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SHORT NOTE

Large-Scale Soil Resource Mapping Using IRS-P6 LISS-IV and Cartosat-1 DEM in Basaltic Terrain of Central India

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Abstract In the present study, an attempt has been made to describe the technique for large-scale soil mapping using remote sensing data. Based on erosional and depositional processes, seven major landforms namely plateau top, scarp slopes, plateau spurs, pediment, undulating plain, valley and floodplain have been delineated using Cartosat-1 DEM (10 m), contour (10 m) and hillshade. Using two seasons high-resolution IRS-P6 LISS-IV data, six land use/land cover classes namely double crop, single crop, orchard, wasteland with and without scrub and degraded forest have been identified using visual interpretation. A detailed slope map has been generated from Cartosat-1 DEM and reclassified into seven classes. On the basis of landform, slope, land use/land cover and ground truth, 37 Physiography-Landuse Units (PLU) were identified and described. PLU-soil relationship was developed by correlating soil-site characteristics and physical and chemical properties of soils. Six soil series were identified in major landforms and soil map depicting phases of soil series was developed. The study revealed that the combined use of Cartosat-1 DEM (10 m) and high-resolution IRS-P6 LISS-IV data will be of immense help in identifying soil patterns for large-scale soil resource inventory useful for village-level agricultural planning.

Keywords Landforms · Soil resource mapping · GIS · Cartosat-1 DEM · IRS-P6 LISS-IV data

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Introduction

The natural resources viz. soil, water and vegetation need to be developed, used and managed in an integrated and sustainable manner to meet food and nutritional security for ever increasing population. These resources need to be characterized and mapped with precision to cover larger areas for sustainable management. The high-spatial resolution remotely sensed data coupled with topographical data provides real time and accurate information related to distinct geological formation and landforms. Soil systems are in dynamic equilibrium. A vital knowledge of the kind of soils and their spatial distribution is a prerequisite in developing rational soil map and land use plan for agriculture, forestry and irrigation (Biswas 1987). The soil maps are prepared on different scales varying from 1:1 million to 1:5000 depending upon the requirements of planning at various levels, because the scale has direct correlation with the information content. Soil resource inventory provides an accurate and scientific inventory of different soils, their kind and nature, and extent of distribution so that one can make prediction about their characters and potentialities (Manchanda et al. 2002). Large-scale soil mapping is mostly done by traditional methods, which is expensive and time consuming due to large number of observations (Simon 2010). Liengsakul et al. (1993) estimated about 60–80 % time is saved using satellite imagery for soil mapping compared to manual methods. The application of satellite remote sensing data products for small and medium scale soil mapping are widely accepted and suggested utilization of high-resolution satellite data like IRS-P6 LISS-III (Velmurugan and Carlos 2009) and IRS-P6 LISS-IV (Walia et al. 2010; Reddy et al. 2012) for soil mapping. Srivastava and Saxena (2004) discussed the technique of large-scale soil mapping (1:12500 scale) in a basaltic terrain with a Physiography Landuse Units (PLU) approach using IRS-1C PAN merged data of two seasons, whereas, cadastral-level soil mapping (1:5000 scale) was discussed by Nagaraju et al. (2014) using high-resolution Cartosat-1 DEM (10 m) for landform, slope analysis and Cartosat-1-sharpened IRS-P6 LISS-IV data for land use/land cover analysis.

Traditionally, landform delineations were carried out using aerial photography. In recent years, the use of Digital Elevation Model (DEM) derived from Cartosat-1 stereo-pair has been used for various topographic and cartographic applications (Ahmed et al. 2007; Jacobsen et al. 2008; Sahu et al. 2014). A Cartosat-1 DEM (10 m) can be utilized by the soil surveyor to provide terrain related data that can assist in mapping and giving a quantitative description of landforms at large-scale (Sahu et al. 2015). Dobos and Montanarella (2007) stated that the use of digital data sources, such as DEM and high resolution satellite data can speed up the compilation of digital soil databases and improve the overall quality, consistency and reliability of the database.

The demand for accurate and detailed soil information is increasing from land use planners for farm-level planning and other agricultural developmental activities. Therefore, the present study aims at characterization and mapping of soil resources in Miniwada Panchayat comprising three villages in a basaltic terrain of Central India using high-resolution IRS-P6 LISS-IV data and Cartosat-1 DEM .

Materials and Methods

Study Area

Miniwada Panchayat is situated in Katol tehsil, 45 km to the west of Nagpur city of Maharashtra (Fig. 1). The panchayat includes three villages, namely, Miniwada, Mhasala and Malkapur, which lies between 21^0 08′ to 21^0 12′ North latitudes and 79^0 08′ to 79^0 15′ East longitudes and covers an area of 1630 ha. The elevation ranges from 407 to 472 m above mean sea level (MSL). The climate is mainly hot sub tropical type with mean annual temperature of 28 °C and mean annual rainfall of 980 mm. The area qualifies for hyperthermic soil temperature regime and Ustic soil moisture regime. The geology of the study area is covered by basaltic lava flows, commonly known as “Traps”. Due to rapid cooling after extrusion, the resultant basaltic rocks possess an aphanitic texture, which is generally dark gray to dark greenish gray in colour. Columnar joints and spheroidal weathering are vital features of these rocks. The main field crops are cotton (*Gossypium spp*.), soybean (*Glycine max*), pigeonpea (*Cajanus cajan*), gram (*Cicer arietinum*), wheat (*Triticum aestivum*) etc. The natural vegetation comprises of teak (*Tectona grandis*), babul (*Acacia spp*.), palash (*Butea frandosa*), neem (*Azadirachta indica*), mahua (*Madhuca longifolia*) etc.

Datasets Used

Survey of India (SoI) toposheet (55 K/12) was used for georeferencing and cadastral map of Panchayat was procured from MRSAC, Nagpur. Multi-temporal geo-referenced IRS-P6 LISS-IV and Cartosat-1 stereo pairs have been used for land use/land cover mapping, extraction of DEM, landforms and slope analysis. The details of satellite data used in the study area is given in Table 1.

Methodology

Georeferencing of Base Maps Based on Survey of India toposheet (55 K/12) on 1:50000 scale, IRS-P6 LISS-IV data (5.8 m) of 5th October, 2012 and 15th April, 2013 were georeferenced using WGS 84 datum, Universal Transverse Mercator (UTM) zone 44 N projection in ArcGIS (Ver. 10.2.2). The cadastral map of the Panchayat, which was in LCC projection, was reprojected to UTM. The rasterized cadastral map and LISS-IV data were co-registered using orthorectified Cartosat-1 data as a reference.

Processing of Satellite Data For DEM and ortho image generation from Cartosat-1 stereo data pairs, Leica Photogrammetric Suite (LPS) was used in the study. The block project has assigned the horizontal and vertical coordinates with UTM projection and WGS 84 datum. The stereo pair images, band *a* and *f* were added to the frame. The interior and exterior orientations corresponding to the Rational Polynomial Coefficients (RPC) files were carried out. LPS automatically generated the tie points; manually additional tie points were added for even distribution throughout the image. Triangulation was performed to check the accuracies of all the tie points. Manually Ground Control Points (GCPs) were added and again triangulation was carried out. The overall image root mean square error (RMSE) achieved was 0.512 pixels. DEM was generated with a cell size of 10 m and finally used for orthorectification using ERDAS IMAGINE software (Fig. 2a). A number of terrain attributes like slope, aspect, contour, drainage and hillshade were derived from Cartosat-1 DEM using watershed tool in terrain of TNT mips software. Hillshade was overlaid with Cartosat-1 DEM (Fig. 2b). Contour map (10 m) was generated using Cartosat-1 DEM and smoothen using ArcGIS software.

The high-resolution LISS-IV (bands 2, 3 and 4) with 5.8 m resolution was sharpened with the orthorectified Cartosat-1 (2.5 m resolution) data using ERDAS IMAGINE software. This resulted in the sharpening of the multi-spectral LISS-IV data with a resultant spatial resolution of 2.5 m. (Fig. 2c).

Landform Mapping The delineation of landforms was carried out using onscreen image visual interpretation techniques. Geomorphic features were interpreted based on key image

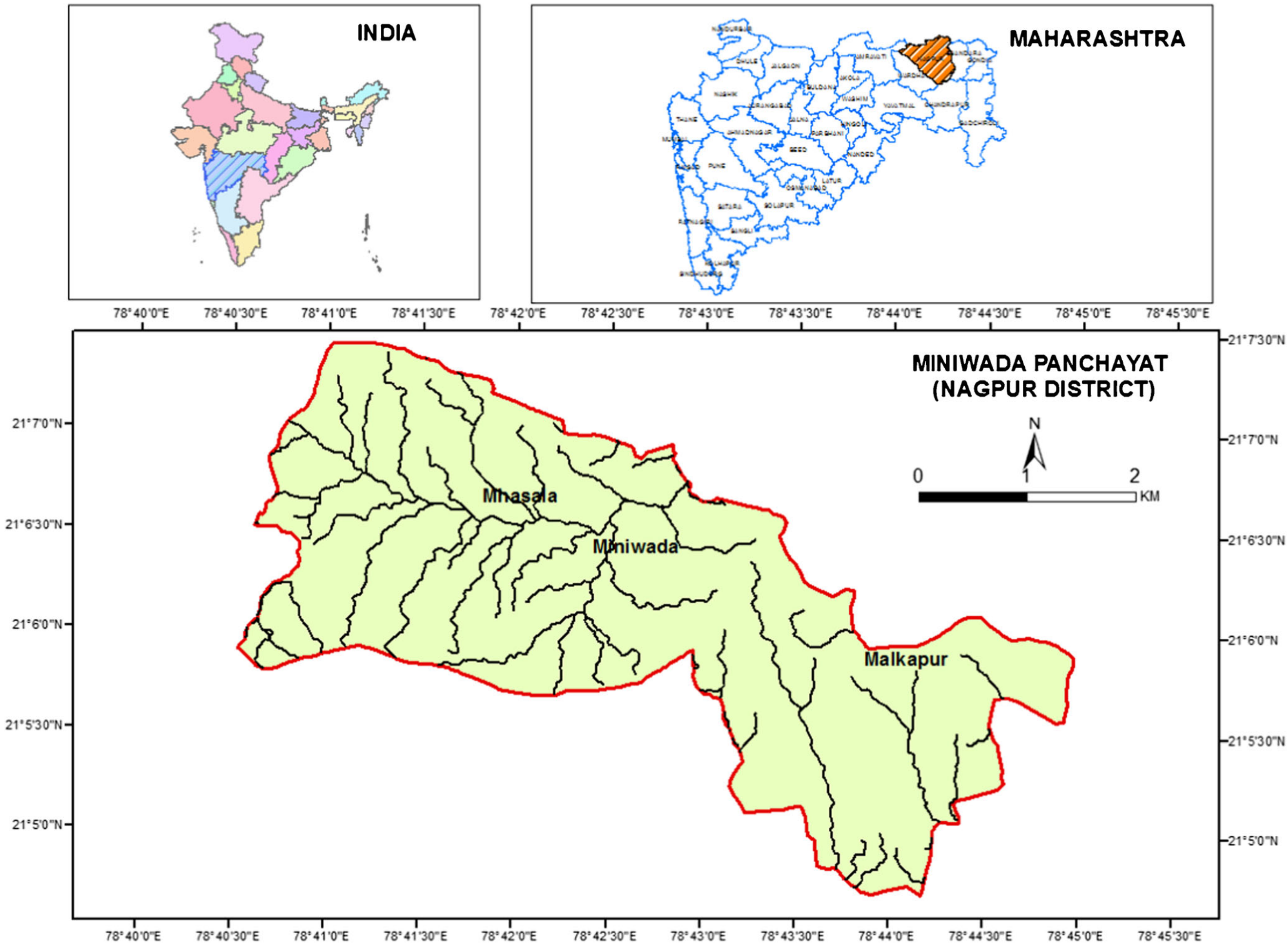

Fig. 1 Location map of Miniwada Panchayat, Katol tehsil, Nagpur district

elements such as shape, tone or colour, pattern, shadow, association and texture. Landform analysis was carried out using elevation information available in the DEM (10 m) generated from the Cartosat-1 stereo pair and hillshade generated from the Cartosat-1 DEM using ArcGIS software. Orthorectified Cartosat-1 data along with hillshade and 10 m contour were superimposed on the Cartosat-1 DEM and a stereo view generated (Fig. 2d). Using the stereo tool, the area was visually interpreted for various landforms in the study area. The Cartosat-1 data sharpened with LISS-IV data of two seasons (October, 2012 and April, 2013) were visually interpreted for land use/land cover information using visual image interpretation. The boundary of the forest was digitized from the Survey of India toposheet and transferred as a layer to satellite data and interpreted various land use/land cover classes. The study area was traversed for identification of different landform units, slope and land use/ land cover classes at random points in field before survey and correlated with image interpretation units using GPS. The boundaries were verified and corrected wherever found necessary. The landform, slope and land use/land cover layer was overlaid over each other in ArcGIS to generate PLU map. The cadastral map was superimposed to understand the distribution of PLU in different fields of the villages.

Table 1 Details of satellite data used

Satellite Sensors	Resolution	Path	Row	Date
Cartosat-1	2.5 m	542	299	3rd March, 2012
IRS-P6 LISS-IV	5.8 m	99	57D	5thOctober, 2012 15th April, 2013

Soil Resource Inventory The study area was traversed and the derived boundaries of landform, land use/land cover and slope were verified and corrected. Based on variability of landform units, slope and land use/ land cover, representative 60 profiles were described for site and soil characteristics in a standard format (Soil Survey Division Staff 2000) and located using handheld Global Positioning System (GPS). Soil samples from each horizon were collected and used for laboratory analysis. The soil samples were initially air dried at room temperature, processed using a wooden pestle and mortar, screened through a 2 mm sieve, properly labeled and stored

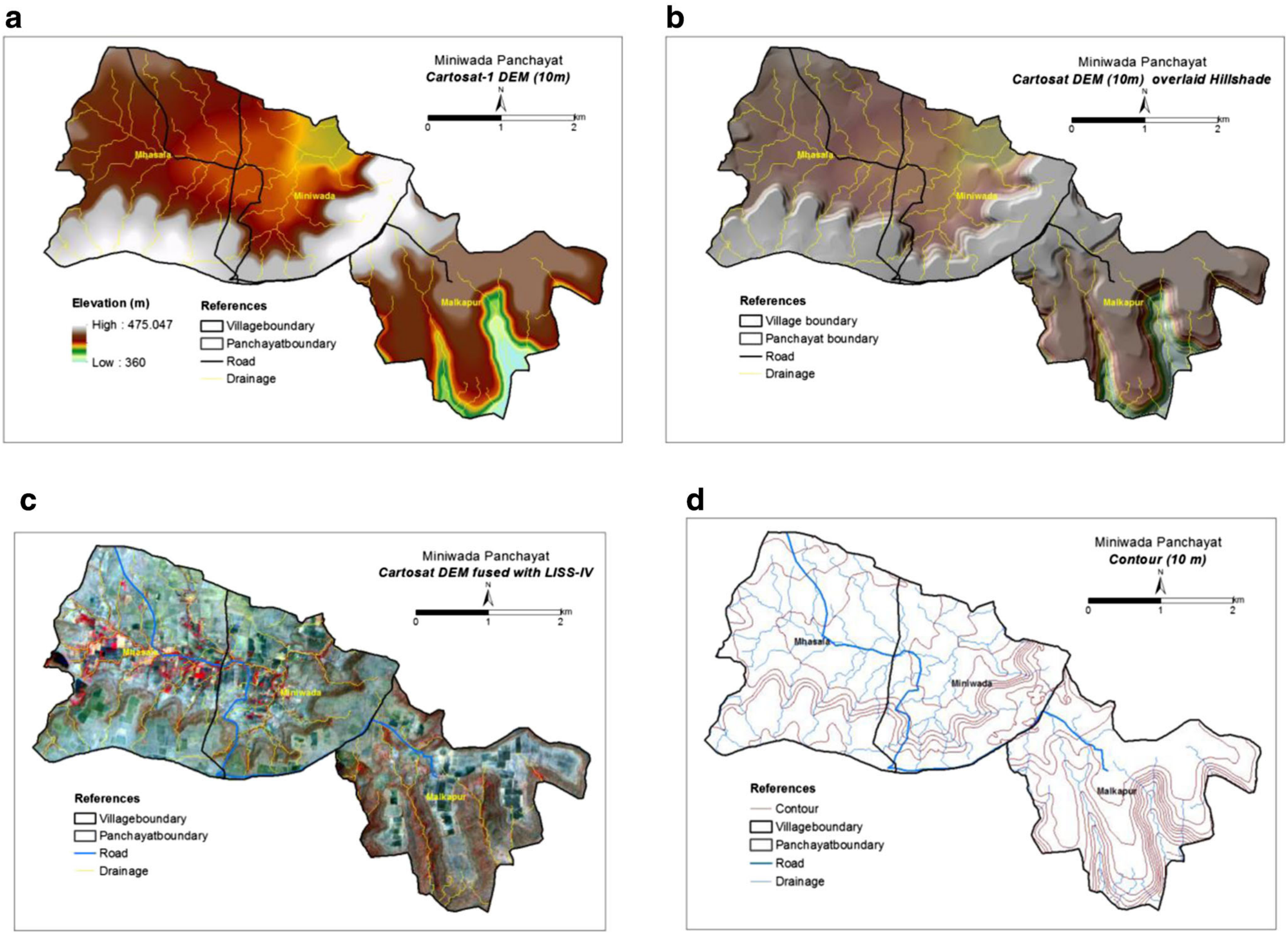

Fig. 2 **a** Cartosat-1 DEM (10 m), **b** Cartosat-1-sharpened IRS-P6 LISS-IV data, **c** Hillshade overlaid on Cartosat-1 DEM and **d** contour (10 m) of Miniwada Panchayat

in plastic bottles for laboratory analysis. Analysis of soil physical and chemical properties was carried out as per standard procedures (Richards 1954; Black et al. 1965; Piper 1966; Jackson 1973; Klute 1986). Soils were classified according to Keys to Soil Taxonomy (2014). Soil map was prepared on 1:10000 scale showing soil series and their phases (surface soil texture, slope, erosion and stoniness). The soil legend depicts the name of series (first three letters) followed by surface texture (one lower case letter), slope (one capital letter), erosion (e1, e2, e3, e4) and stoniness (st1, st2, st3) (ALS&LUS 1971).

Results and Discussion

Terrain Analysis

Precise delineation of landforms is very important for cadastral-level soil mapping (Martha et al. 2012; Nagaraju et al. 2014). Using hillshade information generated from the Cartosat-1 DEM and 3D perspective viewing of the area, various landforms were delineated based on visual interpretation. Slope information was derived from the high-resolution Cartosat-1 DEM and reclassified into different slope classes. Furthermore, the Cartosat-1-sharpened- IRS-P6 LISS-IV data were used to segment the area into different land-use/land-cover classes.

Landforms Delineation

Using stereo vision, the area was characterized into plateau top (450–470 m), scarp slopes (450–460 m), plateau spurs (420–440 m), pediment (430–450 m), undulating plain (410–430 m), broad valley (410–430 m), narrow valleys (410–420 m) and floodplain (400–410 m). The major landforms were further subdivided based on elevation and topoposition. The pediments were subdivided into upper (440–450 m) and lower pediments (430–440 m), whereas, the undulating plain was further subdivided into upper (420–430 m) and lower (410–420 m) (Fig. 3a).

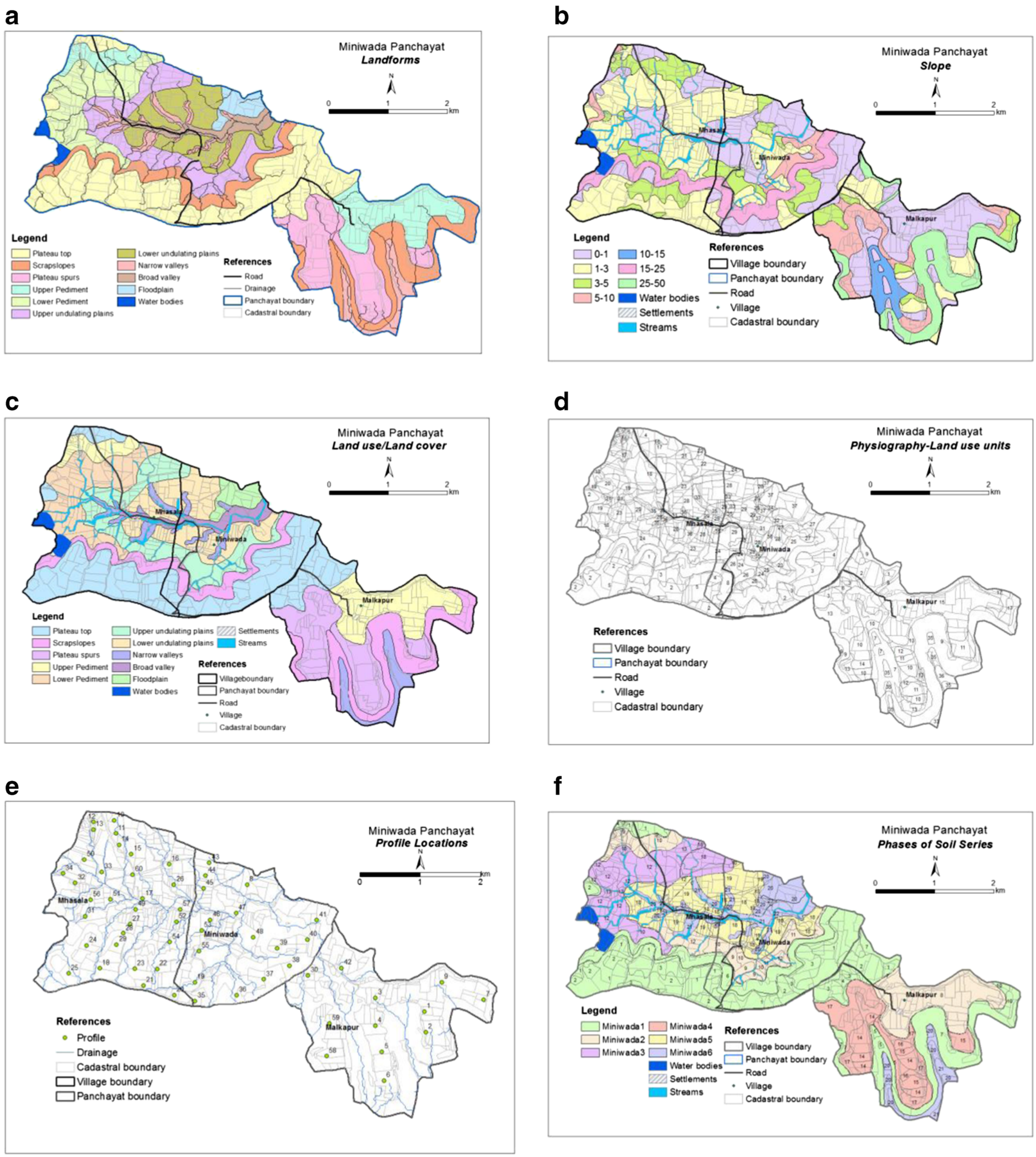

Fig. 3 Detailed mapping of (**a**) landforms, (**b**) slope, (**c**) land use/land cover (**d**) physiography-landuse units (**e**) profile locations and (**f**) phases of soil series of Miniwada Panchayat

Slope

After eliminating the speckle effects due to the high-resolution DEM, the raster slope map was reclassified into seven slope classes, viz. nearly level land (0–1 %) covering 31.9 %, very gently sloping land (1–3 %) with 29.8 % area and gently sloping (3–5 %) land with 11.9 % area. Moderately sloping (5–10 %), strongly sloping (10–15 %), moderately steep to steep sloping (15–25 %) and steep to very steep sloping (25–50 %) lands occupies 8.2, 2.3, 7.3 and 8.6 % of study area, respectively (Fig. 3b).

Table 2 Soil series identified in the study area

Soil series	Soil characteristics	Soil taxanomy
Miniwada-1 (Mw-1)	Very shallow, occurring on gently sloping plateau, well drained, dark yellowish brown (10YR3/4 M) with severe erosion	Loamy-skeletal, mixed, hyperthermic Lithic Ustorhents
Miniwada-2 (Mw-2)	Very shallow, occurring on gently sloping upper pediment, well drained, dark brown (7.5YR3/2 M) with severe erosion	Loamy, mixed, hyperthermic Typic Ustorhents
Miniwada-3 (Mw-3)	Shallow, occurring on very gently sloping lower pediment, well drained, dark brown (10YR3/3 M) with severe erosion	Clayey-skeletal, mixed, hyperthermic Typic Ustorhents
Miniwada-4 (Mw-4)	Moderately deep, occurring on gently sloping lower pediment, moderately well drained, very dark grayish brown (10YR3/2 M) with moderate erosion	Clayey, smectitic, hyperthermic Calcic Haplustepts
Miniwada-5 (Mw-5)	Very deep, occurring on very gently sloping lower undulating plains, moderately well drained, very dark grayish brown (10YR3/2 M) calcareous with moderate erosion	Very-fine, smectitic, hyperthermic Typic Haplusterts
Miniwada-6 (Mw-6)	Moderately deep, occurring on gently sloping valley, moderately well drained, very dark grayish brown (10YR3/2 M) with slight erosion	Very-fine, smectitic, hyperthermic Typic Haplustepts

Land use/ Land Cover Analysis

Six land use/ land cover classes were identified namely double crop, single crop, orchard, waste land with and without scrub and degraded forest (Fig. 3c). Double cropped area is mainly practiced in the landform, which is dominant by depositional processes such as lower pediment, lower undulating plains and in broad and narrow valleys with nearly level to gentle slopes. Area under wheat, gram and vegetables occupy 7.15% of TGA. Single crop occupies 41.55% of TGA and practiced in almost all landforms except scarpslopes due to strong to steep slopes. Soybean and cotton is spread in maximum area of cultivation. Orange orchards occupy 1.46% of TGA with nearly level to moderate slopes in lower pediment and upper undulating plains. Wasteland with and without scrub occupies an area of 13.26 and 2.16%, respectively. Degraded forest is

Table 3 Physical and Chemical properties of Soils

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Water Retention (%)		AWC (%)	pH (1:2.5 H_2O)	EC (dS m^{-1})	OC (%)	$CaCO_3$ (%)	CEC
					−33kPa	−1500kPa						
Miniwada-1 series (gently sloping plateau): loamy-skeletal, mixed, hyperthermic Lithic Ustorhents												
Ap	0–10	49.5	24.8	25.7	24.11	16.42	7.69	7.4	0.11	0.31	1.1	33.2
Miniwada-2 series (nearly level sloping upper pediment): loamy, mixed, hyperthermic Typic Ustorhents												
Ap	0–14	43.5	29.3	27.2	21.1	10.8	10.3	7.3	0.14	0.64	6.3	40.8
Miniwada-3 series (gently sloping lower pediment): clayey-skeletal, mixed, hyperthermic Typic Ustorhents												
A	0–11	22.7	38.4	38.9	25.04	12.69	12.35	6.9	0.19	0.34	2.8	33.3
AC	11–42	19.5	36.2	44.3	23.8	14.7	9.1	7.2	0.16	0.52	4.1	38.2
Miniwada-4 series (very gently sloping lower pediment): clayey, smectitic, hyperthermic Calcic Haplustepts												
Ap	0–20	25.1	32.3	42.6	34.01	26.65	7.36	8.0	0.18	0.66	19.5	47.2
Bw1k	20–35	21.7	34.2	44.1	37.80	22.42	15.38	8.1	0.21	0.79	17.3	51.6
Miniwada-5 series (very gently sloping lower undulating plains): very fine, smectitic, hyperthermic Typic Haplusterts												
Ap	0–21	12.5	28.3	59.2	55.27	38.13	17.14	8.2	0.28	0.89	4.9	64.8
Bw	21–53	12.6	24.2	63.2	54.09	39.43	14.66	8.3	0.19	0.82	7.3	64.9
Bss1	53–86	12.3	22.3	65.4	50.36	33.77	16.59	8.5	0.19	0.73	5.7	65.3
Bss2	86–120	10.6	20.1	69.3	46.68	39.04	7.64	8.5	0.18	0.71	8.1	65.5
Bss3	120–150	7.0	21.4	71.6	48.12	34.09	14.03	8.4	0.20	0.69	9.6	65.9
Miniwada-6 series (nearly level sloping valley): very fine, smectitic, hyperthermic Typic Haplustepts												
Ap	0–16	20.6	33.1	46.3	47.18	33.82	13.36	7.5	0.26	0.77	13.8	54.8
Bw1	16–40	15.9	32.9	51.2	50.23	37.66	12.57	7.9	0.25	0.72	8.9	55.2
Bw2	40–64	16.8	31.3	51.9	52.27	35.00	17.27	8.4	0.22	0.81	7.2	58.3

AWC available water capacity, *EC* electrical conductivity, *OC* organic carbon, *CEC* cation exchange capacity (cmol(p^+) kg^{-1})

Table 4 PLU-soil relationship in the study area.

S.No.	PLU unit	Description	Soil mapping legend	Description	Area (ha)	%
1.	P11	Plateau top with 0–1 % slope, single crop	Mi-1hA3St1	Sandy clay loam, 0–1 % slope, severe erosion, slight stoniness	45.02	2.8
2.	P21	Plateau top with 1–3 % slope, single crop	Mi-1hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	93.92	5.8
3.	P31	Plateau top with 3–5 % slope, single crop	Mi-1hC3St2	Sandy clay loam, 3–5 % slope, severe erosion, moderate stoniness	72.01	4.4
4.	P14	Plateau top with 0–1 % slope, land with scrub	Mi-1hA3St1	Sandy clay loam, 0–1 % slope, severe erosion, slight stoniness	77.40	4.7
5.	P24	Plateau top with 1–3 % slope, land with scrub	Mi-1hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	61.84	3.8
6.	P45	Plateau top with 5–10 % slope, land without scrub	Mi-1hD3St2	Sandy clay loam, 5–10 % slope, severe erosion, moderate stoniness	4.08	0.3
7.	S56	Scarpslopes with 10–15 % slope, degraded forest	Mi-1hE3St1	Sandy clay loam, 10–15 % slope, severe erosion, slight stoniness	40.40	2.5
8.	S66	Scarpslopes with 15–25 % slope, degraded forest	Mi-1hF3St1	Sandy clay loam, 15–25 % slope, severe erosion, slight stoniness	119.32	7.3
9.	S76	Scarpslopes with 25–50 % slope, degraded forest	Mi-1hG3St1	Sandy clay loam, 25–50 % slope, severe erosion, slight stoniness	141.21	8.6
10.	PS11	Plateau spurs with 0–1 % slope, single crop	Mi-4mA2St1	Clayey, 0–1 % slope, moderate erosion, slight stoniness	45.27	2.7
11.	PS21	Plateau spurs with 1–3 % slope, single crop	Mi-4mB2St1	Clayey, 1–3 % slope, moderate erosion, slight stoniness	24.60	1.5
12.	PS31	Plateau spurs with 3–5 % slope, single crop	Mi-4mC2St1	Clayey, 3–5 % slope, moderate erosion, slight stoniness	7.79	0.5
13.	PS41	Plateau spurs with 5–10 % slope, single crop	Mi-4mD2St1	Clayey, 5–10 % slope, moderate erosion, slight stoniness	82.00	5.0
14.	PS12	Plateau spurs with 0–1 % slope, double crop	Mi-4mA2St1	Clayey, 0–1 % slope, moderate erosion, slight stoniness	4.91	0.3
15.	UP11	Upper pediment with 0–1 % slope, single crop	Mi-2hA3St1	Sandy clay loam, 0–1 % slope, severe erosion, slight stoniness	123.52	7.6
16.	UP21	Upper pediment with 1–3 % slope, single crop	Mi-2hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	1.93	0.1
17.	UP31	Upper pediment with 3–5 % slope, single crop	Mi-2hC3St1	Sandy clay loam, 3–5 % slope, severe erosion, slight stoniness	52.93	3.2
18.	LP21	Lower pediment with 1–3 % slope, single crop	Mi-3hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	80.25	4.9
19.	LP22	Lower pediment with 1–3 % slope, double crop	Mi-3hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	17.36	1.1
20.	LP23	Lower pediment with 1–3 % slope, orchard	Mi-3hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	9.85	0.6
21.	LP33	Lower pediment with 3–5 % slope, orchard	Mi-3hC3St1	Sandy clay loam, 3–5 % slope, severe erosion, slight stoniness	17.02	1.0
22.	UUP11	Upper undulating plains with 0–1 % slope, single crop	Mi-5 mA1	Clayey, 0–1 % slope, slight erosion	22.68	1.4
23.	UUP21	Upper undulating plains with 1–3 % slope, single crop	Mi-3hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	59.98	3.7
24.	UUP31	Upper undulating plains with 3–5 % slope, single crop	Mi-2hC3St1	Sandy clay loam, 3–5 % slope, severe erosion, slight stoniness	41.35	2.5
25.	UUP41	Upper undulating plains with 5–10 % slope, single crop	Mi-2hD3St1	Sandy clay loam, 5–10 % slope, severe erosion, slight stoniness	17.83	1.1
26.	UUP24	Upper undulating plains with 1–3 % slope, land with scrub	Mi-2hB3St1	Sandy clay loam, 1–3 % slope, severe erosion, slight stoniness	17.28	1.1
27.	LUP11	Lower undulating plains with 0–1 % slope, single crop	Mi-5 mA1	Clayey, 0–1 % slope, slight erosion	12.76	0.8
28.	LUP21	Lower undulating plains with 1–3 % slope, single crop	Mi-5mB1	Clayey, 1–3 % slope, slight erosion	91.20	5.6
29.	LUP12	Lower undulating plains with 0–1 % slope, double crop	Mi-5 mA1	Clayey, 0–1 % slope, slight erosion	86.91	5.3
30.	B12	Broad valley with 0–1 % slope, double crop	Mi-6 mA1	Clayey, 0–1 % slope, slight erosion	12.90	0.8
31.	B22	Broad valley with 1–3 % slope, double crop	Mi-6mB1	Clayey, 1–3 % slope, slight erosion	11.24	0.7
32.	B32	Broad valley with 3–5 % slope, double crop	Mi-6mC1	Clayey, 3–5 % slope, slight erosion	2.08	0.1

Table 4 (continued)

S.No.	PLU unit	Description	Soil mapping legend	Description	Area (ha)	%
33.	N21	Narrow valley with 1–3 % slope, single crop	Mi-6mB1	Clayey, 1–3 % slope, slight erosion	10.55	0.6
34.	N31	Narrow valley with 3–5 % slope, single crop	Mi-6mC2	Clayey, 3–5 % slope, moderate erosion	1.55	0.1
35.	N12	Narrow valley with 0–1 % slope, double crop	Mi-6 mA1	Clayey, 0–1 % slope, slight erosion	37.35	2.3
36.	N22	Narrow valley with 1–3 % slope, double crop	Mi-6mB1	Clayey, 1–3 % slope, slight erosion	19.93	1.2
37.	F11	Floodplain with 0–1 % slope, single crop	Mi-6 mA1	Clayey, 0–1 % slope, slight erosion	50.72	3.1

prominent in scarpslopes covering an area of 30.25% with strong to steep slopes. The dominant vegetation comprises of teak (*Tectona grandis*), babul (*Acacia spp.*), palash (*Butea frandosa*), mahua (*Madhuca longifolia*) etc.

PLU Units

The landform, slope, and land-use/land-cover maps were integrated in ArcGIS and a PLU map was prepared. Based on integration, 37 PLU units were delineated in the study area (Fig. 3d) and the characteristics of each PLU unit was described (Table 4). On the plateau top, six PLU units (P11, P21, P31, P14, P24 and P45) were identified based on four slope classes (0–1, 1–3, 3–5 and 5–10 %) and three land-use/land-cover classes (single crop, wasteland with scrub and without scrub). Three PLU units (S56, S66 and S76) were identified on the escarpment with three slope classes (10–15, 15–25 and 25–50 %) and one land-use/land-cover class (degraded forest). Five PLU units (PS11, PS21, PS31, PS41 and PS12) were identified on the plateau spurs based on four slopes classes (0–1, 1–3, 3–5 and 5–10 %) and two land-use/land-cover classes (single crop and double crop). Three PLU units (UP11, UP21 and UP31) were identified on the upper pediment based on three slope classes (0–1, 1–3 and 3–5 %) and one land-use/land cover class (single crop). Four PLU units (LP21, LP22, LP23 and LP33) were identified on the lower pediment based on two slope classes (1–3 and 3–5 %) and three land-use/land- cover classes (single crop, double crop and orchard). Five PLU units were identified on the upper undulating plain (UUP11, UUP21, UUP31, UUP41 and UUP24) based on four slope classes (0–1, 1–3, 3–5 and 5–10 %) and two land-use/land-cover classes (single crop and wasteland with scrub). Lower undulating plains were further differentiated into three PLU units (LUP11, LUP21 and LUP12) based on the variation in slopes (0–1 and 1–3 %) and land use (single and double crop). Three PLU units (B12, B22 and B32) were identified on the broad valley based on three slopes (0–1, 1–3 and 3–5 %) and land use (double crop). Four PLU units (N21, N31, N12 and N22) were identified on the narrow valley based on three slopes (0–1, 1–3 and 3–5 %) and land use (single and double crop). One PLU unit (F11) was identified on the floodplain based on slope (0–1 %) and land-use/land-cover class (single crop).

Landform-Soil Relationship

Soils developed on Miniwada-1 (Mw-1) are very shallow, occurring on gently sloping plateau, well drained, dark yellowish brown (10YR3/4 M) with severe erosion and classified as Loamy-skeletal, mixed, hyperthermic Lithic Ustorhents. Miniwada-2 (Mw-2) soils in general are very shallow, occurring on gently sloping upper pediment, well drained, dark brown (7.5YR3/2 M) with severe erosion and qualify for Loamy, mixed, hyperthermic Typic Ustorhents. Two soils have been identified on lower pediment. Soils of Miniwada-3 (Mw-3) are shallow, occurring on very gently sloping lower pediment, well drained, dark brown (10YR3/3 M) with severe erosion and qualify for Clayey-skeletal, mixed, hyperthermic Typic Ustorhents. Soils of Miniwada-4 (Mw-4) are moderately deep, occurring on gently sloping lower pediment, moderately well drained, very dark grayish brown (10YR3/2 M) with moderate erosion and qualify for Clayey, smectitic, hyperthermic Calcic Haplustepts. Miniwada-5 (Mw-5) soils are very deep, occurring on very gently sloping lower undulating plains, moderately well drained, very dark grayish brown (10YR3/2 M) calcareous with moderate erosion and classified as Very-fine, smectitic, hyperthermic Typic Haplusterts. On the other hand, soils of Miniwada-6 (Mw-6) are moderately deep, occurring on gently sloping valley, moderately well drained, very dark grayish brown (10YR3/2 M) with slight erosion and classified as Very- fine, smectitic, hyperthermic Typic Haplustepts (Table. 2). Salient physical and chemical characteristics of the soil series are given in Table. 3. The PLU-soil relationships obtained in the study are presented in Table. 4. Total 60 profiles were studied in the study area (Fig. 3e). For large-scale mapping, soil series are further divided into phases level based on surface soil texture, slope, erosion and stoniness. A total of 23 phases have been identified, seven phases in Mw-1, four phases in Mw-2, two phases in Mw-3, four phases in Mw-4, two phases in Mw-5 and four phases in Mw-6 (Fig. 3f).

Conclusions

High-resolution IRS-P6 LISS-IV and Cartosat-1 DEM in conjunction with GPS and GIS were highly useful for precise delineation of physiographic units. The variation in soil pattern was explained based on landform-soil relationship. Seven major landforms-plateau top, scarpslopes, plateau spurs, pediment, undulating plains, broad valley and narrow valley have been delineated using Cartosat-1 DEM, contour and hillshade. Hillshade map, generated based on Cartosat-1 DEM (10 m) provides better visualization of terrain and helps to delineate landform boundaries precisely. Detailed maps of slope and landuse/land cover classes have been delineated. A total of 37 PLU units have been derived by integrating landform, slope and land use/land cover. Six soil series have been tentatively identified in major landforms and mapped into 37 mapping units with phases of soil series. The study reveals that high-resolution IRS-P6 LISS-IV and DEM (10 m) derived from Cartosat-1 data will be of immense help in precise and faster mapping of soils as compared to the conventional method. The information derived from such large-scale land resource inventory will be highly useful for village-level agricultural land use planning, soil and water resource management, identification of groundwater potential zones and environmental modeling which will form a base for many developmental activities.

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