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Erosion risk mapping in Peruguda micro-watershed of semi-arid tropics of India using remote sensing and GIS

S.K. Gangopadhyay[1], G.P. Obi Reddy[2] and Dipak Sarkar[2]

[1]*National Bureau of Soil Survey and Land Use Planning (ICAR), Regional Centre, Kolkata-700091;* [2]*National Bureau of Soil Survey and Land Use Planning (ICAR), Amravati Road, Nagpur-440 033.*
[1]*Email: samarskg@gmail.com*

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ABSTRACT

Soils of Peruguda micro-watershed, developed on geologically complex terrain under semi-arid tropical climate of Ranga Reddy district, Andhra Pradesh, India were studied for their morphological, physical and chemical characteristics with a view to map the erosion risk zones using Remote Sensing and Geographic Information System (GIS). Soils developed under seven physiographic units *viz.,* mesa top, mesa shoulder, mesa side slope, mesa foot slope, rocky ridge, undulating plain and narrow to broad valley were mapped and 23 soil mapping units have been identified. The soils vary in depth, drainage, surface texture, pH and organic carbon. The study of land use/land cover indicates that about 44.2% area is under rainfed agriculture. Based on the image characteristics, soil and site characteristics and land use/land cover, four erosion classes have been identified in the micro-watershed. The soils of side slopes of undulating plain, mesa shoulder, dissected valley fill as evidenced by the dark to light blue, yellow, white mixed tone covering 33.59% area of the micro-watershed is under the threat of severe erosion hazard while soil of mesa side slope, rocky ridge and narrow to broad valley, covering an area of 5.01%, is under very severe erosion hazard as evidenced by the dark blue, yellow and white mixed tone in the satellite imagery. The study indicates an amount of 8940.2 to 17812.4 tonnes of soil loss yr^{-1} from the micro-watershed. The mapping of erosion risk zones using remote sensing and GIS in the micro-watershed helped to identity high erosion risk zones, which needs more attention towards the protection and conservation of natural resources through suitable soil and water conservation measures.

1. INTRODUCTION

Decline in land quality is attributed to various land degradation processes, amongst them water induced erosion is single most destructive one (Lal, 2001). Soil erosion is associated with about 85% of land degradation in the world, causing up to a 17% reduction in crop productivity (Oldeman *et al.*, 1990). The Food and Agriculture Organization (FAO, 1980) defines the concept of land degradation as the deterioration or total loss of the productive capacity of the soils for present and future use. Also about 1.9 billion ha of land worldwide are affected by land degradation (United Nations, 1997). The countries of the developing world, particularly, those in the arid and semi-arid zones, are the most seriously affected (UNEP, 1986). The most significant landscape function affected by land degradation is the hydrologic balance of catchments. Unfavourable surface soil characteristics of degraded lands and a lack of adequate plant cover lead to reduced surface retention and infiltration, and to higher surface runoff. This results not only in reduced soil moisture content in the soil profile, but also increased rates of soil erosion (Lal, 1990).

The data on the nature, extent and kinds of degraded lands of India have been projected by various agencies from time to time (National Commission on Agriculture, 1976; Bhumbla and Khare, 1984; Sehgal and Abrol, 1994). The problem of soil erosion is prevalent over about 53% of the total land area of India (Dhruvanarayana & Ram Babu, 1983). Recently NBSS&LUP in collaboration with other organizations has harmonised degraded and wastelands datasets of India and reported about 120.72 million hectare (m ha) is under various categories of degraded and wastelands datasets (ICAR and NAAS, 2010). Soil erosion is one of the important land degradation processes and it affects not only genesis and fertility status of the soils but also land use. Soil erosion due to water is a serious problem in semi-arid and sub-humid areas of India (Nalatwadmath, 2007). Soil erosion, generally associated with agricultural practices in tropical and semi-arid countries, leads to decline in soil fertility, brings on a series of negative impacts of environmental problems, and has become a threat to sustainable agricultural production and water quality in the region. It has been estimated that in India about 5334 million tonnes of soil are being removed annually due to various reasons (Dhruvanarayana and Babu, 1983). They also estimated that soils supporting rainfed agriculture are subject to severe sheet and rill erosion with an annual soil loss of 20-100 t $ha^{-1}yr^{-1}$. Often, the intensity of land degradation or soil erosion is taken as the basis for watersheds prioritization (Chaudary and Sharma, 1998). The red soils in India covering about 70 m ha, are another major soil group subject to severe problem of water erosion. Since, soil is the base for every production system, knowledge of soil properties, their problems and potential at watershed level is extremely important for assessing the soil loss.

Remote sensing technology integrated with conventional techniques has emerged an efficient, speedy, cost effective tool for the management of natural resources. Information on vegetation cover, rain use efficiency, surface run-off and soil erosion can be derived from remotely sensed data. Such information can be used to highlight the areas, which are most susceptible to degradation (Symeonakis and Drake, 2004). A large number of studies have been carried out using different methods of remote sensing and GIS to determine the extent of land degradation. Karale *et al.* (1983); Pickup and Nelson (1984); Pickup and Chewings (1988); Dwivedi (1992); Dwivedi *et al.* (1997); Sidhu *et al.* (1998); Kurothe *et al.* (2001); Sharma *et al.* (2001) and Vrieling (2002) have developed various techniques for mapping, monitoring and assessing degraded lands.Deshmukh *et al.* (2007) found that integration of GIS with Modified Universal Soil Loss Equation (MUSLE) is found useful in assessment of sediment yield in Banha catchment of upper Damodar valley in Jharkhand state. The information of erosion risk areas at the micro-watershed level particularly in the semi-arid tropics in India is very meager. Spatial and quantitative information on soil erosion on a micro-watershed scale contributes significantly to the planning for soil conservation, erosion control, and management of the watershed environment. In the present study, an attempt has been made to quantify the soil loss and to map the erosion risk in geologically complex terrain of Peruguda micro-watershed in semi-arid tropics of Ranga Reddy district, Andhra Pradesh, India using remote sensing and GIS techniques.

2. MATERIALS AND METHODS

The Peruguda micro-watershed of Bachpalli sub-watershed under Yeliminedu Vagu macro-watershed is situated between 17°02'13" to 17°02'49" N latitude and 78°25'35" to 78°26'14" E longitude in Ranga Reddy district of Andhra Pradesh covering an area of 677.78 ha and consists of Peruguda, Akabarjaguda and part of Nednur and Bachpalli villages. The study area is represented by granitic terrain with undulating topography. The upper relief zone comprises basalt with conspicuous mesa top. The main stream is developed by alluvial material carried and deposited from upstreams. The broad physiography units in the study area are mesa top, side slopes, foot slopes, summit under basaltic landscapes and summit under granitic landscapes and narrow to broad valley derived from alluvium. The area is drained by Yeliminedu vagu and its numerous tributaries which are seasonal in nature. The drainage intensity in the hilly areas and upper slopes is high and moderate in the lower slopes. The drainage pattern is dendritic. The elevation of the area ranges from 620 to 700 m above msl. The relief of the area is mostly normal to sub-normal in the valley except- the mesa slopes and ridges where it is excessive. The study area is characterised by semi-arid tropical climate with a mean annual rainfall of 764 mm of which nearly 80% is received from June to September. The annual potential evapo-transpiration (1756 mm) far exceeds the precipitation. Evaporation rates are highest in May (15 mm/day). The mean annual rainfall covers about 48% of the mean annual PET in most of the years. The vegetation is tropical dry deciduous type and common trees are *Acacia arabica* (babul), *Anona squamosa* (sitaphal), *Azadirachta indica* (neem) and *Ficus religiosa* (pipal). The common grass types are *Cynodan daclylan* (*Garica gaddi*).

Interpretation of Remote Sensing Data

The Peruguda mico watershed area was delineated from the drainage pattern of the Yeliminedu vagu. It was delineated from the Yeliminedu vagu macro watershed and Bachpalli sub watersheds based on the minor stream pattern. The micro-watershed area is divided into nine nano watersheds with the help of stereoscopic analysis of aerial photos. Indian Remote Sensing (IRS)-1C LISS-III merged with PAN data of Peruguda micro-watershed (Path 99 Row 60) of 5th May, 1996 (1:12,500 scale) was geo-referenced and was used for visual interpretation for delineation of the physiographic units based on the photo elements like tone, texture, size, shape, pattern, association, *etc.*The relationship among the image characteristics and physiographic units has been established (Table 1). The watershed was interpreted stereoscopically on 1:10,000 scale using Panchromatic aerial photographs for detailed analysis of the terrain. Initially broad physiographic units were identified with the help of SOl toposheet at 1:50,000 scale. The physiographic map thus generated was enlarged to a scale of 1:4000 scale and the ground truth was checked

Table: 1
Relationship among the image characteristics and physiographic units in Peruguda micro-watershed

Geology	Broad Landform units	Tone/ Colour	Texture	Shape and Size	Pattern	Association	Present land use
Basalt	Mesa top	Dark blue blackish blue	to Fine	Varying	Continuous elongate	Associated with elevated, plain land with fine soils having swelling and shrinking properties, mostly cultivated in kharif season	Irrigated dry lands, irrigated wetlands and barren lands
	Mesa shoulders	Dark and light blue mixed with white, gray and pink	Medium coarse	to Varying	Scattered	Associated with shallow, gravelly soils at slightly higher elevation which is mainly used for rainfed cultivation	Irrigated dry lands, and irrigated wetlands
	Mesa side slopes	Dark to light blue white and pink mixed	Fine medium	to Varying	Patchy	Association with shallow, gravelly soils on side slope with severe erosion and stoniness which require appropriate soil-water conservation measure	Predominantly rainfed agriculture and barren lands in isolated places
	Mesa foot slopes	Dark to light blue and white mixed	Fine	Varying	Patchy	Associated with moderately deep soil on moderately sloping foot slope cultivated in kharif season and mostly remains fallow in rabi season	Predominantly rainfed agriculture and barren lands in isolated places
Granite	Rocky ridges	Dark blue with yellow and white mixed	Fine to medium	Varying	Elongated/ Dendritic	Associated with shallow soils on rocky ridge with severe erosion and stoniness, mostly remains fallow may be used for social forestry purposes	Predominantly barren land
	Granitic undulating plains-	Blue, white and gray mixed	Medium to coarse	Varying	Continuous	Associated with elevated plain land and adjoining narrow valley mostly cultivated in low lands may be cultivated for vegetables in rabi season	Predominantly rainfed agri-culture. Irrigated wetlands and barren lands are noticed in isolated places
Alluvium	Narrow to broad valley	Light blue, yellow, white and pink mixed	Medium to coarse	Varying	Continuous	Associated with low lying areas and used for cultivation of paddy in kharif season and vegetables in rabi season	Predominantly rainfed dry land and wet agriculture in isolated places.

with the help of cadastral map of the area (1:4000 scale) and the base map was produced by overlying the remotely sensed data with the ground truth checking.

Soil Resource Inventory and Mapping

The soil profiles were exposed and the horizon wise soils were studied for their morphological, physical and chemical characteristics following standard procedure (AIS & LUS, 1970; Black, 1965; Jackson, 1967). The soils were classified as per Soil Taxonomy (Soil Survey Staff, 1998). The soil map prepared after establishing physiography-soil relationship and assessed the kind and distribution of soils in the micro-watershed along with their extent.

Land Use/Land Cover Mapping

The land use /land cover map of the area was generated based on the interpretation of the Aerial Photographs and satellite imagery of both *kharif* and *rabi* seasons followed by ground truth checking. The imagery was visually interpreted to prepare land use/land cover map using knowledge-based supervised classification. Based on the heterogeneity of the land use/land cover in the micro-watershed, eight land cover classes have been identified. Each land use/cover class was then validated by visual inspection of original images, reference data, and ground survey of the study area.

Erosion Risk Mapping

The various layers of thematic maps including soil map were prepared by interpretation of satellite data along with cadastral map as inputs to ArcGIS (Ver. 10.0) system for the generation of database. The ultimate maps were generated on 1:25,000 scale after considerable reduction. Using the soil morphological and physico-chemical properties, attribute/non-spatial data was compiled for all the 23 soil mapping units in the micro-watershed. This attribute data was linked to the spatial data of soils by adding items in the polygon attribute table (PAT) of soil coverage following map generalization procedure. These were subsequently reclassified to generate different derivative thematic maps of the study area. In order to assess and delineate distinct erosion risk zones, the thematic information on physiography, slope, soil depth soil drainage, surface texture and pH covers were overlayed in GIS (Sujatha, 2000). The relationship between erosion risk classes and associated parameters viz. slope, landform processes, soil depth and land use/land cover conditions were analysed. The selected erosion risk units were verified in the ground and found in association with the defined characteristics.

3. RESULTS & DISCUSSION

Physiography and Slope

Visual interpretation of FCC's generated from spectral bands 2,3 and 4 in conjugation with detailed ground truth data, seven physiographic units *i.e.* mesa top, mesa shoulder, mesa side slope, mesa foot slope, rocky ridge, undulating plain and narrow to broad valley were identified and delineated (Table 1). In the micro-watershed, using contour information available on Survey Of India (SOI) toposheet (1:25,000 scale) and intensive ground truth checking, total six slope classes viz. nearly level (0-1%), very gently sloping (1-3%), gently sloping (3-5%), moderately sloping (5-10%), strongly sloping (10-15%), moderately steeply sloping (15-30%) have been identified (Table 2). The analysis shows that very gently slope occupies majority of the area (42.6%) followed by gently slope (22.7%), nearly level (20.8%), moderately slope (4.9%), moderately steeply slope (3.8%) and strongly slope (1.2%).

Soils

Based on the slope and position of physiographic units, the seven physiographic units have been further sub divided into 23 landform units. Based on the detailed soil survey conducted in the study area, 23 soil mapping units have been

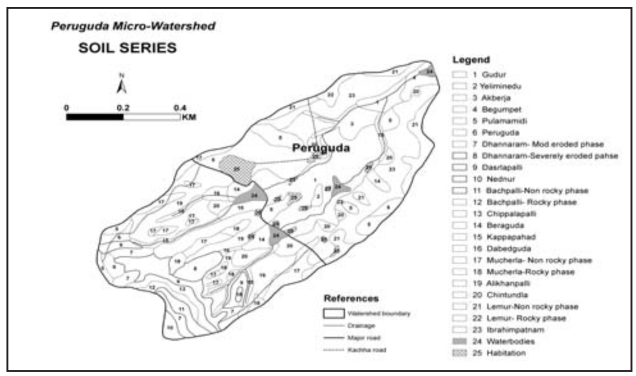

Fig. 1. Soil series map of Peruguda micro-watershed

identified and mapped (Fig. 1 and Table 2). Soil series identified on landform units like Valley (Narrow-level), Valley fill (Dissected) and Mesa top (Central zone) have occupied highest area of 17.20, 15.70 and 14%, respectively of total geographical area of the watershed. Soils developed from basalt are generally black in colour, clayey texture with varying depth. The soils of the mesa shoulders and side slopes are shallow in depth, skeletal in nature and are mostly classified as Lithic Ustorthents. The soils of mesa top, periphery, foot slopes and undulating plains are deep with high clay content and are classified as Typic Haplusterts/ Typic Haplustepts/ Typic Ustorthents. In the granite landscape, except the rocky ridges and side slopes of undulating plain with rills/ gullies and gravel, all the soils are deep, mostly loamy in texture and are classified as Typic Haplustepts/ Typic Ustorthents/ Typic Haplusterts/ Typic Rhodustalfs. The valley soils are mostly very deep, fine - loamy to course - loamy in texture and developed from the deposition of alluvial material carried by the surface runoff water from the surrounding uplands and mostly classified as Udic Ustifluvents.

Soil Depth

Soils of mesa top, periphery, foot slopes and undulating

Table: 2

Erosion risk status of different physiographic units in Peruguda micro-watersheds

Soil map -ping unit	Geology	Landform	Depth	Drainage	Texture	Slope(%)	Erosion	Soil Taxonomy	Area (ha)	%TGA
1	Basalt	Mesa top	Deep	Imperfect	Fine	0-1	Moderate	Fine, montmorillonitic, hyperthermic Typic Haplustert	94.99	14.00
2	Basalt	Mesa top (Periphery)	Moderately deep	Well	Fine	0-1	Slight	Fine, mixed, hyperthermic Typic Ustorthent	2.65	0.40
3	Basalt	Mesa shoulder (Upper part)	Shallow	Excessive	Clayey	3-5	Severe	Clayey, mixed, hyperthermic, Lithic Ustorthent	9.79	1.40
4	Basalt	Mesa shoulder (Lower part)	Shallow	Excessive -skeletal	Clayey	3-5	Severe	Clayey-skeletal, mixed, hyperthermic Lithic Ustorthent	8.02	1.20
5	Basalt	Mesa side slope shallow	Very	Excessive -skeletal	Loamy	15-30	Severe	Loamy-skeletal, mixed, hyperthermic Lithic Ustorthent	25.87	3.80
6	Basalt	Mesa foot slope (Upper smooth)	Deep	Well	Fine	3-5	Moderate	Fine, mixed, hyperthermic, Typic Ustochrept	53.40	7.90
7	Basalt	Mesa foot slope (Upper hills)	Deep	Well	Fine	3-5	Severe	Fine, mixed, hyperthermic, Typic Ustochrept	21.1	3.10
8	Basalt	Mesa foot slope (Lower)	Shallow	Excessive	Clayey	5-10	Severe	Clayey, mixed, hyperthermic, Lithic Ustorthent	10.9	81.60
9	Basalt	Undulating plain (Summit)	Deep	Imperfect	Fine	1-3	Moderate	Fine, montmorillonitic, hyperthermic, Typic Haplustert	25.53	3.80
10	Basalt	Side slope of undulating plain	Shallow	Well	Clayey	3-5	Severe	Clayry, mixed, hyperthermic, Lithic Ustorthent	3.73	0.60
11	Granite	Rocky ridge	Shallow	Excessive	Loamy -skeletal	10-15	Severe	Loamy-skeletal, mixed, hyperthermic, Lithic Ustorthent	8.09	1.20
12	Granite	Undulating plain (Summit smooth)	Moderately deep	Well	Fine-loamy	0-1	Slight	Fine-loamy, mixed, hyperthermic,Typic Ustochrept	6.71	1.00
13	Granite	Undulating plain (Summit-gravel/ stone) deep	Moderately	Well	Coarse -loamy	1-3	Moderate	Coarse-loamy, mixed, hyperthermic, Typic Ustorthent	10.54	1.60

14	Granite	Undulating plain (Summit-Rock outcrop)	Moderately	Well	Coarse	1-3	Moderate	Fine-loamy, mixed, hyperthermic, Typic Ustorthent	12.44	1.80
15	Granite	Side slopes of undulating plain	Deep	Well	Fine-loamy	1-3	Slight	Fine-loamy, mixed, hyperthermic, Typic Haplustalfs	16.78	2.50
16	Granite	Side slopes of undulating plain (Gently undulating)	Deep	Well	Fine-loamy	3-5	Moderate	Fine-loamy, mixed, hyperthermic, Typic Rhodustalfs	12.62	1.90
17	Granite	Side slopes of undulating plain (Un-dulating rills/ gullies)	Moderately deep	Excessive	Loamy-skeletal	3-5	Severe	Loamy-skeletal, mixed, hyperthermic, Typic Ustorthent	33.19	4.90
18	Granite	Side slopes of undulating plain (Un-dulating with gravel)	Moderately deep	Well	Loamy-skeletal	3-5	Severe	Loamy-skeletal, mixed, hyperthermic, Typic Ustorthent	11.82	1.70
19	Granite	Valley (Narrow-level)	Deep	Well	Fine	1-3	Slight	Fine, mixed, hyperthermic Udic Haplustalfs	116.79	17.20
20	Granite	Valley (Narrow-broad)	Moderately deep	Well	Loamy-skeletal	5-10	Very severe	Loamy-skeletal, mixed, hyperthermic, Typic Ustorthent	22.64	3.30
21		Alluvium Valley fill (Level)	Very deep	Moderately well	Coarse-loamy	0-1	Slight	Coarse-loamy, mixed, hyperthermic, Udic Ustifluvents	31.42	4.60
22	Granite	Valley fill (Concave)	Very deep	Imperfect	Coarse-loamy	0-1	Slight	Coarse-loamy, mixed, hyperthermic, Udic Ustifluvents	5.41	0.80
23	Granite	Valley fill (Dissected)	Very deep	Imperfect	Fine-loamy	1-3	Severe	Fine-loamy, mixed, hyperthermic, Udic Ustifluvents	106.41	15.70
		Habitation and tanks	-	-	-	-	-	-	26.85	4.00
Total									677.78	100.00

plains are deep, where as the soils of mesa shoulder and side slopes are shallow in depth. In the granitic landscape, except the rocky ridges and undulating side slopes with rills/gullies and gravels, all the soils are deep. The valley soils are mostly deep and developed from the deposition of alluvial material carried by the surface runoff water from the surrounding uplands. In the micro-watershed, based on the soil information of different soil units, total five depth classes *viz.* very shallow (0-7.5 cm), shallow (7.5-22.5 cm), moderately deep (22.5- 45 cm), deep (45-90 cm) and very deep (> 90 cm) were identified. The data revealed that deep soils occupy major areas (50.3%) followed by very deep (21.1%), moderately deep (14.8%), shallow (6.0%) and very shallow (3.8%), respectively (Fig. 2 and Table 2).

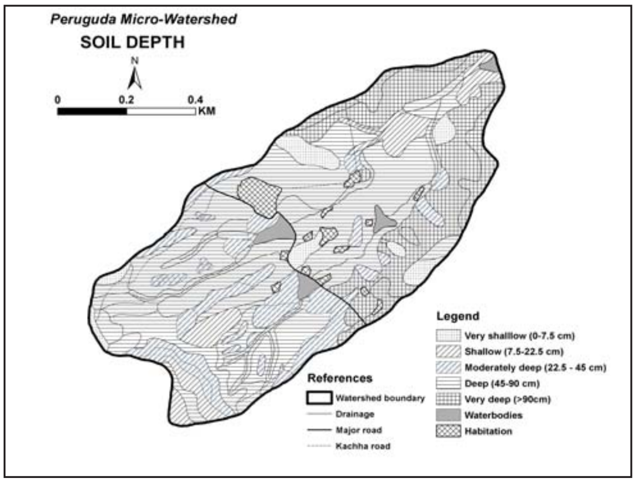

Fig. 2. Soil depth map of Peruguda micro-watershed

Soil Drainage

Soils of mesa top, periphery, foot slopes and undulating plains are imperfect to excessive drainage. Soils of mesa shoulder and side slopes are excessively drained. Well drained soils have been noticed in granitic landscape, except the rocky ridges. The valley soils are coarser and are moderately well to imperfectly drained. Based on the soil information of different soil units, total four drainage classes *viz.*, imperfect, well, moderately well and excessive have been noticed (Table 2).

Surface Texture

Soils developed from basalt are generally black in colour and clayey in texture. The soils of mesa top, periphery, foot slopes and undulating plains are fine to very fine in textural class. Soils of mesa shoulder and side slopes are skeletal in nature. Loamy textured soils have been noticed in granitic landscape, except the rocky ridges and undulating side slopes with rills/gullies and gravels. The valley soils are coarser in texture. In the micro-watershed, based on the soil information of different soil units, total six texture classes *viz.,* fine, clayey, clayey-skeletal, loamy-skeletal, fine-loamy and coarse loamy have been noticed (Fig. 3 and Table 2).

Land Use/Land Cover

The analysis of land use/land cover in the micro-watershed based on two season's satellite data shows that the watershed area is predominantly under rainfed agriculture and it accounts for 44.2 per cent of the micro-watershed area. The principal crops under rainfed agriculture are jowar, pulses, ragi, castor and sunflower. Only 1.5% area is under irrigated dry lands and the major crops under irrigated conditions are rice and vegetables. About 7.8% of the area under irrigated wetlands and 3.1% area is under barren rocky stony waste in the watershed.

Erosion Risk Mapping on Different Geological Formations

Soil erosion is the process of loss of soil from both agriculture and non-agriculture lands. During soil survey in the field, based on the satellite image characteristics, slope gradient, soil site characteristics and land use/land cover, four categories of soil erosion classes have been identified and the type of erosion is given qualitatively as none to slight erosion (e1) for sheet or rill erosion, moderate erosion (e2) for deep rills, severe erosion (e3) for deep gullies and very severe erosion (e4) for ravinous land (Fig. 4 and Table 3). Later, the soil erosion was quantitatively represented by

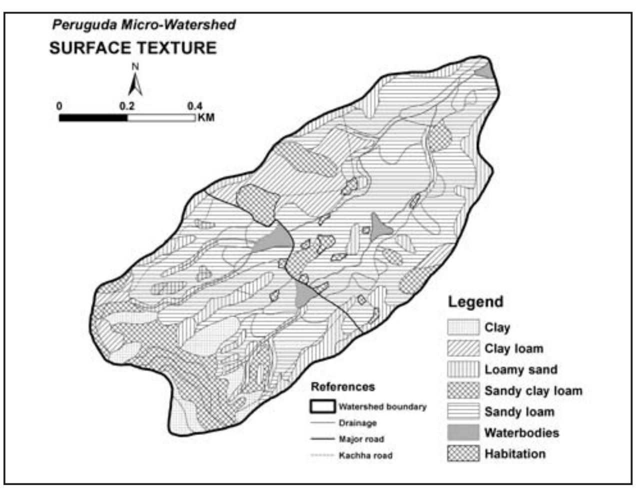

Fig. 3. Surface texture map of Peruguda micro-watershed

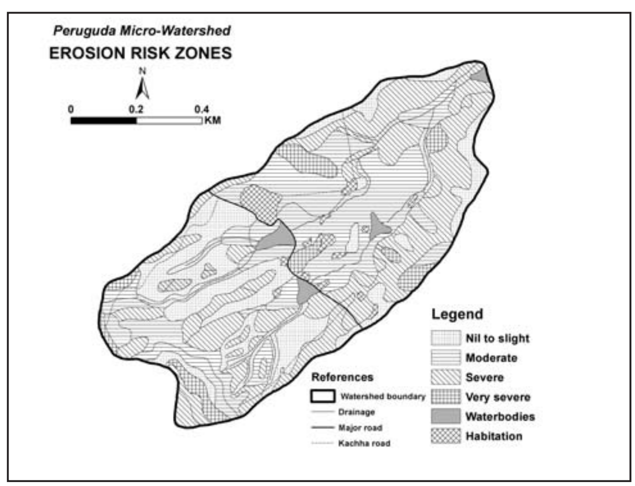

Fig. 4. Erosion risk zones map of Peruguda micro-watershed

Table: 3
Erosion risk zones in Peruguda micro-watershed

Degree of erosion	Kind	Symbol	Soil loss (estimated in t $ha^{-1}yr^{-1}$)	Area (ha)	Area (%)	Ranges in quantified value of soil loss (t yr^{-1})
None or slight	Sheet	e1	5-10	179.76	26.52	898.80-1797.60
Moderate	Rill	e2	10-20	209.52	30.91	2095.2-4190.40
Severe	Gullied	e3	20-40	227.69	33.59	4553.8-9107.60
Very severe	Ravinous	e4	> 40	33.96	5.01	1392.36-2716.80
Others	-	-	-	26.85	3.96	-
Total				677.78	100.00	-

Table: 4
Erosion risk zones and land resource management strategies in Peruguda micro-watershed

Sl. No.	Erosion risk category	Mapping units	Constraints	Conservation strategies	Area (ha)	% of TGA
1	e_1	2.12,15,19,21,22	Some of the units have moderately deep soils and moderately well to imperfect drainage. Coarse loamy texture was also noticed under mapping units 21 and 22.	Double cropping and intensive crop production in irrigated areas. Augment irrigation facilities through tube wells and surface tanks.	179.76	26.52
2	e_2	1,6,9,13,14,16	Some of the units have moderately deep soils and Imperfectly drained.	Increase the irrigation facilities for double cropping and intensive crop production with cereal-pulses/ oil seeds. *In situ* soil and water conservation in moderately deep soils.	209.52	30.91
3	e_3	3,4,7,8,10,17,18, 20,23	Some of the units have shallow and excessively drained soils associated with loamy- skeletal and coarse loamy texture soils.	Fallow lands on upland areas need to be brought under silvi-pasture and agri-horti-system. *In situ* soil and water conservation in shallow soils and check dams need to be constructed on undulating lands.	227.69	33.59
4	e_4	5,11	Very shallow to shallow and excessively drained soils associated with loamy- skeletal soils.	Introduction of pasture, grasses and legumes in very shallow soils. Contour terraces to be constructed on excessively drained soils. Agro-forestry systems need to be developed in marginal lands.	33.96	5.01
	Others	-	-	-	26.85	3.96
	Total	-	-	-	677.78	100.00

the soil loss in tones per ha per year (t ha^{-1} yr^{-1}) (Table 3). The soils of the micro-watershed were grouped under four types of soil erosion classes *viz.* none to slight (5-10 t $ha^{-1}yr^{-1}$) (e_1), moderate (10-20 t $ha^{-1}yr^{-1}$) (e_2), severe (20-40 t $ha^{-1}yr^{-1}$) (e_3), and very severe (>40 t $ha^{-1}yr^{-1}$) (e_4).

Nil to slight erosion risk (e_1)

Soils of mesa top (Periphery), undulating plain (Summit smooth), side slopes of undulating plain (very gently sloping), valley (Narrow-level), valley fill (Level) and valley fill (Concave) have been noticed under none to slight erosion (5-10 t $ha^{-1}yr^{-1}$) risk category. These soils occupy nearly 26.52% of the total area as evidenced by the dark to light blue, yellow, white and pink mixed tone in the satellite imagery. The soils representing these units are moderately deep to very deep, well to imperfectly drained, coarse-loamy to fine-loamy to fine in textural classes, developed on nearly level to very gently sloping plain and are the most productive soils in the micro-watershed.

Moderate erosion risk (e_2)

Soils of mesa top (Central zone), mesa foot slope (Upper smooth), undulating plain (Summit), undulating plain (Summit-gravel/ stone), undulating plain (Summit-Rock outcrop) and side slopes of undulating plain (Gently undulating) have been noticed under moderate erosion (10-20 t $ha^{-1}yr^{-1}$) risk category. These soils occupy an area of about 30.91% of the total area as evidenced by the dark to light blue, white and gray mixed tone in the satellite imagery. The soils representing these units are moderately deep to deep, well to imperfectly drained, mostly coarse-loamy and fine in textural classes, developed on nearly level to gently sloping plain and are moderately productive soils in the micro-watershed.

Severe erosion risk (e_3)

The soils of undulating side slopes with rills/gullies, mesa shoulder, dissected valley fill possesses severe erosion (20-40 t $ha^{-1}yr^{-1}$) hazard (33.6% of the micro-watershed) as evidenced by the dark to light blue, yellow, white mixed tone in the satellite imagery and cover an area of about 33.59% of the total micro-watershed. The soils representing these units are shallow to very deep, excessive to imperfectly drained, dominantly clayey-skeletal, loamy-skeletal with fine-loamy to fine textural classes in patches, developed on gently to moderately sloping landform and possesses several constraints towards crop production.

Very severe erosion risk (e_4)

Soils of mesa side slopes, rocky ridges and narrow to broad valley possesses very severe erosion (>40 t $ha^{-1}yr^{-1}$) hazard (5.01%), which is reflected by dark blue, yellow and white mixed tone in the imagery. Moderately deep ravines have been noticed in this unit. The soils representing these units are shallow to very shallow, excessively drained, dominantly loamy-skeletal to clayey in textural classes, developed on moderately steep to steeply sloping landform and are mostly not suitable for agriculture. Based on the standard soil loss in t $ha^{-1}yr^{-1}$ under different erosion risk areas were quantified in the Peruguda micro-watershed and the data was found to be 8946.2 to 17812.4 t ha^{-1} yr^{-1}.

Land Resource Conservation and Management Plan

The analysis of erosion risk through water erosion in the study area reveals that the moderately severe, severe and very severe erosion risk zones occupy about 30.91, 33.59 and 5.01% of the watershed area. Soil erosion due to water can be controlled by adopting suitable mechanical and agronomic measures. The soil information generated at physiographic unit wise can be used for prioritization of areas and develop suitable soil and water conservation measures. In severe and very severe erosion risk zones, fallow lands on upland areas can be brought under silvi-pasture and agri-horti-system. *In situ* soil and water conservation works like *viz.,* Contour trenching and contour ditching in shallow soils and check dams and rockfill dams need to be constructed on undulating lands.Contour terraces to be constructed on excessively drained soils. Agronomic measures like plant protection, pasture/grass land development, tree plantation, horticulture, and agro-horticulture need to be adopted. Safe disposal runoff water and introduction of silvi-pastoral systems need to be developed in marginal lands (Table 4).

4. CONCLUSIONS

The study demonstrates that IRS-1C LISS-III and PAN fused data and GIS techniques are highly helpful in identification and assessment of erosion risk zones in geologically complex terrain of Peruguda micro-watershed which represents a unique combination of landscape, geo-agro climatic scenario where three geological formations gives rise to the formation of soils under seven identified landforms. As per the quantified data of soil loss in t ha^{-1} yr^{-1}, the micro-watershed is facing alarming soil loss per year causing depletion of soil fertility and productivity. To combat such a situation and to reduce soil erosion risk, the area should be brought under vegetation cover and to set up structures (terraces, bunds, vegetation strips) to reduce the speed and volumes of water flow over the soil. From this perspective tree crops and perennial crops are preferred, as are intercropping and reduced-tillage systems. The study demonstrated that application of remote sensing and GIS will be of immense helpful in soil resource inventory and identification of erosion risk zones for adoption of suitable soil and water conservation measures in order to optimal utilization of available natural resources to achieve higher productivity at micro level. The areas with severe and very severe soil erosion warrant special priority for the implementation of suitable soil and water conservation measures.

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