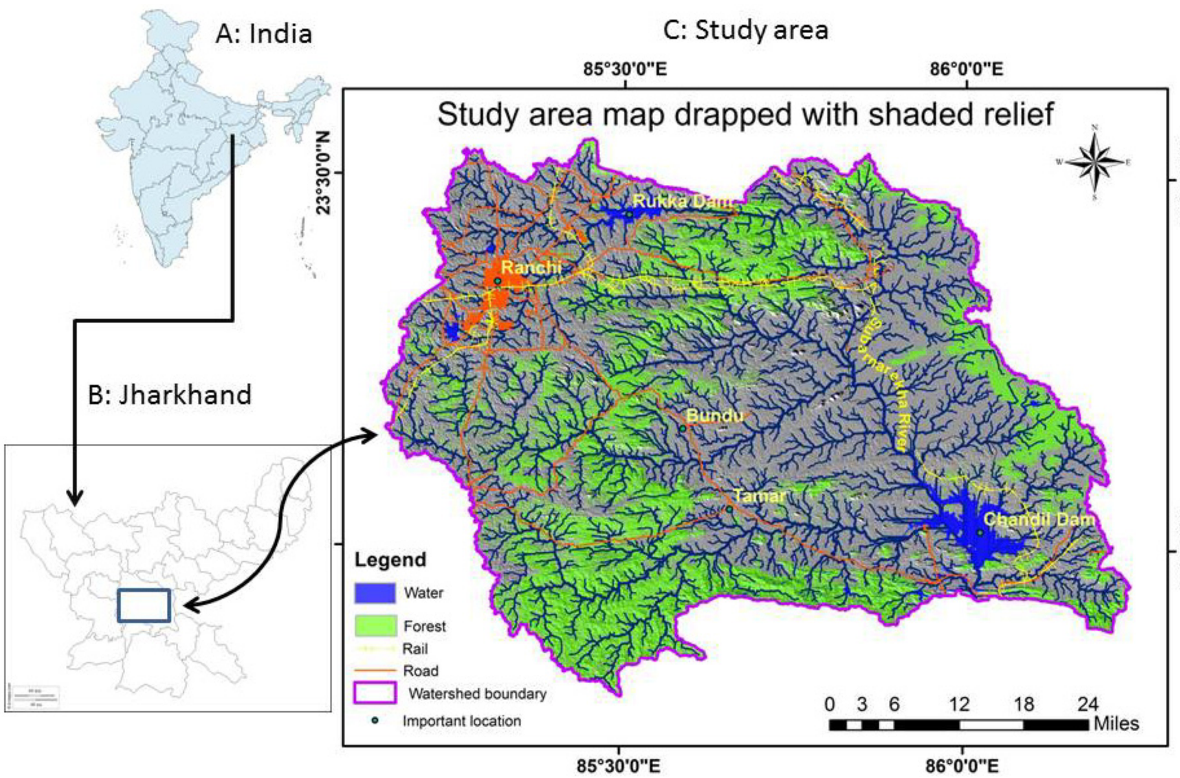

Figure 1. The location of the study area.

The altitude varies from 134 m to 1039 m from mean sea level (MSL). The climate of the area is humid subtropical. The decadal average annual rainfall from the year 1993 to year 2002 varies from 1164 mm to 1263 mm (www.indiawaterportal.org/data), on an average of which 75–80 % is received during the periods June to September and the rest in the remaining months. Temperature is the lowest during December and January and highest during April and May. The summer temperature range is from 20°C to 43°C and winter temperature range is from 0°C to 25°C.

The forests of this area can be best described as Tropical dry deciduous, tropical moist deciduous, dry deciduous Sal and moist deciduous Sal. *Shorea robusta*(sal) is the dominant species, whereas the other predominant species are *Butea frondosa*, *Diospyros sp*, *Bassia latifolia*, *Schleicher trijuga*, *Phyllanthus emblica*. *Azadirachta indica*, Bombax and *Dalbergia sissoo*. *Vitex negundo, Gymnosporia montana, Anona squamosa. Acacia arabica, Zizyphus jujuba*, *Holarrhena antidysenterica* constitute the under growth especially towards the fringes of the forest.

3. Materials and Methods

3.1. Image processing

The satellite data used for the analysis was Landsat 8 (Path/row = 140/44) (dated 23-12-2013 and 9-05-2015) having a spatial resolution of 30 meter (OLI bands) and 100 meter (TIRS bands). The projection parameters are WGS84 UTM zone 45. The geo-referenced satellite data was downloaded from portal of United States Geological Survey (USGS). The bands used for the analysis are NIR (5), Red (4), and Green (3). Thermal bands 10 are used for TOA Brightness Temperature. The image processing software used are ERDAS Imagine (version 9.0) and Arc GIS spatial analyst (version 10.0). ASTER DEM with resolution of 30 meter was downloaded from the portal of USGS and used to generate different thematic layers such as watershed, slope and drainage. Flow diagram (Figure 2) shows in detail about the methodology.

3.2. Image classification (to delineate Land use/Land cover)

The visual interpretation technique was used to interpret and delineate various land cover classes. The technique is based on tone, texture, colour and appearance of various physical features on ground [30]. Training sets were given for each land cover class distributed uniformly throughout the area of interest. Further, supervised classification (maximum likelihood technique) was executed to delineate twelve land cover classes. A forest mask was generated from false colour composite and utilized to demarcate agriculture and forest boundaries clearly. The vegetated areas in the non-forest mask were assigned to the agriculture class. For the analysis purpose, the water body was considered as a restricted category by giving it the weightage 999. Figure 3 shows the land use/land cover map.

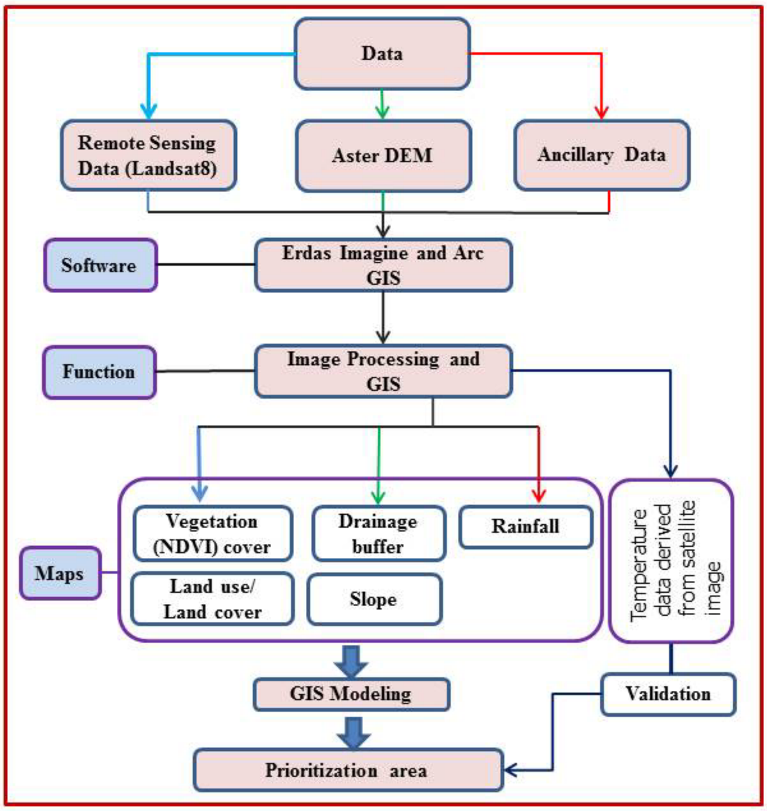

Figure 2. Flow diagram showing methodology.

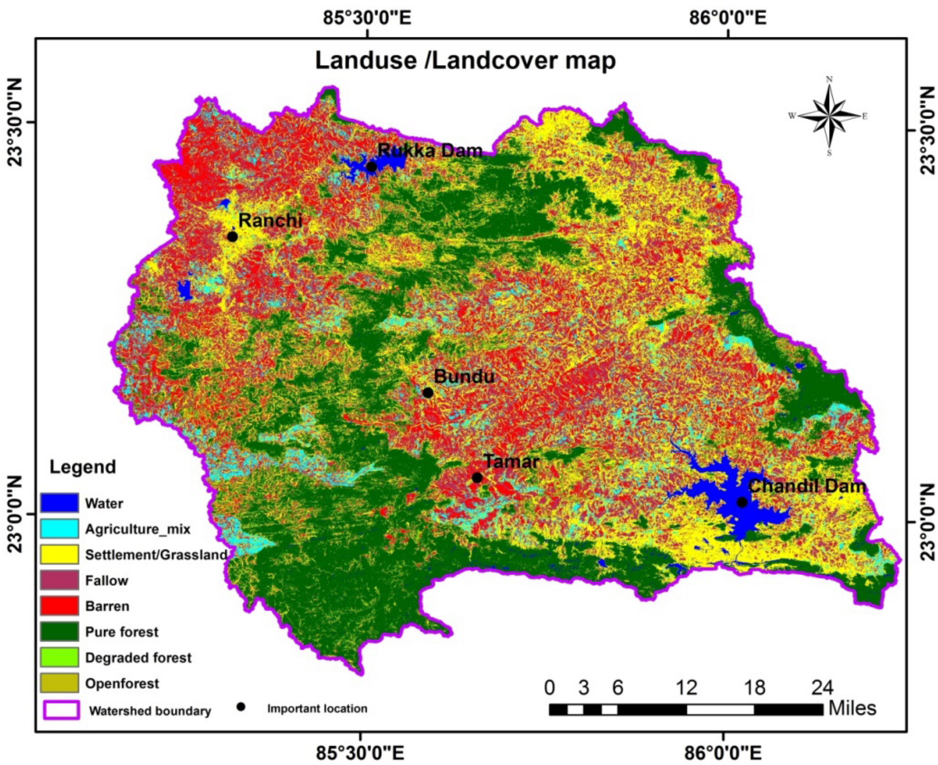

Figure 3. Land use/Land cover map.

3.3. *Vegetation map (Normalized Difference Vegetation Index)*

The Normalized Difference Vegetation Index (NDVI) is the most commonly used vegetation index. NDVI map was generated using the formula (for Landsat 8) (Figure 4).

$$NDVI = (NIR - R) / (NIR + R) \tag{1}$$

where NIR and R values are reflectance values.

This vegetation index is a correlation between the spectral response and the vegetation cover. This approach indicates that healthy vegetation exhibits low reflectance in the visible portion of the electromagnetic spectrum (EMS) (due to the presence of chlorophyll and other pigments) whereas it shows high reflectance by the middle part of the leaf (mesophyll spongy tissue) [31]. Its values range from −1 to +1. Vegetation is represented by NDVI values between 0.1 and 1 whereas higher NDVI values exhibit healthy vegetation.

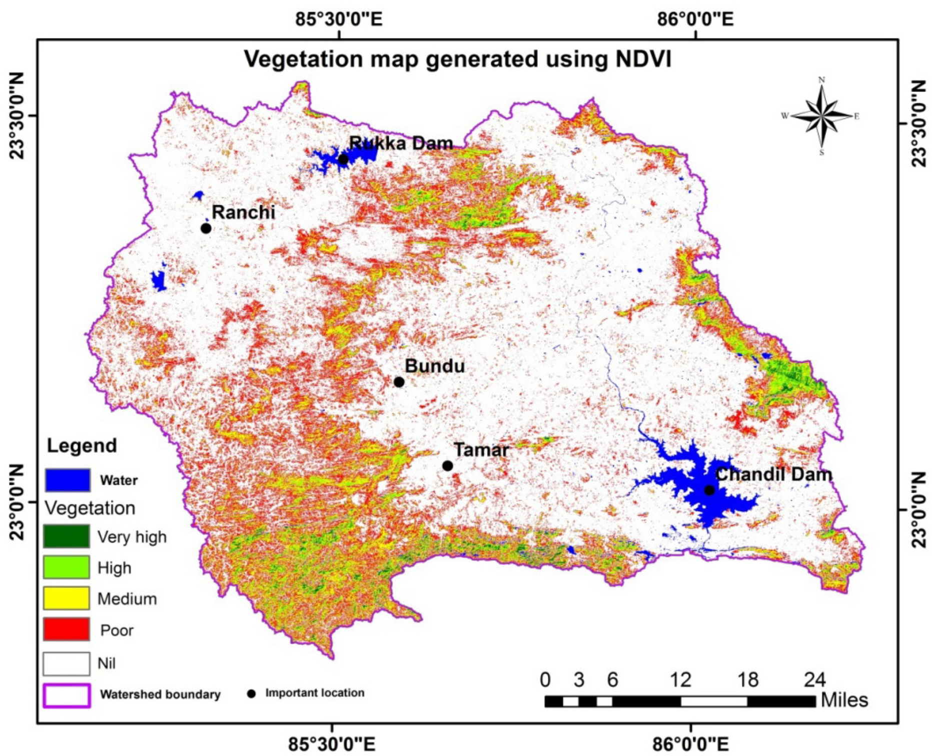

Figure 4. Vegetation Index map.

3.4. *Watershed and Drainage*

Model applied to delineate watershed and drainage was given in figure 5. Arc GIS Spatial Analyst Tool (hydrology) was used to extract watershed and drainage layer from DEM using the standard procedure. Arc GIS Analysis Tool (Proximity) was used to create multiple buffer rings of drainage. Three categories were delineated (0–200 meter, 200 to 400 meter and greater 400 meter buffer) (Figure 6).

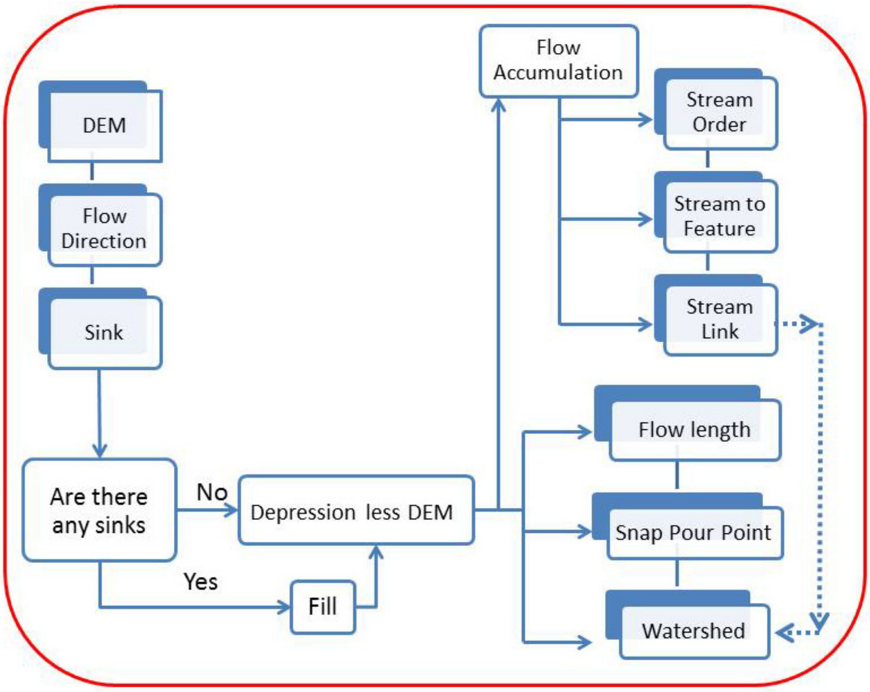

Figure 5. Model applied to delineate watershed and drainage.

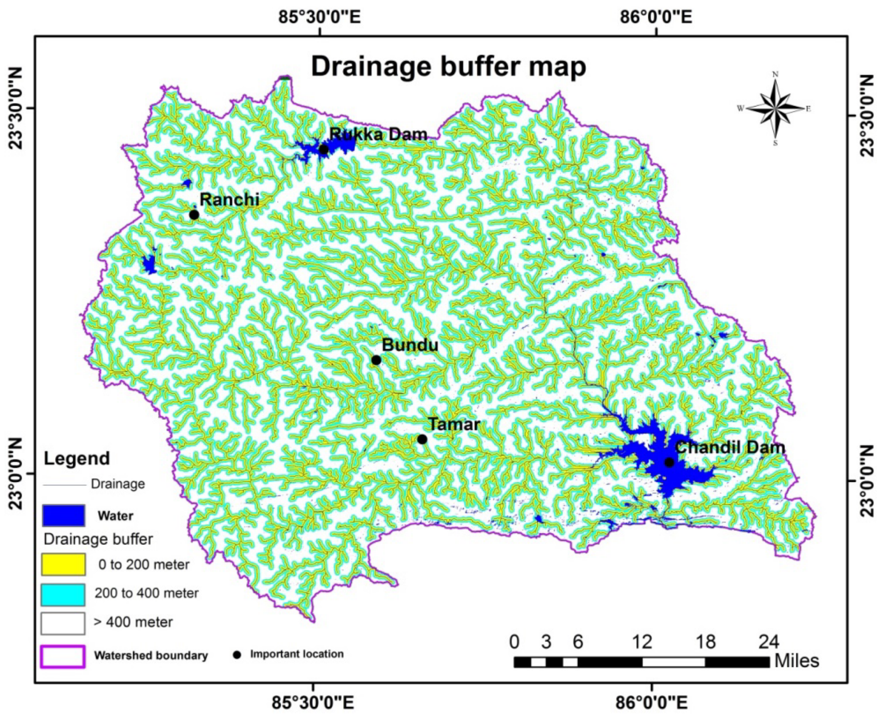

Figure 6. Drainage buffer map.

3.5. Slope

Arc GIS spatial analyst tool "surface" helped in extracting the slope map from the DEM. The slope is one of the important parameter directly related to soil erosion. It is reclassified into the various classes given in the Figure 7.

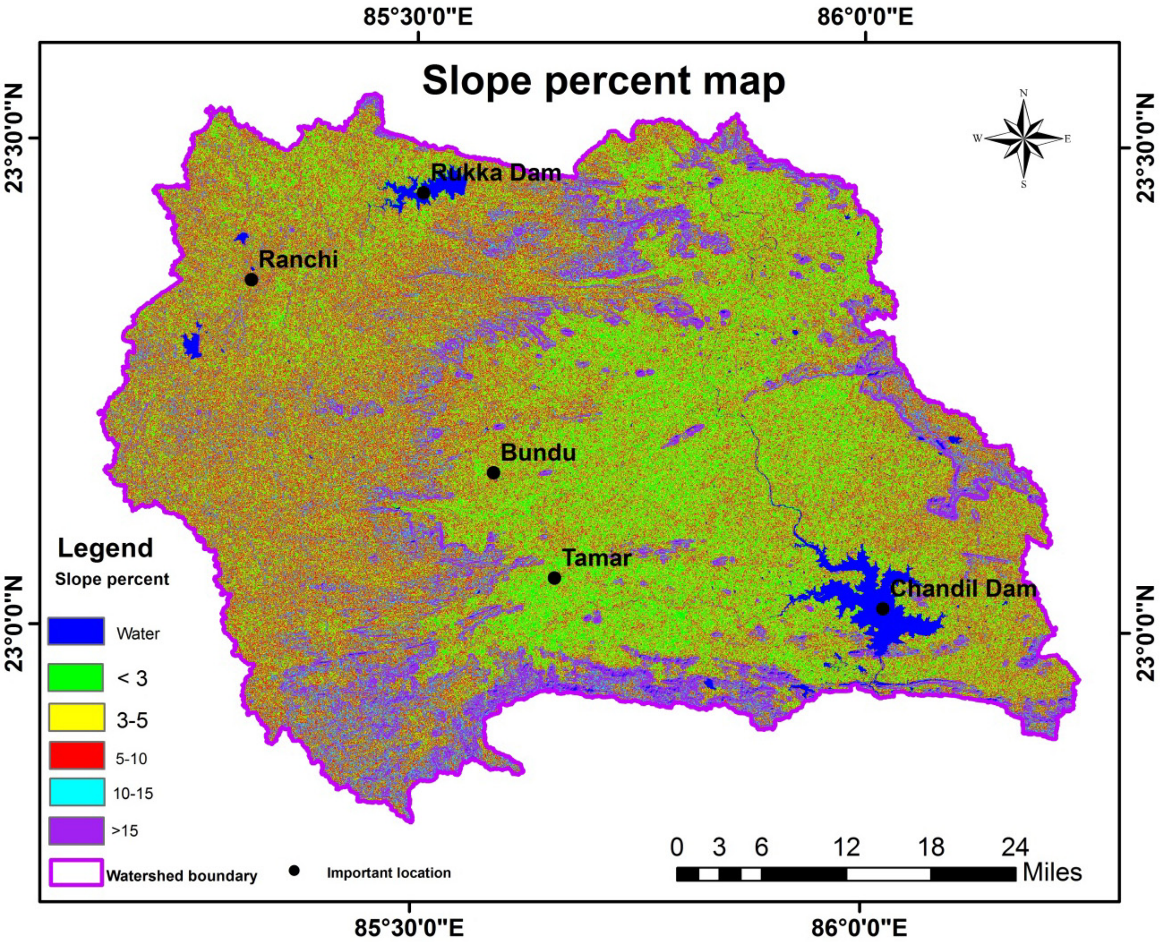

Figure 7. Slope map.

3.6. Rainfall

The rainfall map was generated by the method of interpolation using Spatial Analyst tool of Arc/GIS. The rainfall data from (1993 to 2002) was downloaded (Indian Water Portal 2016). The average annual rainfall for 10 years was used to generate spatial rainfall pattern (continuous surface) by the Kriging Interpolation method. Five categories were delineated (< 1180 mm, 1180 mm to 1210 mm, 1210 mm to 1240 mm and > 1240 mm) (Figure 8).

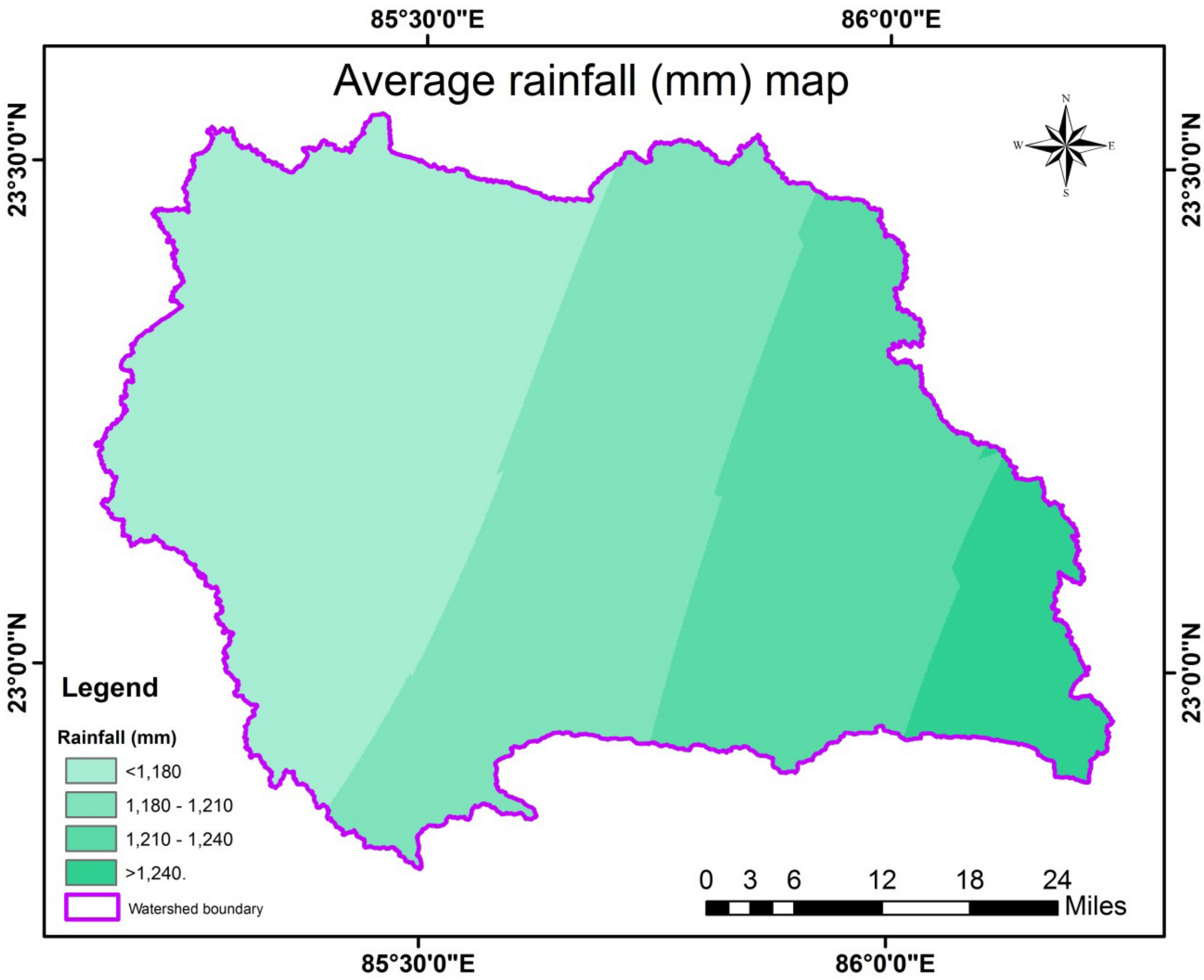

Figure 8. Average rainfall map.

3.7. Watershed priority area mapping

The criteria adopted for weightage values to delineate priority area for soil and water conservation is given in the table 1. Similar criteria for weightage based on its importance and ground knowledge have been assigned by several others authors [32–35]. The geospatial model was utilized to obtain watershed priority area mapping using spatial multicriteria decision making technique. Watershed priority area surface was obtained by integrating the various parameters given in the table 2. The weight of each parameter has been calculated based on the pairwise comparison (Table 3 & 4) used in AHP introduced by Saaty [36]. The Consistency Ratio (CR) and Principal Eigen Value was 1.5% and 5.069 respectively. The threshold for Consistency Ratio is maximum 10% whereas the value less threshold limit is considered as good (http://bpmsg.com/ahp-consistency-ratio-cr/).

Table 1. Criteria adopted for weightage values.

Parameter	***Source***	***Criteria adopted for weightage values***
1. LULC	Landsat data	The pure forest, degraded forest, open forests play a vital role in reducing the soil erosion and in providing good environment for the infiltration of the rain water [37–40].
2. NDVI	Landsat data	The NDVI values indicate how dense or sparse a vegetation cover is? A good dense vegetation cover protects the soil from erosion by reducing the water runoff [41–43] and by increasing the water infiltration into the soil matrix [37,44]. Higher the values of NDVI, more dense is the vegetation.
3. Drainage	ASTER DEM	It is observed that the erosion occurring close to the rivers and the streams more likely contributes to the sediment yield [45,46] at the basin level, thus while giving weightage , the inverse distance was used by giving larger weight to areas close to rivers [47,48].
4. Slope	ASTER DEM	The slope gradient as a topography factor plays an important role on soil erosion intensity. As the slope increases the soil infiltration rate decreases which, can increase the runoff amount [49,50]. The degree of erosion is influenced by the slope gradient, thus higher the slope, higher the erosion.
5. Rainfall	Indian Water Portal(2016)	Rainfall is an important climatic parameter that affects the soil erosion [51,52]. It is an active agent in the process of erosion by water, it is extremely important to assess the response of the soil to different characteristic of precipitation (depth, duration and intensity) [53].

Table 2. Weights given for thematic layers.

Environmental factor	*Weight*	*Class interval*	*Ranks*	*Degrees of Vulnerability*
Land use/ land cover class	29.8	Water	999	Restricted
		Agriculture mix	3	Medium
		Settlement/Grassland	4	High
		Fallow	4	High
		Barren	5	Very high
		Pure Forest	1	Very low
		Degraded Forest	2	Low
		Open Forest	2	Low
Vegetation class (NDVI)	22.7	Very Dense	1	Very low
		Vegetation	2	Low
		Dense Vegetation	3	Medium
		Medium Vegetation	4	High
		Poor Vegetation	5	Very high
		No (Nil) Vegetation		
Rainfall	8.1	<1180 mm	2	Low
		1180- 1210 mm	3	Medium
		1210-1240 mm	4	High
		>1240	5	Very high
Slope	25.7	<3	1	Very low
		3-5	2	Low
		5-10	3	Medium
		10-15	4	High
		>15	5	Very high
Drainage buffer	13.7	0-200 meter	3	Medium
		200- 400 meter	2	Low
		>400 meter	1	Very low

Table 3. Normalized matrix of various thematic layer with weight.

Criteria	*Normalized pairwise comparison matrix*						
	LULC	*Slope*	*NDVI*	*Drainage*	*Rainfall*	*Weight (fraction)*	*Weight (%)*
LULC	0.3000	0.2609	0.4138	0.2667	0.2500	0.2983	29.8
Slope	0.3000	0.2609	0.2069	0.2667	0.2500	0.2569	25.7
NDVI	0.1500	0.2609	0.2069	0.2667	0.2500	0.2269	22.7
Drainage	0.1500	0.1304	0.1034	0.1333	0.1667	0.1368	13.7
Rainfall	0.1000	0.0870	0.0690	0.0667	0.0833	0.0812	8.1
Consistency Ratio (CR) = 1.5%			Principal Eigen Value = 5.069				$\sum = 100$

Table 4. Pairwise comparison matrix.

Criteria	*Pairwise comparison matrix*				
	LULC	*Slope*	*NDVI*	*Drainage*	*Rainfall*
LULC	1	1	2	2	3
Slope	1	1	1	2	3
NDVI	1/2	1	1	2	3
Drainage	1/2	1/2	1/2	1	2
Rainfall	1/3	1/3	1/3	1/2	1

3.8. Brightness Temperature

The importance of TOA Brightness Temperature is being increasingly recognized and is used to study in various applications and its correlation is being analyzed [54,55]. It indicates how hot the surface of the Earth is and is dependent of various land use and land cover [56]. The spatial pattern of land surface temperature of peak summer season was generated using Erdas Imagine (version 14) from the satellite data of 9th May 2015 (Landsat TIRS), further it was correlated with results obtained.

4. Results and Discussion

The results obtained were depicted on a map showing three priority areas (Figure 9). They are high priority, medium priority and low priority areas (Table 5).

Table 5. Priority areas for soil and water conservation in a watershed.

Priority area in watershed	*Area in Hectare (ha)*	*Percentage (%)*
Low	173722.51	28.99
Medium	311600.34	51.99
High	99687.85	16.63
Water	14320.13	2.39
Total	599330.83	100.00

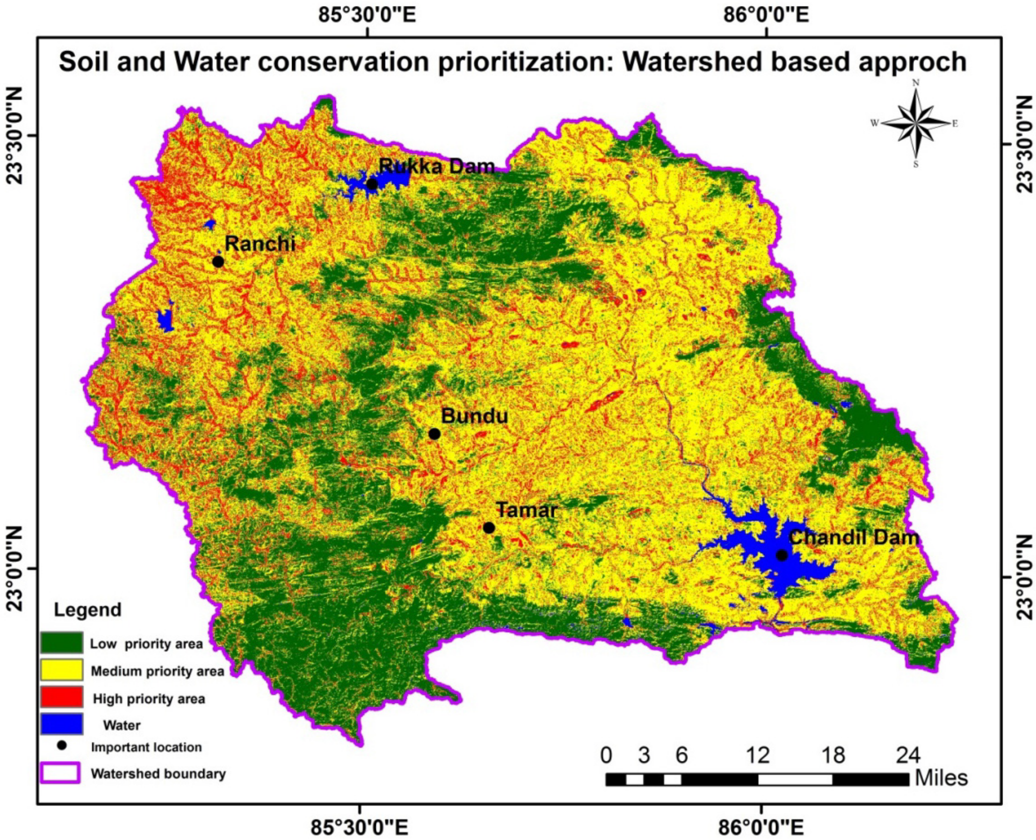

Figure 9. Priority map for soil and water conservation.

High priority: The high priority areas were found to be in steep slopes, having no vegetation to poor vegetation, barren, fallow land and near to drainage. This category accounts for 996.88 km^2 (16.63% of the total area).

Medium priority: This area was generally dominated by gentle to moderate slope having agriculture, medium to poor vegetation status dominated by grassland cover. This category accounts for 3116 km^2 (51.99%).

Low priority: This region is generally dominated by pure forest area to open forest with dense to very dense vegetation, having nearly level to gentle slope, away from drainage. This category accounts for 1737.23km^2 (28.99%). In this region during rains, infiltration and percolation of rain water is high and soil erosion is less relatively as compared to other areas.

Water: water accounts for 143.2 km^2 (2.39%).

Validation of result with Brightness Temperature:

The TOA Brightness Temperature manifest that the high priority area of the watershed during the peak summer exhibit high mean temperature when compared with the low priority area.This reflects that the area has comparatively less green cover [56,32]. TOA Brightness Temperature (Figure 10) provides valuable information for ecological restoration. Table 6 shows the temperature variation in the priority areas.

Table 6. Temperature variation in priority areas.

	Minimum (Temp.)	Maximum (Temp.)	Mean (Temp.)	Standard deviation (Temp.)
High priority area	26	45	35.2	2.84
Medium priority area	26	44	34.2	2.57
Low priority area	26	43	33.5	2.74
Water	25	41	28.7	2.43

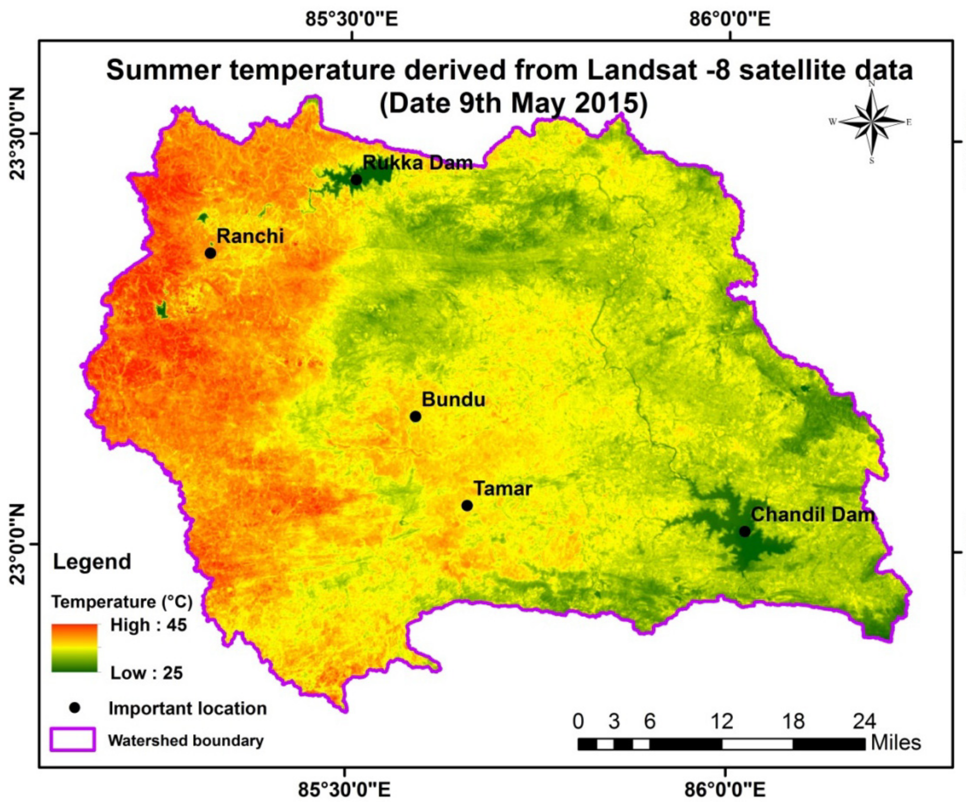

Figure 10. Land surface temperature.

4.1. Watershed characteristics of the Subarnarekha basin

The study area, the Subarnarekha basin is smaller than many of the major river basins in India. In an exclusive study by Kumar and Joshi, the hydrogeological characteristics of the river basin were analysed [57], wherein it concluded about various features within the upper watershed of the river basin. The major features of drainage were dendritic pattern, homogenous texture. The morphometric analysis had given insight that this basin is dependent on monsoon rainfall and is highly affected by seasonal water flow. Seldom, the cyclones occurring in Bay of Bengal affect it when it experiences high rainfall and flash floods which are temporary. The surface is undulating. The subsurface stratum is supposed to be more or less permeable owing to the rocky structure dominating the riverbed. Other characteristics include high infiltration capacity, low runoff rate and is tectonically stable.

Bhaduri reports that the source of the river near its origin in Ranchi has dried up and now reminiscence of a small rivulet can be seen [58]. Eminent environmentalist Dr. Nitish Priyadarshi further elaborates that deforestation at large was responsible for soil erosion.

In light of these factors and the above study, it is observed that the major cause is lack of good vegetation cover in high priority area of the basin which is the root cause of its deterioration. This in turn affects the climate pattern wherein frequent drought and floods are experienced as well as high levels of water pollution. A similar case was observed in the watershed of Krishna river basin in southern India, where heavy deforestation was reported in recent years whereas less than 3% of forest cover remains, the rest has been cleared for urbanization and agriculture expansion. (http://www.globalforestwatch.org).

In the vicinity of the study area (high priority area), the loss in vegetation cover has given rise to residential and commercial buildings to meet the demands of growing population and industrialization. Increase in cropland is also observed in the fringes of forested areas. The land cover shows barren, fallow and settlement in the very high priority areas. Recent years have seen a steady decline in rainfall and increase in the summer temperatures too. Rainfall is less and quiet erratic.

4.2. Conservation approach at watershed level

The basic manageable unit is the watershed wherein conservation measures can be employed. Some notable areas have been recognized within the watershed which need due attention. These are in the north west of watershed, towards the east of the Ratu basti, villages such as Manhatu, Sukarhuttu, Jaipur, Garu and Cheru. In the middle of watershed, villages such as Sonhatu and Bantahazam. In the eastern side, places such as Nekre and Genrua. In the south west places like Kachbari, Bandu and Chandpara.

These areas should be given attention in terms of planting new seedlings indigenous to the area in the deforested regions, steps to accelerate forest regeneration and agroforestry practices should be encouraged. Besides, rainwater harvesting techniques should be popularized to ensure water security. This helps agriculture productivity in the long run. Traditional and conventional approaches concentrate on soil and water conservation measures. This is not sufficient to achieve sustainability. An integrated watershed management approach opens up more opportunity for conserving the natural resources and simultaneously exploiting the gains in a controlled manner. To achieve this, a proper database of the present condition of watershed, its physical features and factors affecting it is necessary. Some physical geo-environmental parameters such as slope, soil and rainfall (which are a climatic factor) cannot be altered by human intervention. The scope is left to change the land use and vegetation pattern and introduce soil and water conservation measures. These measures should enhance ground water recharge, be capable of surface water detection, addressing the soil moisture replenishment by planting more trees, advocating suitable measure for soil and water conservation by incorporating both traditional and latest scientific technology. A healthy watershed will sustain many more livelihoods as well as contribute significantly to the environment.

5. Conclusion

The above study concludes that satellite remote sensing data analysis and combination of various thematic layers in GIS domain are capable of delineating priority areas for soil and water conservation in a watershed. Watershed management plans by the government can use this data for their conservation efforts. A spatial view obtained from remote sensing is an advantage over the traditional methods of surveying. However, traditional methods of water conservation like rainwater harvesting can be encouraged to practice along with latest technology like remote sensing to monitor the changes over a period of time. Soil and water conservation are the need of the hour as they have direct/indirect consequences which regulate the environment, economy and social issues. Increased urbanization and land use change would increase the demand for potable water. Such studies when used in conservation practices ensure water security and suffice the needs of the future generations.

Acknowledgement

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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