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Characterization and classification of soils of Malli-1 micro-watershed of Yedrami taluka, Kalaburagi district, Karnataka

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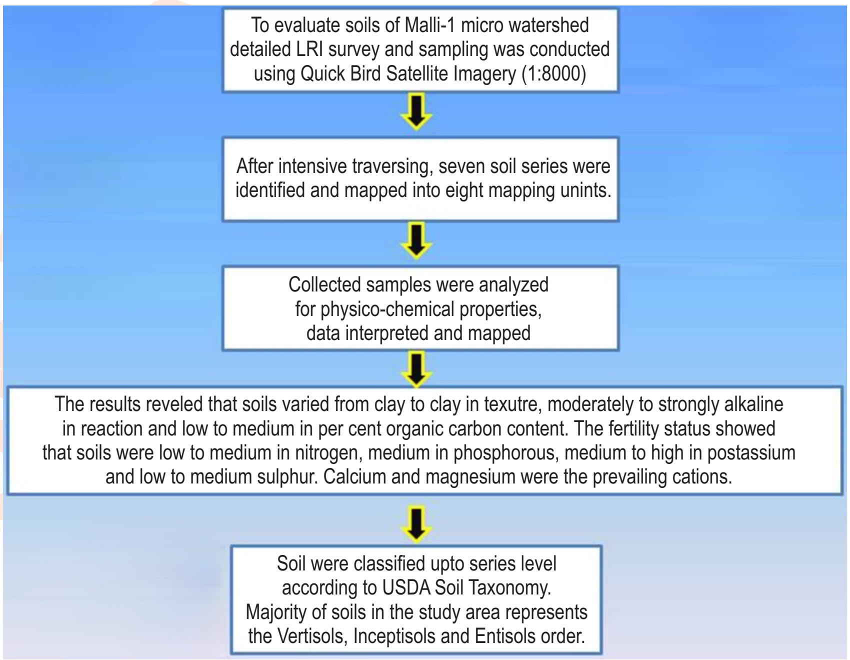
Abstract

Aim: To evaluate the soils of Malli-1 micro watershed situated in the North-Eastern Dry Zone (Zone-2) of Karnataka for sustainable crop development.

Methodology: Eight soil profiles covering all soil types occurred in the study area were selected and studied for their detailed morphological, physical and chemical properties using standard soil testing procedures.

Results: Soils of Malli-1 microwatershed varied from clay to clay loam in texture, moderately to strongly alkaline in reaction with low salt content and low to medium in per cent organic carbon content. Calcium and magnesium were the prevailing cations followed by sodium and potassium. Soils were classified upto the series level as per revisions in Soil Taxonomy by utilizing soil characteristics. Majority of soils in study area represents the *Vertisols, Inceptisols* and *Entisols* order.

Interpretation: These results indicate that soils were less fertile due to deficit in soil nutrients. Recommended doses of organic bio-fertilizer and inorganic fertilizer should be practiced for reclamation of soil status.



Key words: Electro chemical stability index, microwatershed, Soil resources, Soil survey

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Introduction

Soil is a fundamental natural asset, whose legitimate use relies upon the existence supporting frameworks of a country and the financial improvement of its residents. Soil provides food, fodder and fuel to meet essential human and animal needs. With the expansion of population, nutrient exhaustion of soils occur to meet the food production for growing populations (Silver *et al.,* 2021). The ability of a soil to produce restricted production is set by inborn qualities, agro-ecological settings and crop management practices. This demands the scientific approach of land resources with respect to their area of extent, distribution, soil characteristics, and use potential, which is essential for fostering a viable land use framework for enhancing farming on a sustainable basis. Land Resource Inventory (LRI) at site specific locations for sustainable development of watershed has attracted in recent times because of improper usage of available natural resources and lack of conservation measures that have led to the deterioration of watersheds in the country. The land resources in Karnataka state are under severe stress due to Land degradation and soil degradation of degradation. In recent times, the land degradation has boomed as serious constraints and affected about 38.0 lakh ha cultivable area in Karnataka. Soil erosion alone has degraded approximately 35.0 lakh ha land (Geetha *et al.,* 2017). Nowadays, the abnormal behavior of weather due to climate change has added number of additional constraints and unpredictable situations to be tackled by farmers.

The challenge before us is not only to expand the production efficiency per unit area, to meet the food grain demand of increased population, but also to conserve natural resources in the state. Consequently, a basic stage has come where appropriate conservation measures of soil and water on watershed basis are quickly justified to diminish soil erosion, re-establish land use efficiency and to improve the socio-economic status of the area. In these days idea of watershed based comprehensive improvement has arisen as one of the expected methodologies in rainfed regions, which helps to prompt sustainability in agricultural production. Remote sensing provides multi-spectral information of earth's surface with greater precision and it is highly efficient in collecting the data and precise mapping of land resources than the conventional method (Kasturirangan *et al.,* 1996). Malli-1 micro-watershed of Kalaburagi district comes under rainfed farming with unpredictable rainfall appropriation which related with low crop yield and soil erosion was major constraints in declining soil resources, which in turn affect agricultural productivity. In order to address this problem, Land Resource Inventory (LRI) study was conducted in Malli-1 micro-watershed of Kalaburagi district under Sujala-III Project.

Materials and Methods

The Malli-1 microwatershed area is situated in Yedrami taluka, Kalaburagi district, Karnataka state. It occupies the total area of 537.18 ha that lies between 17˚35'57.431" to 17˚37'17.861" N latitude and 77˚58'33.611" to 77˚00'59.361" E longitude, 450 m above mean sea level. The average annual rainfall of this region is 724.9 mm with much spatial and temporal variability.

Soil sampling and analysis: Detailed soil survey was carried out in 2019 using Quick bird satellite imagery at the scale of 1:8,000 and toposheet of 1:50,000 from Survey of India. Intensive traversing of each physiographic unit like hills, up lands, mid lands and low lands were carried out. Based on the soil variability observed on the surface, transects were selected across the slope covering all the physiographic units identified in the study area. In the selected transect, eight soil profiles were located. Soil samples were collected from representative master profiles (horizon wise) for the laboratory analysis of morphological characters like physiography, soil colour, soil structure, consistency, slope, erosion and physico-chemical properties of soil like particle size analysis (International pipette method; Piper, 1966), bulk density (Core method; Piper, 1966), particle density (Pycnometer; Blake 1965), water holding capacity (Keen's cup method; Bernyard and Henry, 1965), pH (Potentiometric method (Hesse, 1971), electrical conductivity (EC bridge (Jackson, 1973)), per cent organic carbon (Wet oxidation method (Walkley and Black, 1934)), available N (Alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (Olsen's method (Jackson, 1973), available potassium (Flame photometry (Jackson, 1973)), available sulphur (Turbidometric method (Jackson, 1973), exchangeable Ca and Mg (Versenate titration method (Jackson, 1973), exchangeable Sodium and potassium (Flame photometry (Jackson, 1973), micronutrients (DTPA extractable method, (Lindsay and Norvell, 1978), available boron (Colourimetric method (Berger and Troug, 1939), cation exchange capacity (sodium saturation method (Richards, 1954), etc., were studied for profile samples. The surface samples (0-20 cm) collected from farmers fields at 320 m grid interval, analyzed and mapped for fertility status. Thus, the data base generated helped in preparation of maps using Arc view 3.2a GIS software. Soils were classified upto series level as per the revisions in soil taxonomy (Soil Survey Staff, 1999) using soil characteristics. The location map of the study area is given in Fig. 1.

Results and Discussion

Eight pedons from Malli-1 micro watershed of Yedrami taluka, Kalaburagi district in the North Eastern Dry Zone (Zone-2) representing eight different mapping units of seven soil series viz., Bhimanahalli, Novinihal, Margutti, Gutti, Rajhnal, Mahagoan and Dinsi series were identified and these soils were studied for their morphological and physico-chemical properties. Soils were very gently sloping (1-3 %) in all the soil series except Margutti series and Margutti series has gently sloping (3-5%). Rajesh *et al.* (2018) mentioned very gently and gently sloping land in Kalmali north-2 micro-watershed of Raichur district. The solum depth of study area varied from very shallow (0-25 cm) to very deep (> 150 cm) (Table 1).

Soils of mid land and low land were deeper as compared to soils of upland. The soils were well drained, their colour varied from 7.5 YR to 10 YR. Thick dark matrix of soil colour was due to the presence of more organic matter content in the top surface

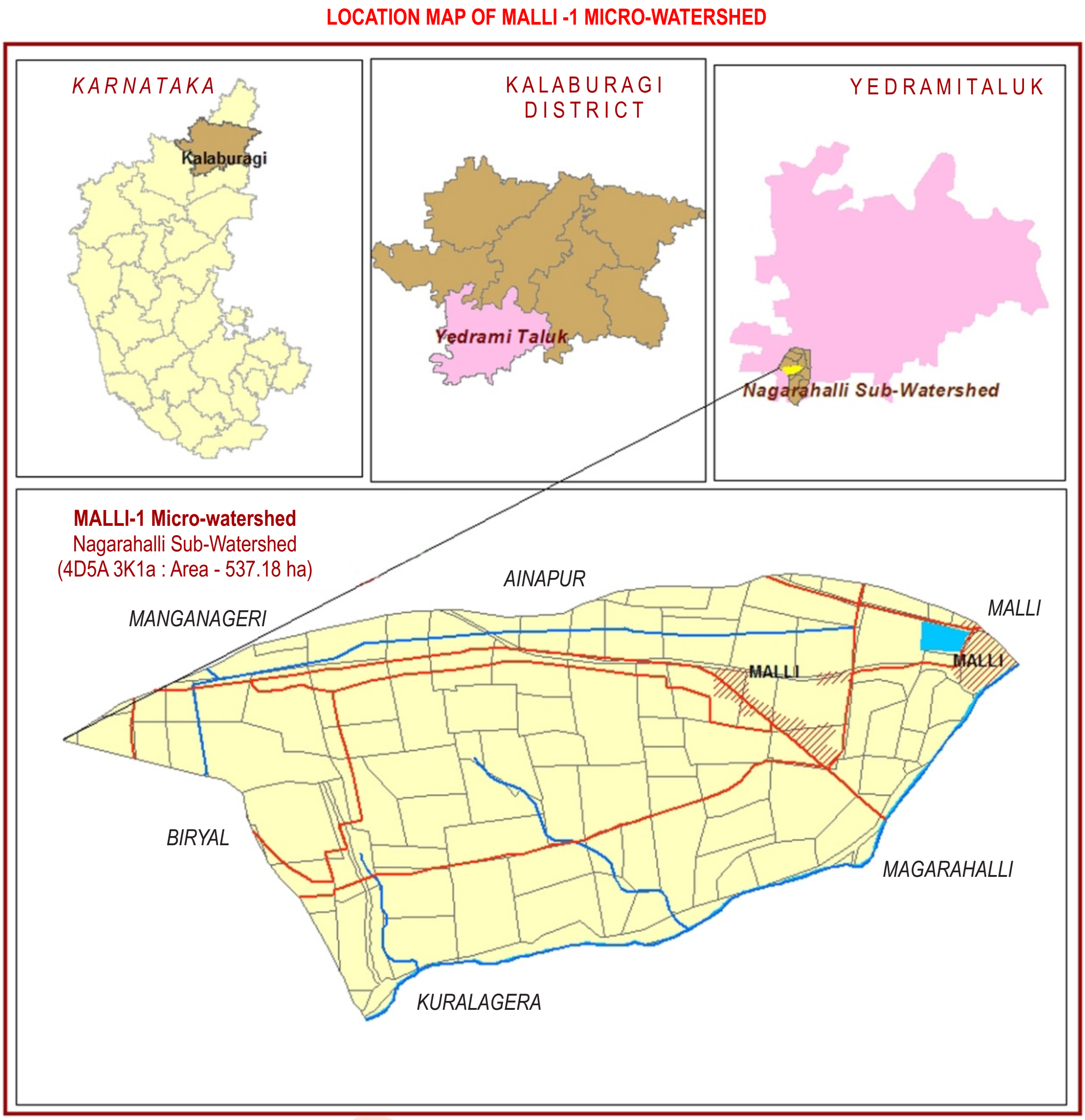

Fig. 1: Map indicating location of Malli-1 micro watershed.

horizons as documented by Nagendra and Patil (2015) in Shirol West-1 micro-watershed. All the soil series exhibited dry consistency that varied from loose in surface horizon and hard to very hard in subsequent sub surface horizons. The surface horizons of pedons exhibited slightly sticky and slightly plastic to moderately sticky and moderately plastic, loose and firm to friable and slightly sticky and slightly plastic to very sticky and very plastic, hard to very hard and firm to friable in sub-surface horizons in wet, dry and moist conditions, respectively (Table 1). Meenakshi *et al.* (2018) noticed that these qualitative variations in physical behavior of soils were influenced due to textural make up and type of clay minerals present in these soils. More stickiness and plasticity may be due to the presence of high silt and clay content. The soils of Malli-1 micro watershed showed wide range of textural variation, *i.e.,* from clay to clay loam. Moderate medium sub angular blocky structure was predominant in both surface and sub-surface horizons of soil series (Bhimanahalli, Novinihal, Margutti and Gutti series) whereas structure of soil in soil series (Rajhnal, Mahagoan and Dinsi series) varied from moderate, medium sub-angular blocky in surface to moderate medium angular blocky in sub-surface horizons (Table 1).

Table 1: Morphological properties of soil series of Malli-1 micro watershed

PedonNo.	Horizon	Depth (cm)	Colour		Structure	Consistency		
			Dry	Wet		Dry	Moist	Wet
			BHIMANAHALLI SERIES (BHImB2g1)					
P 1	Ap	0-12	7.5YR 3/2	7.5YR 3/2	2m sbk	l	fr	sssp
P 1	Bw	12-30	7.5YR 3/2	7.5YR 3/2	2m sbk	h	fr	sssp
			NOVINIHAL SERIES (NHAmB2g0)					
P 2	Ap	0-9	10YR3/2	10YR3/2	2m sbk	l	fr	sssp
P 2	Bw1	9-20	10YR3/2	10YR3/2	2m sbk	h	fr	sssp
P 2	Bw2	20-44	10YR3/2	10YR3/2	2m sbk	h	fr	sssp
			MARGUTTI SERIES (MGTmC2g1)					
P 3	Ap	0-8	7.5YR3/2	7.5YR3/2	2m sbk	l	fr	msmp
P 3	Bw	8-25	7.5YR3/2	7.5YR3/2	2m sbk	h	fr	msmp
			GUTTI SERIES (GTTmB2g1)					
P 4	Ap	0-9	10YR3/2	10YR3/2	2m sbk	l	fr	msmp
P 4	Bw1	9-38	10YR3/2	10YR3/2	2m sbk	h	fr	msmp
P 4	Bw2	38-52	10YR3/2	10YR3/2	2m sbk	h	fr	msmp
			MARGUTTI SERIES (MGTfB2g1)					
P 5	Ap	0-10	7.5YR3/2	7.5YR3/3	2m sbk	l	fr	msmp
P 5	Bw	10-25	7.5YR3/2	7.5YR3/3	2m sbk	h	fr	msmp
			RAJHNAL SERIES (RNLmB2g0)					
P 6	Ap	0-10	10YR3/1	10YR3/2	2m sbk	l	fr	sssp
P 6	Bw	10-38	10YR3/1	10YR3/2	2m sbk	h	fr	sssp
P 6	Bss1	38-70	10YR3/2	10YR3/3	2m abk	h	fi	vsvp
P 6	Bss2	70-110	10YR3/3	10YR3/3	2m abk	h	fi	vsvp
P 6	Bss3	110-143	10YR3/3	10YR3/4	2m abk	vh	fi	vsvp
			MAHAGOAN SERIES (MANmB2g0)					
P 7	Ap	0-10	10YR3/2	10YR3/2	2m sbk	l	fi	sssp
P 7	Bw	10-30	10YR3/2	10YR3/2	2m sbk	h	fi	sssp
P 7	Bss1	30-70	10YR3/1	10YR3/1	2m abk	h	fi	sssp
P 7	Bss2	70-109	10YR3/1	10YR3/1	2m abk	h	fi	vsvp
P 7	Bss3	109-128	10YR3/1	10YR3/1	2m abk	h	fi	vsvp
P 7	Bss4	128-156	10YR3/1	10YR3/1	2m abk	vh	fi	vsvp
			DINSI SERIES (DSImB2g0)					
P 8	Ap	0-10	10YR3/2	10YR3/2	2m sbk	l	fr	msmp
P 8	Bw	10-35	10YR3/1	10YR3/1	2m sbk	h	fr	msmp
P 8	Bss1	35-69	10YR3/1	10YR3/1	2m abk	h	fr	msmp

Pedon No.	Horizon	Depth (cm)	Slope (%)	Erosion	Drainage	Physiography
		BHIMANAHALLI SERIES (BHImB2g1)				
P 1	Ap	0-12	1-3	Moderate	Well	Upland
P 1	Bw	12-30				
		NOVINIHAL SERIES (NHAmB2g0)				
P 2	Ap	0-9	1-3	Moderate	Well	Upland
P 2	Bw1	9-20				
P 2	Bw2	20-44				
		MARGUTTI SERIES (MGTmC2g1)				
P 3	Ap	0-8	3-5	Moderate	Well	Upland
P 3	Bw	8-25				
		GUTTI SERIES (GTTmB2g1)				
P 4	Ap	0-9	1-3	Moderate	Well	Upland
P 4	Bw1	9-38				
P 4	Bw2	38-52				
		MARGUTTI SERIES (MGTfB2g1)				
P 5	Ap	0-10	1-3	Moderate	Well	Upland
P 5	Bw	10-25				

Table continue

			RAJHNAL SERIES (RNLmB2g0)			
P 6	Ap	0-10				
P 6	Bw	10-38	1-3	Moderate	Well	Lowland
P 6	Bss1	38-70				
P 6	Bss2	70-110				
P 6	Bss3	110-143				
			MAHAGOAN SERIES (MANmB2g0)			
P 7	Ap	0-10				
P 7	Bw	10-30				
P 7	Bss1	30-70				
P 7	Bss2	70-109	1-3	Moderate	Well	Lowland
P 7	Bss3	109-128				
P 7	Bss4	128-156				
			DINSI SERIES (DSImB2g0)			
P 8	Ap	0-10				
P 8	Bw	10-35	1-3	Moderate	Well	Upland
P 8	Bss1	35-69				

In the study area, the solum weighted average of sand, silt and clay, content in horizons ranged from 16.96 to 28.93, 22.40 to 31.50 and 39.20 to 55.90 per cent, respectively. The highest (55.90 %) clay content was observed in Novinihal series, while the lowest (39.20 %) in Margutti (P-2) series (Table 2) mainly due to several processes like illuviation, argilli pedoturbation and movement of finer fraction at lower depth. The highest (31.50 %) silt content was recorded in Margutti (P-2) series while the lowest (22.40 %) in Mahagoan series. In all the series, silt content exhibited an increasing trend with decreasing depth of pedon. The coarse, fine and total sand contents decreased with depth in all the series. The accumulation of sand fraction in surface horizons might be due to clay eluviations as reported earlier by Vedadri and Naidu (2018) in the soils of Chillakur mandal of Nellore district, Andhra Pradesh.

The bulk density and particle density (SWA) ranged from 1.21 to 1.33 mg m^{-3} and 2.43 to 2.60 mg m^{-3} (Table 3). The bulk density of lower solum was higher than the upper solum. This progressive compaction due to filling of pores by alluvial materials and lower organic matter was also observed by Okubay *et al.* (2015) in Vertisols of Southern Tigray, Ethiopia. The highest (2.60 mg m^{-3}) particle density was observed in Margutti (P-2) series that could be due to higher amount of sand and low (2.43 mg m^{-3}) particle density in Novinihal series due to greater amount of clay content. In all the soil series, the particle density followed the increasing trend with depth. Porosity (SWA) in all the seven series ranged from 49.13 to 50.25 per cent. In all the series, porosity followed a decreasing trend with depth. Brady and Weil (2002) revealed that, the ideal values of total pore space, which are acceptable for production of crops, were approximately 50 per cent. Hence, most series in the study area were in closely acceptable range of total porosity values for crops production.

The water holding capacity (SWA) of all the soil series ranged from 38.36 to 48.92 per cent (Table 3). The variations in values were due to variations in soil depth, amount of clay and silt content and organic carbon status. The higher water holding capacity was observed in Mahagoan series due to the presence of higher amount of clay and deeper soil depth. Among eight pedons, the highest (13.4 %) available water capacity was recorded in Novinihal series and the lowest (10.5 %) in Margutti (P-2) series (Table 3). Singh *et al.* (2013) observed that the soil moisture constant was influenced by texture and it indicated that soil moisture constant increased with increase in the clay and silt content. In the study area, soils were moderately to strongly alkaline in reaction (pH 8.1-9.1) (Table 4). Higher pH in these pedons were due to assemblage of bases in solum as these were very poorly leached. In study area, the salinity (EC) values (SWA) of the soils ranged from 1.1 to 2.4 dS m^{-1} (Table 4).

The upper part of solum was relatively low in salts than the lower part in these soils due to leaching of salts from surface layer to lower depth due to infiltration and their assemblage in the lower depth as reported by Niranjana *et al.* (2021) in Bisarahalli-1 Micro watershed. The soils were low to medium in per cent organic carbon (SWA) content and ranged from 0.34 to 0.65 per cent. Higher value (0.65 %) was observed in Novinihal series, while the lowest value (0.34 %) in Margutti (P-2) series (Table 4). The per cent organic carbon content at surface soil was greater than lower horizons in all the soil series and it decreased with depth due to application of farm yard manure and accumulation of plant residues at surface horizons. These results were in line with the findings of Meenakshi *et al.* (2018) in Pannur North-3 microwatershed and they observed that majority of soils were low in organic carbon. Higher (14.10 %) amount of free calcium carbonate was seen in Novinihal series and lowest (10.43 %) in Margutti (P-2) series (Table 4). The calcium carbonate content increased with depth due to the accumulation of calcium released from calcium rich parent material and also precipitation of calcium and magnesium as carbonates and bicarbonates in the solum. Ravikumar *et al.* (2009) observed that free calcium carbonate levels were in safe zone in 48A distributary of Malaprabha right bank command of Karnataka. The gypsum requirement (SWA)

Table 2: Particle size distribution of soil series of Malli-1 micro watershed

Soil phases	Horizon	Depth (cm)	Coarse sand	Fine sand	Total sand	Silt	Clay	Soil textural class
			← % of fine earth →					
			Bhimanahalli series					
BHImB2g1	Ap	0-12	12.64	16.96	29.60	24.80	45.10	Clay
	Bw	12-30	11.45	15.65	27.10	25.80	46.30	Clay
SWA			12.05	16.30	28.35	25.30	45.70	Clay
			Novinihal series					
NHAmB2g0	Ap	0-9	7.75	12.15	19.90	25.30	54.20	Clay
	Bw1	9-20	6.93	10.06	16.99	27.10	55.90	Clay
	Bw2	20-44	4.98	9.02	14.00	28.90	56.9	Clay
SWA			6.55	10.41	16.96	27.10	55.90	Clay
			Margutti series					
MGTmC2g1 (P-1)	Ap	0-8	8.96	19.94	28.90	30.50	40.20	Clay
	Bw	8-25	7.51	19.08	26.59	31.10	41.90	Clay
SWA			8.24	19.51	27.75	30.80	41.10	Clay
			Gutti series					
GTTmB2g1	Ap	0-9	5.38	18.42	23.80	24.10	52.50	Clay
	Bw1	9-38	5.08	16.32	21.20	25.30	53.60	Clay
	Bw2	38-52	3.55	14.25	17.40	27.50	54.30	Clay
SWA			4.67	16.23	20.80	25.60	53.50	Clay
			Margutti series					
MGTfB2g1 (P-2)	Ap	0-10	8.05	21.25	29.30	31.40	38.80	Clay loam
	Bw	10-25	7.66	20.90	28.56	31.60	39.60	Clay loam
SWA			7.86	21.08	28.93	31.50	39.20	Clay loam
			Rajhnal series					
RNLmB2g0	Ap	0-10	10.12	20.38	30.50	19.30	49.90	Clay
	Bw	10-38	8.03	20.17	28.10	21.30	50.50	Clay
	Bss1	38-70	5.71	18.49	24.20	22.20	53.40	Clay
	Bss2	70-110	4.12	16.17	20.29	24.60	54.60	Clay
	Bss3	110-143	2.61	15.30	17.91	25.40	56.10	Clay
SWA			6.12	18.10	24.20	22.60	52.90	Clay
			Mahagoan series					
MANmB2g0	Ap	0-10	14.02	24.20	38.22	12.80	48.60	Clay
	Bw	10-30	12.24	21.16	33.40	16.10	50.20	Clay
	Bss1	30-70	9.18	19.12	28.30	19.10	52.40	Clay
	Bss2	70-109	6.36	15.94	22.30	24.10	52.80	Clay
	Bss3	109-128	4.69	13.88	18.57	27.40	53.60	Clay
	Bss4	128-156	3.10	6.30	9.40	35.30	54.70	Clay
SWA			8.26	16.77	25.03	22.40	52.00	Clay
			Dinsi series					
DSImB2g0	Ap	0-10	9.09	19.91	29.00	20.20	50.60	Clay
	Bw	10-35	8.15	18.56	26.71	21.60	51.20	Clay
	Bss1	35-69	5.62	13.78	19.40	26.50	53.60	Clay
SWA			7.62	17.41	25.03	22.80	51.80	Clay

ranged from 11.58 to 12.11 t ha^{-1} (Table 4) and increased with increasing soil depth (Joachim and Verplancke, 2010). The exchangeable bases in all the soil series were in the order: Ca^{+2}> Mg^{+2}> Na^{+}> K^{+} on the exchangeable complex. Due to higher mobile nature of magnesium ions which was present in lesser amount than calcium ions and the lesser value of exchangeable monovalents (Na^{+}, K^{+}) compared to divalents (Ca^{+2}, Mg^{+2}) was due to easy leaching of monovalents and preferential adsorption of divalent as reported by Ravikumar *et al.* (2009) in 48A distributary of Malaprabha right bank command of Karnataka. The CEC showed the increasing trend with lower soil depth in all soil series as it varied from (SWA) 39.99 to 57.16 cmol (p^{+}) kg^{-1} (Table 5) due to deposition of clay, especially presence of expanding clay minerals. Base saturation and ESP (SWA) ranged from 91.88 to 95.11 and 6.94 to 9.30 per cent, respectively. Base saturation values increased with the profile depth and it was correlated to

Table 3: Physical properties of soil series of Malli-1 micro watershed

Soil phases	Horizon	Depth (cm)	BD	PD	Porosity	MWHC	SMC (%)		
			Mg m^{-3}		(%)		0.33Bar	15Bar	AWC
			Bhimanahalli Series						
BHImB2g1	Ap	0-12	1.24	2.47	49.80	44.79	29.4	17.3	12.1
	Bw	12-30	1.28	2.51	48.93	45.51	30.7	17.8	12.9
SWA			1.26	2.49	49.37	45.15	30.1	17.6	12.5
			Novinihal Series						
NHAmB2g0	Ap	0-9	1.18	2.40	50.83	44.91	30.4	18.1	12.3
	Bw1	9-20	1.21	2.43	50.21	45.78	31.5	18.4	13.1
	Bw2	20-44	1.23	2.45	49.74	47.97	33.9	19.1	14.8
SWA			1.21	2.43	50.25	46.21	31.9	18.5	13.4
			Margutti Series						
MGTmC2g1 (P-1)	Ap	0-8	1.31	2.58	49.22	43.49	26.4	15.5	10.9
	Bw1	8-25	1.32	2.59	49.03	44.21	27.1	16.3	10.8
SWA			1.32	2.59	49.13	43.85	26.8	15.9	10.9
			Gutti Series						
GTTmB2g1	Ap	0-9	1.22	2.46	50.41	45.88	29.8	17.2	12.6
	Bw1	9-38	1.23	2.47	50.20	46.26	31.6	18.3	13.3
	Bw2	38-52	1.27	2.51	49.40	46.46	31.9	18.4	13.5
SWA			1.24	2.48	50.00	46.20	31.1	18.0	13.1
			Margutti Series						
MGTfB2g1 (P-2)	Ap	0-10	1.32	2.60	49.21	37.98	25.3	15.4	9.9
	Bw	10-25	1.33	2.61	49.04	38.73	26.9	15.8	11.1
SWA			1.33	2.60	49.13	38.36	26.1	15.6	10.5
			Rajhnal Series						
RNLmB2g0	Ap	0-10	1.21	2.44	50.34	44.81	27.3	16.2	11.1
	Bw	10-38	1.25	2.48	49.70	46.12	28.1	16.4	11.7
	Bss1	38-70	1.27	2.49	49.08	47.42	30.1	17.9	12.2
	Bss2	70-110	1.29	2.51	48.61	49.13	31.5	18.5	13.0
	Bss3	110-143	1.31	2.55	48.67	51.27	32.3	18.7	13.6
SWA			1.27	2.49	49.28	47.75	29.9	17.5	12.3
			Mahagoan Series						
MANmB2g0	Ap	0-10	1.19	2.39	50.37	45.91	26.4	15.2	11.2
	Bw	10-30	1.22	2.45	50.23	47.47	27.6	15.3	12.3
	Bss1	30-70	1.28	2.52	49.06	47.81	28.6	16.2	12.4
	Bss2	70-109	1.29	2.53	49.01	48.91	29.9	17.3	12.6
	Bss3	109-128	1.30	2.52	48.67	50.56	30.6	17.8	12.8
	Bss4	128-156	1.33	2.63	48.29	52.87	31.3	18.6	12.7
SWA			1.27	2.51	49.27	48.92	29.1	16.7	12.3
			Dinsi Series						
DSImB2g0	Ap	0-10	1.26	2.48	49.14	43.56	26.8	15.9	10.9
	Bw	10-35	1.28	2.51	48.95	47.59	27.1	16.1	11.0
	Bss1	35-69	1.30	2.56	49.35	49.41	28.3	16.7	11.6
SWA			1.28	2.52	49.15	46.85	27.4	16.2	11.2

soil reaction. The increasing trend of base saturation with depth is due to the illuviation of bases from upper horizon to lower horizons as documented by Meenakshi *et al.* (2018) in soils of Pannur North-3 microwatershed. The highest (9.30 %) exchangeable sodium percentage was observed in Margutti (P-1) series and the lowest (6.94 %) in Dinsi series (Table 5). ESP followed an increasing pattern with the depth in all the series which indicated the initiation of sodiumization process in downward direction.

The electrochemical stability index in all the soil series of Malli-1 micro watershed ranged from (SWA) 0.13 to 0.28. The highest ESI (0.28) was observed in Novinihal series and the lowest (0.13) in Margutti (P-1 and P-2) series (Table 5). Electrochemical

Table 4: Chemical properties of soil series of Malli-1 micro watershed

Soil phases	Horizon	Depth (cm)	pH (1:2.5; Soil: water ratio)	EC (dS m^{-1}) (1:2.5; Soil: water ratio)	SOC (%)	Free $CaCO_3$ (%)	Gypsum Requirement (t ha^{-1})
			Bhimanahalli Series				
BHImB2g1	Ap	0-12	8.2	1.2	0.60	12.30	-
	Bw	12-30	8.3	1.3	0.51	12.90	-
SWA			8.3	1.3	0.56	12.60	-
			Novinihal Series				
NHAmB2g0	Ap	0-9	8.9	1.9	0.69	13.20	11.47
	Bw1	9-20	9.1	2.5	0.66	14.10	12.11
	Bw2	20-44	9.3	2.7	0.60	15.20	12.53
SWA			9.1	2.4	0.65	14.10	12.04
			Margutti series				
MGTmC2g1							
(P-1)	Ap	0-8	8.1	1.1	0.44	10.80	-
	Bw	8-25	8.3	1.3	0.35	11.95	-
SWA			8.2	1.2	0.39	11.38	-
			Gutti Series				
GTTmB2g1	Ap	0-9	8.4	1.6	0.63	12.85	-
	Bw1	9-38	8.5	1.7	0.60	14.35	-
	Bw2	38-52	8.6	1.7	0.57	14.45	12.11
SWA			8.5	1.7	0.60	13.88	12.11
			Margutti Series				
MGTfB2g1							
(P-2)	Ap	0-10	8.0	0.9	0.46	10.20	-
	Bw	10-25	8.2	1.3	0.21	10.65	-
SWA			8.1	1.1	0.34	10.43	-
			Rajhnal Series				
RNLmB2g0	Ap	0-10	8.1	1.3	0.71	10.15	-
	Bw	10-38	8.2	1.4	0.67	10.90	-
	Bss1	38-70	8.4	1.7	0.60	12.50	-
	Bss2	70-110	8.4	1.7	0.51	13.60	-
	Bss3	110-143	8.6	2.3	0.48	13.80	11.90
SWA			8.3	1.7	0.59	12.19	11.90
			Mahagoan Series				
MANmB2g0	Ap	0-10	8.2	1.4	0.72	9.55	-
	Bw	10-30	8.3	1.6	0.68	10.90	-
	Bss1	30-70	8.3	1.6	0.65	11.40	-
	Bss2	70-109	8.4	1.7	0.57	12.55	-
	Bss3	109-128	8.6	1.8	0.51	12.55	11.47
	Bss4	128-156	8.8	1.9	0.46	13.00	11.68
SWA			8.4	1.7	0.60	11.66	11.58
			Dinsi Series				
DSImB2g0	Ap	0-10	8.2	1.1	0.65	10.10	-
	Bw	10-35	8.4	1.2	0.55	11.55	-
	Bss1	35-69	8.4	1.3	0.34	12.50	-
SWA			8.3	1.2	0.51	11.38	-

stability index is used as an indicator to determine the structural stability of fertile soil (Kumarnaik *et al.,* 2020). The dispersive soil should have ESI value <0.05. The ESI values of the study area were greater than 0.05, that exhibited good soil structure resulting in soil aggregates. The higher value of ESI of the study area indicates that the significant portion of the study area has good, stable soil structure and soils with potentially low soil dispersion.

The fertility status of all soil series ranged from low to medium (157 to 435 kg ha^{-1}) in nitrogen, medium (27.4 to 36.8 kg ha^{-1}) in phosphorous, medium to high (208 to 375 kg ha^{-1}) in potassium and low to medium (6.7 to 13.4 ppm) in sulphur content. Total nitrogen content decreased with depth. Novinihal series recorded the highest available nitrogen content whereas the lowest was recorded in Margutti (P-2) series, which was due to higher per

Table 5: Exchangeable cations and cation exchange capacity of soil series of Malli-1 micro watershed

Soil phases	Horizon	Depth (cm)	Ca	Mg	Na	K	CEC	Ca:Mg	Ca:Na	BS	ESP	ESI
			cmol (p+) kg-1							(%)		
Bhimanahalli Series												
BHImB2g1	Ap	0-12	34.2	10.3	4.48	1.25	54.23	3.32	7.63	94.47	8.26	0.15
	Bw	12-30	34.6	10.5	4.91	1.04	55.05	3.30	7.05	94.55	8.92	0.15
SWA			34.4	10.4	4.70	1.15	54.64	3.31	7.34	94.51	8.60	0.15
Novinihal Series												
NHAmB2g0	Ap	0-9	37.1	9.5	4.34	1.79	55.73	3.91	8.55	94.89	7.79	0.24
	Bw1	9-20	37.6	10.6	4.91	1.74	57.85	3.55	7.66	95.15	8.49	0.29
	Bw2	20-44	38.5	11.3	5.21	1.61	57.92	3.41	7.39	95.28	9.00	0.30
SWA			37.7	10.5	4.82	1.71	57.16	3.62	7.87	95.11	8.43	0.28
Margutti Series												
MGTmC2g1	Ap	0-8	22.1	7.3	3.35	0.98	38.53	3.11	6.60	92.21	8.69	0.13
(P-1)	Bw	8-25	22.4	7.7	3.95	0.91	39.96	2.91	5.67	92.49	9.88	0.13
SWA			22.3	7.5	3.65	0.95	39.25	3.01	6.13	92.35	9.30	0.13
Gutti Series												
GTTmB2g1	Ap	0-9	33.7	9.4	3.91	1.41	54.42	3.59	8.62	94.49	7.18	0.22
	Bw1	9-38	35.2	10.8	4.61	1.38	56.99	3.26	7.64	94.74	8.09	0.21
	Bw2	38-52	39.6	12.9	4.91	1.31	58.72	3.07	8.07	95.14	8.36	0.20
SWA			36.2	11.0	4.47	1.37	56.71	3.30	8.11	94.79	7.88	0.21
Margutti Series												
MGTfB2g1	Ap	0-10	19.9	7.1	3.13	0.75	35.88	2.80	6.36	91.64	8.72	0.10
(P-2)	Bw	10-25	21.4	7.8	3.35	0.54	38.09	2.74	6.39	92.12	8.79	0.15
SWA			20.7	7.4	3.24	0.65	36.99	2.77	6.37	91.88	8.76	0.13
Rajhnal Series												
RNLmB2g0	Ap	0-10	25.9	8.9	4.31	1.28	50.38	2.91	6.01	92.57	8.55	0.15
	Bw	10-38	27.8	9.5	4.65	1.2	52.12	2.93	5.98	92.88	8.92	0.16
	Bss1	38-70	28.1	10.7	5.22	1.14	56.16	2.63	5.38	93.5	9.29	0.18
	Bss2	70-110	30.4	10.9	5.27	1.02	58.49	2.79	5.77	93.81	9.01	0.19
	Bss3	110-143	31.6	12.7	5.91	0.81	59.02	2.49	5.35	94.12	10.01	0.23
SWA			28.8	10.5	5.07	1.09	55.23	2.75	5.70	93.38	9.18	0.18
Mahagoan Series												
MANmB2g0	Ap	0-10	21.8	9.1	3.13	1.16	40.18	2.40	6.96	91.71	7.79	0.18
	Bw	10-30	22.6	10.5	3.22	1.14	42.46	2.15	7.02	91.99	7.58	0.21
	Bss1	30-70	22.7	10.7	3.43	1.12	42.65	2.12	6.62	92.62	8.04	0.20
	Bss2	70-109	25.2	12.4	4.23	0.98	46.71	2.03	5.96	92.98	9.06	0.19
	Bss3	109-128	28.7	12.7	4.31	0.91	47.52	2.26	6.66	93.69	9.07	0.20
	Bss4	128-156	30.4	14.6	4.61	0.84	50.23	2.08	6.59	94.03	9.18	0.21
SWA			25.2	11.7	3.82	1.02	44.95	2.17	6.64	92.83	8.50	0.20
Dinsi Series												
DSImB2g0	Ap	0-10	22.1	7.1	2.35	0.98	38.53	3.11	4.13	92.21	6.10	0.18
	Bw	10-35	22.4	7.7	2.95	0.91	39.96	2.91	3.76	92.49	7.38	0.16
	Bss1	35-69	24.7	8.3	3.13	0.84	42.97	2.98	4.03	93.02	7.28	0.18
SWA			23.1	7.7	2.81	0.91	40.49	3.00	3.98	92.57	6.94	0.17

cent organic carbon content in the, soils of Novinihal series. The lower nitrogen content in the study area may be due to the rapid degradation and consequent removal of organic matter, combined with less amount of nitrogen fertilization leading to nitrogen deficiency. The highest content of available phosphorous was noticed in Novinihal series due to higher CEC and clay content. The available phosphorus content showed the decreasing trend with soil depth which was attributed to its higher removal than replenishment in sub-surface horizons and also higher fixation of phosphorous as discussed by Sathish and Badrinath (1994) and Gurumurthy *et al.* (2019). Higher content of available potassium was seen in the surface layer and showed more or less a decreasing trend with solum depth due to rapid weathering of rocks, release of labile K from organic residues, application of potash fertilizers and upward movement of potassium from lower depths along with capillary rise of ground water as observed by Rajeshwar and Mani (2013) in red laterite soils of Chettinad of Sivagangai district of Tamil Nadu.

Table 6: Fertility status of the soil series of Malli-1 micro watershed

Soil phases	Horizon	Depth (cm)	Available nutrients				DTPA extractable micronutrients				Available B
				Primary	Secondary						
			N	P_2O_5	K_2O	S	Zn	Fe	Cu	Mn	
			← kg ha^{-1} →			ppm	← ppm →				
					Bhimanahalli Series						
BHImB2g1	Ap	0-12	295	30.0	235	11.2	0.21	3.91	0.90	3.29	0.29
	Bw	12-30	280	29.3	227	10.1	0.32	3.62	0.59	3.04	0.26
SWA			288	29.7	231	10.7	0.27	3.77	0.75	3.17	0.28
					Novinihal Series						
NHAmB2g0	Ap	0-9	502	40.7	268	15.1	0.61	5.31	1.49	4.29	0.34
	Bw1	9-20	439	38.4	183	13.2	0.54	4.56	1.34	3.39	0.23
	Bw2	20-44	364	31.4	180	11.8	0.55	3.71	1.10	2.57	0.22
SWA			435	36.8	210	13.4	0.57	4.53	1.31	3.42	0.30
					Margutti series P-1						
MGTmC2g1	Ap	0-8	173	30.8	205	8.1	0.53	1.89	1.21	3.29	0.25
(P-1)	Bw	8-25	162	25.5	189	6.3	0.61	3.42	1.34	3.24	0.22
SWA			168	28.2	197	7.2	0.57	2.66	1.28	3.27	0.24
					Gutti Series						
GTTmB2g1	Ap	0-9	310	32.3	402	14.0	0.52	2.26	1.23	3.95	0.30
	Bw1	9-38	298	31.4	378	9.8	0.44	2.83	1.43	3.04	0.28
	Bw2	38-52	285	29.6	346	9.3	0.25	4.01	1.41	3.16	0.26
SWA			298	31.1	375	11.0	0.40	3.03	1.36	3.38	0.28
					Margutti Series P-2						
MGTfB2g1	Ap	0-10	163	29.1	278	7.0	0.27	2.06	1.25	2.48	0.23
(P-2)	Bw	10-25	151	25.6	257	6.4	0.29	0.93	1.03	2.23	0.21
SWA			157	27.4	268	6.7	0.28	1.50	1.14	2.36	0.22
					Rajhnal Series						
RNLmB2g0	Ap	0-10	477	36.7	453	12.1	0.58	3.47	1.52	3.72	0.29
	Bw	10-38	425	35.8	380	11.2	0.24	5.01	0.96	2.03	0.29
	Bss1	38-70	312	34.5	335	9.5	0.25	4.06	1.20	1.94	0.26
	Bss2	70-110	292	32.3	305	8.7	0.32	3.14	1.52	3.52	0.25
	Bss3	110-143	279	26.9	289	7.9	0.37	4.38	1.41	1.85	0.23
SWA			357	33.2	352	9.9	0.35	4.01	1.24	2.61	0.26
					Mahagoan Series						
MANmB2g0	Ap	0-10	512	35.4	442	11.2	0.33	4.37	1.50	4.19	0.30
	Bw	10-30	481	32.7	418	10.9	0.31	4.56	1.42	4.00	0.28
	Bss1	30-70	423	30.9	368	7.9	0.35	3.99	1.39	3.00	0.26
	Bss2	70-109	333	27.8	356	7.6	0.26	5.39	1.12	2.54	0.25
	Bss3	109-128	298	26.9	335	7.0	0.37	5.59	1.26	2.90	0.21
	Bss4	128-156	275	23.7	289	6.2	0.29	3.97	1.20	2.89	0.20
SWA			387	29.6	368	8.5	0.32	4.65	1.32	3.25	0.25
					Dinsi Series						
DSImB2g0	Ap	0-10	213	34.0	224	8.4	0.42	2.09	1.17	3.37	0.28
	Bw	10-35	163	33.2	202	7.9	0.24	3.99	1.17	3.29	0.24
	Bss1	35-69	138	30.5	197	7.6	0.39	3.78	1.22	2.89	0.21
SWA			171	32.6	208	7.8	0.35	3.29	1.19	3.18	0.24

The highest (13.40 ppm) amount of sulphur was seen in Novinihal series, while the lowest (6.7 ppm) in Margutti (P-2) series (Table 6). Surface layer showed higher amount of available sulphur than the sub surface in all the series due to the presence of higher amounts of organic matter in surface layers than in sub-surface layers. DTPA extractable Zn, Fe, Cu, and Mn ranged from (SWA) 0.27 to 0.57, 1.50 to 4.65, 0.75 to 1.36 and 2.36 to 3.42 ppm, indicating that soils were deficient (<0.6 ppm) in Zn and Fe (<4.5 ppm) in all the soil series, which might be due to the presence of high pH and calcareous nature of soil as observed by Kumarnaik *et al.* (2020) in soils of Jantapur-1 microwatershed. Deficiency of Fe observed mainly due to the precipitation of iron

Table 7: Classification of soil of Malli-1 micro watershed

Series	Order	Suborder	Great group	Sub group	Family	Description
Bhimanahalli (BHI) Novinihala (NHA) Gutti (GTT)	*Inceptisols*	*Tropepts*	*Ustropepts*	*Vertic Ustropepts*	Very Fine, montmorillonitic, isohyperthermic	Very Fine, montmorillonitic, isohyperthermic family of *Vertic Ustropepts*
Dinsi (DSI) Margutti (MGT)	*Entisols*	*Orthents*	*Ustorthents*	*Typic Ustorthents*	Fine, montmorillonitic, isohyperthermic	Fine, montmorillonitic, isohyperthermic family of *Typic Ustorthents*
Rajhnal (RNL) Mahagoan (MAN)	*Vertisols*	*Usterts*	*Haplusterts*	*Typic Haplusterts*	Very Fine, montmorillonitic, isohyperthermic	Very Fine, montmorillonitic, isohyperthermic family of *Typic Haplusterts*

by free calcium carbonate and inturn decrease the Fe availability. The DTPA extractable Cu and Mn were found sufficient in all the soil series of study area. The available boron in the soil series of study area ranged (SWA) from 0.22 to 0.30 ppm. The highest (>0.33 ppm) boron content was observed in Novinihala series and the lowest (<0.33 ppm) in Margutti (P-2) series (Table 6). The available boron content at surface horizon was higher than sub surface horizon in all the soil series and it decreased with depth, which might be due to the accumulation of higher amount of organic residues in the surface horizons (Geetha and Naidu, 2013).

Based on the soil characteristics of pedons and climate of the study area, eight pedons from the Malli-1 microwatershed area were classified up to the series level (Table 7). Bhimanahalli, Novinihal, Gutti and Dinsi series were classified as *Inceptisols* due to shallow to moderately shallow (25-75 cm) soil depth. Margutti series was classified as Entisols owing to the soil depth of less than 25 cm (very shallow). Rajhnal and Mahagoan series were categorized as *Vertisols* because these pedons did not show lithic or paralithic contact within 50 cm of soil surface but had a weighted average of >50 per cent clay in all horizons as the moisture regime was *Ustic*, Rajhnal and Mahagoan series were classified as *Usterts*, Margutti series was classified as Orthents. Similarly, Bhimanahalli, Novinihal, Gutti and Dinsi series were classified as *Tropepts*. Meenakshi *et al*. (2018) observed that the soils of Pannur north-3 were categorized as Vertisols at order level and Ustert at suborder level as they had cracks in normal year that were measuring in length of 5 mm or more through a thickness of 25 cm or more within 50 cm of mineral soil surface, for more than 90 cumulative days per year. At great group level, Bhimanahalli, Novinihal, Gutti and Dinsi series were classified as *Ustropepts* and at sub group level they were categorized as *Vertic*. Margutti series was classified as Ustorthents and at the sub group level it was classified as *Typic*. At the great group level, Rajhnal and Mahagoan soil series were classified as *Haplusterts*. At the sub group level they were classified as *Typic* because they did not show densic, lithic, paralithic contact and duripan, hallic, sodic and petrocalcic horizon within 100 cm from mineral soil surface. The results are in line with Meenkshi *et al.* (2018) who classified soils of Pannur north-3 into *Udic* haplusterts and *Typic* haplusterts.

The LRI database in the form of maps and tables showed different types of soils, their spatial distribution and extent, classification, characteristics and use-potentials on an appropriate base map. The Malli-1 micro watershed varied from very gently to gently sloping and very shallow to very deep in depth. The pH of soil series of study area was moderately alkaline to alkaline in reaction and EC was non saline. Soils were low to medium in soil organic carbon content. The available N was low to medium, P_2O_5 was medium, K_2O was medium to high and S was low to medium in range. All these nutrients decreased with depth of soils. Soils were sufficient in copper and manganese but deficient in zinc, iron and boron. Majority of soils in study area represents the *Vertisol* fallowed by *Inceptisols* and *Entisols* order. The land resource information system thus generated for the micro watershed can be used as decision support system to the land users, policy makers and administrators for identifying areas that are deficient or sufficient in major and micronutrients, thus facilitating preparation of soil health cards for each land parcel/ survey number. Site specific suitable conservation measures such as Trench cum bunds, contour bunds, graded bunding and staggered trenching are adopted to improve the soil productive constraints such as soil slope, erosion and soil depth. Finally, the LRI database helps in preparing optimum land use plans for the microwatershed that helps not only in restoring the ecological balance but also in improving the production on a sustainable basis.

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