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Technique of Large Scale Soil Mapping using Remote Sensing Satellite Data in Basaltic Terrain of Peninsular Region in the North-West Gujarat, India

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Techniques for large scale mapping of natural resources is region specific. The technique of large-scale soil mapping using remote sensing data in basaltic terrain of Peninsular Region. The data used for the study are toposheet of Survey of India (1:50 000 scale); cadastral map of the Pata Meghpar village (1:4000 scale); and IRS P6 LISS-IV digital data of August (*kharif* season) and December (*rabi* season) 2012. Images were interpreted visually and ground truths were collected manually and prepared landscape ecological units (LEUs) map which was used for conducting soil survey and generation of soil map. The LEU units explained a three-tier approach comprising land form, slope and land use characteristics of each parcel of land. Soils occurring in different LEU units were examined and a LEU–soil relationship was developed. The soil map depicting phases of soil series was prepared using ArcGIS 10.0 software.

Key words: Large scale soil mapping, basaltic terrain, Gujarat, remote sensing, GIS

Large scale soil maps can be produced after detailed land resource characterization of prioritized area. Substantial progress has been made in the land resource inventory (LRI) programme on 1:10000 scale initiated in phased manner by ICAR-NBSSLUP, Nagpur during 2014-15 (Annual Report ICAR-NBSS&LUP 2016) and subsequent years. Soil maps can be produced on different scales, such as small scale for example 1:250000, 1:1000000 or smaller, medium scale like 1:100000, 1:63360, 1:50000, and large scale like 1:25000, 1:10000 or larger, depending upon the purpose and requirement of user agencies (Srivastava and Saxena 2004). Remote sensing data are widely used for developing small (country or state level) and medium scale (district or state level) soil maps (Soil Survey Division Staff 1995) but recent advancements in space technologies provides higher resolution satellite data for development of large-scale soil maps. Earlier large-scale soil mapping was mostly done with conventional methods. These were difficult, time consuming, expensive with low repetitive value especially in hilly and mountainous regions, wetlands, and other problematic areas. However, with the availability of high resolution IRS P6 LISS-IV (5.8 m) data, it is now possible to utilize these data for large scale soil mapping, *i.e.* up to 1:4000 scale. The detailed maps show spatial variations of the terrain features, which in turn, assist in soil survey and mapping and finalize the soil mapping units in the region (Sahu *et al.* 2015). Rao *et al*. (1996) reported that high resolution (PAN and LISS III) satellite sensor data can be registered with cadastral maps with remarkable accuracy and the cadastral information in the form of maps and records can be updated. For village-level planning, large-scale soil maps are very useful because individual soil series and their phases can be delineated (Srivastava and Saxena 2004; Sharma *et al.* 2018). The present study deals with the applicability of high-resolution IRS P6 LISS-IV data in large-scale soil mapping of Pata Meghpar village, one of the basaltic terrains of Jamnagar District in Gujarat.

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Materials and Methods

Study area

The study was carried out in Pata Meghpar village of Kalavad Taluka in Jamnagar district,

Gujarat. It is a basaltic terrain of Peninsula of Saurashtra region. It is spread between 21°47′ to 22°57′ N latitudes and 68°57′ to 70°37′ E longitude covering approximately 1703 ha area. The rock formation (geology) of the area is diverse in nature but mostly it is Deccan trap (Cretaceo-Ecocene) with elevation ranging from 97 to 121 m above mean sea level. The seasonal river crosses the village roughly at middle. This river originates near the village Bedia in Rajkot district at a height of 140 m. It flows past Khad Dhoraji and Pata Meghpar, on its left and Nana Sagalia, Nana Khijadia and Khokhri on its right. Climate of the area is tropical semi-arid characterized by hot summer and intense winter. The analysis of climatic data for last 20 years has showed an increasing trend in annual rainfall pattern. Average rainfall from 1993 to 2012 is 739 mm; about 95% of it is received during the south-west monsoon season. The average annual minimum temperature is 20 °C and maximum temperature is 34 °C. The area qualifies for Ustic soil moisture and Hyperthermic soil temperature regimes.

The natural vegetation of the area is tropical dry deciduous forest and some grasses. Commonly occurring species of trees are Babul (*Acacia* spp.), Neem (*Azadiracta indica*), Vilayati Babul (*Prosopis juliflora*), Ber (*Ziziphus jujuba*), Doob (*Cynadon dactylon*).

Farming is the main occupation of the people in the area. The majority of the farmers follow traditional methods of cultivation. There is no canal in the village. Wells are the major source of irrigation. The agricultural crops grown in the area are cotton, groundnut and pigeon pea in *kharif*; whereas wheat, gram and cumin are taken during *rabi* under irrigation or stored moisture. Crop yields are generally moderate.

The data used for the study are toposheet of Survey of India (1:50000 scale); cadastral map of the Pata Meghpar village (1:4000 scale); and IRS P6 LISS-IV digital data of August (*kharif* season) and December (*rabi* season) 2012.

Methodology

Geo-referencing: The cadastral map of the village was scanned using a Cannon IPF 771 Plotter cum Scanner at 600 dpi. The rasterized cadastral map and digital data of IRS P6 LISS-IV were co-registered using toposheet as a reference. This was achieved by collecting ground control points (GCPs) on actual site using global positioning system (GPS) enabled equipment. After the geo-referencing process, the rasterized cadastral map was screen digitized using editor tool to prepare the cadastral map of the village (showing plot boundaries) (Fig. 1).

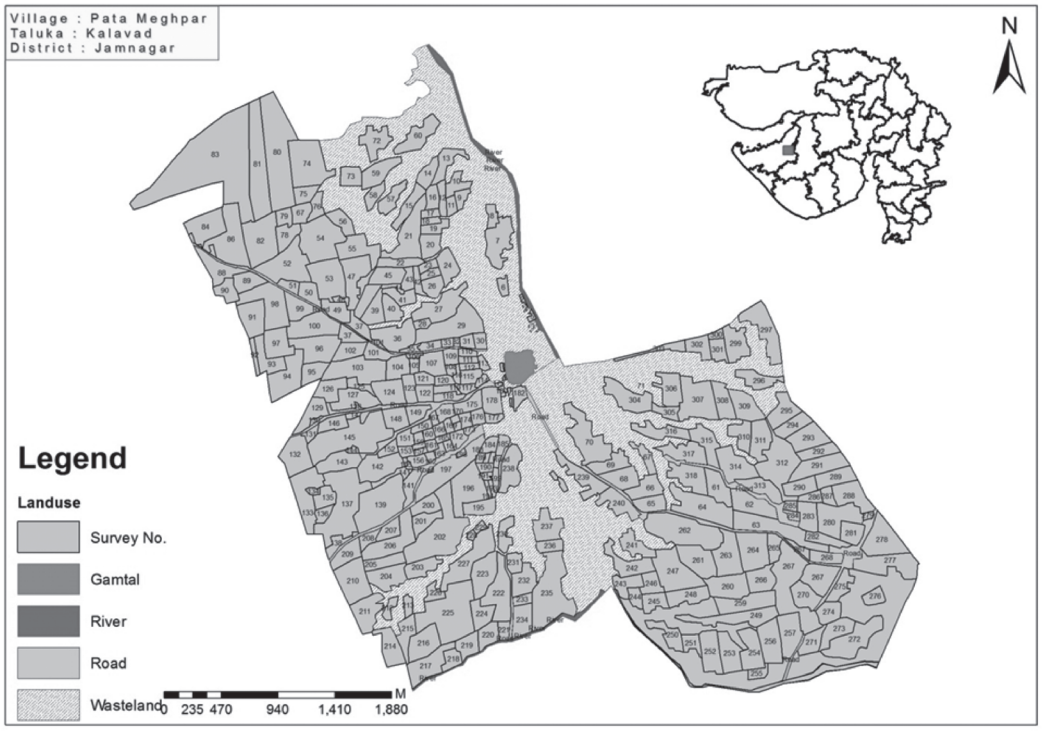

Fig. 1. Geo-referenced cadastral map of Pata Meghpar village showing land parcel with survey number

Interpretation of data: Digital data of village were visually interpreted in conjunction with Google map and the available ground data to prepare the landform, slope and land use/land cover maps of the village. Three maps prepared in this way were overlaid over each other to generate a landscape ecological unit (LEU) map. The LEU map was for conducting soil survey and generation of soil map.

Ground truth collection: The cadastral map was super imposed over the LEU map to understand the distribution of LEUs in different fields of the Pata Meghpar village. Depending upon the homogeneity and heterogeneity in LEU units, the area was traversed and the representative sites were selected for detailed soil profile study as per the Soil Survey Manual (Soil Survey Division Staff 1995). At each site, the variation in surface soil texture, slope, erosion, stoniness and land use were recorded. Soil profiles were studied at different sites and morphological data were recorded for correlation and classification of soils and identification of soil series. Horizon-wise soil samples were collected from the representative soil series for physical and chemical analysis as per standard procedures (Jackson 1973; Page *et al*. 1982; Klute 1986). Soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 2014). The flow chart showing the methodology of soil mapping using remote sensing data is shown in fig. 2.

Soil mapping legend: Soil map showing soil series and their phases were developed on a 1:4000 scale. The physical factors like surface soil texture, slope, erosion and stoniness were considered for delineation of phase boundaries. The delineated mapping units in the village were shown on the map in the form of symbols. For naming the phases, a combination of letters, both in upper and lower case, and numeral were used (Soil Survey Staff 2014). For example, the map unit Ptm-1 cB1 occurring in Pata Meghpar village is a phase of Pata Meghpar-1 series. In this the first four letters (Ptm-1) indicate the name of the series *i.e.,* Pata Meghpar-1, the fifth lower case letter (c) indicate the texture of surface soil *i.e.,* clay, the sixth upper case letter (B) indicates the slope of the land *i.e.* very gently sloping (1-3%) and the seventh numeral 1 indicates the severity of erosion class (slight).

Results and Discussion

Landscape ecological units (LEUs)

The area was categorized into four landform units (undulating upland, ravenous land, very gently sloping plain and nearly level plain), four slope classes (0–1, 1–3, 3–8 and 8–15%). Area and extent of different landforms is given in table 1 and delineations are presented in fig. 3. Based on

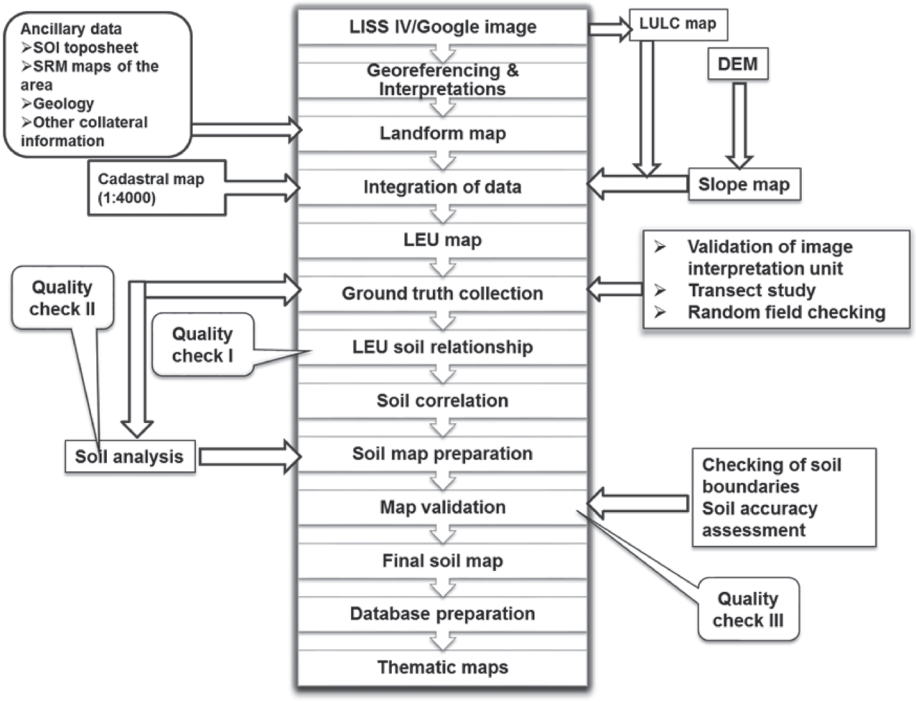

Fig. 2. Flow chart of large scale soil mapping

Table 1. Landform units and their extent

Landform Unit	Area (ha)	% of TGA
Undulating upland	119.3	7.1
Ravenous land	409.6	24.3
Very gently to gently sloping plain	543.9	32.3
Nearly level plain	610.0	36.2
Total area	1682.6	100.0

integration of landform, slope and land use/land cover maps, 10LEUs were delineated in the village Pata Meghpar. The characteristics of each LEU are given in table 2.

LEU–Soil relationships

Jenny (1941) stated that soil is an open system; properties are functionally related; if system changes

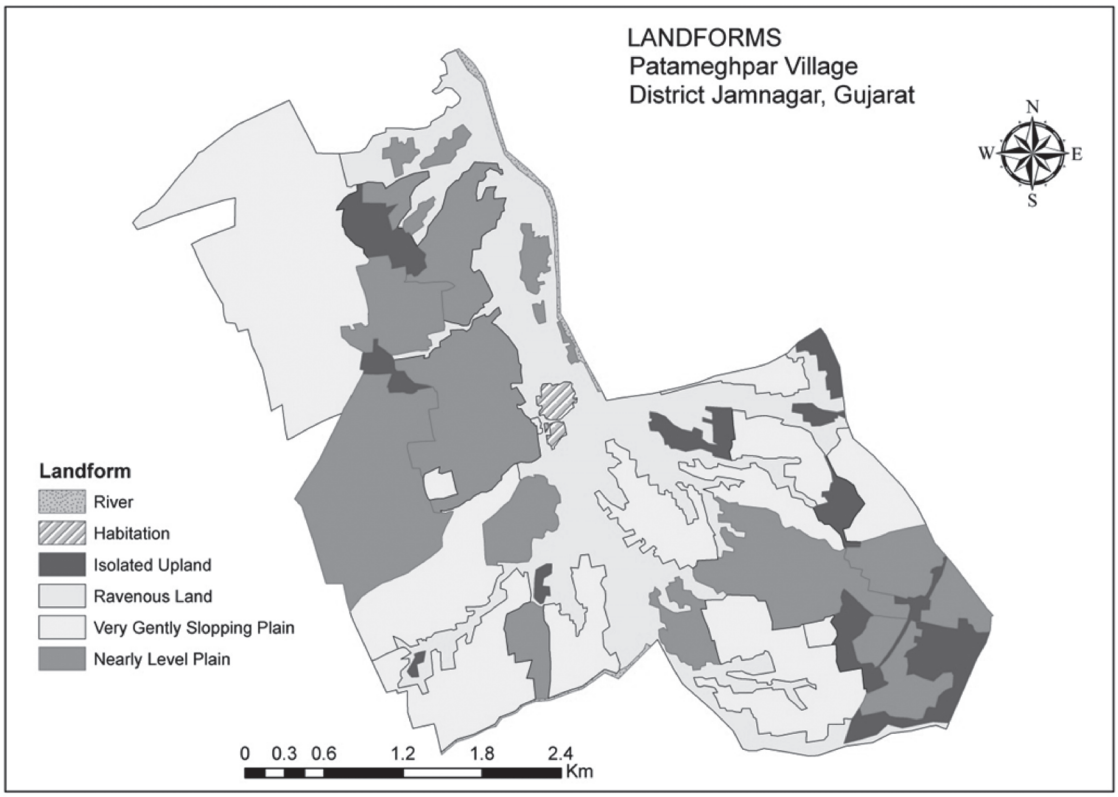

Fig. 3. Landforms of Pata Meghpar village

Table 2. Characteristics of LEU units

Mapping unit	LEU unit*	Description
2	GwC_pU3s	Undulating upland with 3-8% slope, single crop (*kharif*)
10	GwC_pU4fb	Undulating upland with 8-15% slope, fallow land (both *rabi* and *kharif*)
9	GwC_pU3g	Undulating upland with 3-8% slope (grazing land)
8	GwC_pU2s	Undulating upland with 1-3% slope, single crop (*kharif*)
1	GwC_pR4ft	Ravenous land with 8-15% slope, waste land (gullies and ravines with forest)
4	GwCpV2d	Very gently sloping plain with 1-3% slope, double crop (both *rabi* and *kharif*)
5	GwC_pV2s	Very gently sloping plain with 1-3% slope, single crop (*kharif*)
6	GwC_pV3d	Gently sloping plain with 3-8% slope, double crop (both *rabi* and *kharif*)
3	GwC_pN1d	Nearly level plain with 0-1% slope, double crop (both *rabi* and *kharif*)
7	GwC_pN1dg	Nearly level plain with 0-1% slope, double crop (both *rabi* and *kharif*) surrounded with intermittent gullies/pasture

GwC_p= Gujarat west coast plain of Kathiawar peninsula. U = Undulating, R = Ravinous, V = Very gently, N = Nearly level; 1 = 0-1% slope, 2 = 1-3% slope, 3 = 3-8% slope, 4 = 8-15% slope; s = Single crop, fb = Fallow land, g = Grazing land, ft = Forest, d = Double crop, dg = double crop surrounded with gullies; *Symbols used as per Singh *et al*. (2016)

Table 3. Mapping unit wise soil characteristics and soil map legend of Pata Meghpar

Series name	Soil unit No.	Mapping symbol	Brief description	Area (%)
Soils of undulating upland: Pata Meghpar-1series (Ptm-1): Very shallow, excessively drained, brown loam (Lithic Ustorthents)				
Pata Meghpar-1	2	Ptm-1GdC3	Gravely loam (gravels >50 %) on 3-8 % slope with severe erosion	32.9 (1.9%)
	10	Ptm-1GdD4	Gravely loam (gravels >50 %) on 8-15 % slope with very severe erosion	32.5 (1.9%)
Soils of undulating upland: Pata Meghpar-2 series (Ptm-2): Very shallow, somewhat excessively drained, dark yellowish brown, loam (Lithic Ustorthents)				
Pata Meghpar-2	9	Ptm-2GdC3	Gravely loam (gravels > 30 %) on 3-8 % slope with severe erosion	32.7 (1.9%)
	8	Ptm-2GdB2	Gravely loam (gravels > 30 %) on 1-3% slope with moderate erosion	21.1 (1.2%)
Soils of ravenous land: Pata Meghpar-3 series (Ptm-3): Slightly deep, excessively drained, dark yellowish brown, silt loam (Typic Ustorthents)				
Pata Meghpar-3	1	Ptm-3GeD4	Gravely silt loam (gravels > 50 %) on 8-15 % slope with very severe erosion	409.6 (24%)
Soils of very gently to gently sloping plain: Pata Meghpar-4 series (Ptm-4): Slightly deep, moderately well drained, very dark grayish brown, fine(Typic Haplustepts)				
Pata Meghpar-4	4	Ptm-4fB2	Clay loam on 1-3 % slope with moderate erosion	248.1 (14.6%)
Soils of very gently to gently sloping plain: Pata Meghpar-5 series (Ptm-5): Slightly deep, moderately well drained, very dark grayish brown, fine(Vertic Haplustepts)				
Pata Meghpar-5	5	Ptm-5mB2	Clayey on 1-3 % slope with moderate erosion	160.5 (9.4%)
	6	Ptm-5mC2	Clayey on 3-8 % slope with moderate erosion	201.4 (11.8%)
Soils of nearly level plain: Pata Meghpar-6 series (Ptm-6): Slightly deep, moderately well drained, very dark gray fine(Leptic Haplusterts)				
Pata Meghpar-6	3	Ptm-6mA2	Clayey on 0-1 % slope with moderate erosion	238.4 (14.0%)
Soils of nearly level plain: Pata Meghpar-7 series (Ptm-7): Deep, moderately well drained, very dark gray, fine(Typic Haplusterts)				
Pata Meghpar-7	7	Ptm-7mA2	Clayey on 0-1 % slope with moderate erosion	305.5 (17.9%)

Abbreviations: Ptm-Pata Meghpar, G-Gravelly, d-loam, e-silt loam, f-clay loam, m-clay, A- slope 0-1%, B- slope 1-3%, C-slope 3-8%, D-8-15%, 2-Moderate erosion, 3-Severe erosion, 4-Very severe erosion.

then soil properties are change. Soil formation is directly related to the factors of soil formation which is expressed as:

S= f (cl, o, r, p, t,…..)

where, *S* denotes any soil property, such as pH, nitrogen, clay; *cl*, environmental climate (rainfall, temperature); *o*, flora and fauna as biosphere organisms; *r*, relief/elevation, slope and depth of water table as relief; *p*, parent material; and t, time or age of land.

Since the study area is too small, where climate, parent material and time or age of the land are almost similar, the major factors influencing the soil properties can be attributed to variation in relief or topography (r) and flora and fauna biosphere organisms (o). The concept of LEU used for mapping soils in the study area justifies the same.

LEU–soil relationships obtained in the study area have been presented in table 3 and the soil map is shown in fig. 4.

Soil resources

Soil map of the Pata Meghpar village is prepared on 1:4000 scales. Seven soil series were identified (Table 3) and mapped into 10 soil mapping units (or say 10 LEUs) at the level of phases of soil series (Fig. 4). Out of the seven, first three soil series *viz.*Pata Meghpar-1, Pata Meghpar-2 and Pata Meghpar-3 belongs to Entisols soil order, Pata Meghpar-4 and Pata Meghpar-5 belongs to Inceptisols soil order whereas remaining Pata Meghpar-6 and Pata Meghpar-7 soil series belongs to Vertisols soil order.In hierarchical system of soil taxonomy these represents soils of four suborder, three great group,

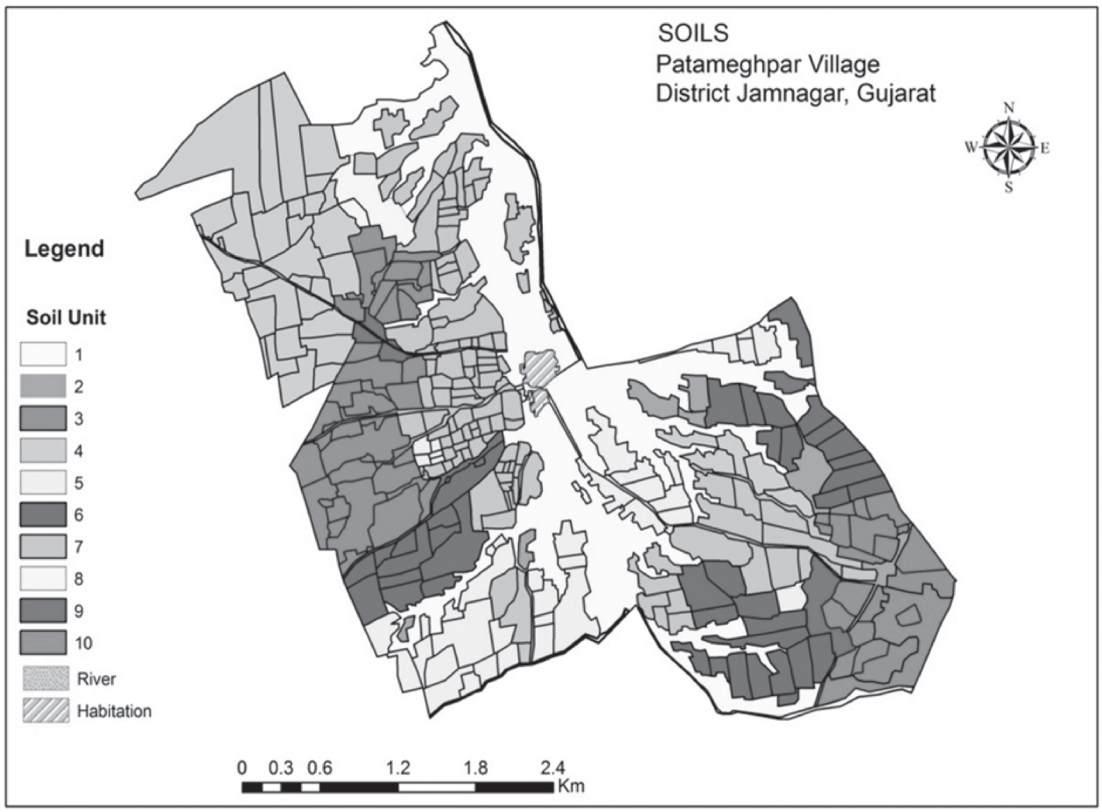

Fig. 4. Soil map of Pata Meghpar village (soil map units are described in table 3)

six subgroups and seven soil families. Physico-chemical characteristics of different series are described in table 4.

Soils of undulating upland

Soils on undulating upland (LEU no. GwC_pU4s, GwC_pU5fb, GwC_pU4g and GwC_pU2s) are very shallow, excessively drained, brown to yellowish brown, gravely loam having slightly alkaline (pH 7.2-7.8) reaction. Pata Meghpar-1 and 2 series are the members of the loamy skeletal, mixed hyperthermic family of Lithic Ustorthents. These soil series are occurring on varied slopes ranging from 1 to 15%. Available water capacity of these soils are very low (<50 mm m^{-1}), cation exchange capacity (CEC) is medium and the organic carbon (OC) content is low (<0.5%). Gravel content is high (30-50%) and increases significantly with depth. These soils are very severely eroded, degraded land/scrub land. The natural vegetation of the area is locally grown seasonal grasses and tree species like neem, babul, ber *etc.*

Soils of ravenous land

These soils are comprised of LEU no. GwC_pR5ft. They are moderately shallow, excessively drained, strongly calcareous, dark yellowish brown, weak fine sub-angular blocky structure, slightly alkaline to moderately alkaline (pH 7.7 to 8.6) in reaction. Pata Meghpar-3 series is a member of fine-loamy, mixed, calcareous hyperthermic family of Typic Ustorthents. These soils occur on undulating topography with moderate slope (8-15%). The available water capacity of these soils is low (50-100 mm m^{-1}), with high content of organic carbon (1.5%) in surface layer. These soils are formed from alluvium of basaltic parent material deposited by Und river. The content of gravels is high and increases with depth. Coarse nodules of calcium carbonate are very prominent after 30 cm depth. Soils of this landform are highly disturbed due to close vicinity of Und river. Soil forming processes operated in these soils to a limited extent therefore, they are pedologically not developed due to severe erosion. The area is under scattered and degraded forest. The natural vegetations such as seasonal grasses and tree species like neem, ber, babul are prominent in the ravenous landform.

Soils of very gently to gently sloping plain

The LEU no. GwCpV2d, GwC_pV2s and GwC_pV4d represents the soils of very gently to gently

Table 4. Physical and chemical characteristics of soils of Pata Meghpar village, Jamnagar, Gujarat

Horizon	Depth (cm)	Sand	Silt	Clay	pH	EC*	OC*	$CaCO_3$	Ca	Mg	Na	K	CEC*	BS*	ESP*	AWC*
		(%)			1:2 H_2O		(%)		[cmol(p^+)kg^{-1}]					(%)		
Pata Meghpar-1 series (Ptm-1) Loamy Skeletal, mixed, hyperthermic, Lithic Ustorthents																
A	0-15	41.2	40.2	18.6	7.4	0.45	0.3	3.65	23.2	11.2	1.2	0.1	38.2	93.5	3.4	4.5
Cr	15-30	Weathered basalt														
Pata Meghpar-2 series (Ptm-2) Loamy Skeletal, mixed, hyperthermic, Lithic Ustorthents																
A	0-25	46.2	37.4	16.4	7.6	0.6	0.3	2.4	26.3	13.5	0.4	0.1	42.1	95.7	1.0	5.3
Cr	25-35	Weathered basalt														
Pata Meghpar-3 series (Ptm-3) Fine loamy, mixed (Cal.), hyperthermic, Typic Ustorthents																
A1	0-30	46.6	27.8	25.6	7.7	0.1	1.5	5.5	33.4	15.6	0.5	0.1	46.2	107.4	1.0	6.6
A2	30-60	45.5	40.8	13.7	8.6	0.2	0.5	21.7	35.7	17.3	0.5	0.1	49.2	108.9	0.9	5.1
Cr	60-74	Weathered basalt														
Pata Meghpar-4 series (Ptm-4) Fine, mixed (cal), hyperthermic, TypicHaplustepts																
Ap	0-10	17.3	26.0	56.7	8.1	0.5	0.5	3.8	44.5	20.0	0.7	0.2	68.2	95.9	1.1	9.8
Bw1	10-25	15.2	25.1	59.7	8.2	0.5	0.5	4.1	47.7	22.4	2.0	0.1	76.5	94.4	2.8	11.7
Bw2	25-45	17.6	21.1	61.3	8.3	0.3	0.4	4.6	46.9	21.2	1.7	0.1	74.2	94.2	2.4	10.5
BC	45-60	62.3	13.5	24.2	8.4	0.3	0.3	4.9	21.3	11.2	1.4	0.1	36.8	92.4	4.1	7.6
Cr	60-74	Weathered basalt														
Pata Meghpar-5 series (Ptm-5) Fine, smectitic (cal), hyperthermic, Vertic Haplustepts																
Ap	0-15	35.1	27.2	37.7	8.6	0.4	0.7	14.4	32.2	12.2	2.5	0.1	51.2	91.8	5.3	14.0
Bss1	15-30	20.6	28.4	51.0	8.5	0.4	0.6	11.9	40.8	13.5	2.7	0.1	60.4	94.5	4.7	10.9
Bw1	30-55	16.7	40.2	43.1	8.7	0.4	0.6	11.2	43.2	12.6	3.5	0.1	63.1	94.1	5.9	9.6
Bw2	55-70	14.7	39.7	45.7	8.8	0.4	0.6	17.4	44.5	7.8	3.4	0.1	57.6	96.9	6.1	9.4
Ck	70-85	Weathered basalt mixed with calcium carbonate														
Pata Meghpar-6 series (Ptm-6) Fine, smectitic (cal), hyperthermic, Leptic Haplusterts																
Ap	0-15	16.7	32.1	51.3	8.1	0.9	0.8	9.8	40.8	16.7	1.7	0.2	62.8	94.6	2.9	13.4
Bss1	15-40	20.4	27.2	52.4	8.2	0.7	0.7	11.5	41.6	14.7	2.0	0.2	61.6	95.0	3.4	10.6
Bss2	40-65	17.4	27.2	55.4	8.2	0.7	0.6	12.1	40.8	15.1	2.3	0.2	61.7	94.7	3.9	10.1
Bss3	65-75	17.3	41.6	41.1	8.3	0.5	0.7	16.8	36.7	16.7	2.0	0.2	58.6	94.9	3.6	11.3
Cr	75-85	Weathered basalt														
Pata Meghpar-7 series (Ptm-7) Fine, smectitic (cal), hyperthermic, Typic Haplusterts																
Ap	0-15	25.0	27.7	47.4	8.4	1.1	0.7	11.9	34.7	19.2	2.3	0.3	58.4	96.7	4.1	12.3
Bss1	15-38	15.6	46.9	37.6	8.5	0.7	0.7	11.9	42.0	15.5	2.5	0.2	63.2	95.3	4.2	7.0
Bss2	38-65	15.0	41.3	43.8	8.2	0.6	0.6	12.1	43.7	14.7	2.7	0.2	64.8	94.6	4.4	10.1
Bss3	65-85	18.7	30.6	50.7	8.3	0.6	0.6	15.7	44.2	16.4	2.1	0.1	66.4	94.6	3.3	10.0
Bss4	85-105	24.0	34.5	41.5	8.5	0.6	0.4	23.6	31.4	12.6	1.8	0.1	48.1	95.4	3.9	13.6
Cr	105-140	Weathered basalt														

*EC = Electrical conductivity (dS m^{-1}); OC = Organic carbon; CEC = Cation exchange capacity; BS = Base saturation; ESP = Exchangeable sodium percentage; AWC = Available water content.

sloping plain. These soils are slightly deep (50-75 cm), moderately well drained, slight to moderately calcareous, very dark grayish brown, moderate medium sub angular blocky, moderate to strongly alkaline (pH 8.1 to 8.8) in reaction. Pata Meghpar-4 series is a member of fine, mixed, calcareous hyperthermic family of Typic Haplustepts. Another series on the same landform is Pata Meghpar-5 which is a member of fine, smectitic, calcareous hyperthermic family of Vertic Haplustepts. These soils occur on very gently sloping (1-3%) to gently sloping area. The OC content is low to medium and available water capacity of these soils is medium with high cation exchange capacity. These soils are formed from basaltic parent material containing zeolites. These are the soils with slight stoniness, moderate erosion with double crop of groundnut-wheat/gram or cotton.

Soils of nearly level plain

Soils of nearly level plain constituted by LEU no. GwC_pN1d and GwC_pN1dg. These soils are slightly deep (50-75 cm) to deep (100-150 cm), clayey, moderately well drained, very dark grayish brown to very dark gray, weak fine angular blocky to moderate medium angular blocky structure, moderately calcareous and moderately alkaline (pH 8.0-8.5) in reaction. Pata Meghpar-6 series is a member of fine, smectitic, hyperthermic family of Leptic Haplusterts. These soils occur in the nearly level plain on 0-1% slope with moderate erosion. The content of clay is high (>50%) and increases with depth. Deep wide cracks were seen on soil surface and slickensides were observed within 100 cm of soil depth which intensified in Bss2 and Bss3 horizons (40-75 cm depth). The OC content of these soils is medium to high with uneven distribution down the depth. The available water capacity is medium and cation exchange capacity is high. These soils are slightly eroded under double crop.

Pata Meghpar-7 series is a member of fine, smectitic, hyperthermic family of Typic Haplusterts. These soils occur on 0-1% slope in the lower part of nearly level plain. These are deep, moderately well drained, clayey, dark brown to very dark grayish brown in colour, moderate medium angular blocky structure, calcareous, moderately alkaline (pH 8.0-8.5) in reaction. Slickensides are clearly visible in B horizons. The typical expanding and contracting type clay minerals are present which is evident by presence of deep and wide cracks during summer season. The organic carbon content is medium and available water capacity and CEC of these soils is high. These soils are moderately eroded and cultivated for double crops.

Conclusions

In the present study, it can be stated that soil heterogeneity at phase level can be better explained based on LEU–soil relationship. Since the land use/ land cover of an area is not a permanent feature. It changes with time and largely depends on the accessibility of other natural resources such as ground water and socio-economic status of the farmers. Therefore, it is necessary to establish the LEU–soil relationship after intense field traversing and sufficient ground truthing. Once the relationship between LEU and soil has been established, it can be used for faster and precise soil mapping in basaltic terrains.

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