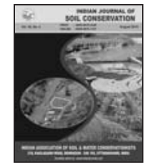
Vol. 44, No. 2, pp 168-176, 2016
Indian Journal of Soil Conservation
Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Need for site specific land resource database for integrated watershed management

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ARTICLE INFO

Article history :
Received : May, 2013
Revised : February, 2016
Accepted : May, 2016

Key words :
Management unit,
Remote sensing data,
Soil database,
Soil erosion,
Watershed characterisation

ABSTRACT

Lack of site specific land resource database is main limitation for success of any watershed programs. Detailed site-specific land resources database and associated socio economic studies help to identify the inherent potentials and constraints of watershed for drawing appropriate natural resource management plan. The present study was carried out in Muttala watershed, Atmakur Mandal, Anantapur district, Andhra Pradesh to demonstrate the applicability of site-specific land resource database for watershed management. The high resolution satellite data of Cartosat-1 merged IRS LISS IV data in conjunction with cadastral map (1:10000 scale) was used for identification of soils and different management units. Seven soil series were identified in the watershed and mapped into 33 management units. Each management unit is unique with respect to properties and requires specific soil and water conservation plan and management to improve the plot wise productivity. Soil erosion from each management unit was estimated and maximum study area of 469.2 ha is found under moderate erosion class (5-10 t ha^{-1}) followed by very severe (20-40 t ha^{-1}) class of 399.7 ha. Similarly, various other land resource constraints and potentials were assessed and appropriate soil and water conservation measures were suggested. The database also serves as baseline database for enabling departments to monitor and evaluate the effectiveness of watershed development programs in the area.

1. INTRODUCTION

Watershed is an ideal unit for management of natural resources for land use planning (Akhouri, 1996). Integrated watershed management programs are aimed to optimize the use of land, water, vegetation, livestock, man and other environmental factors to prevent land degradation, improve water availability and increase the food, fuel, fodder and fibre production on a sustainable way (Bhardwaj and Dogra, 1997; Sahai, 1988). The major objective of the watershed programs is not only protection and conservation of the environment but also support livelihood security. In India, huge amount of financial resources are invested in the watershed development programs, but most of them are failed or not given expected level of output.

Most of the watershed management plans were based on small scale map of 1: 250, 000 or 1: 50, 000 scale. Mostly the recommended conventional soil water conservation practices are blanket like contour or graded bunds by involving local peoples through participatory approach. They are mainly based on slope (>30%), rainfall (>600 mm/<600 mm) and soil type (heavy/light texture soil). These conventional measures may not give desirable effects in sloping lands or plains due to significant difference in soil and land characteristics. So, such database were failed to give any site specific information which is essential for drawing appropriate management measures.

Detailed site-specific land resources database and socio economic studies provide scientific diagnosis of the area and help to identify the inherent potentials and constraints of land and also evaluate their suitability for various land use options (Wani *et al.,* 2002; Ghorbani and KakehMami, 2013). This can be obtained only by conducting cadastral level detailed surveys and delineate homogenous areas based on soil-site characteristics into management units. Thus, detailed database is essential to identify different management units at watershed/village level which will form the basis for undertaking any developmental work later. This site specific soil database strengthen the science base of watershed management by enhancing the understanding of soil related constraints and potentials, hydrological dynamics, socio economic issues and climatic variability and also helps in implementing, monitoring, reviewing the watershed developmental programs.

Remote sensing and geographic information system (GIS) is very useful tool for developing a proper watershed development plan. It helps in creation of natural resource database in effective way, integration of information with the ancillary data for generating action plan and watershed prioritisation for soil conservation for the watershed (Kalgapurkar *et al.,* 2012; Pandey *et al.,* 2007; Sharada *et al.,* 2008). Srivastava and Saxena (2004) discussed the technique of large-scale soil mapping (1:12,500 scale) in a basaltic terrain with a physiographic land unit approach and differentiated soil types using toposheet and IRS-1C PAN merged data of two seasons. In a part of Basaltic terrain of Vidharbha region, Nagaraju *et al.* (2014) have generated a detailed soil map through the physiography-soil relationship for preparation of action plan using Cartosat-1 merged IRS LISS IV data. It was found that the high resolution satellite Cartosat-1 merged IRS LISS IV data has the potential for precise and accurate delineation of landforms by understanding the soil-forming environment and their boundaries for faster mapping. At present, not much information is available on application of site specific land resource database for watershed management. The uniqueness of the present study was to map the soils of watershed at cadastral level using cartosat-1 merged IRS LISS IV data and suggest suitable scientific conservation measures based on problems and potentials and socio economic issues for better management of watershed.

2. MATERIALS AND METHODS

Study Area

Muttala watershed is located in Muttala village, Atmakur mandal of Anantapur district, Andhra Pradesh, India (Fig.1). Since the watershed is located inside the administrative boundary of Muttala village, the village is taken as a unit for this study. The study area having total geographical area (TGA) of 1,788 ha lies between 77°24'7.7" and 77°20' 30.5" East longitudes and 14°35'41.4"and 14°34'42.6" North latitudes. The elevation of the area ranges from 470-520 m above msl. Three different geological formations were identified in the watershed *viz.*, granite and gneiss, dyke and chlorite-schist. The most remarkable individual geomorphic features in the basin are residual hills characterized by the abundance of rock out crops. Number of households in the village is 198 and almost all the households are involved in agriculture as a primary occupation. The area is mainly drained by Pedda Vanka river. The major crops grown in the area are groundnut, pigeon pea, castor and horticultural crops like mango and sweet orange with supplemental irrigation in rainfed uplands and vegetables like tomato, chillies and okra in the irrigated lowlands.

Climate

The climate of Muttala watershed is warm and mainly classified as hot and dry type. April and May are the hottest months with mean temperature of 38.3°C. Highest maximum temperature recorded was 42.2°C. The mean diurnal variation in temperature ranges between 10-12°C. The average rainfall is 575 mm and it is the driest part in the state of Andhra Pradesh. There are extremes in some years, which range from the lowest rainfall of 245 mm in 2006 and highest of 762 mm in 2005 over the last 15 years. Last 10 years climatic data shows that length of growing period is 11 weeks (70-80 days only) which starts from the last week of August and continues up to the end of October (Fig. 2). Ground water exploration data shows that most of the potential zones were encountered in the depth range 150-200 m which falls under semi critical category (CGWB, 2007).

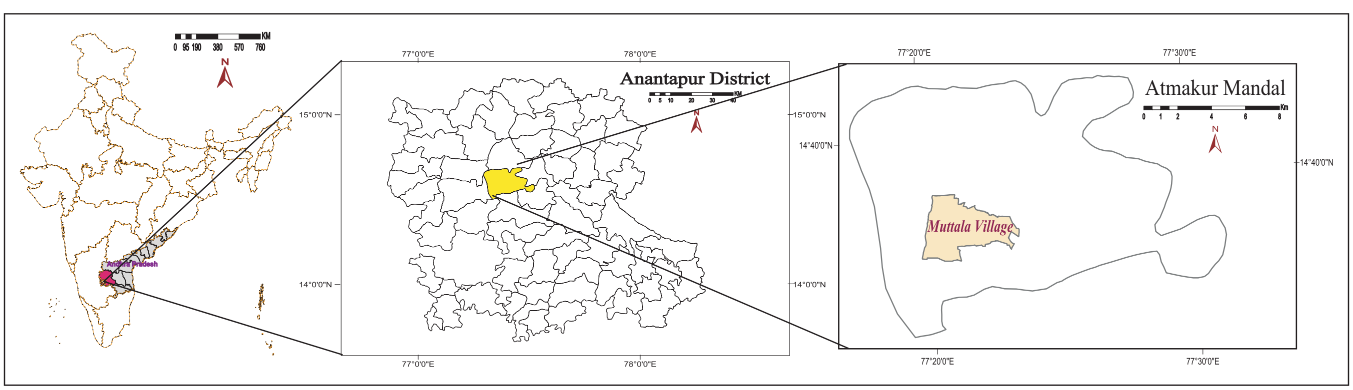

Fig. 1. Location map of Muttala Atmakur Mandal, Anantapur District, Andhra Pradesh

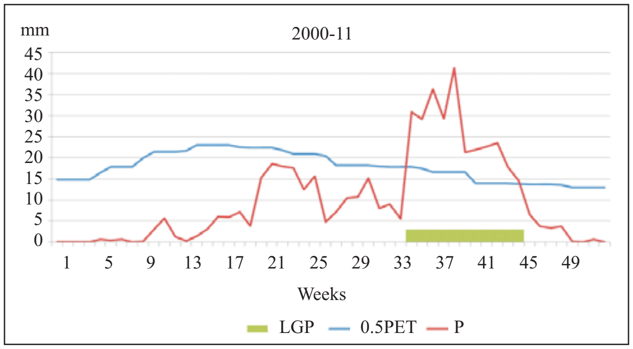

Fig. 2. Length of growing period

Data used for Land Resource Inventory

The detailed survey of the land resources of the watershed was carried out by using cadastral map (1: 10000 scale) as a base. Apart from the cadastral map, remote sensing data products from IRS LISS IV (Indian remote sensing satellite- Linear imaging self scanning sensor- IV) (5.8 m resolution) pertaining to *kharif* and *rabi* seasons of 2012 and Cartosat-1 (2.5 m resolution) were used to identify the landforms and other surface features. IRS-P6 LISS IV data and Cartosat-1 data was merged using image processing software ERDAS 4.1 and FCC was generated using 2, 3, 4 bands. The FCC was visually interpreted based on texture and tonal variations for identification of different landform units (Moore *et al.,* 1993). Pre-field landform map was verified following the standard procedure (Wright, 1993) and relationship between landform, land use and image characteristics were established.

Soil Resource Inventory and Laboratory Analysis

Preliminary traverse was carried out by using 1:10000 cadastral maps and location of transect/representative pedons were identified based drainage pattern, surface features, slope characteristics and land use (Natarajan and Dipak Sarkar, 2010). In the selected transects soil profiles were opened and studied in detail for all their physical and morphological characteristics. The soil and site characteristics were recorded for all profile sites on standard proforma as per the guidelines given in USDA Soil Survey Manual (Soil Survey Staff, 2003). Based on the soil-site characteristics, the soils were grouped into different soil series. The area under each series was further divided into phases and their boundaries delineated on the cadastral map based on the variations observed in the texture of the surface soil, slope, erosion, presence of gravels and stoniness. Horizon-wise samples were collected for laboratory analysis. Particle size analysis was carried out by International Pipette method (Piper, 1966). Organic carbon was estimated by Walkley and Black (1934) method. The soil reaction (1:2.5 soil water suspension), electrical conductivity, cation exchange capacity and exchangeable bases were determined by standard procedures (Jackson, 1973).

Finalization of Maps

Pre-field soil maps were modified based on laboratory information and the final soil map was prepared. The soils were classified as per USDA Soil Taxonomy at series and phases level. Soil attribute data collected from field and laboratory results were entered by keeping the soil units as a base domain and thematic maps on landforms, slope, depth, drainage, erosion, texture, gravelliness, soil OC, pH and EC were generated in ArcGIS platform.

Soil Suitability Evaluation

The soil site suitability for pigeon-pea, groundnut and mango has been evaluated as per the FAO frame work on land evaluation (FAO, 1983) modified by Naidu *et al.,* 2006. The specific requirements of each crop compared with the characteristics of land and based on the extent of matching, the suitability of the area for the crop is arrived. For the present study, the major three crops *viz*., groundnut, pigeon pea and mango predominantly cultivated by farmers were assessed for their suitability. Soil characteristics like depth, texture, gravelliness, pH and calcareousness, land features like slope, erosion and drainage and climatic factors such as amount of rainfall and its distribution and length of growing period were used to assess the suitability of land for different crops. The "Overlay" analysis concept in GIS environment was used to delineate the extent of different suitability classes.

Soil Loss Estimation

Soil erosion from each management unit was estimated by using Universal Soil Loss Equation (A=RKLSCP) (Wischmeier and Smith, 1978). Soil erodibility factor (K), topographic factor (LS) and conservation and management factor (C&P) were derived from land resource database by assigning suitable values for each mapping unit (Martin and Saha, 2007). Rainfall erodibility factor (R) was assumed to be constant assuming similar rainfall throughout the watershed and soil loss map was generated in the GIS environment. Soil erodibility factor (K) value is assigned as per the soil characteristics of the watershed *viz.,* size, texture, structure, organic matter content and infiltration rate for each mapping unit. Topographic factor (LS) is estimated based on slope percentage and slope length for respected mapping units. Rainfall erodibility factor (R) for Atmakur region of Anatapur (325) has been considered for the soil loss computation (Reddy *et al.,* 2005). The crop management and conservation factors are assigned as per the crops and supporting practices followed in the watershed. The soil map, slope map and soil erosion map were integrated for developing suitable soil and water conservation interventions.

Socio-economic Survey

The socio-economic study was taken up to assess the adoption of soil and water conservation measures under different size classes of farmers in the watershed. Detailed information were collected using structured, pre-tested questionnaire covering various aspects of household characteristics and the results were analysed to identify the major socio economic issues affecting soil erosion and adoption of soil water conservation measures.

3. RESULTS AND DISCUSSION

Landform Analysis

Landform analysis is important tool to identify the different soil types, hence soil development related to lithology and water movement. The topography of landform influences the water distribution and solar radiation in the landscape which affect the pedogenesis and soil characteristics (Wilson and Gallant, 2000). Pre-field landform map was prepared by visual interpretation of high resolution satellite imagery and it was verified in the field. The major identified landforms are granitic uplands, chloritic-schist uplands, lowlands and rocky lands. The granitic uplands are further divided into very gently sloping uplands (1-3%), gently sloping uplands (3-5%), strongly sloping (10-15%) which occupy 38.6, 32.8, 13.7% of TGA, respectively. The chloritic-schist uplands constitute 4.57% and lowland occupies 10.3% of TGA. The granitic uplands having slope classes of 3-5 and 10-15% are having higher gravel content on the soil surface which is an indication of erosional remnants.

Soil Morphological Properties

The soils of granitic uplands are yellowish red (5YR4/6) to dark red (2.5YR 3/6) which may be due to release of iron from parent material under well drained condition whereas the soils of chloritic- schist uplands are dark grey (10YR 4/1) to very dark grey colour (10 YR 3/1). The surface texture of the soils of granitic uplands is mostly gravelly sandy loam and sub-surface varies from sandy clay loam to loam which is due to the downward movement of finer material from the surface. The texture of chloritic-schist uplands soil varies from clay loam to clay due to parent material composition. The surface texture of lowland soils is sandy clay loam to sandy loam and sub-surface varies from sandy clay loam to sandy. It is observed that weak to moderate sub angular blocky structure were found in soils of granitic uplands whereas moderate to strong sub angular block structure were found in chloritic schist uplands. Sub surface horizons have angular blocky structures which are wedge shaped and have pressure faces on ped surface indicating vertic properties. The uplands soils are well drained whereas lowlands soils are moderately well drained. The chloritic-schist landform and lowlands soil are deep (100-150 cm) whereas soils developed over granitic uplands are varied from very shallow (<25 cm) to moderately shallow (50-75 cm). Coarse fragments (>2cm) found only in granitic upland soils and it varied from 25-60% and it is related to catena (Table 1).

Soil Physiochemical Properties

Physio-chemical properties of watershed soils are presented in Table 2. The soils of chloritic-schist landform have high clay content (38.5-53.5 %) compared to granitic uplands (10.9 to 25.9%). The clay content in granitic uplands showed increasing trend of clay down to the slope. The soil pH in granitic uplands is low (5.66-7.93) compared to chloritic- schist landforms (7.89-8.58) and lowlands (7.68-8.41). The low pH observed in granitic uplands is due to acidic parent material. Increasing pH with depth in chloritic- schist landforms and lowlands is due to presence of calcium carbonate. Electrical conductivity ranged from 0.001 to 0.2 dS m^{-1} in surface and 0.002 dS m^{-1} to 0.28 dS m^{-1} in sub surface. It shows that soils of the study area have very low soluble solids and indicated that soils have no salinity hazards (Richards, 1954). Organic carbon content ranged from 0.08-1.55% in surface and 0.15-1.83% in sub-surface. Cation exchange capacity of soil varied from 4.7-18.7 c mol (p+) kg^{-1} and it is mostly related to organic carbon and clay content of the soil (Pal and Deshpande 1987; Dharumarajan *et al*., 2013). Among the exchangeable basic cations calcium is predominant followed by magnesium and the higher amount of sum of cations recorded in chloritic-schist uplands.

Table: 1
Major soil and site characteristics

Soil	Soil A	Soil B	Soil C	Soil D	Soil E	Soil F	Soil G
Climatic characters							
Total rainfall (mm)	550	550	550	550	550	550	550
Mean max temp.(°C)	33.3	33.3	33.3	33.3	33.3	33.3	33.3
Mean min temp.(°C)	21.9	21.9	21.9	21.9	21.9	21.9	21.9
Site characteristics							
Slope (%)	1-3	3-5	3-5	1-3	0-1	0-1	0-1
Drainage	Well	Well	Well	Well	Well	Moderately well	Well
Flooding	F0	F0	F0	F0	F0	F0	F0
Soil characteristics							
Texture	gsl	sl	sl	sl	cl	scl	sl
Depth (cm)	15	39	60	42	109	110	127
Gravels (%)	50	50	25	25	-	-	10
Effervescence with acid	e 0	e 0	e 0	e 0	e v	e v	e 0

F0- No flooding, gsl- gravelly sandy loam, sl-sandy loam, cl-clay loam, scl-sandy clay loam, e0- Nil effervescence, ev- violent effervescence

Table: 2
Soil physiochemical properties

Horizon	Depth (cm)	Coarse fragments (%)	Particle size distribution (%)			Textural class	pH (1:2.5)	EC (dS m^{-1})	OC (%)	CEC (cmol(p^+)kg^{-1})	BS (%)
			Sand	Silt	Clay						
Soil A: Sandy-skeletal, mixed, isohyperthermic, Lithic Ustic Torriorthents											
Ap	0-15	50	64.0	22.0	10.9	sl	5.66	0.02	0.08	4.7	66.0
Soil B: Loamy-skeletal, mixed, isohyperthermic, Lithic Ustic Haplargids											
Ap	0-17	50	65.4	21.8	12.7	sl	5.15	0.001	0.48	6.3	46.0
Bt1	17-39	40	64.0	12.2	22.4	scl	5.61	0.002	1.11	9.3	69.9
Soil C: Loamy-skeletal, mixed, isohyperthermic, Ustic Haplargids											
Ap	0-13	25	62.4	22.0	14.4	sl	7.06	0.01	1.47	8.8	34.1
Bt1	13-26	50	58.2	17.8	22.4	scl	6.79	0.01	0.71	10.7	66.4
Bt2	26-60	60	57.4	15.2	25.9	scl	6.67	0.10	0.12	10.2	65.2
Soil D: Loamy-skeletal, mixed, cal, isohyperthermic, Lithic Haplocambids											
Ap	0-12	25	57.4	26.7	14.9	sl	7.85	0.14	1.55	7.5	49.3
Bw1	12-25	40	55.3	25.5	20.1	scl	7.93	0.15	1.83	10.1	66.3
Bw2	25-42	40	52.0	19.8	24.7	l	8.10	0.13	0.16	12.5	69.8
Soil E: Fine, mixed, isohyperthermic, cal, Ustertic Haplocambids											
Ap	0-14	-	27.3	31.3	38.5	cl	7.89	0.17	0.16	18.7	73.6
Bw1	14-40	-	20.5	26.6	41.4	c	8.18	0.16	0.71	17.6	71.6
Bw2	40-69	-	27.7	31.6	44.8	c	8.50	0.23	0.44	19.5	75.4
Bw3	69-94	-	21.3	26.5	48.3	c	8.58	0.28	0.56	19.8	72.6
Bw4	94-109	-	25.4	10.0	53.5	c	8.57	0.26	0.39	21.9	80.4
Soil F: Fine loamy-skeletal, mixed, isohyperthermic , cal, Ustic Haplocambids											
Ap	0-18	-	47.2	24.8	19.6	scl	7.68	0.20	0.03	7.5	82.7
Bw1	18-44	-	53.8	26.4	19.6	scl	8.03	0.19	0.15	9.6	63.5
Bw2	44-69	-	55.3	24.0	20.7	scl	8.20	0.22	0.95	10.2	65.9
Bw3	69-110	-	60.9	15.4	23.6	scl	8.41	0.24	0.08	8.8	70.5
Soil G: Sandy, mixed, isohyperthermic ,Ustic Torripsamments											
Ap	0-10	10	72.5	13.5	11.5	sl	7.74	0.09	0.91	8.8	90.9
A2	10-26	-	54.0	19.2	30.5	scl	8.01	0.05	0.39	9.1	61.5
C1	26-53	10	90.6	2.4	10.4	s	8.16	0.05	0.15	6.1	35.8
C2	53-78	10	93.0	4.4	8.05	s	8.20	0.05	0.08	6.6	40.1
C3	78-127	-	79.8	10.6	13.2	sl	8.06	0.04	0.44	7.7	42.5

Mapping and Classification

The information pertaining to soils, extent, and distribution are presented in Table 3 and Fig. 3. Seven soils with 33 phases were identified in the study area. Out of this, four soils (23 phases) in granitic landform, two soil series (5 phases) identified in lowland and one soil (one phase) were identified in chloritic schist landform. In the granitic uplands, moderately shallow red loamy soils (Soil B) and shallow red loamy soils (Soil C) occur extensively, occupying about 63.7% (1138. 9 ha) area and soil A (very shallow red loamy soils) and D (shallow calcareous red loamy soils) occupies 7.6% of TGA. Two soils (Soil F and G) identified in the lowlands are deep (100-150 cm) and occupy about 185.3 ha (10.3%) of the watershed. Soil E identified in Chloritic-schist uplands occupies 4.57% of TGA. Rocky lands and rock outcrops occupies 8.4% of TGA. Similarly gullied and severely eroded lands occur all along the footslopes which are classified as miscellaneous lands occupies about 50 ha (2.57%). As per the soil taxonomy (soil survey staff, 2008), the soils of the study area classified into two orders *viz.,* Aridisols (94.58%) and Entisols (5.42%).

Land Suitability Evaluation

Drastic change in temperature and rainfall over years shows that there is no stable length of growing period which limits the choice and even failure of crop. The study area is water scarce, so land use system should emphasize on cultivation of high value and low water requiring crops such as millets, pulses and oilseeds. The soil morphological and physiochemical parameters obtained from field as well as laboratory along with climate were evaluated for suitability of groundnut, pigeon-pea and mango (Table 4). Rainfall and length of growing period is moderately suitable for groundnut and pigeon-pea whereas it is marginally suitable for mango. The non parametric approach revealed Soil A is non-suitable for all the three crops due to shallow depth. Soil B, C and D are also non suitable for mango due to depth constraint (Whiley, 1984). Soil E, F and G are moderately suitable for groundnut and pigeon-pea because of low organic carbon and heavy soil texture (Gajendragiri, 2002). Soil A& B are non suitable whereas C&D are marginally suitable for groundnut and pigeon pea due to depth limitation, coarse fragments, organic carbon and soil reaction. Electrical conductivity and cation exchange capacity are not limiting factor for these crop growth. The area analysis revealed that 853.8 ha is moderately and 652.4 ha is marginally suitable, whereas, 232.3 ha is non suitable for groundnut (Table 5). In case of pigeon pea, 668.4 ha is marginally suitable followed

Table: 3
Distribution of soils

Soil	Description	Mapping units	Area (ha)
Granitic uplands			
Soil A	Very shallow, well drained gravelly loam soil, developed from granite gneiss, occurring on very gently sloping side slopes under cultivation.	1bB2g1, 1cB2g2, 1hB3g2	36.12
Soil B	Shallow, well drained gravelly loam soil, developed from granite occurring on gneiss, nearly level summit and very gently to gently sloping uplands under cultivation.	2bB2g2, 2bB3g2, 2bC3g2, 2bE3R3, 2cB2g3, 2cB3g1, 2cC3g1, 2cC3g2	477.00
Soil C	Moderately shallow, well drained gravelly loam soil, developed from granite gneiss, occurring on nearly level summit and very gently to gently sloping side slopes under cultivation.	3bB2g2, 3bB3g2, 3bC3g1, 3bC3g3, 3bC3R3, 3cB3g2, 3cC3cb, 3hB2g2	661.85
Soil D	Shallow, well drained gravelly loam transition soil, developed from granite gneiss, occurring on nearly level summit and very gently to gently sloping uplands under cultivation.	4bB3g1, 4bC3g2, 4cB3g2, 4hC3g2	100.17
Chloritic-schist uplands			
Soil E	Deep, well drained cracking clay soil, developed from chlorite schist, occurring on nearly level summits and uplands under cultivation.	5m A2	81.74
Lowlands			
Soil F	Deep, moderately well drained clay soils, developed from alluvium, occurring on nearly level low lands.	6hA, 6iA,6iB	124.57
Soil G	Deep, well drained sandy soils, developed from alluvium, occurring on nearly level low lands.	7bAg1, 7Ha	60.82
Miscellaneous lands			45.99
Rock out crops			150.19
Settlements and water bodies			49.22

Texture: b - Loamy sand, c - Sandy loam, h - Sandy clay loam, i - Sandy clay, m - clay; Slope: A - 0-1%, B - 1-3%, C - 3-5%; Erosion: 1 - slight erosion, 2 - moderate erosion, 3 - severe erosion; Gravels: g1 - 15-35%, g2 - 35-60%, g3 - >60%; Rockiness: R

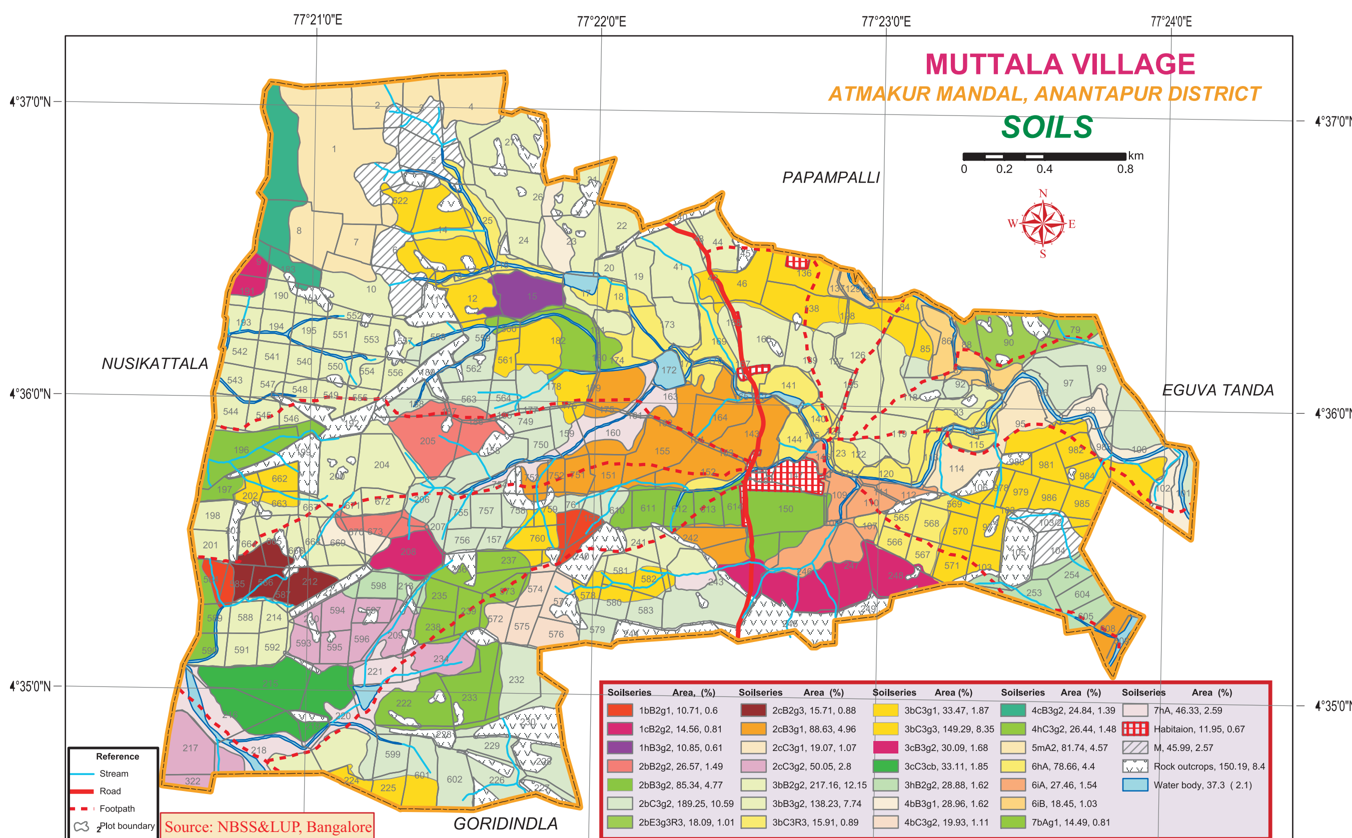

Fig. 3. Distribution of soil phases or management units in the study area

Table: 4
Agro ecological and pedological related limitation and suitability for the cultivation of major crops

Soil	Soil A			Soil B			Soil C			Soil D			Soil E			Soil F			Soil G		
	GN	PP	MG	GN	PP	MG	GN	PP	MG	GN	PP	MG	GN	PP	MG	GN	PP	MG	GN	PP	MG
Climatic characteristics																					
Total annual rainfall (mm)	S2	S2	S3	S2	S2	S3	S2	S2	S3	S2	S2	S3	S2	S2	S3	S2	S2	S3	S2	S2	S3
Mean annual temperature (°C)	S1	S1	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2
Site characteristics																					
Slope (%)	S1	S1	S1	S2	S2	S2	S2	S2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Drainage	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S2	S2	S1	S1	S1	S1
Flooding	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Soil characteristics																					
Texture	S1	S1	S2	S1	S1	S2	S1	S1	S2	S1	S1	S2	S2	S1	S1	S2	S1	S1	S1	S1	S2
Coarse fragments (vol %)	S2	S3	S2	S2	S3	N	S1	S2	N	S1	S2	N	S1	S1	S1	S1	S1	S1	S1	S1	S2
Depth (cm)	N	N	N	S3	N	N	S2	S3	N	S3	S3	N	S1	S1	S3	S1	S1	S3	S1	S1	S2
Soil fertility																					
Apparent CEC cmol(p$^+$)kg^{-1} of clay	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
BS (%)	S1	S1	S1	S1	S1	S1	S2	S2	S2	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S2	S2	S2	S2	S2	S2	S2	S1	S1	S1	S1	S1	S2	S2	S2	S2	S2	S2	S2	S2	S2
EC (dS m^{-1})	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH (1:2.5)	S2	S2	S1	S3	S2	S2	S1	S1	S1	S1	S2	S2	S1	S2	S2	S1	S2	S2	S1	S2	S2
Suitability class for Dominant soil	N	N	N	S3	N	N	S2	S3	N	S3	S3	N	S2	S2	S3	S2	S2	S3	S2	S2	S3

S1: Highly suitable, S2: Moderately suitable, S3: Marginally Suitable and N- Non Suitable, GN: Ground nut, PP: Pigeon Pea, MG: Mango

Table: 5
Soil site suitability for different crops

Suitability criteria	Moderately suitable (S2)		Marginally suitable (S3)		Non suitable (NS)	
	Area (ha)	% TGA	Area (ha)	% TGA	Area (ha)	%TGA
Groundnut	853.8	48	652.4	37	232.3	13
Pigeon-pea	267.1	15	668.4	37	802.9	45
Mango	-	-	973.9	54	817.6	46

by 267.1 ha moderately suitable. For mango, 973.9 ha area is found marginally suitable and about 817.6 ha is non suitable for cultivation because of depth limitation. Though, climate is a major constraint for production of ground nut and pigeon-pea, adoption of suitable site specific soil and water conservation measures are needed for sustainable production.

Soil Erosion Assessment

High intensity of rainfall in short period affects the crop production by removing the fertile top soil. The estimation of soil loss in watershed helps in prioritization of soil conservation measures for planning and management of watershed. Values of K, LS, C and P used in USLE equation are given in Table 6 and Table 7. The potential soil loss was estimated in GIS environment and grouped into six erosion classes (Table 8). Maximum area (469.2 ha) is falling under moderate erosion class (5-10 t ha^{-1}) followed by very severe (20-40 t ha^{-1}) class found an area of 399.7 ha. Nearly 80.7% of study area is having soil

Table: 6
K and LS factor used in soil erosion estimation

Series	K factor	LS factor
1	0.15-0.18	0.66
2	0.14-0.17	0.66-5.77
3	0.15-0.18	0.66-1.05
4	0.14-0.20	0.6-1.05
5	0.24	0.55
6	0.2	0.49-0.66
7	0.13-0.17	0.49

Table: 7
Conservation and management (CP factor) used in soil erosion estimation

Land use	Supporting practice	CP factor
Fallow	Nil	1
Kharif Groundnut	Bunds surrounding the plot	0.20
Kharif Groundnut	No bunding	0.40
Pigeon-pea	Bunds surrounding the plot	0.19
Sweet Orange	Bunds surrounding the plot	0.14
Vegetables	bunded	0.21

erosion potential of more than 5 t ha^{-1}. From this estimation, it is found that area having slope range 3-5 % having moderate to severe soil erosion potential. In general, the runoff and soil loss is increased with increase in slope length and steepness (Walter *et al.,* 1978). But in some plots of watershed, minimum soil loss were observed even in high slope length attributed to low erosive velocity and trap efficiency (Nalatwadmath *et al.,* 2004). The soil loss is less where the land parcels are covered with more than 70% of gravels which act as mulching agent, compared to unprotected and fallow land. There is a need to protect the top soil immediately by adopting appropriate soil and water conservation measures.

Soil and Water Conservation Measures

The study area needs a combination of short and long-term measures of soil and water conservation. The measures like breaking slopes, contour farming, broad bed and furrows, conservation furrows and mulching are to be taken up at each management units based on the land resources database (Ramakrishnan *et al.,* 2008). Based on slope, surface texture, soil depth and gravelliness of the each management unit, soil and water conservation measures were arrived and presented in Table 9. Contour bunds with the dimensions of top width 0.5 m, bottom width 2.45 m, height of 0.65 m and cross sectional area of 0.96 m^2 is designed and suggested for an area 573 ha along with vegetative furrows where the slope varies from 1-3%. The area with 3-5% slope are recommended to construct contour bunds with the dimension of top width 0.5 m, bottom width 2.45 m, height of 0.75 m and cross sectional area of 1.22 m^2. In areas having deep soil, nearly level to very gently sloping land and soil loss of less than allowable limit (12.5 t ha^{-1}) normal conservation structures like mulching and conservation tillage are recommended to conserve soil and water (Singh *et al.,* 1981). Continuous contour trenches along with agroforestry and silvipasture are recommended for 64 ha area where the slope is steep. This will conserve soil and water by minimizing the velocity of surface run-off.

Table: 8
Estimated soil loss by USLE equation

S.No.	Erosion class	Area (ha)	% TGA
1	Slight (0-5 t ha^{-1})	144.28	8.1
2	Moderate (5-10 t ha^{-1})	469.17	26.2
3	Strong (10-15 t ha^{-1})	223.68	12.5
4	Severe(15-20 t ha^{-1})	138.06	7.7
5	Very severe (20-40 t ha^{-1})	399.7	22.4
6	Extremely severe (>40 t ha^{-1})	213.37	11.9
7	Rocky lands	150.19	8.4
8	Settlements and water bodies	49.22	2.8

Socio-economic Issues

Socio-economic issues affecting soil erosion and adoption of soil water conservation were analysed in the study area. The major issues linked are poverty, labour availability, farming practices, appropriateness of technology transfer and economic incentives. Small and marginal farmers are very much concerned on their immediate needs and most of them kept their lands as fallow due to financial constraints which resulted in severe erosion. Migration of agricultural labours to nearest cities in search of employment opportunities resulted in use of heavy machineries which increased the risk of erosion. Shallow soil with stony surface may not be suitable for wide range of crops thereby reducing the choice of alternate crops (Boardman and Hazeldent, 1986). So continuous mono cropping situation lead to nutrient mining and poor yield and also low market price. Govt is providing subsidies for cultivation of horticultural crops and equipping drip irrigation system. For getting such incentives, farmers are changing land use in spite of constraints of topography, rainfall, soil depth and access to market (Arnalds and Barkarson, 2003). This practice ultimately led to increase soil erosion and reduce ground water availability. Adoption of technology and its production potential is very poor due to blanket recommendation. The mapping unit derived from detailed soil resource database (1: 10000 scale) will form the basis for selection and transfer of suitable technology.

4. CONCLUSIONS

Cadastral level soil mapping using remote sensing and GIS technologies are effective in formulation of soil conservation strategies based on the degree of slope, depth

Table: 9
Suggested Soil and water conservation measures

S.No	Soil and water conservation measures	Mapping units	Area (ha)
1	Contour farming, Strengthening of field boundary bunds, conservation furrows and mulching	1cB2g2, 1bB2g1, 1hB3g2	34.17
2	Contour cultivation, contour bunds with 0.96 m^2 C/S, and vegetative furrows	2bB2g2, 2bB3g2, 2cB2g3, 2cB3g1, 3bB2g2, 3bB3g2, 3cB3g2, 3hB2g2, 4bB3g, 4cB3g2	573.4
3	Contour cultivation, contour bunds with 1.22 m^2 C/S, strengthening existing bunds with vegetation	2bC3g2, 2cC3g1, 2cC3g2, 3bC3g1, 3bC3g3, 3bC3R3, 3cC3cb, 4bC3g2, 4hC3g2	536.5
4	Continuous contour trenches, Agro forestry, silvipasture,	2bE3R3,M	64.08
5	Mulching	5mA2, 7hA, 7bAg1	142.56
6	Provision of sub-surface drainage system	6hA, 6iA,6iB	124.57

of soil and rate of erosion. The study proved that detailed land resources database can be effectively used for implementing the site specific soil and water conservation measures and comprehensive developmental plans. This also provides for making scientific estimate for farm infrastructure development. Thus the resources can be conserved and improved with the help of detailed land resource database and effective utilization of public funds during the watershed program implementation which can result in sustainable development of the area. Socio economic factors increase the vulnerability of soil erosion associated land degradation problems. Scientific assessment of land resources at large scale and identification of plot level problems and potentials form a basis for transfer and adoption of technology. Detailed land resource inventory can form the best scientific foundation for arriving at a suitable management strategy to combat land degradation in the arid and semi arid tropics of the country.

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