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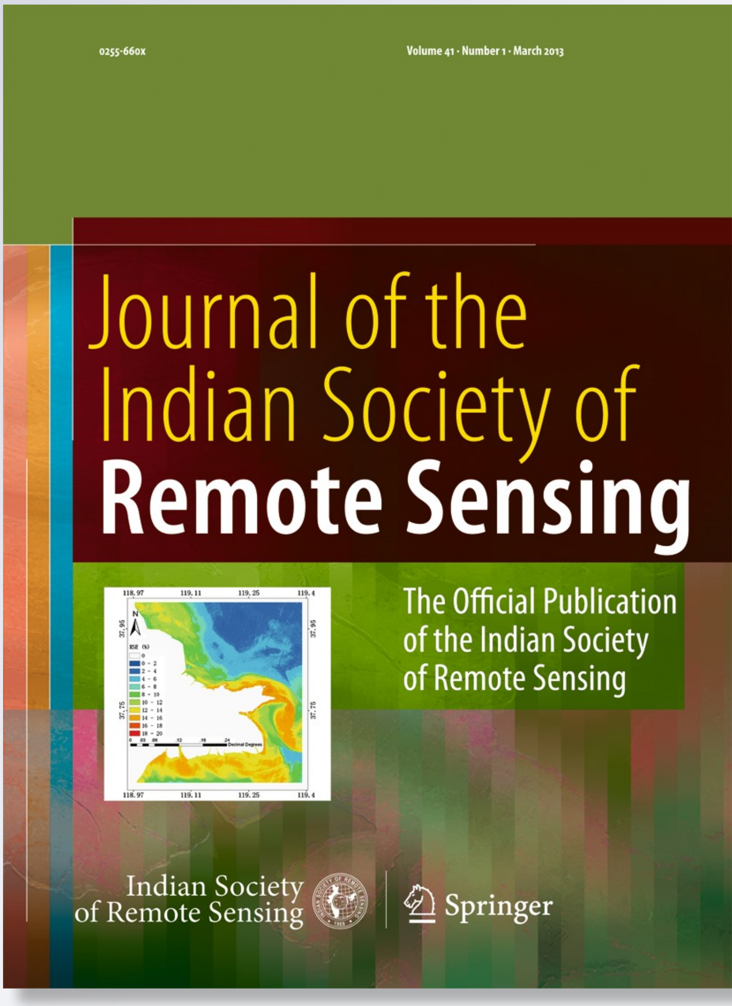

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RESEARCH ARTICLE

Characterization of Landforms and Soils in Complex Geological Formations—A Remote Sensing and GIS Approach

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Abstract The present investigation has been designed to analyze the landform and soil relationship in a geologically complex terrain of Tirora tahsil of Gondia district, Maharashtra using remotely sensed data and GIS technique. The geomorphologic units of the study area were delineated through visual interpretation of IRS–ID LISS-III data based on the spatial variation of the image characteristics. Thirteen landform units have been identified in the tahsil. The slope varied from level to nearly level with an area of about 63.76% of the tahsil. Rest of the area ranged from very gentle to moderately steep slopes. During soil survey, soil profiles were studied for morphological features. Horizon-wise soil samples were collected from the representative soil profiles on each landform unit. The depth of soil varied from 25 to 160 cm and colour from dark brown to very dark grayish brown. The texture ranged from clay loam to clayey in accordance with higher and lower topographic positions respectively. Higher available water holding capacity (AWC 285 mm) is found in low-lying area and low to medium AWC (140 mm) is noticed in the soils developed at higher elevation. The soils reaction (pH) is strongly acidic in nature (pH 5.2) on dissected hills, linear ridge and moderately weathered pediments, whereas, the soils are moderately to slightly acidic in nature (pH 5.5 to 6.5) on hills, shallow weathered pediments, moderately weathered pediments, deeply weathered pediments, narrow valleys, and broad valley floors. Slightly alkaline condition (pH 7.6) was observed on foot slopes and aggraded valley fills. The electrical conductivity of the soils is found almost same in all landforms. The cation exchange capacity of the area varies from 10.5 to 51.5 cmol(p^+)kg^{-1}. The base saturation increases with decreasing elevation and slope. The four major soil orders viz, Entisols, Alfisols, Inceptisols and Vertisols are found in the study areas which are further classified into suborder and great group levels. The landform and soil relationship was analyzed to appraise the land resources in the tahsil. The study shows that the application of remotely sensed data and GIS are immensely helpful in land resources appraisal for their management on sustainable basis.

Keywords Geologically complex terrain · Landforms · Soil characterization · Soil classification · Remote sensing · GIS

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Introduction

The optimal management of land resource with minimal adverse environmental impact is essential, not only for sustainable development, but also for the sustenance of the human being. Detail information on landform units, their genetic processes and soils formed on them are useful in evaluation and management of land resources, environmental planning and developmental activities of any area (Cook and Doornkamp 1974; Demek 1982). Landform features are manifestations of under laying parent material and the nature and duration of their processes operating on them. Site-specific geomorphological interpretation is a pre-requisite for landforms mapping for effective analysis of the landform-soil relationship. The landform and soil relationship on a toposequence plays a vital role in classification of soils (Adams and Walker 1975). The geomorphological mapping of a terrain and analysis of their processes is necessary for soil resources mapping, identification of ground water potential zones, landscape ecological planning, hazard mapping and other environmental applications (Reddy et al. 2001). Soil genesis studies have shown that soils developed from different parent materials show variation in morphological properties like depth, colour, texture, structure, consistence and development of diagnostic subsurface horizons (Tamgadge et al. 1999) and these variations are attributed to the orientation of topography and landforms.

Remotely sensed data provides the information of landscapes synoptically, repetitively and objectively with reliable and accurate information on land resources (Pandey et al. 2011). Remote sensing data is being used as an efficient tool for land resource inventory and their monitoring (Stach et al. 2009). Remote sensing has become an indispensable scientific tool for mapping and monitoring of natural resource (Kasturirangan et al. 1996), and has been frequently used in the characterization of the soil resources and prioritization of watersheds (Saxena et al. 2000; Srivastava and Saxena 2004). Ahuja et al. (1992) also used remote sensing to delineate problematic lands at watershed level including salinity and sodicity.

Geographic Information System (GIS) is a powerful tool for geo-environmental analysis and appraisal of natural resources. It allows the user to integrate the database generated from various sources including remotely sensed data on a single platform and analyze them efficiently in a spatio-temporal domain. GIS techniques are being used in land evaluation studies, land capability and land irrigability assessment, soil suitability for crops, watershed management, irrigation water management, natural resources management and prioritization of watersheds (Sharada et al. 1993). Maji and Krishna (1996) and Maji et al. (2002) used GIS for soil survey and cited the capabilities of GIS such as reclassification techniques for thematic map generation and criterion based analysis for soil suitability evaluation. The present investigation has been carried out in this context of analyzing the geomorphological features, soils and their physical and chemical characteristics for their characterization in complex geological formations of Tirora tahsil, Gondia district, Maharashtra using IRS-ID-LISS-III data and GIS.

Study Area and Methodology

The study area, Tirora tahsil is located in north-western part of Gondia district, Maharashtra and lies between 21° 13′ 05″ to 21° 33′ 30″ North latitudes and 79° 47′ 50″ to 80° 05′ 00″ East longitudes covering an area of around 617.10 sq km (Fig. 1). Climate of the study area is sub-humid, sub-tropical with well defined summer (March–May), rainy season (June–September) and mild winter (November–February). The mean annual temperature is 26.4°C with a mean maximum of 29.3°C and mean minimum of 24.1°C. The mean annual precipitation of the tahsil is 1,400 mm of which nearly 85% is received during south-west monsoon period (June–September). Wainganga river flowing from North to south in the western part of the tahsil forms a major drainage system having the lower elevation ranging from 240 to 280 m above MSL, whereas, the higher elevation ranges from 350 to 500 m above MSL.

Geocoded IRS-ID-LISS-III Standard False Colour Composite (FCC) of 8th March 2000 (Path 100, Row 57) generated from bands 4,3,2 on 1:50,000 scale has been used in present study (Fig. 2). The satellite data of the study area was geo-referenced using SOI topographical sheets at 1:50,000 scale in EASI/PACE (ver 7.0) image analysis system (PCI 1997). Survey of India (SOI) topographical maps of tahsil area on 1:50 000 scale were used for the generation of base maps like contours, drainage pattern and road network. Using the contour information of toposheet, the Digital Elevation Model (DEM) was generated using the standard inbuilt algorithm of SPANS GIS ver 7.0 (PCI 1997) and subsequently the slope analysis has been carried out. Slope map was prepared and subsequently corrected, wherever necessary, based on ground

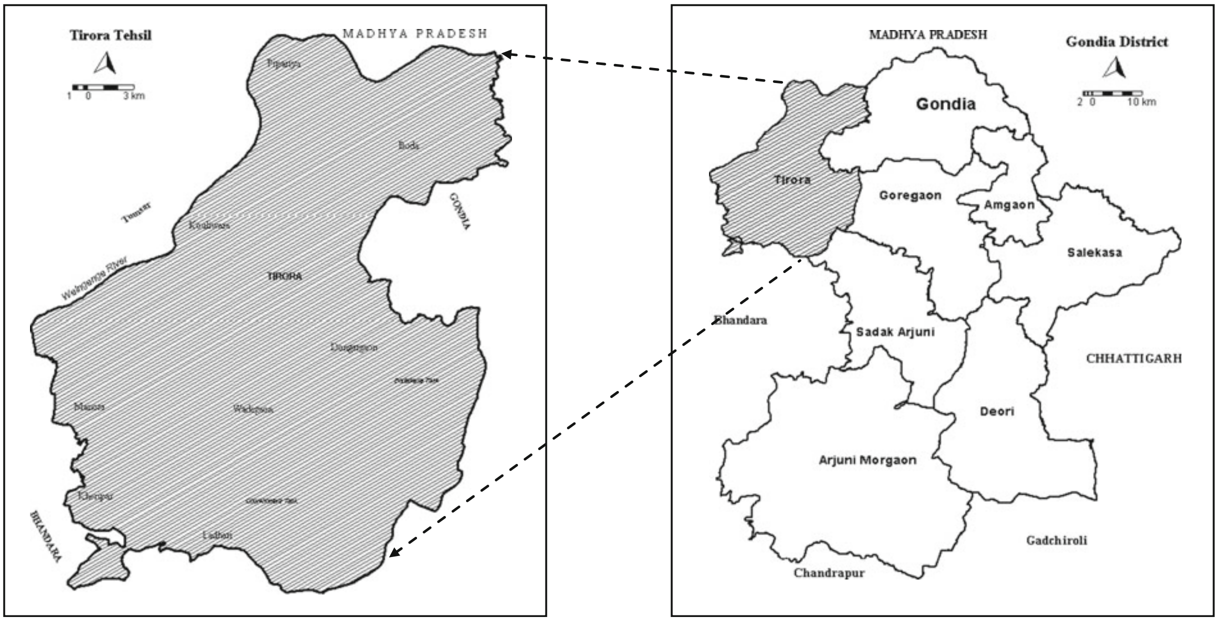

Fig. 1 Location map of the study area

truth. The geological map of the study area has been generated through the interpretation of the satellite data in conjunction with the geological map generated by Geological Survey of India (GSI 1978). The boundaries of the geological units have been refined based on the image characteristics and field observations. The geomorphologic units of the study area were delineated through visual interpretation of IRS-1D-LISS-III data based on the variation in tone, texture, shape, drainage, pattern, colour and differential erosional characteristics of the satellite images. The drainage, contour and delineated geological units have been overlaid on enhanced IRS-1D-LISS-III satellite imagery to delineate and characterize different landform units. Subsequently, detailed geomorphological analysis has been carried out based on their genesis and processes (Wright 1993). Necessary ground verifications were carried out for finalization of geomorphology map of the area. The locations for representative soil profiles were identified in each landform unit. Soil profiles were exposed upto murrum layer or 150 cm depending upon the depth of the soil. The profiles were studied for morphometric characteristics (Soil Survey Staff 1995). Horizon-wise soil samples collected from the representative soil profiles were analyzed for physical and chemical characteristics following standard analytical methods (Jackson 1958). Soils were classified according to Soil Taxonomy (Soil Survey Staff 1999). The landform and soil relationship was analyzed to appraise the land resources in the tahsil.

Results and Discussion

Geologically, the study area is complex and represented by different formations comprising of Amgaon Gneissic Complex (Granite Gneisses and Quartzitic, grity quartzitic), Tirodi Gneissic Complex (Archaean-Palaeo Proterozoic), dongargarh Granite, Sakoli Group, Sausar Group and Khairagarh Group (Meso-Proterozoic), the rocks of Vindhyan Supergroup equivalent (Neo Proterozoic), and Gondwana Supergroup (Permo-Carboniferous), occur as isolated outcrops overlying the Amgoan gneissic rocks in the southern part (Table 1). Alluvium is developed along the Wainganga river and its tributaries. Isolated laterite cappings are also observed in the study area.

Landforms

Geomorphic unit is defined as an individual and genetically homogeneous landform produced by a

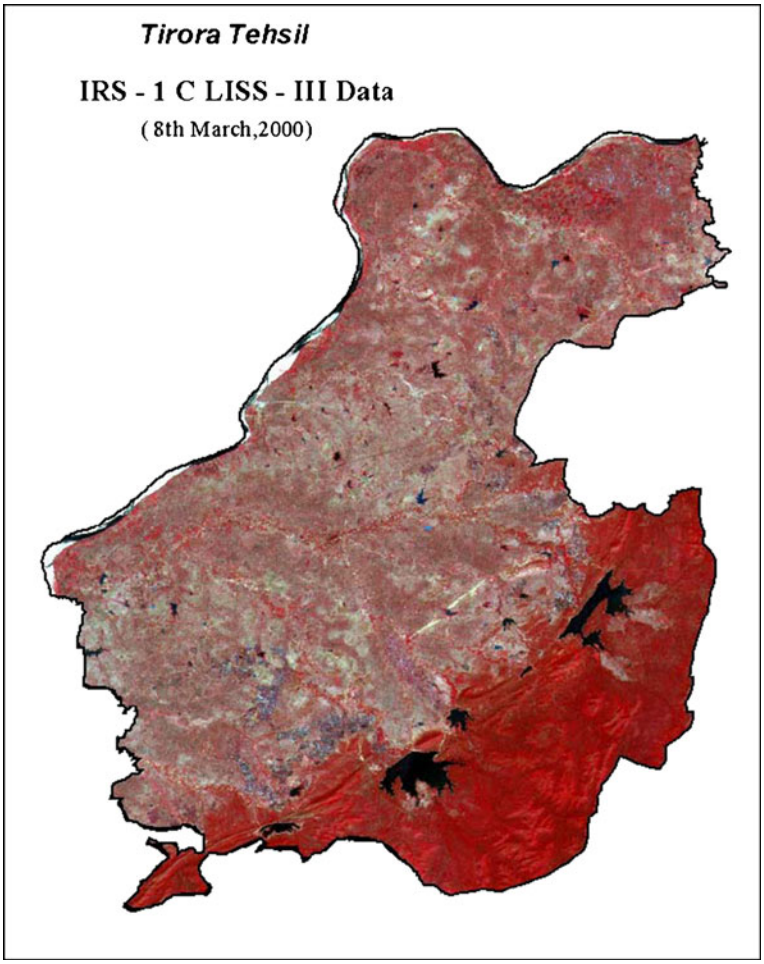

Fig. 2 IRS-ID LISS-III satellite imagery (FCC) of the study area

definite constructional or destructional geomorphic process (Fairbridge 1968). The geomorphic units distinctly separated each other by topographic change in slope segments similar to the morphological mapping techniques (Savigear 1965; Dalrymple et al. 1968). In the present study, landform units have been delineated and analyzed based on the visual interpretation of IRS-1D-LISS-III satellite imagery using with the interpretative tools (Table 2). Based on the analysis of IRS-1D-LISS-III satellite data in conjunction with collateral data 13 distinct landform units were delineated (Fig. 3)

The altitudinal variations noticed from the analysis of toposheets and imagaries led to the following categorization. *Dissected hill tops* are associated with extreme flatness, long slope length and medium to high infiltration capacity. This unit is spread mainly in eastern and south-eastern parts of the tahsil on dissected hill and hills. *The hills* have their origin due to active physico-chemical weathering followed by sheet and gully erosion processes leading to the development of undulating topography with dotted residual mounds and are found in the eastern and south-eastern parts of the tahsil. *Linear ridges*, mainly associated with meta basalt and mica-schist formations are formed due to weathering and detachment of material by fluvial processes. These units are narrow and linear in shape and are found in association with hills. *Scarp slopes* are associated with dissected hills and hills with steep to very steep slopes. Boarder on either side by slope discontinuities, they merge with surrounding foot slopes with a sharp angle. Slope wash is the dominant geomorphic process followed by rill and protogully formations. *Isolated mounds* located in the study area are narrow and restricted in nature and are found in association with hills.

Table 1 The regional geological succession of the study area

Lithology	Strategraphic status	Age	Nature and characteristics
Alluvium		Holocene-Pleistocene (Quaternary)	Loose sand, silt and clay. Locally silica is high in sand and can be used in glass industry. Yellow to reddish brown, usually ferruginous, porous, displays pisolitic texture; used as construction material.
Cherty quartzite	Sakoli Group	Mesa Proterozoic	Thin to thick intercalated fine grained, hard and compact chert bands; contain copper mineralization at places.
Meta-rhyolite/tuff			Light gray to dark grey, very fine grained tuffaceous to massive rock; contains copper and gold mineralization.
Mica-schist			Silvery, grayish white to greenish grey, medium to coarse grained, well foliated
Phyllite, tuffaceous phyllite and carbonaceous phyllite			Grey, light greenish to brownish grey and reddish brown, soft, well foliated rock.
Meta-basalt			Earthy green, fine grained, porphyritic, vesicular to amygdular hard rock.
Banded iron formation (BIF)			Banded rock with steel grey to grey, brown to reddish brown iron oxide and white silica; contains iron ore
Grity quartzite, meta-arkose and conglomaerate			Medium to coarse grained, granular rock with thin intercalated bands of phyllite
Amphibolites, hornblende schist	Amgaon Gneissic complex	Archean-Palaeo Proterozoic	Dark green, medium to coarse grained, hard and massive rock; suitable as road metal
Quartzite, gritty quartzite			Pink, white and grey rocks at places black due to presence of magnetite; suitable as road metal
Calc-silicate rock			Greenish to brown, medium to coarse grained and well banded rock
Granite gneisses	Granitic gneisses with migmatite/granite. Granulite. Tirodi Gneissic Complex		Migmatite-coarse to medium grained, mesocratic, distinctly gneissose and often porphyroblastic rock
			Gneiss-light greenish to grey, medium to coarse grained and banded rock; suitable as dimension stone
			Granite-light grey, medium to coarse grained and massive
			Pale brownish, medium to coarse grained, greasy rock.

(GSI 2000)

The tops of mounds are gently flat with sharp side slope and these units are disintegrated due to various geomorphic processes and stand as remnants. *Dissected hills* basically consist of hilly topography in south-eastern and southern parts of the tahsil. These clusters of hills are sharp to very sharp associated with hill and valley topography and characterized by rill and gully formation.

Plateau is relatively at higher elevation and formed by the action of differential weathering processes. These isolated units are characterized by moderate slopes and laterization processes. *Shallow weathered pediments* are associated with moderate slopes with shallow weathered material in sub surface. They are restricted in the toe slope of hills and dissected hills. These units are associated with granite/gneiss formation and noticed in central and northern part of the tahsil. *Moderately weathered pediments* are low in relief and are associated with semi-stratified to stratified deposition, which are admixed with sandy loam to clay fragments. These units are noticed on granite and gneiss formation. *Deeply weathered pediments*

Table 2 Satellite image characteristics of different landform units of Tirora tahsil

Landform unit code	Landform unit	Tone/colour	Texture	Shape and size	Pattern	Association	Area (sq.km)	Area (%)
1.1	Dissected hill tops	Brown to dark red	Coarse	Irregular and medium	Elongated	Dissected hills	6.42	1.04
1.2	hills	Light to dark red	Coarse	Irregular and large	Elongated	Dissected hills	96.45	15.63
1.3	Linear ridges	Light gray to light red	Coarse	Linear and small	Linear and scattered	hills	2.84	0.46
1.4	Scarp slopes	Light to dark red	Coarse	Linear to circular and small	Linear to circular	Dissected and hills	1.48	0.24
1.7	Isolated mounds	Light to dark red	Coarse	Circular and small	Isolated	Dissected, and residual hills	3.15	0.51
1.8	Dissected hills	Dark red	Coarse	Irregular and medium	Elongated	hills	33.39	5.41
2.2	plateau	Light gray to light red	Medium	Irregular and widespread	Irregular	Plateau to and shallow weathered pediments	2.65	0.43
3.1	Shallow weathered pediments	Light gray to light brown	Medium	Irregular and widespread	Irregular	Deep and moderately weathered pediments	113.61	18.41
3.2	Moderately weathered pediments	Light gray to light red	Fine	Irregular and large	Irregular	Deep and shallow weathered pediments	96.02	15.56
3.3	Deeply weathered pediments	Light gray to dark red	Fine	Irregular and large	Irregular	Shallow and moderately weathered pediments	112.62	18.25
4.1	Narrow valley	Brown to light red	Fine	Irregular and small	Isolated and linear	Shallow, moderateand deeply weathered pediments	40.11	6.50
4.2	Broad valley floors	Light gray to dark red	Fine	Irregular and medium	Isolated and linear	Shallow, moderate and deeply weathered pediments	21.66	3.51
4.4	Aggraded valley fills	Light red to dark red	Fine	Irregular and linear	Linear	Moderate and deeply weathered pediments	49.12	7.96
5	Water bodies						37.58	6.09
	Total						617.10	100.00

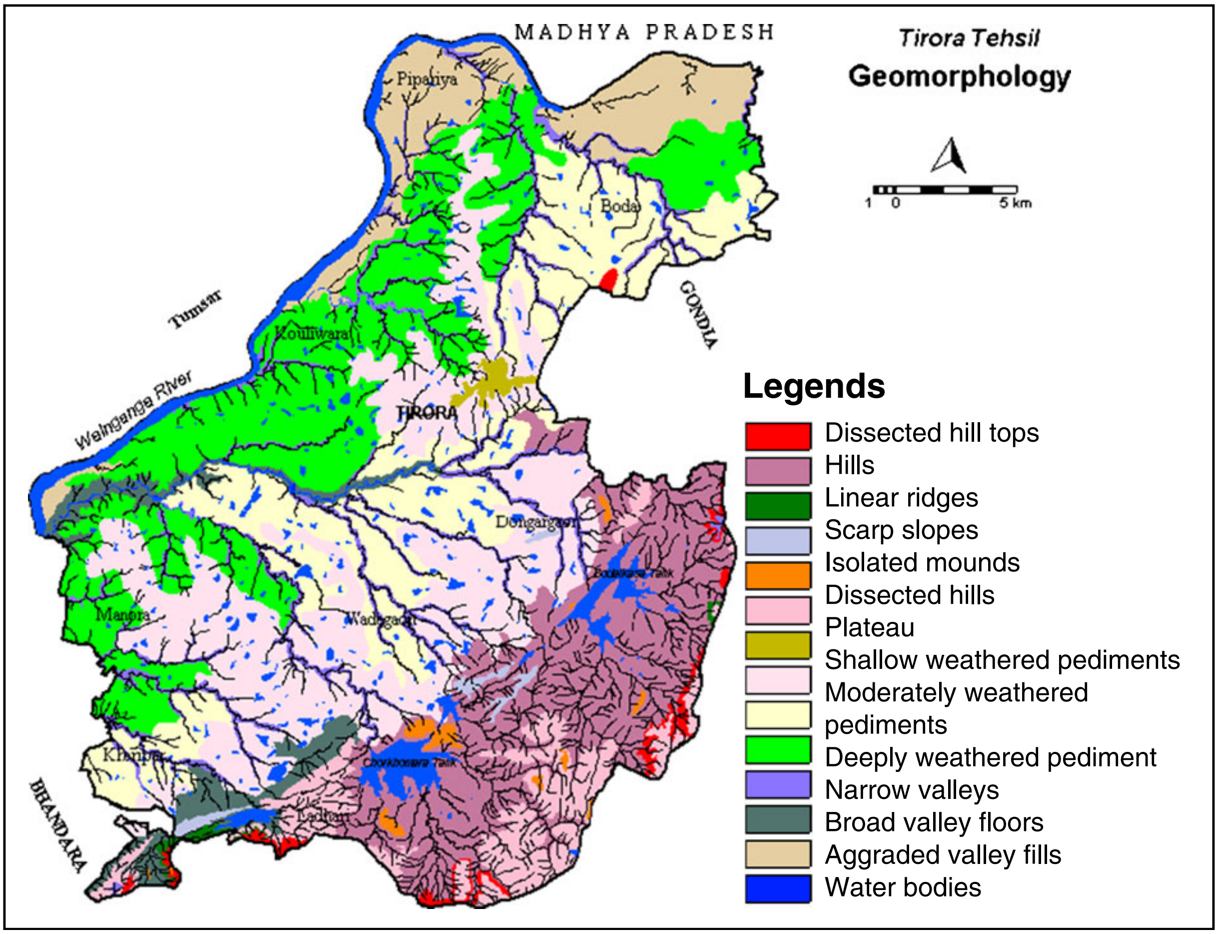

Fig. 3 Geomorphology map of the study area

are characterized by low in relief, high infiltration capacity and stratified deposits of admixture of sandy loam to clay loam soils. These units are formed on granite/gneiss and alluvium and noticed in lower elevation of the tahsil along the Wainganga river. *Narrow valleys* have moderate slopes in the higher elevation and level to nearly level slopes in the lower areas. These are controlled by local morphological structures. The deposited material in the lowland area was basically carried down form higher elevations. *Broad valley floors* are low-laying flat zone formed by the action of fluvial and depositional processes. The stratified sediments were noticed in the lower parts of the valley. *Aggraded valley fills* are associated with level slopes and deep to very deep soils. These units are found along the Wainganga river.

Soil Site Characteristics

The slope analysis reveals that the major area is under level to almost level slopes (0–1%) and geomorphologically associated with shallow, moderate and deeply weathered pediments, narrow valley and broad valley floors. The very gentle slopes (1–3%) are associated mainly with shallow and deeply weathered pediments. The shallow weathered pediments are in association with gentle slopes (3–8%). The moderate slopes (8–15%) occupy mainly the shallow and moderately weathered pediments. The moderately steep slopes (15–30%) are in association with linear ridges, isolated mounds, dissected hilltops and shallow weathered pediments. The eastern part of the tahsil is under steep (30–50%) to very steep slopes (>50%) with dissected hills, narrow scarp slopes, linear ridges and hills the analysis of surface drainage shows that soils are under well drained conditions in majority of the areas mainly on dissected hill tops, hills, linear ridges, scarp slopes, isolated mounds, dissected hills, plateau, foot slopes, upper piedmont, lower piedmont and narrow valley floor. The study reveals that nearly 30.09% of the tahsil in the south-east and north-west parts is covered by moderately well drained soils. Well-drained soils are found in the western and eastern parts with an area of 63.82% of the tahsil. Four major textural classes identified in the study area are clay, clay loam, sandy clay loam and sandy loam. The textural class distribution of the soils indicates that 30.89% of the area is covered by clayey textured soils. The clay loam soils occupy nearly 28.88% of total geographical area (TGA). The sandy clay loam and sandy loam soils occupy nearly 18.69% and 15.45% of TGA, respectively.

Soil Physical Characteristics

The soils developed on isolated mounds and denuded plateau spurs are shallow (<50 cm). Upper and lower sectors of main valley-side slopes and narrow drainage floor have deep to very deep soils (>100 cm). Shallow soils are found on the upper elevated area and isolated mounds and this area pose a major of limitations of soil depth for cultivation of crops. Moderately deep soil is found in the eastern part of the tahsil. Deep to very deep soils are found at lower zone. Various depth classes of the area show that 6.92% are having very shallow (10–25 cm) to shallow (25–50 cm) soils, which are in association with hummocky landforms (Figs. 4 and 5). Nearly 11.58% of area is under moderately deep (75–100 cm) and very deep soils (>100 cm) occupy nearly 75.41% of TGA. These soils are found on level to gently sloping lands and moderately plain regions. The area occupied by the water bodies is nearly 6.09% of the TGA. The particle size distribution shows that majority of the soils have fairly high amount of clay as compared to sand and silt fraction (Table 3). Basalt, being the parent material of these soils is known to produce higher amount of clay (Murthy et al. 1994). Soils developed on shallow weathered pediments (Sk), moderately weathered pediments (Pd and Jn), deeply weathered pediments (Sd and Bp) and aggraded valley fills (An) have higher clay content ranged from 49.2 to 64.2%. Development of varied particle size fraction may be attributed to the transportation of finer particles from higher to lower elevation and partly because of active churning process resulting from swelling and shrinking nature of the clay minerals. In general, increasing trend of clay is observed down the slope except in dissected hills, linear ridges and hills, which is situated at a much lower position than the lower sectors, has lesser clay percentage, which may be due to migration of clay trough runoff.

The bulk density of soils varies from 1.5 to 2.0 Mg m^{-3} (Table 3). Variation in bulk density of these shrink-swell soils may be attributed to the moisture content and high content of expanding type of clay mineral present. Increase of bulk density with soil depth may be due to over-burden pressure causing compacted in the subsurface horizons (Ahuja et al. 1988), while the surface soils are less compaction probably due to high amount of organic matter and plant root concentration (Coughlan et al. 1986). The AWC was found to be high to extremely high in the study area. The AWC values of the soils vary from 140 to 285 mm (Table 3) and are related to physiographic position, clay content and organic matter. The AWC values have been found to increase with increasing depth and clay content of the soils (Antony et al. 1981). The soils on the dissected hills, linear ridges, hills are having low AWC as compared to the soils on the shallow weathered pediment, moderately weathered pediment, deeply weathered pediments and aggraded valley fills. The low AWC in shallow weathered pediments may be due to shallow depth of the soils and gentle to moderate slope condition, whereas, the higher AWC on the aggraded valley fills may be due to higher moisture retention by the clayey soils.

Soil Chemical Characteristics

The overall pH values of the soils ranged from 4.7 to 7.7 grouping into moderately acidic to slightly alkaline (Table 4). The soils developed on the different soils mapping units have the pH values are on hills (pH 4.7) and moderately weathered pediment, dissected hills and linear ridges (pH 5.2) are moderately acidic with an area about of 15.5%. Soils developed on moderately weathered pediments and linear ridges (pH 5.8), dissected hills (pH 6.2), shallow weathered pediments and deeply weathered pediments (pH 6.3),

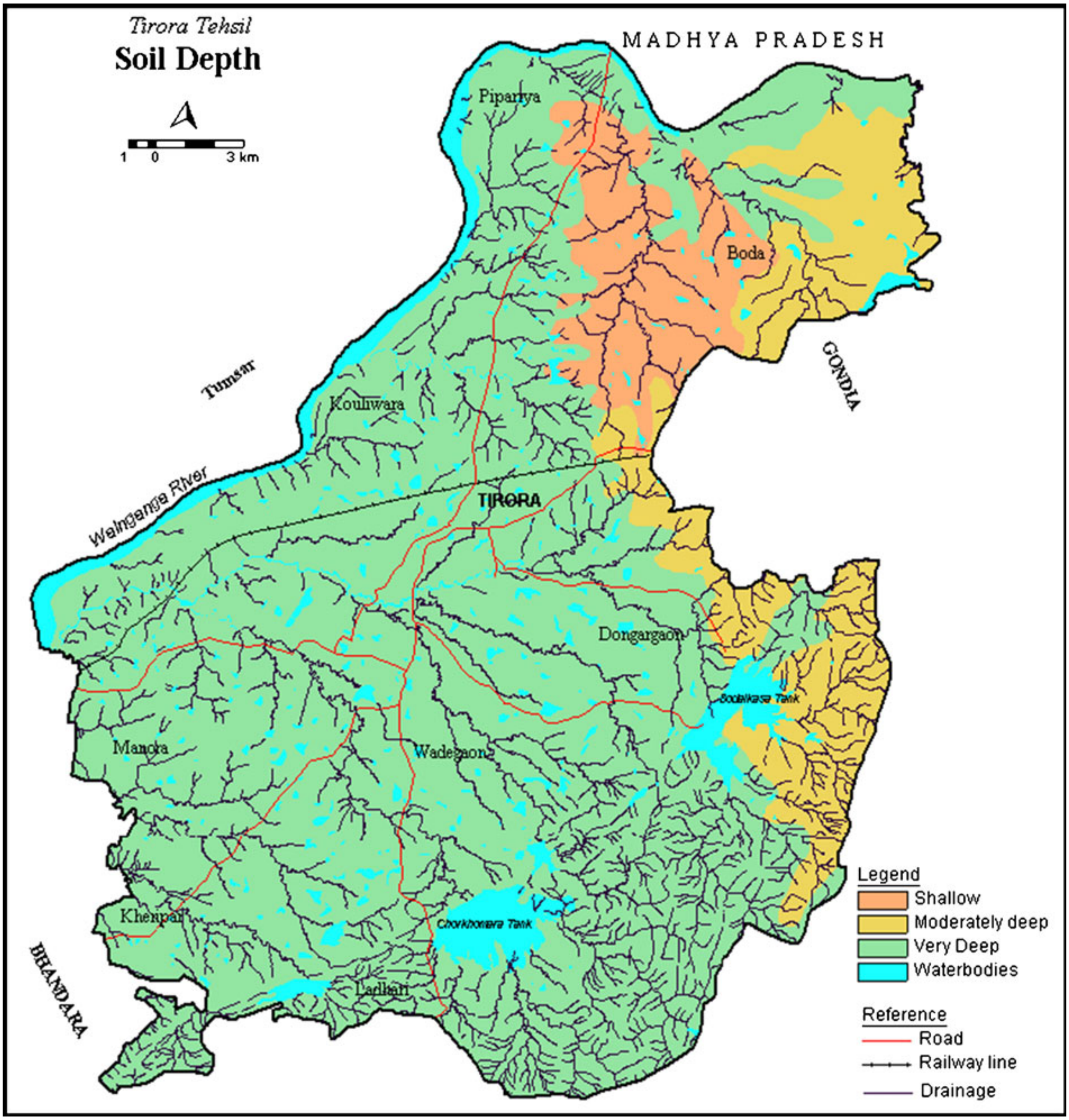

Fig. 4 Soil depth map of the study area

moderately weathered pediments (pH 6.6), shallow weathered pediments (pH 6.9) and deeply weathered pediments (pH 7.1) are slightly acidic to neutral having the area 47.7 and 10.3% respectively. The soils on the aggraded valley fills (pH 7.7) are slightly alkaline with an area about 20.4%. The pH of the soils was found to decrease with increasing altitude and is in continuity with the observation of Minhas and Bora (1982). The data on electrical conductivity shows that the soils are very low in soluble salt concentration with EC values of 0.2 dSm^{-1} (Table 4) and have no salinity hazards. These soils are free from salts and hence they are responsive to fertilizer

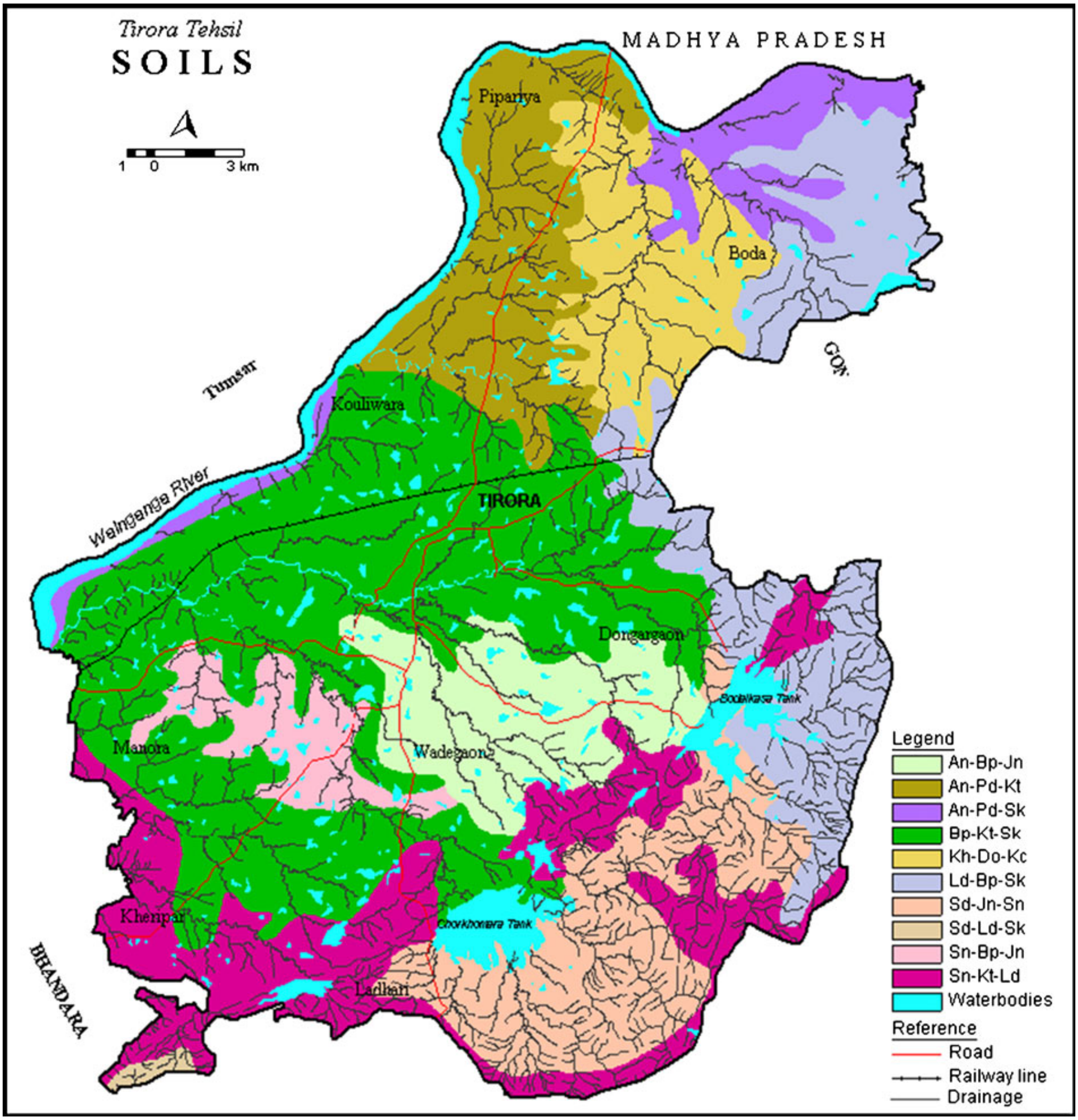

Fig. 5 Soil map of the study area

and management practices (Richards 1954). The organic carbon content in the soils ranged from 0.3 to 1.8% (Table 4). The soil developed on dissected hills (Kh) had comparatively more organic carbon than other soils, may be due to forest cover. The soils developed on moderately weathered pediment (Jn and Sn) and hills (Ld) also contain comparatively more organic carbon than the remaining soils. The soils developed on the deeply weathered pediments and aggraded valley fills have less organic carbon and may be due to intensive cultivation.

Cation exchange capacity (CEC) of soils varies from 10.5 to 51.5 cmol$(p^+)kg^{-1}$ (Table 4). These high values of CEC are attributed to the smectite type of

Table 3 Physical characteristics of Soil in Tirora tehsil (weighted means)

Soil series	Landforms	Depth	Particle size distribution			Bulk density	Water retention		AWC
			Sand	Silt	Clay		33 kPa	1,500 kPa	
		cm	….%…..			Mg m^{-3}	……% ….		mm
Khmtalao (Kh)	Dissected hills	25	22.1	36.2	41.6	1.7	28.7	15.6	217
Kochi (Kc)	Dissected hills and Linear ridges	50	45.8	21.3	32.9	1.7	18.1	8.5	161
Deori (Do)	Linear ridges	37	37.9	22.3	39.8	1.6	24.8	12.5	192
Bampewada (Bp)	Deeply weathered pediments	155	22.6	27.3	50.1	1.8	30.6	17.3	252
Sonegaon (Sn)	Moderately weathered pediments	115	38.7	29.8	31.5	1.7	23.3	11.9	188
Lakhandure (Ld)	hills	55	45.0	16.2	24.2	1.5	15.4	7.1	147
Karati (Kt)	Shallow weathered pediments	115	42.5	17.1	40.5	1.7	19.0	10.7	140
Jamnapur (Jn)	Moderately weathered pediments	156	27.4	23.4	49.2	1.7	32.3	17.7	247
Sakoli (Sk)	Shallow weathered pediments	160	20.1	21.3	58.0	1.8	31.6	16.2	274
Paraswada (Pd)	Moderately weathered pediments	135	29.1	19.6	51.3	1.8	25.9	12.6	240
Sawarbandh (Sd)	Deeply weathered pediments	151	32.8	21.3	49.2	1.9	29.1	15.8	247
Arjuni (An)	Aggraded valley fills	150	15.5	22.3	64.2	2.0	36.7	22.0	285

clay minerals and high amount of clays. Sum of the exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) contributes near about 90% of CEC of these soils. Presence of these bases in sufficient quantity in the soils is favourable for plant growth. Calcium is the dominant cation followed by magnesium, sodium and potassium. It varies from 5.4 to 41.0 cmol(p^{+})kg^{-1}. The dominance of Ca^{2+} may be due to basalt, which is the source of high calcium. Magnesium varies from 1.1 to 7.7 cmol(p^{+})kg^{-1} (Table 4). Soils of the area exhibit variation in their base saturation percentage. It ranged from 52.6 to 98.0% (Table 4). Higher amount of exchangeable calcium fallowed by magnesium contribute towards high base saturation condition.

Characterization of Soils

The 12 typifying pedons representing dominant soils developed on various landforms were studied and

Table 4 Chemical characteristics of soils in Tirora tehsil (weighted means)

Soil series	Landforms	Depth	pH (1:2.5 H_2O)	EC (1:2.5 H_2O)	Organic carobn	Exchangeable bases				Cation exchange capacity	Base saturation
						Ca^{++}	Mg^{++}	Na^{+}	K^{+}		
		cm		dSm^{-1}	%	……….Cmol (p^{+}) kg^{-1}…………..					%
Khmtalao (Kh)	Dissected hills	25	6.2	0.2	1.8	21.5	6.2	0.6	0.4	35.7	80.5
Kochi(Kc)	Dissected hills and Linear ridges	50	5.2	0.2	0.6	5.4	1.5	0.2	0.1	10.5	66.5
Deori (Do)	Linear ridges	37	5.8	0.2	0.6	10.7	4.4	0.2	0.2	17.5	87.9
Bampewada (Bp)	Deeply weathered pediments	155	6.3	0.2	0.3	14.4	7.3	0.3	0.3	27.8	80.4
Sonegaon (Sn)	Moderately weathered pediments	115	5.2	0.2	0.7	8.5	4.6	0.2	0.2	21.3	64.1
Lakhandure (Ld)	hills	55	4.7	0.2	0.7	7.2	1.1	0.2	0.2	14.2	52.6
Karati (Kt)	Shallow weathered pediments	115	6.9	0.2	0.3	19.6	4.7	0.3	0.2	27.2	91.0
Jamnapur (Jn)	Moderately weathered pediments	156	5.8	0.2	0.8	18.9	5.6	0.3	0.3	25.5	98.0
Sakoli (Sk)	Shallow weathered pediments	160	6.3	0.2	0.4	22.7	6.3	0.4	0.3	33.1	89.9
Paraswada (Pd)	Moderately weathered pediments	135	6.6	0.2	0.3	20.6	7.7	0.3	0.2	32.2	89.3
Sawarbandh (Sd)	Deeply weathered pediments	151	7.1	0.2	0.4	10.8	4.0	0.4	0.3	23.2	68.9
Arjuni (An)	Aggraded valley fills	150	7.7	0.2	0.4	41.0	7.1	0.3	0.2	51.5	96.3

classified following the criteria of Soil Taxonomy (Soil Survey Staff 1999). The soils map of the tahsil has been generated and shows 12 distinctly identified soils occurring in various landforms of the study area and mapped as soil series association (Fig. 5 and Table 2). Based on field morphology and laboratory characterization, the soils occurring on various landforms have been classified into four soil orders viz. Alfisols, Entisols, Inceptisols and vertisols. The soils developed on dissected hills and linear ridges are classified for the order Entisols and suborder Orthents and Great groups Ustorthents because of ustic moisture regime. These soils are further divided into Lithic subgroup based on presence of lithic contact within 50 cm of the surface and other features qualifying for respective category. The Sawarbandh (Sd) and Bampewada (Bp) soil series developed on deeply weathered pediment are classified as the Alfisols and suborder Ustalfs because of ustic soil moisture regime. The soils series like Sonegaon(Sn), Lakhandure (Ld), Karati (Kt), Jamnapur (Jn) and Paraswada (Pd) are classified as the order Inseptisols. Because of prevailing ustic moisture regime in the study area these soils are further classified into suborder Ustepts and qualify for Haplustepts at great group level. The great group is further divided into four subgroups viz., Typic Haplustepts and Vertic Haplustepts, Lithic Haplustepts and Udic Haplustepts. Out of these five soils, three soils Sn, Jn and Pd developed on moderately weathered pediment and are classified as Typic Haplustepts, Vertic Haplustepts and Udic Haplustepts respectively. these soils are well drained, deep, dark yellowish brown to dark brown and clay loam to clayey in texture. The Ld soil developed on hills has been classified as Lithic Haplustepts and the soil Pd developed on moderately weathered pediments is deep, well drained clay loam to clayey in texture and is classified as Udic Haplustepts. The soils Sakoli (Sk) and Arjuni (An) developed on Shallow weathered pediments and aggraded valley fills respectively qualifies for Vertisols and further classified as Usterts Suborder and Haplusterts Great group. These soils are deep to very deep, black coloured, clayey (>30% clay) and characterized by deep wide cracks that open and close periodically due to the action of water, micro-relief and intersecting slickensides.

Landform Soil Relationship

The inter-relationship between landforms and soils has been studied by establishing landforms and soils relationship (Gerrard 1990). The impact of landform affects the soil depth, colour, slope, erosion and physico-chemical properties of soils. Dissected hill tops are associated with extreme flatness long slope length and medium to high infiltration capacity. This unit is spread mainly in eastern and south-eastern parts of the tahsil on dissected hills and hills. The hills have their origin due to active physico-chemical weathering followed by sheet and gully erosional processes leading to the development of undulating topography with dotted residual mounds found in the eastern and south-eastern parts of the tahsil. Linear ridges are mainly associated with meta basalt and mica-schist formations. These units are formed due to weathering and detachment by fluvial processes. These units are narrow and linear in shape and are found in association with hills. Scarp slopes are associated with dissected hills and hills with steep to very steep slopes. Bordered on either side by slope discontinuities, they merge with surrounding foot slopes with a sharp angle. Slope wash is the dominant geomorphic process followed by rill and protogully formations. Isolated mounds located in the study area are narrow and restricted in nature and are found in association with hills. The tops of mounds are gently flat with sharp side slope and these units are disintegrated due to various geomorphic processes and stand as remnants. Dissected hills basically consist of hilly topography in south-eastern and southern parts of the tahsil. These clusters of hills are associated with hill and valley topography and characterized by rill and gully formation. These are sharp to very sharp hills. plateau is relatively at higher elevation and formed by the action of differential weathering processes. These isolated units are characterized by moderate slope and laterization process. Shallow weathered pediments are associated with moderate slopes with shallow weathered material in subsurface. They are restricted in the toe slope of hills and dissected hills. These units are associated with granite/gneiss formation and noticed in central and northern area of the tahsil. Moderately weathered pediments are low in relief and are associated with semi-stratified to stratified deposition, which are admixed with sandy loam to clay fragments. These units are noticed in granite and gneiss formation. Deeply weathered pediments are characterized by low in relief, high infiltration capacity and stratified deposits, which are admixture of sandy loam to clay loam soils. These units are formed on granite/gneiss and alluvium and are noticed in lower elevation of the tehsil along the Wainganga river. Narrow valleys have moderate slopes in the higher elevation and level to nearly level slopes in the lower areas. These are controlled by local morphological structures. The deposited material in the lowland area was basically carried from higher elevations. Broad valley floors are low-laying flat zone are formed by the action of fluvial and depositioned processes. The stratified sediments were noticed in the lower parts of the valley. Aggraded valley fills are associated with level slopes and deep to very deep soils. These units are found along the Wainganga river.

Conclusions

The analysis of landform-soil relationship slows strong clue for the differentiation in soils. Many of the differences in soils that vary with landforms are seem to be the effect of the geological surficial materials, microclimatic conditions and associated pedogenesis. The analysis reveals that bedrock geology, hydrological systems and ground climate influence soils and landforms genesis and processes and resultant effects are reflected through the variations in physical and chemical properties of the soils. The remote sensing and GIS approach helps in effective mapping, characterization and classification of the soils.

These properties of soils show variations due to its position on the landscape. Variations in particle size distribution are attributed to the transportation of finer materials from higher to lower elevation as well as churning processes operating in the solum. Elevational positions also dictate the AWC status of the soils. However, variation in organic carbon status is dependent on land use. Variation in CEC was attributed to the nature and amount of clay present in the soils. The reaction of the soils is strongly acidic in nature on plateau, shallow weathered pediments, narrow valleys, linear ridges and broad valley floors. The soils are moderately to slightly acidic in nature on plateau, shallow valleys and broad valley floors. The soils are slightly alkaline in nature on foot slopes and aggraded valley fills. The study shows that the application of remotely sensed data and GIS are very helpful in land resources appraisal.

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