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Remote Sensing and GIS Based Catchment Area Treatment Plan for Soil Conservation Measures

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ABSTRACT

The fast growing development and ignorance of catchment area treatment plan during and after implementation of water resource project accelerating rate of sedimentation and disturbing the ecological balance in reservoirs and watersheds. The scientifically developed catchment area treatment plan identifies environmentally stressed areas, necessity and intensity of mechanical and biological measures to arrest further soil erosion and selection of spatial distributed locations of appropriate soil conservation measures. The Saaty's analytical hierarchal process (AHP) based multi-criteria decision making tool based on nine spatially distributed erosion hazard parameters (EHPs) was applied for identification of priority sub-watersheds. Various thematic layers such as geology, land use, soil, slope, drainage, geomorphology in weighted overlay technique (WOT) with decision rules were used to identify suitable sites for mechanical structures and areas for agronomic and biological measures of soil conservation. The Kodar reservoir is situated on river Kodar, a tributary of river Mahanadi in Chhattisgarh state of India has been selected for the study and divided in sixty seven sub-watersheds where nine EHPs were estimated and participated in Saaty's AHP tool for identification of priority sub-watersheds. From the analysis, 117 km^2 area of Kodar catchment can be put for intensify soil conservation measures because of high and very high priorities. The CAT plan for Kodar catchment consists of 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams under mechanical measures with 101.61 ha land for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land under biological measures. Under Panchayati rules in India, the gram panchayats are

considered the administrative units for implementation of various conservation works and the areas of various agronomic and biological measures and mechanical structures suggested for different gram panchayats will be helpful for local administration to work in better way.

Key words: analytical hierarchal process (AHP); CAT plan; geomorphology; prioritization; soil loss

Introduction

The soil erosion in catchment areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the catchment areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Soil being one of the potential resources of a watershed demands proper conservation and management and it could only be possible if its degree of degradation is assessed properly. The catchments and watersheds have been identified as the planning units for administrative purpose to conserve soil and water resources in CAT plan (FAO, 1985; 1987; Honore, 1999; Khan, 1999). The catchment area treatment plan pertains to preparation of a management plan for treatment of erosion prone area of the catchment through agronomic, biological and mechanical measures. A well designed CAT plan should not only control the sedimentation of the reservoir but also provide a life support system to the local population through their active involvement in soil conservation and livelihood works (Jaiswal et al, 2014a). The development of CAT plan for a watershed or catchment essentially comprises the prioritization of erosion prone sub-watersheds or areas, selection of suitable conservation measures, implementation and impact assessment (Jaiswal et al, 2012).

The prioritization of watershed helps in taking up soil conservation measures on the priority basis. Jain and Goel (2002) suggested an index based approach based on surface factor including soil type, vegetation, slope and various catchment properties such as drainage density, form factor, etc for watershed prioritization. Panda et al. (2005) and Shinde et al. (2010) described soil conservation planning methods on the basis of the quantified soil erosion rate in different catchments. The soil erosion rate was determined as a function of land topography, soil texture, land use/land cover, rainfall erosivity and crop management and practice in the watershed using the Universal Soil Loss Equation (for Indian conditions), remote sensing imagery, and GIS. Khan et al. (2001) used sediment yield index (SYI) for priority watershed delineation with the objective of selecting watersheds to undertake soil and water conservation measures using remote sensing and Geographical Information System (GIS) techniques. Vittala et al. (2004), Chopra et al. (2005), Hlaing et al (2008), Sharma et al. (2010), Akram et. Al, 2009, Mishra and Nagarajan (2010) and several others used geomorphological characteristics such as stream order, stream length, stream frequency, drainage density, texture ratio, farm factor, circulatory ratio, elongation ratio, bifurcation ratio and compactness ratio for prioritization of sub-watersheds in different watersheds in India.

The remote sensing and Geographical System (GIS) have been found very useful in the field of CAT development and prioritization of sub-watersheds by coupling spatial information on various soil erosion parameters and natural resource conservation. The remotely sensed data has the advantage of providing synoptic view and large area coverage, which impart knowledge about conditions of the earth surface that change over the period of time. GIS has held in making a number of useful suggestions for the development of the watershed. It allows variety of manipulation including map measurement; map overlay transformation, graphic design and database management etc. Shrimali et al. (2001) presented mapping, monitoring and prioritizing the areas based on their susceptibility to degradation using remote sensing and GIS. Remote sensing and Geographic Information Systems are effective tools for inventory, monitoring and management of spatially distributed resources. Recent studies revealed that remote sensing and GIS techniques are of great use in characterization and prioritization of watershed areas (Pandey et al., 2007; Yoshino and

Ishioka, 2005; Chowdhary et al., 2004; Sharma et al., 2001; Khan et al., 2001; Sidhu et al., 1998).

An effective CAT plan of a water resources project is a key factor to make the project eco-friendly and sustainable. Tyagi and Joshi (1994) developed catchment area treatment plan for Himalayan region and suggested contour bunding, graded bunding, bench terracing, strip cropping and mixed cropping for soil conservation. Pandey et al. (2007) divided Karso watershed of Hazaribagh, Jharkhand (India) into 200 × 200 m grid cells and average annual sediment yields were estimated for each cell of the watershed to identify the critically prone areas of watershed for development of CAT plan. In the present study, based on prioritization results of Saaty's analytical hierarchical process (AHP), spatial distribution of agronomic and biological measures and site specific mechanical measures were identified for Kodar reservoir catchment in Chhattisgarh state of India.

Study Area

The Kodar reservoir is constructed across river Kodar, a tributary of river Mahanadi. The dam is constructed on Raipur – Sambalpur national highway at a distance of 65 km from Raipur near village Kowajhar in Mahasamund district. The base map showing location of Kodar reservoir has been given in Fig 1. The catchment area of the river up to dam site is 317.17 km2. and mean annual rainfall in the catchment area is about 1433.1 mm. The dead storage capacity and gross storage capacity of reservoir are 11.33 Mm3 and 160.35 Mm3 respectively. The Kodar dam is an earthen dam of 2363 m length, height of 23.32 m and waste weir of 183m long to pass designed flood and head regulators on both the flanks to feed the canal system. Two canals of length 23.30 km (Left Bank Canal) and 10.60 km (Right Bank Canal) are envisaged from the sluices located on left and right flanks of the earthen dam to provide irrigation to 16,066 ha and 7,406 ha respectively. The topography of the catchment area of Kodar reservoir is undulating, soil is loamy type and most of area is under agriculture from where soil loss is more due to lack of conservation measures.

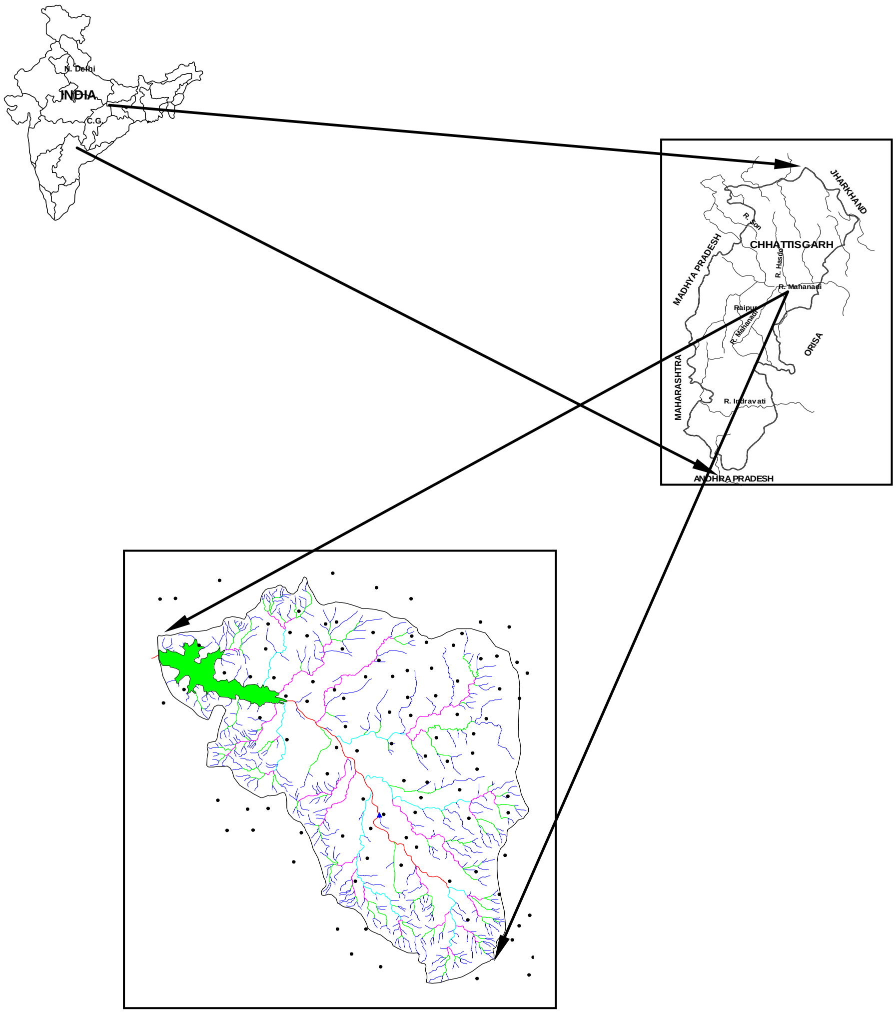


Fig. 1. Base map of Kodar reservoir in Chhattisgarh (India).

Methodology

The methodology for preparation of management plan based on scientific inputs and knowledge base consist of prioritization of sub-watersheds based on multiple erosion hazard parameters under Saaty's AHP decision support tool and devise areas suitable for soil conservation measures based on weighted overlay technique in GIS environment.

Identification of priority sub-watersheds

The Saaty's AHP has been applied which is a structured technique to deal with complex decision by building a hierarchy (ranking) among decision elements and then making comparisons between each pair in each cluster (matrix). This gives a weighting for each element within a cluster (or level of the hierarchy) and also a consistency ratio (useful for checking the consistency of the data). The AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team thus reducing bias in decision making. The AHP is very useful when the decision-making process is complex, for instance, by being unstructured. Indeed, when the decision cycle involves taking into account a variety of multiple criteria which rating is based on a multiple-value choice, AHP splits the overall problem to solve into as many evaluations of lesser importance, while keeping at the same time their part in the global decision. The steps for applying AHP include decomposing, weighing, evaluating and selection. In the present study, nine spatially distributed erosion hazard parameters including soil based on topography, geomorphology, soil loss and yield criterions were used and weigh in AHP for determination of relative hazard ultimately provided priority sub-watersheds. The details regarding AHP based prioritization can be seen in different literature (Ranjan, 2013; Jaiswal et al 2014b)

Development of Catchment Area Treatment Plan

The drainage line treatment is very important and most relevant aspect in CAT plan for arresting the soil erosion and checking the velocity of runoff, harnessing the rainwater lost through drains and impounding them through various soil and water conservation measures would result in improving the water resources of an area. The soil and water conservation measures required in CAT plan can be classified in to three broad groups as, mechanical measures, agronomic measures and biological measures being described below:

The mechanical measures of soil and water conservation include various engineering techniques and structures constructed across the direction of the flow of rainwater with the objective of division of long slopes in to a series of shorter ones in order to reduce the velocity of runoff water thereby reduce the soil and water losses. The important mechanical measures are check dams, gully plugs, boulder bunds, percolation tanks, farm ponds, bench terracing, contour bunding, graded bunding, land levelling etc. The agronomic measures of soil and water conservation help in reducing the impact of raindrops through interception and thus reduce splash erosion. These practices also help in increasing infiltration rate and thereby reduce runoff and overland flow. The contour farming, strip cropping, vegetative barriers, grassed waterways, mulching etc are some of important agronomic measures. The biological measures are preferred in catchment area treatment plan as they are eco- friendly, sustainable and cost effective. The underlying principle here is that soil erodes only if it is bare and expose to erosive forces and if the soil can be kept under a permanent or near-permanent cover of vegetation, then little or no erosion will occur. The agroforestry, grazing management, affroestation, reforestation etc .are some of the important biological measure in CAT plan.

The CAT plan was prepared by weighted overlaying technique of spatially distributed maps using ARC GIS software. The land use map obtained from digital image analysis of LISS IV RS data, soil, geology, geomorphology, slope and sub-watershed themes were built as raster features, whereas streams and roads were built as line features. All the thematic maps were overlaid in GIS environment by giving suitable weights and appropriate conservation measures along with sites for mechanical measures have been identified using the criterions given in Table 1. The slope, land use and soil map were joined spatially and all combinations were examined for suitability of various agronomic and biological measures considering different combination of soil and slope for agriculture land. After this a separate column has been added and suitable conservation measures given in the column. The map generated from this column can be used for identification of areas for agronomic measures for agricultural land and biological measures for barren and open forest.

Table 1. Criteria adopted in suggesting soil and water conservation measures

Structure	Slope (%)	Drainage	Soil	Land use/ Land cover	Geomorphological land form	Advantage
Bench Terracing	6-10%	_	Shallow Soil not having permeability	Agriculture Field	Steep slope, low rainfall	Uniform impounding of water, Reduced the existing steep slope to mild slope.
Contour Farming	2-10%	_	Alluvial and black deep lateritic soils	Agriculture Field	Area where runoff is 10% of precipitation lower point of natural Depressions	Prevention of soil erosion, increased supply of moisture to the plant, control flash floods
Strip Cropping	< 3	_	All type	Agriculture Field	Gently sloping land	Shortening length of slope , reducing velocity of runoff,
Land leveling	any slope	_	Non Shallow Soil		Agricultural Land with rainfall	Reduce the velocity of water, reduced the chance of soil erosion
Check dam	more than 3%	3rd order & higher stream	Sandy Gravel zone	waste land on either bank, forest land	Buried pediment	Surface water harvesting life irrigation, Drinking water facility, partially recharges structure.
Vegetative barriers	Perpendicular to the dominant slope less than 10%	_	All type	Agriculture Land	On crop land fields where water or wind erosion is a problem, or where water to be needs conserved.	Facilitate benching of sloping topography, reduced surface runoff, divert runoff to a stable outlet, provide wildlife habitat
Farm Pond	1-2%	_	Semi Pervious to impervious, All soil except in light textured soils	Single crop area	Area where runoff is 10% of precipitation lower point of natural depressions.	Life saving irrigation , drinking water for live stock horticulture development recharge to ground water
Boulder Bund	2-3%	1st to 3nd	severe soil erosion semi pervious to pervious	Single crop area	Buried pediment (M),Buried pediment (S),Buried pediplain, pediment	Soil conservation runoff retardant, delay recharge of water, Recharge to ground water.
Gully Plug	2-3%	1st to 2nd	Soil erosion	Forest and waste land	pediment, Buried pediment (S)	Soil conservation runoff retardant structure's soil moisture, recharge to ground water.
Percolation tank	2-3 %	3rd to 4th	Semi pervious to pervious	waste land	Buried pediment fractured and weathered rock zone	Induced artificial drinking water, well in downstream.
Contour Bund	1-6%	_	All type except deep clayey soils	Agricultural land	steep slope, low rainfall	Reduced soil loss, increase infiltration time, reduced velocity of flow
Graded Bunding	0.1-0.4%	_	Clay soil even with lesser rainfall	Agricultural land	on crop land fields where water or wind erosion is a problem as where water to be needs conserved	Acts primarily as drainage channels for reducing and regulating the excess runoff water and draining the same with a mild and non erosive velocity.

Analysis of Results

Assessment of Priority Sub-watersheds

For prioritization purposes, the whole Kodar catchment has been divided into sixty seven sub-watersheds with area ranging from 0.05 sq. km. to 13.05 sq. km. In the present study, spatial distribution of all selected EHPs including soil loss using USLE/RUSLE model, sediment production rate, sediment yield, sediment transport index or sediment transport index, slope, drainage density, channel frequency, form factor and circulatory ratio for all 67 sub-watersheds in Kodar reservoir catchment have been computed and converted to its normalized value. Considering the relative importance of each parameter on others, the priority matrix and subsequently the weights for each parameters using Saaty's AHP have been computed. The soil loss being the most important parameter got weight of 0.33 while circulatory ratio attained minimum weight of 0.02 in Satty's AHP decision tool (NIH, 2013). The final priority for each watershed was determined as a product of multiplication of priority weights and normalized values of all parameters for categorization in various groups including very high, high, moderate, low and very low priority groups. The sub-watershed map and its priority of Kodar catchment has been given in Fig. 2 and areas under different priorities in Table 2.

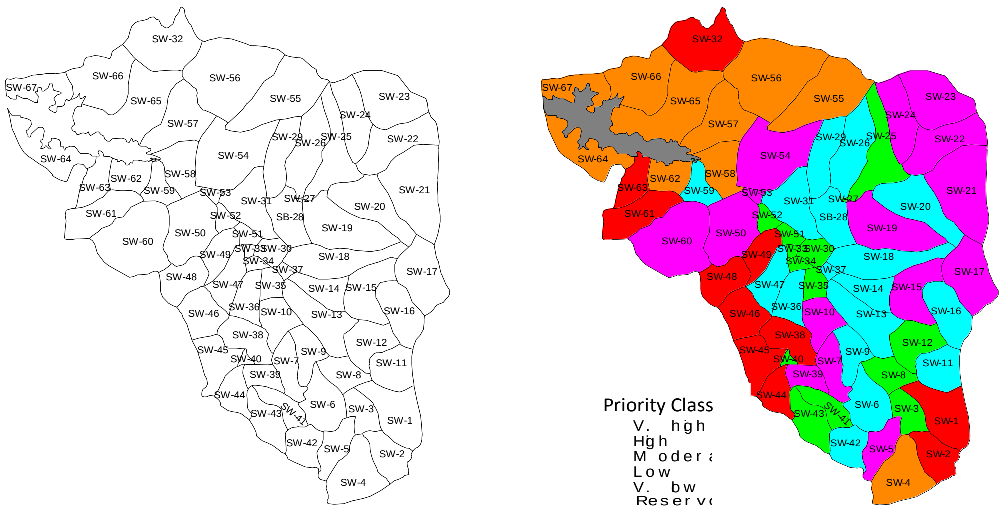


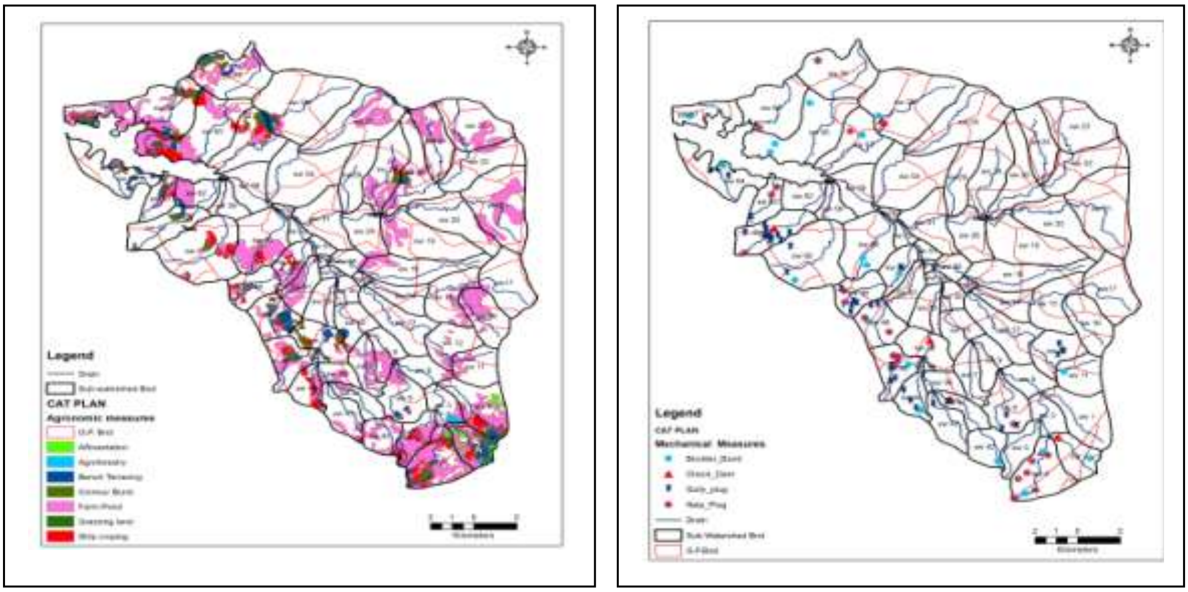
Fig. 2. Sub division of watershed and priority sub-watersheds in Kodar reservoir catchment

Table 2. Sub-watersheds under different priorities in Kodar catchment

S.N.	Priority	Range of	Watershed	No. of watershed	Total (sq. km)
1.	V. low	Less than 0.17	SW-3, SW-8, SW-12, SW-25, SW-27,SW-30, SW-33, SW-34, SW-35, SW-40, SW-41, SW-43, SW-51 and SW-52	14	29.00
2.	Low	0.20 to 0.17	SW-6, SW-9, SW-11, SW-13, SW-14, SW-16, SW-18, SW-20, SW-26, SW-28, SW-29, SW-31, SW-36, SW-37, SW-42, SW-47 and SW-59	17	72.11
3.	Moderate	0.25 to 0.20	SW-5, SW-7, SW-10, SW-15, SW-17, SW-19, SW-21, SW-22, SW-23, SW-24, SW-39, SW-50, SW-53, SW-54 and SW-60	15	88.75
4.	High	0.30 to 0.25	SW-4, SW-55, SW-56, SW-57, SW-58, SW-62, SW-64, SW-65, SW-66 and SW-67	10	70.03
5.	V. high	Up to 0.30	SW-1, SW-2, SW -32, SW-38, SW-44, SW-45, SW -46, SW-48, SW-49, SW -61 and SW-63	11	47.81
6.	Total area				307.71

CAT Plan

The CAT plan for the Kodar catchment has been designed by crossing of landuse, soil, slope and geomorphology maps. The standard guidelines have been used for demarcation of areas suitable for agronomic and biological measure. The spatial join of tables was used to determine suitable areas under different gram panchayats in the study area. The mechanical measures in the catchment have also been suggested including check dams, gully plug, nala plugs and boulder bunds considering suitable criterions on drainage lines. The map showing CAT plan of the study area consisting of suitable areas for agronomic and biological soil conservation measures and location of mechanical measures have been given in Fig. 3. The CAT plan suggests 101.61 ha land for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land with 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams in Kodar catchment. The agronomic measures should be used in all agriculture fields. The gram panchayat wise suggested areas for soil conservation measures will be useful for local administration for implementation of CAT plan.



(a) Agronomic and biological measures (b) Mechanical measures

Fig. 3. Areas for agronomic and biological measures and sites for mechanical structures

Conclusions

For development of CAT plan for environmentally stressed areas in Kodar reservoir, various thematic layers such as geology, land use, soil, slope, drainage, geomorphology have been used for selection of soil and water conservation measures in sub-watersheds of Kodar reservoir catchments. It may be concluded that nearly 41 sq. km area in Kodar catchment is suitable for farm ponds. The CAT plan suggests 101.61 ha land can be used for afforestation, 114.86 ha for agro-forestry and 11.41 ha land for development of grazing land which will be beneficial for rural population for their additional income and environmental health of the watershed. The mechanical measure under the CAT plan of Kodar reservoir catchment includes 37 gully plugs, 22 nala plugs, 21 boulder bunds and 6 check dams. Gram panchayats break up of agronomic, biological and mechanical measures have been provided in the study will be useful for administrative authority to take up these measures systematically. The design of check dams provided in the report will be helpful to implement agencies for cost estimation and construction. It is recommended that the participation of local governance, rural development organizations and local people should be ensured in the implementation of

CAT plan. The awareness regarding agronomic and biological measures should be developed among the farmers by local level awareness program.

References

Akram J, Yousuf K M and Rizwan A. 2009. Prioritization of Sub-watersheds Based on Morphometric and Land use Analysis using Remote Sensing and GIS Techniques, J. Indian Soc. Remote Sens. 37: 261-274.

Chopra R, Raman D D and Sharma P K. 2005. Morphometric Analysis of Sub-watersheds in Gurdaspur District, Punjab using Remote Sensing and GIS Techniques. J. Indian Soc. Remote Sens. 33(4): 532-539.

Chowdhary V M, Chakraborthy D, Jeyaram A, Krishna Murthy Y V N, Sharma J R and Dadhwal V K. 2013. Multicriteria Decision Making Approach for Watershed Prioritization using Hierarchy Process Technique and GIS, Water Resour. Manag. 27(10): 3555‑3571. doi: 10.1007/s11269-013-0364-6

Food & Agricultural Organization. 1985. Watershed Development with Special Reference to Soil and Water Conservation, Soil Bulletin 44, Rome.

Food & Agricultural Organizations. 1987. Soil and Water Conservation in Semi-arid Areas, Soil Bulletin *57,* Rome.

Hlaing T K, Haruyama S and Maung A M. 2008. Using GIS-Based Distributed Soil Loss Modeling and Morphometric Analysis to Prioritize Watershed for Soil Conservation in Bago River Basin of Lower Myanmar, Earth. Sci. Chin. 2(4): 465‑478.

Honore G. 1999. Our Land, Ourselves- A Practical Guide to Watershed Management in India, Indo-German Bilateral Project, “Watershed Management”, New Delhi, India.

Jain S K and Goel M K. 2002. Assessing the Vulnerability to Soil Erosion of the Ukai Dam Catchments using Remote Sensing and GIS, Hydrol. Sci. 47(1): 31–40.

Jaiswal R K, Dehariya D K,NemaA K, Thomas T and Galkate R V. 2012. Soil Erosion based Prioritization and Development of CAT Plan for Catchment of Rangawan Reservoir in Bundelkhand Region of Madhya Pradesh (India), Nat. Symp. Water Resour. Manage. Changing Environ. (WARMICE 2012) Roorkee (India) Feb 8‑9 2012: 409‑420.

Jaiswal R K, Thomas T, Galkate R V, Ghosh N C and Singh S. 2014a. Catchment Area Treatment (CAT) Plan and Crop Area Optimization for Integrated Management in a Water Resource Project, J. Inst. Eng. India Ser. A. DOI 10.1007/s40030-014-0052-4

Jaiswal R K, Thomas T, Galkate R V, Ghosh N C and Singh S. 2014b. Watershed Prioritization Using Saaty’s AHP Based Decision Support for Soil Conservation Measures, Water Resour. Manag. doi:10.1007/s11269-013-0494-x

Khan M A. 1999. Water Balance and Hydrochemistry of Precipitation Components in Forested Ecosystem in the Arid Zone of Rajasthan, India, Hydrol. Sci. J. 44: 149-161.

Khan M A, Gupta V P and Moharanam P C. 2001. Watershed Prioritization Using Remote Sensing and Geographical Information System: A Case Study from Guhiya, India, J. Arid Environ. 49: 465-475.

Mishra S S and Nagarajan R. 2010. Morphometric Analysis and Prioritization of Subwatersheds Using GIS and Remote Sensing Techniques: A Case Study of Odisha, India, Int. J. Geomat. Geosci. 1(3): 501-510.

National Institute of Hydrology. 2013. Study of Reservoir Sedimentation, Impact Assessment & Development of Catchment Area Treatment Plan for Kodar Reservoir in Chhattisgarh State, TR /BR-1/2013, World Bank Funded PDS under HP II (Contact No. 4749-IN).

Panda S S, Andrianasolo H and Steele D D. 2005. Application of Geotechnology to Watershed Soil Conservation Planning at the Field Scale, J. Environ. Hydrol. 13(16): 1-22.

Pandey A, Chowdary V M and Mal B C. 2007. Identification of Critical Erosion Prone Areas in the Small Agricultural Watershed using USLE, GIS and Remote Sensing, Water Resour. Manage. 21: 729-746.

Ranjan R, Jhariya G, Jaiswal R K. 2013. Saaty’s Analytical Hierarchical Process based Prioritization of Sub-watersheds of Bina River Basin using Remote Sensing and GIS, Am. Sci. Res. J. Engg. Technol. Sci. 3(1): 36-55.

Sharma J C, Prasad J, Saha S K and Pande L M. 2001. Watershed Prioritization Based on Sediment Yield Index in Eastern Part of Doon Valley Using RS and GIS, Indian J. Soil Cons. 29 (1): 7-13.

Sharma S K, Rajput G S, Tignath S and Pandey R P. 2010. Morphometric Analysis and Prioritization of a Watershed using GIS, J. Indian Water. Res. Soc. 30 (2): 33-39.

Shinde V, Tiwari K N, Singh M. 2010. Prioritization of Micro Watersheds on the Basis of Soil erosion Hazard using Remote Sensing and Geographic Information System, Int. J.Water Resour. Environ. Engg. 2(3): 130-136.

Shrimali S S, Aggarwal S P and Samra J S. 2001. Prioritizing Erosion-Prone Areas in Hills using Remote Sensing and GIS - A Case Study of the Sukhna Lake Catchment, Northern India, Int. J. Applied Earth Observ. Geoinformatics. 3 (1): 54-60.

Sidhu G S, Das T H, Singh R S, Sharma R K and Ravishankar T. 1998. Remote Sensing and GIS Techniques for Prioritization of Watershed: A Case Study in Upper Mackkund Watershed, Andhra Pradesh, Indian J. Soil Cons. 2 (3): 71-75.

Tyagi P C and Joshi B P. 1994. Resources Conservation Techniques for Sustainable Crop Production in Western Himalayan Region, Indian J. Soil. Cons. 22 (1 & 2): 72-83.

Vittala S S, Govindaiah S and Gowda H H. 2004. Morphometric Analysis of Sub-Watersheds in the Pavagada Area of Tumkar District, South India using Remote Sensing and GIS Techniques, J. Indian Soc. Remote Sens. 32 (4): 351-362.

Yoshino K and Ishioka Y. 2005. Guidelines for Soil Conservation towards Integrated Basin Management for Sustainable Development: A New Approach Based on the Assessment of Soil Loss Risk Using Remote Sensing and GIS, Paddy Water Environ. 3: 235-247.