Chapter 19
Characterization and Mapping of Soils for Sustainable Management Using Geospatial Techniques: A Case Study of Northeastern Bihar, India

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Abstract Poor knowledge on location specific data, mostly on soils, and of situation-specific recommendations has been the causes of failure for most of the agricultural related development schemes that operated in the country in the past. The land resource inventory (LRI) may be filled these gaps by generating data on location specific soil and other land resources. LRI involves systematic surveys of soils on 1:10,000 scale for land use planning scientifically in the GIS platform. The present work was undertaken in Kadwa block, Katihar district in northeastern Bihar, India. Four major landforms like old alluvial plains (9.12%), young alluvial plains (24.46%), meander plains (39.48%) and flood plains (4.61%) were identified after visual interpretation of Indian Remote Sensing Satellite (IRS) R2-LISS-IV data in conjunction with cadastral map. The detailed soil survey was carried out and eight soil series viz. Chauni, Sitalpur, Kumaripur, Asiani, Kaliganj, Sikarpur, Dangi and Mahinagar were identified in different landforms and mapped into 14 soil mapping units (phases of series). Soils developed on meander plains are very deep, moderately well drained, brown to gray, loam to silt loam texture with reddish brown mottles and

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classified as Coarse-loamy, mixed hyperthermic Fluventic Endoaquepts (Kumaripur series), Coarse-loamy, mixed, hyperthermic Aquic Haplustepts (Asiani series) and Fine-loamy, mixed, hyperthermic Aeric Endoaquepts (Kaliganj series). Young alluvial plains soils are very deep, well to somewhat poorly drained, yellowish brown to dark gray, silt loam in texture with brown mottles and classified as Coarse-loamy, mixed, hyperthermic Typic Ustifluvents (Sikarpur series) and Fine-loamy, mixed, hyperthermic Typic Haplustepts (Dangi series). Soils developed on old alluvial plains are very deep, moderately well drained, light brownish gray to dark gray, silt loam to clay loam in texture dark brown mottles and classified as Coarse-loamy, mixed, hyperthermic Typic Haplustepts (Chauni series) and Fine-loamy, mixed, hyperthermic Typic Endoaquepts (Sitalpur series). Flood plains soil are very deep, well drained, light yellowish brown to brown, silt loam surface texture, severe erosion and very frequent flooding and classified as mixed, hyperthermic Typic Ustipsamments (Mahinagar series). Surface soils of the block were grouped into eight soil reaction classes. It was observed that very strongly acid to moderately acidic soils are occupying 50.84% and neutral soils 7.53% of total geographical area (TGA). Organic carbon status (medium to high) occupied 64.10% and available phosphorus is low in 45.82% of TGA. Based on interpretation of soil survey data, the study area is divided into three land capability classes viz. II, III and IV. The results on suitability indicates that crops grown in the study area are moderate to marginally suitable due to coarse texture, fertility and ponding of water for long period limitations. Considering the major problems and potentials four land management units (LMUs) were identified and suggested alternate land use for each LMU of the study area.

Keywords Land resource inventory · Remote sensing · GIS · Mapping · Land evaluation · Crop suitability · Sustainable land use options

19.1 Introduction

Land is a delineable area of the earth's surface and the basic unit of all material production. The limited and inexpansible land resource has to be used very judiciously to meet the expectations of the people and competing demands. Though, India represents only 2.4% of the geographical area but it supports 17.5% of the total world's population (Mythili and Goedecke 2016; Jangir et al. 2020). Globally, present-day global crisis on food, fuel and energy, increasing food prices in the international market, conversion of arable lands to several non-agricultural uses, demand of good quality agricultural land for industry and urbanisation etc., the growing population need to be fed with shrinking and deteriorating land and water resources. Therefore, a systematic survey of the land resources and their mapping are essential for managing the resources in a sustainable way (Sarkar 2011; Supriya et al. 2019).

Soil mapping is basically an inference process. Soil is described as a function of climate, organisms, relief, parent material and time, referred to as CLORPT (Jenny 1941) and interactions among these soil-forming factors is potentially important because it is a possible source to understand soil pattern (McBratney et al. 2003) and thereby assist in mapping the distribution of various soils. In small areas where climate, parent material, and time are almost similar, the major factors influencing the soil properties can be attributed to variation in relief and flora and fauna (Dobos et al. 2000; Srivastava and Saxena 2004). Depending upon the requirement of the users, soil mapping can be done at various scales, such 1:250,000, 1:1,000,000 or smaller scale, medium scale like 1:100,000, 1:50,000, and large scale like 1:25,000, 1:10,000 or larger scale (Srivastava and Saxena 2004; Sharma et al. 2019). Soil survey has been carried out by different sources and at various scales for the Bihar state. However, to increase the, productivity of crops and other farm produce at block level, detailed information on soil landscape features, soils, land use, etc. are essential for the overall development of the region.

The satellite remote-sensing data products are widely accepted for small (country level) and medium scale (district level) soil mapping (Soil Survey Division Staff 2000). But, their utility is limited for large scale soil mapping due to the large resolution of satellite data**.** Previously large scale soil mapping was mostly done with conventional methods. These were time consuming, expensive with low repetitive value especially in hilly and mountainous regions, wetlands and other problematic areas (Adam et al. 2010). In the course of time, with advent of high spatial, spectral and radiometric resolution satellite data/remote sensing data along with stereo capabilities and digital elevation model, new studies have been undertaken to characterize soils at large scale through the physiography-land use-soil relationship. The technique of large scale soil mapping (1:12,500 scale) was discussed by Srivastava and Saxena (2004) in a basaltic terrain with a physiography-land use (PLU) approach and differentiated soil types using topographic information available in the Survey of India toposheet and land use/land cover information from IRS-1C PAN merged data. In a basaltic terrain with a PLU approach using landform, slope, and land use/land cover, large scale (1:5000 scale) soil map was also prepared by Nagaraju et al. (2014).

The entire state of Bihar has been mapped at 1:250,000 scale with soil series association as soil mapping units (Haldar et al. 1996). It provided information on physiographic units and soil information at smaller scale. Land resource inventory (LRI) on 1:10,000 scales provides adequate information on characteristics and spatial distribution soils and properties of soils that support land management in sustainable manner, that includes possibilities of irrigation, control of soil erosion, management of soil fertility and choice of crops (van de Wauw et al. 2008; Seid et al. 2013; Singh et al. 2016). After characterization from soil resources the land evaluation is essential to know the suitability of a particular crop or a group of crops. For evaluation of capability and suitability of the soils for particular land use, the detailed studies on specific soil-related constraints like soil fertility, available water content, degradation hazards and soil erosion are necessary (AbdelRahman et al. 2016; Fekadu et al. 2020; Mandal et al. 2020).

Further, this information's are pre-requisite for developing a land use plan for a block. Land use planning involves right land use and right technology in site-specific mode may be one of the options that may help in meeting out the demand of food as well as in preserving the quality of land for future. LRI on 1:10,000 scales is helped in developing such site-specific information, which paves the way for applying right land use, right technology at the right place. Hence, the present study is proposed as an attempt to supplement the information gap in the Kadwa block, Katihar district, Bihar especially in characterization and mapping soil resources at 1:10,000 scale, modelling soil physiographic relation, finding crop suitability, land-use options and conservation of natural resources.

19.2 Study Area

The area selected for investigation belongs to the Kadwa block, Katihar district, northeastern Bihar, India extended to 25° 30′–25° 47′ N latitude and 87° 35′–87° 55′ E longitude covering an area of 340.47 km^2 (Fig. 19.1). It is bounded by Baisi and Dagarua blocks of Purnia district in the north, south by Azamnagar block of Katihar district, east by Balrampur and Barsoi blocks of Katihar district, and west Hasanganj and Dandkhora blocks of Katihar district. The topography of the study area is more or less flat topography (1–3% slope) with the slope gradient towards south. In other words areas towards north are at higher elevation than those at south. The regional slope takes a slight tilt from west to east. The entire Kadwa block is underlain by

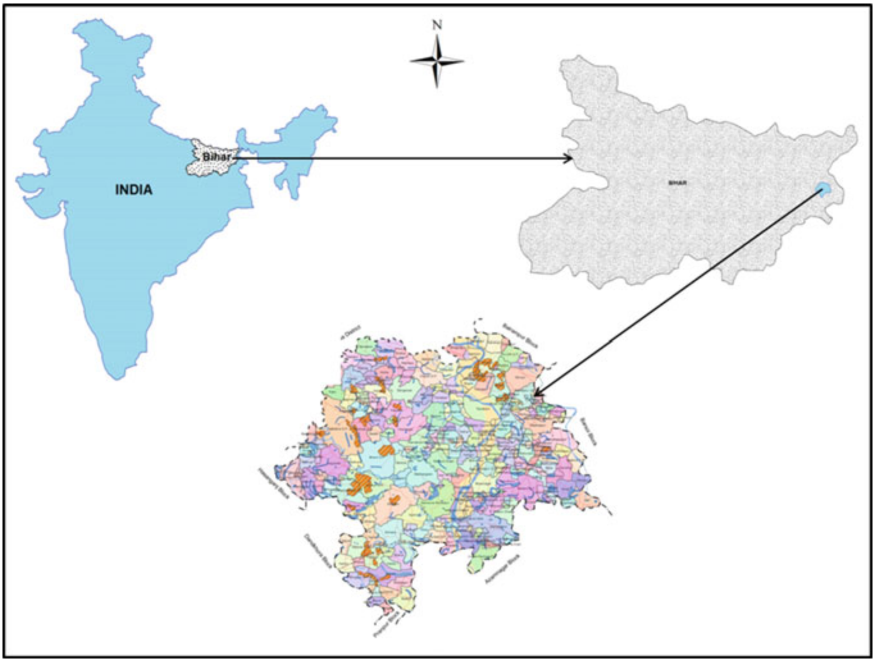

Fig. 19.1 Location map of the study area

thick unconsolidated sediment of Quaternary period (GSI 1998). Climate is moderate during the winter and hot in summer, the maximum mean temperature is 43 ºC and minimum mean temperature is 8 ºC. The mean annual rainfall is 2194 mm and the majority (about 85%) of rainfall is from south-west monsoon during the months of July to September (Reza et al. 2021). The mean summer and mean winter soil temperature difference in the block is more than 5 °C; hence, the soil temperature class is "hyperthermic". The soil moisture regime is "aquic" and "ustic" (Soil Survey Staff 2003). The area belongs to agroecological sub-region (AESR) 13.1, North Bihar and Avadh plains, hot dry to moist subhumid transitional ecological sub-region with deep, loamy alluvium-derived soils. Natural vegetation of the block consists of trees, shrubs, grasses and weeds. The major tree species are Mango (*Mangifera indica*), Jamun (*Syzigium cumini*), Arjun (*Terminalia arjuna*), Date palm (*Phoenix sylvestris*), Neem (*Azadirachta indica*), *Babul* (*Acacia nilotica*), Aswatha (*Ficus religiosa*), Ber (*Zizyphus mauritiana*), Sajina (*Moringa oleifera*), Bamboo (*Bambusa sp.*) etc.

19.3 Materials and Methods

19.3.1 Preparation of Base Maps

Toposheets of Survey of India on 1:50,000 scale, IRS-R2 LISS-IV data (5.8 m resolution) of 9th November 2013 and 13th February 2014 (Fig. 19.2) were georeferenced using WGS 84 datum, Universal Transverse Mercator (UTM) projection and ground control points (GCPs) (Nagaraju et al. 2014). The village map of the block was scanned and co-registered using orthorectified LISS-IV data as a reference. The rasterized village map was digitized on-screen after the geo-referencing. Land use/land cover, landform analysis was carried out by onscreen visual interpretation using IRS-P6 LISS-IV data in ArcGIS software. A LEU layer was prepared by integrating the landform, slope, and land-use/land cover layers in a GIS environment (ArcGIS ver. 10.5) and LEU units are relatively homogeneous in terms of the main

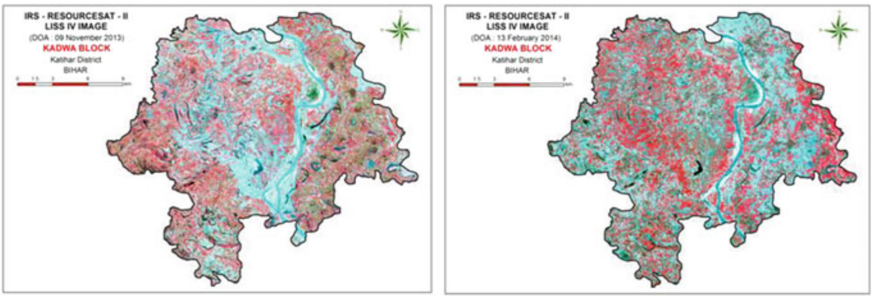

Fig. 19.2 IRS-P6 LISS-IV satellite data (9th November 2013 and 13th February 2014) of Kadwa block

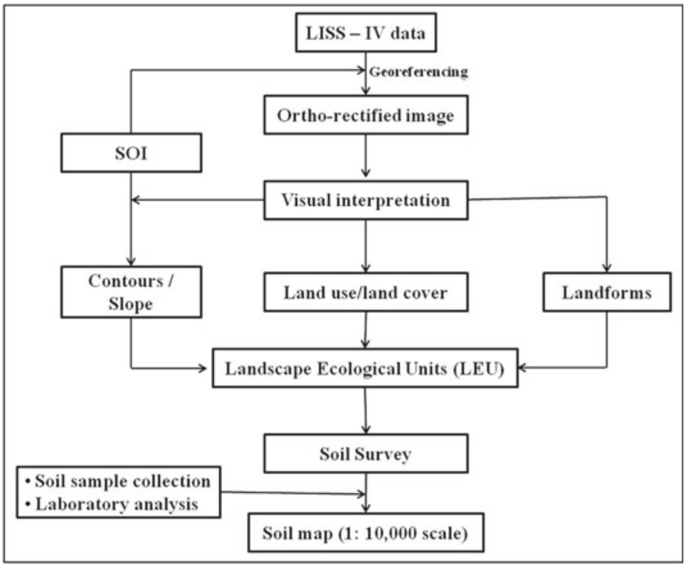

Fig. 19.3 Flowchart of the methodology

factors of soil formation and typical predictors of soil characteristics and used as a base map for ground truth verification and soil mapping. The flow chart showing the methodology of detailed soil mapping using LISS-IV data derived products was presented in Fig. 19.3.

19.3.2 Ground-Truth Verification

The identified different landform units, slope and present land use/land cover of the study area was traversed and correlated with image interpretation units. The originally derived boundaries of base maps were verified and corrected wherever necessary. Representative sites on each physiographic units using handheld Global Positioning System (GPS) were selected to understand the soil variability in the study area and profiles observations have taken as per variation in phases and were described for site and soil characteristics such as depth, colour (matrix and mottle), boundary, structure, texture, cutans, etc. following the guidelines for field soil descriptions (Soil Survey Staff 1995).

19.3.3 Soil Sampling and Analysis

The soil samples collected during the soil survey fieldwork were air dried at room temperature in the laboratory. The dried soil samples were grounded using a wooden pestle and mortar, sieved through a 2 mm sieve. After properly labeled the samples were stored in polythene bags for laboratory analysis. Standard procedures were used for analysis of soil physical and chemical parameters in the laboratory. International pipette method was used for particle size analysis. A combined glass-calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soil/solution ratio). Organic carbon (OC) was determined using the wet digestion method of Walkley and Black (1934) whereas, available nitrogen (N) was measured by the alkaline permanganate method as described by Subbiah and Asija (1956). Bray II method (Bray and Kurtz 1945) was used for estimation of available phosphorus (P). Cation exchange capacity (CEC) of soil was determined as per the standard procedure outlined by Jackson (1976). For determination of exchangeable cations [calcium (Ca), potassium (K), and magnesium (Mg)] soil samples were extracted with 1 M ammonium acetate (NH_4OAc) (pH 7.0). K content was estimated by flame photometry (Rich 1965), while Ca and Mg were determined in ethylene diamine tetra acetic acid (EDTA) titration. 1 N potassium chloride (KCl) solution was used for extracted of exchangeable Al and titrated the aliquot with 0.1 N sodium hydroxide (NaOH) solution. Soils of the study area were classified as per guidelines outlined by Keys to Soil Taxonomy (Soil Survey Staff 2014).

19.3.4 Soil Classification

The following criteria (Soil Survey Staff 2014) are used to classify the soils of the study area.

Order: Inceptisols-presence cambic (Bw) horizon and structural development in subsurface horizon and Entisols—soils that do not show any profile development and no diagnostic horizons, and most are mostly unconsolidated sediments with little or no alteration from their parent materials.

Suborders: Aquepts—Inceptisols that have a aquic soil moisture regime, Ustepts—Inceptisols that have a ustic soil moisture regime, Aquents—Entisols that have a aquic moistire regime, Psamments—Other Entisols that doesn't fit in any suborder and within the particle-size control section have a texture class of loamy fine sand or coarser in all layers (sandy loam lamellae are permitted), Fluvents—Entisols that show decrease in organic carbon content irregular within a depth of 25 cm and either a depth of 125 cm below the mineral soil surface.

Great groups: Haplustepts—Ustepts, which doesn't meet the requirement of the great group of Ustepts suborder; Endoaquepts—Aquepts with endo-saturation; Endoaquents—Aquents with endo-saturation; Ustifluvents—other Fluvents that having an ustic soil moisture regime and Ustipsamments—Psamments, which doesn't meet the requirement of the great group of Psamments suborder.

Subgroups: Typic Haplustepts—Haplustepts, which doesn't meet the requirement of the subgroup of Haplustepts greatgroup; Typic *Endoaquepts—Endoaquepts*, which doesn't meet the requirement of the subgroup of *Endoaquepts* great group; Fluventic Endoaquepts—Endoaquepts that show decrease in organic carbon content irregular within a depth of 25 cm and either a depth of 125 cm below the mineral soil surface.; Aquic Haplustepts—Haplustepts great groups that have redoxmorphic characteristics with chroma of 2 or less in one or more horizons within 75 cm of the mineral soil surface and also some time in normal years having aquic conditions; Aeric Endoaquepts—Endoaquepts that have Chroma value 2 or more in one or more than one horizons between the A or Ap horizon and below the mineral soil surface of a depth of 75 cm; Typic Ustifluvents- Ustifluvents, which doesn't meet the requirement of the subgroup of Ustifluvents great group and Typic Ustipsamments—Ustipsamments, which doesn't meet the requirement of the subgroup of Ustipsamments great group.

19.3.5 Development of Soil Mapping Legend

Phases of the soil series were considered as mapping units in the present study. The soil series may be defined is a group of soils or polypedons that have similar arrangement and in differentiating characteristics in horizons and sets of properties with narrow range (Soil Survey Division Staff 2000). Soil depths, surface texture, slope, erosion and flooding criteria were considered for defining the soil phases within a soil series (Nagaraju et al. 2014). The pedons were studied during the soil survey work and correlated for identification of soil series in each major landform. The extension of soil series were verified using the diagnostic soil characteristics from soil profile and augur observations. A soil map were prepared at 1:10,000 scale showing soil series and their phases and the soil legend code developed indicates the name of the series followed by surface texture, slope, erosion and flooding (Singh et al. 2016).

19.3.6 Land Evaluation

Land capability classification (LCC) was used to find out the general capability of soil resources of an area which was suitable for agricultural, forestry and other uses. Based on their limitations to field crops and the way they respond to management the mapping units were grouped into various capability units. The capability classes were identified based on their inherent soil characteristics, external land features and environmental factors that limit the use to of land (AIS&LUS 1970). The characteristics used to group the land resources identified in the study area are: texture, slope, erosion and drainage. In the capability system, mapping units are generally grouped at three levels- capability class, sub-class and unit. The broadest groups of capability classes were designed by Roman numerals I to VIII and increasing the numerals indicate progressively greater limitations and narrow choice for practical use. The eight classes Class I–VIII were used in the system whereas, Class I–IV indicates these were suitable for cultivation with increasing limitations. They are capable of producing commonly cultivated crops of the region under good management. Classes V to VII are suited to adopted native plans, pasture or forestry. Class VIII was not suitable for agriculture as well as for silviculture.

Capability sub-classes were described based on the limitations observed within the capability classes. There are designed by adding a lower case letter like e, s, w or c to the class numeral. For example in sub class IVe, the letter e shows that the main hazard in class IV land is the risk of erosion. Similarly, the symbol ‘w’ indicates drainage or wetness as a limitation for plant growth; the symbol ‘s’ indicate root zone limitations and ‘c’ indicates climate or rainfall with short growing period.

Some important soil characteristics namely soil texture, depth, available water retention capacity of soils, salinity, infiltration and permeability were used for soil irrigability classification. In addition to soil irrigability class, land irrigability classification was made by taking the consideration the quantity of water as well as quality, requirement of drainage, topography and economic condition. Criteria for classes are qualitatively defined in such a way that a soil can qualify for only one class (AIS&LUS 1970). The most limiting property is determined for classification. For example, the soil may have all the properties of the most desirable class except one, but due to one undesirable property it is assigned to a lower class. Irrigability classes are further divided in su-bclasses to indicate the dominant limitations such as ‘s’ for soil limitation, ‘d’ for drainage limitation and ‘t’ for topography limitation.

Evaluation of soil site suitability has been done by maximum likelihood method (Sys et al. 1993; Naidu et al. 2006). The suitability criteria included climatic attributes (c) viz. rainfall and temperature; wetness aspect (w) viz. drainage and flooding; physical condition (s) viz. surface texture, rooting condition as soil depth (d) and soil fertility factor (f) viz. pH, OC, apparent CEC, base saturation and sum of cations. Soils have been evaluated as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), temporarily not suitable (N1) and permanently not suitable (N2) classes.

19.4 Results and Discussion

19.4.1 Land Use/Land Cover

IRS-P6 LISS-IV data (09th November 2013 and 13th February 2014) were interpreted and four land use/land cover classes were identified. The land use data (Fig. 19.4) indicates that about 77.36% of total geographical area (TGA) of the

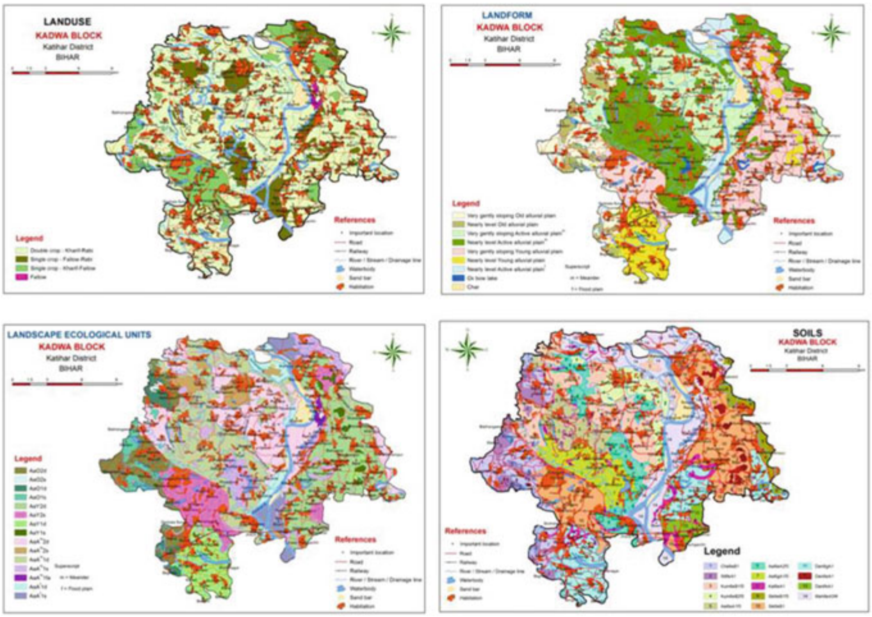

Fig. 19.4 Land use/land cover, landform, landscape ecological units and soil maps of Kadwa block

study area is under agriculture, 0.31% is under fallow and 22.33% TGA under miscellaneous viz. habitation, ox bow lake, sand bar and river system.

19.4.2 Landform and Landscape Ecological Units (LEUs)

Visual interpretation of LISS-IV data indicated that the block was characterized into old alluvial plain, active alluvial plain, young alluvial plain, ox bow lake and char. The major landforms were further subdivided based on elevation, land-uses and other local features. The old alluvial plain were sub-divided into very gently sloping and nearly level old alluvial plain, young alluvial plain into very gently sloping and nearly level young alluvial plain and active alluvial plain into very gently sloping and nearly level active alluvial plain (meander plain) and nearly level active alluvial plain (flood plain) (Fig. 19.4). The landform, slope and land-use/land-cover maps were integrated in ArcGIS and LEU map was prepared. Based on integration, 16 LEU units were delineated in the study area and the characteristics of each LEU unit was described (Table 19.1) and mapped (Fig. 19.4). On the alluvial plain, eight LEU units were identified based on two slope classes (0–1 and 1–3%) and two land use/land cover classes (single crop and double crop). Five LEU units were identified on the meander plain with two slope classes (0–1 and 1–3%) and three land use/land cover classes (single crop, double crop and fallow). Three LEU units were identified

Table 19.1 Landscape ecological units (LEU) of Kadwa block

Landscape ecological unit (LEU)	Area (ha)	TGA (%)
Very gently sloping old alluvial plain under double crop (AaO2d)	1824	5.36
Very gently sloping old alluvial plain under single crop (AaO2s)	48	0.14
Nearly level old alluvial plain under double crop (AaO1d)	548	1.61
Nearly level old alluvial plain under single crop (AaO1s)	684	2.01
Very gently sloping young alluvial plain under double crop (AaY2d)	4440	13.04
Very gently sloping young alluvial plain under single crop (AaY2s)	1916	5.63
Nearly level young alluvial plain under double crop (AaY1d)	1679	4.93
Nearly level young alluvial plain under single crop (AaY1s)	295	0.86
Very gently sloping active alluvial plain under double crop (AaA^m2d)	4757	13.97
Very gently sloping active alluvial plain under single crop (AaA^m2s)	962	2.83
Nearly level active alluvial plain under double crop ((AaA^m1d))	5299	15.56
Nearly level active alluvial plain under single crop ((AaA^m1s))	2317	6.81
Nearly level active alluvial plain under fallow (AaA^m1fa)	105	0.31
Nearly level active alluvial plain plain under double crop (AaA^f1d)	734	2.15
Nearly level active alluvial plain under single crop (AaA^f1s)	838	2.46
Ox bow lake (AaOx)	127	0.38
Total cultivated area	26,573	78.05
Miscellaneous	7474	21.95
Total area	34,047	100

with two land use/land cover classes (single crop and double crop) and single slope class (0–1%) and one LEU unit in ox bow lake.

19.4.3 Soil-Landform Relationship

Soils of old alluvial plains and meander plains are very deep and having two genetic horizons A–B with clear smooth and gradual smooth boundary in surface and subsurface horizons, respectively (Table 19.2). The pedons showed difference in surface and subsurface matrix colour. The surface horizon colours are dark yellowish brown (10YR 4/4) and dark grey (2.5Y 4/0) in old alluvial plains (Chauni and Sitalpur series), and light brownish grey (10YR 6/2) and greyish brown (10YR 5/2) in meander plains (Kumaripur, Asiani and Kaliganj series). Whereas, the subsurface colour for old alluvial plains and meander plains varied from brown (10YR 5/3) to dark grey (2.5Y 4/0) and brown (10YR 5/3) to dark grey (10YR 4/1), respectively. Soils of young alluvial and flood plains deep to very deep and having A horizon except Dangi series of young alluvial plains (Table 19.2) with clear smooth and gradual smooth boundary in surface and subsurface horizons, respectively indicating the

Table 19.2 Morphological properties of soils

Depth (cm)	Horizon	Boundary	Matrix colour (moist)	Texture	Structure	Mottle colour	Roots
Old alluvial plains							
Chauni series: *Coarse-loamy, mixed, hyperthermic Typic Haplustepts*							
0–13	Ap	cs	10YR 4/4	Silt loam	m2sbk	–	cf
13–31	Bw1	gs	10YR 4/3	Silt loam	m2sbk	7.5YR 4/6	fvf
31–55	Bw2	gs	10YR 4/3	Silt loam	m2sbk	7.5YR 4/4	fvf
55–85	Bw3	gs	10YR 4/3	Silt loam	m2sbk	7.5YR 4/4	–
85–115	BC1	gs	10YR 4/4	Loam	f1sbk	–	–
115–155	BC2	–	10YR 5/3	Sandy loam	f1sbk	–	–
Sitalpur series: *Fine-loamy, mixed, hyperthermic Typic Endoaquepts*							
0–13	Ap	cs	2.5Y 4/0	Silty clay loam	m2sbk	–	fm
13–45	Bw1	gs	2.5Y 4/1	Clay loam	c2sbk	7.5YR 5/8	ff
45–68	Bw2	gs	2.5Y 4/2	Loam	f1sbk	7.5YR 5/8	fvf
68–110	Bw3	–	2.5Y 4/2	Sandy loam	f1sbk	7.5YR 5/8	–
Meander plains							
Kumaripur series: *Coarse-loamy, mixed hyperthermic Fluventic Endoaquepts*							
0–26	Ap	cs	10YR 6/2	Silt loam	m2sbk	–	cm
26–54	Bw1	gs	10YR 5/2	Silt loam	c2sbk	5YR 4/4	ff
54–79	Bw2	gs	10YR 4/2	Silt loam	c2sbk	5YR 3/4	ff
79–115	Bw3	–	10YR 4/1	Silt loam	c2sbk	5YR 3/4	ff
Asiani series: *Coarse-loamy, mixed, hyperthermic Aquic Haplustepts*							
0–17	Ap	cs	10YR 5/2	Silt loam	m2sbk	–	cf
17–46	Bw1	gs	10YR 5/1	Silt loam	m2sbk	7.5YR 5/8	fvf

(continued)

Table 19.2 (continued)

Depth (cm)	Horizon	Boundary	Matrix colour (moist)	Texture	Structure	Mottle colour	Roots
46–77	Bw2	gs	10YR 5/3	Silt loam	f1sbk	7.5YR 4/4	fvf
77–112	BC	–	10YR 5/2	Loam	f1sbk	7.5YR 4/4	
Kaliganj series: *Fine-loamy, mixed, hyperthermic Aeric Endoaquepts*							
0–18	Ap	cs	10YR 6/2	Silty clay	m2sbk	–	cm
18–40	Bw1	gs	10YR 5/1	Silty clay loam	m2sbk	7.5YR 4/6	fvf
40–70	Bw2	gs	10YR 4/3	Silty clay	m2sbk	7.5YR 4/4	fvf
70–110	Bw3	–	10YR 4/3	Silt loam	m2sbk	7.5YR 4/4	–
Young alluvial plains							
Sikarpur series: *Coarse-loamy, mixed, hyperthermic Typic Ustifluvents*							
0–16	Ap	cs	10YR 4/1	Silt loam	m2sbk	–	mf
16–38	C1	gs	10YR 4/4	Sandy loam	massive	–	ff
38–80	C2	gs	10YR 4/4	Silt loam	m2sbk	–	ff
80–121	2C3	gs	10YR 4/3	Silt loam	m2sbk	5YR 2.5/2	–
121–176	3C4	–	10YR 4/4	Silt loam	m2sbk	–	–
Dangi series: *Fine-loamy, mixed, hyperthermic Typic Haplustepts*							
0–15	Ap	cs	10YR 5/1	Clay loam	m2sbk	-	cm
15–45	Bw1	gs	10YR 5/3	Silty clay loam	m2sbk	7.5YR 4/4	fvf
45–72	Bw2	gs	10YR 5/3	Silty clay loam	m2sbk	7.5YR 3/4	fvf
72–109	Bw3	gs	10YR 4/4	Silt loam	f1sbk	7.5YR 4/4	-
109–151	BC	-	10YR 4/4	Silt loam	f1sbk	7.5YR 3/4	-
Flood plains							
Mahinagar series*: mixed, hyperthermic Typic Ustipsamments*							

(continued)

Table 19.2 (continued)

Depth (cm)	Horizon	Boundary	Matrix colour (moist)	Texture	Structure	Mottle colour	Roots
0–20	Ap	gs	10YR 4/4	Silt loam	f1sbk	–	–
20–54	C1	gs	10YR 6/1	Loamy sand	sg	–	–
54–90	C2	gs	10YR 6/1	Loamy sand	sg	–	–
90–150	C3	-	10YR 5/2	Loamy sand	sg	–	–

these soils were developed under fluvial process. The soils of young alluvial plains showed difference in surface and subsurface matrix colour. The surface horizons are dark grey (10YR 4/1) (Sikarpur series) and grey (10YR 5/1) (Dangi series) with subsurface colour dark yellowish brown (10YR 4/4) to brown (10YR 5/3). The soils of flood plains (Mahinagar series) are light yellowish brown (surface) and brown (subsurface) colour with brown mottles.

Sitalpur series of old alluvial plains, and Kumaripur series and Kaliganj series of mender plains showed grey matrix colour with chroma 0–2, which indicates that these soils were under prolonged submergence and subsequently developed under reducing conditions during flooding. The low chroma of soils judged the severity of gleying due to poor drainage conditions high groundwater table in lower topographical position (Stoop and Eswaran 1985). When these soils become dry, the reduced iron (Fe^{3+}) is oxidized and precipitates by releasing of H^+ ions to acidify and disintegrate the clay. Under saturated condition for a long time these soils developed distinctive gley horizons resulting from oxidation and reduction process and has iron and manganese mottles or streaks in B horizons due to slow diffusion process (Ponnamperuma 1972, 1985). These soils are also known as hydromorphic soils and gleization as the major pedogenic process operating for their developments (Khan et al. 2012).

The variation of soil properties with depths indicates the dominant soil processes operating over the course of profile development. In initial stage, the OM input and mineral weathering occurs in weakly developed soils (Entisols and Inceptisols). Soils of the study area varied to a great extent with depths due to different pedogenic processes. Kumaripur series of meander plains (coarse-loamy, mixed hyperthermic Fluventic Endoaquepts), Sikarpur series of young alluvial plains (coarse-loamy, mixed, hyperthermic Typic Ustifluvents) and Mahinagar series of flood plains (mixed, hyperthermic Typic Ustipsamments) showed irregular distribution of OC, clay content and CEC (Table 19.3). Such irregular distribution could be attributed to the pedogenic processes namely, mass movement, periodic flooding and deposition of alluvium brought down by water during different fluvial cycles (Huggett et al. 1975, 1976). However, soils of Chauni series (coarse-loamy, mixed, hyperthermic Typic Haplustepts) and Sitalpur series (fine-loamy, mixed, hyperthermic

Table 19.3 Physical and chemical properties of soils

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH H_2O (1:2.5)	OC (%)	Exchangeable cations				CEC
							Ca	Mg	Na	K	
							cmol(p+) kg^{-1}				
Old alluvial plains											
Chauni series: *Coarse-loamy, mixed, hyperthermic Typic Haplustepts*											
0–13	Ap	7.0	78.2	14.8	5.5	0.52	1.2	0.6	0.1	0.2	3.5
13–31	Bw1	3.4	81.6	15.0	5.9	0.42	3.1	0.9	0.1	0.1	6.8
31–55	Bw2	4.0	76.0	20.0	5.8	0.34	3.8	2.4	0.1	0.1	9.0
55–85	Bw3	4.1	79.9	16.0	6.3	0.25	0.7	0.4	0.1	0.1	3.8
85–115	BC1	51.3	36.6	12.1	7.4	0.07	0.8	0.7	0.1	0.1	2.7
115–155	BC2	54.6	37.2	8.2	7.1	0.03	0.7	0.5	0.1	0.1	2.4
Sitalpur series*: Fine-loamy, mixed, hyperthermic Typic Endoaquepts*											
0–13	Ap	19.6	49.3	31.1	5.4	0.95	1.7	1.2	0.2	0.4	6.6
13–45	Bw1	21.2	46.1	32.7	6.7	0.30	3.5	1.6	0.1	0.3	6.7
45–68	Bw2	30.0	47.5	22.5	7.3	0.18	2.2	1.0	0.2	0.2	4.7
68–110	Bw3	42.0	40.5	17.5	7.5	0.12	2.0	1.5	0.1	0.2	4.0
Meander plains											
Kumaripur series: *Coarse-loamy, mixed hyperthermic Fluventic Endoaquepts*											
0–26	Ap	14.2	69.6	16.2	6.0	0.67	1.7	1.2	0.2	0.4	7.4
26–54	Bw1	23.4	63.8	12.8	6.6	0.31	1.5	1.6	0.1	0.3	4.9
54–79	Bw2	21.7	61.1	17.2	6.9	0.18	2.2	1.0	0.2	0.2	6.0
79–115	Bw3	29.7	53.5	16.8	6.7	0.32	2.0	1.5	0.1	0.2	5.8

(continued)

Table 19.3 (continued)

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH H_2O (1:2.5)	OC (%)	Exchangeable cations				CEC
							Ca	Mg	Na	K	
							cmol(p+) kg^{-1}				
Asiani series: *Coarse-loamy, mixed, hyperthermic Aquic Haplustepts*											
0–17	Ap	18.1	59.2	22.7	5.9	0.68	3.4	1.0	0.1	0.2	6.9
17–46	Bw1	19.5	62.9	17.6	7.2	0.23	2.9	0.8	0.1	0.1	5.3
46–77	Bw2	13.3	71.7	15.0	7.3	0.18	2.4	1.1	0.1	0.1	4.9
77–112	BC	37.2	49.1	13.7	7.1	0.10	2.0	1.0	0.1	0.1	4.3
Kaliganj series: *Fine-loamy, mixed, hyperthermic Aeric Endoaquepts*											
0–18	Ap	1.5	55.6	42.9	5.5	0.52	1.2	0.6	0.1	0.2	3.5
18–40	Bw1	3.0	60.4	36.6	5.9	0.32	3.1	0.9	0.1	0.1	6.8
40–70	Bw2	8.8	50.3	40.9	5.8	0.31	3.8	2.4	0.1	0.1	9.0
70–110	Bw3	1.4	66.5	32.1	6.3	0.25	0.7	0.4	0.1	0.1	3.8
Young alluvial plains											
Sikarpur series: *Coarse-loamy, mixed, hyperthermic Typic Ustifluvents*											
0–16	Ap	21.8	68.8	9.4	4.4	0.43	1.6	0.7	0.4	0.4	4.7
16–38	C1	47.5	46.6	5.9	6.2	0.13	1.7	0.8	0.3	0.1	4.0
38–80	C2	26.7	66.4	6.9	6.3	0.12	2.0	0.9	0.2	0.2	4.5
80–121	2C3	9.5	76.3	14.2	6.3	0.18	2.4	1.4	0.2	0.3	6.0
121–176	3C4	26.2	69.4	4.4	6.8	0.07	1.3	1.0	0.5	0.2	3.9

(continued)

Table 19.3 (continued)

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH H_2O (1:2.5)	OC (%)	Exchangeable cations				CEC
							Ca	Mg	Na	K	
							cmol(p+) kg^{-1}				
Dangi series: *Fine-loamy, mixed, hyperthermic Typic Haplustepts*											
0–15	Ap	22.0	49.0	29.0	6.0	0.67	4.9	1.0	0.3	0.3	8.5
15–45	Bw1	16.1	55.2	28.7	7.0	0.30	4.7	1.1	0.2	0.3	7.4
45–72	Bw2	10.5	58.9	30.6	7.1	0.28	4.6	1.5	0.1	0.2	7.4
72–109	Bw3	5.5	73.7	20.8	6.8	0.18	4.0	1.4	0.2	0.1	7.1
109–151	BC	9.3	71.5	19.2	6.8	0.16	3.0	1.3	0.2	0.2	6.0
Flood plains											
Mahinagar series*: mixed, hyperthermic Typic Ustipsamments*											
0–20	Ap	31.2	54.2	14.6	5.5	0.17	0.16	0.63	0.24	0.10	6.9
20–54	C1	80.0	17.5	2.5	5.4	0.26	0.32	0.32	0.18	0.05	3.2
54–90	C2	83.3	12.7	4.0	4.7	0.30	0.48	0.79	0.14	0.04	3.0
90–150	C3	78.3	20.7	4.0	5.6	0.13	0.32	0.63	0.20	0.03	3.8

Typic Endoaquepts) in old alluvial plains, Asiani series (coarse-loamy, mixed, hyperthermic Aquic Haplustepts) and Kaliganj series (fine-loamy, mixed, hyperthermic Aeric Endoaquepts) in meander plains and Dangi series (fine-loamy, mixed, hyperthermic Typic Haplustepts) in young alluvial plains shows systematic variation with depth may be due to presence of uniform parent materials from where soil profiles developed and reflect pedogenesis (Table 19.3).

19.4.4 Soil Mapping

Soil is an open system and its properties are related to the functions operating in the system (Jenny 1941). With the changing in the system the soil properties change and directly depend to soil formation factors of which was expressed as follows:

$$S = (cl, o, r, p, t, \dots)$$

where, S denotes soil property; cl, climate (rainfall and temperature); o, organisms (flora and fauna); r, relief; p, parent material; and t, time or age.

The present study area is almost similar in climate, parent material and time or age, the soil properties varies mainly depends on variation in relief or topography (r) and flora and fauna biosphere organisms (o). Hence, the LEU concept was used in the study area for mapping soils. The morphological characteristics observed during soil survey and analyzed soil properties, the soils were classified up to family level as per the Keys to Soil Taxonomy (Soil Survey Staff 2014). Eight soil series have been identified and mapped on 1:10,000 scale with 14 soil mapping units (phases of series) (Fig. 19.4). The brief description of the soil series identified along with their taxonomic classification is given in the mapping legend (Table 19.4).

19.4.5 Soil Survey Interpretation

Soil maps and other its interpretation maps are the ultimate products of soil survey. They provide valuable information on various aspects like physiography/landform, geology, vegetation, soils, drainage, etc. and are useful to the planners, administrators and other user agencies. Land use/agricultural planning of any particular area are largely based on soil resource interpretations (site characteristics and soil properties).

Following the criteria outlined in the Field Manual (Sehgal et al. 1987) and Hand Book of Agriculture (Takkar 2009), various thematic maps such as surface texture, slope, drainage, soil reaction (pH), OC, available N, P and K have been prepared. The site characteristics and the soil properties of the surface soils of each soil phases have been considered for the preparation of different thematic maps.

Table 19.4 Soil series and phases of Kadwa block

Landform	LEU map unit	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Very gently sloping old alluvial plain	AaO2d	Chauni	1	Cha6eB1	Very deep, moderately well drained, yellowish brown to dark gray, medium texture soils on very gently sloping old alluvial plain with silt loam surface texture and slight erosion (*Coarse-loamy, mixed, hyperthermic Typic Haplustepts*)	1872	5.50
Nearly level old alluvial plain	AaO1d	Sitalpur	2	Sit6kA1	Very deep, poorly drained, dark gray to dark grayish brown, fine texture soils on nearly level old alluvial plain with silty clay surface texture and slight erosion (*Fine-loamy, mixed, hyperthermic Typic Endoaquepts*)	1232	3.62

(continued)

19.4.5.1 Surface Texture

The particle-size distribution like sand, silt and clay relatively expressed as soil texture and one of the most important soil physical variable that governing nearly all properties of soils (Zhai et al. 2006; Adhikari et al. 2009). Soil texture affects water availability and retention in soil, and transform (Katerji and Mastrorilli 2009; Reza et al. 2016), leaching and erosion potential (Reza et al. 2011, 2018), plant nutrient storage (Kettler et al. 2001), and organic matter dynamics (Kong et al. 2009), it plays

Table 19.4 (continued)

Landform	LEU map unit	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Very gently sloping active alluvial plain (meander pain)	$AaA^{m}2d$	Kumaripur	3	Kum6eB1f3	Very deep, well drained, brown to dark yellowish brown, medium texture soils on very gently sloping meander plain with silt loam surface texture, slight erosion and frequent flooding (*Coarse-loamy, mixed hyperthermic Fluventic Endoaquepts*)	3361	9.87
	$AaA^{m}2s$		4	Kum6eB2f3	Same as Kumaripur series with moderate erosion	1225	3.60
Nearly level active alluvial plain (meander pain)	$AaA^{m}1d$	Asiani	5	Asi6eA1f3	Very deep, moderately well drained, brown to gray, medium texture soils on nearly level meander plain with silt loam surface texture, slight erosion and frequent flooding (*Coarse-loamy, mixed, hyperthermic Aquic Haplustepts*)	1493	4.38
	$AaA^{m}1d$		6	Asi6eA2f3	Same as Asiani series with moderate erosion	1787	5.25

(continued)

Table 19.4 (continued)

Landform	LEU map unit	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
	AaA^{m}1d		7	Asi6gA1f3	Same as Asiani series with silty clay loam surface texture	1685	4.95
Nearly level active alluvial plain (meander scars)	AaA^{m}1s	Kaliganj	8	Kal6eA1	Very deep, poorly drained, brown to gray, fine texture soils on nearly level meander scar with silt loam surface texture and slight erosion (*Fine-loamy, mixed, hyperthermic Aeric Endoaquepts*)	871	2.56
Very gently sloping young alluvial plain	AaY2d	Sikarpur	9	Sik6eB1f3	Very deep, well drained, brown to dark yellowish brown, medium texture soils on very gently sloping young alluvial plain with silt loam surface texture, slight erosion and frequent flooding (*coarse-loamy, mixed, hyperthermic Typic Ustifluvents*)	627	1.84
	AaY2d		10	Sik6eB1	Same as Sikarpur series with no flooding	4365	12.82

(continued)

Table 19.4 (continued)

Landform	LEU map unit	Soil series	Soil map unit	Mapping legend	Brief description of soil series	Area (ha)	TGA (%)
Nearly level young alluvial plain	AaY1d	Dangi	11	Dan6gA1	Very deep, moderately well drained, brown to dark yellowish brown, fine texture soils on nearly level young alluvial plain with silty clay loam surface texture and slight erosion (*Fine-loamy, mixed, hyperthermic Typic Haplustepts*)	2912	8.55
	AaY1s		12	Dan6eA1	Same as Dangi series silt loam surface texture	387	1.14
	AaY1d		13	Dan6kA1	Same as Dangi series silty clay surface texture	534	1.57
Nearly level flood plain	AaA^f1d	Mahinagar	14	Mah6eA3f4	Very deep, well drained, light yellowish brown to brown, coarse texture soils on nearly level flood plain with silt loam surface texture, severe erosion and very frequent flooding (*mixed, hyperthermic Typic Ustipsamments*)	4095	12.03
Total cultivated area						26,446	77.67
Miscellaneous						7601	22.33
Total area						34,047	100

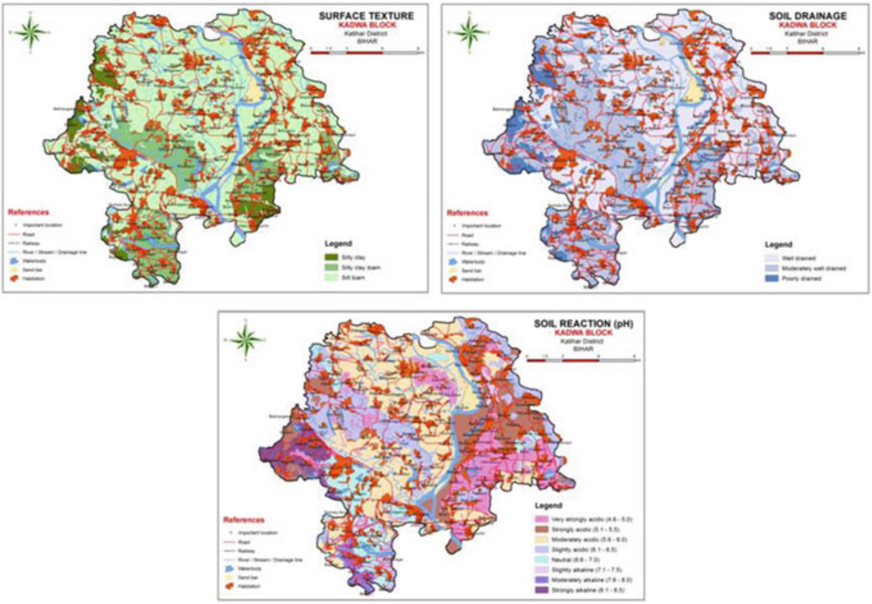

Fig. 19.5 Surface texture, soil drainage and soil reaction (pH) maps of Kadwa block

a key role in total behaviour of soil. Based on soil texture the study area grouped into three classes (Fig. 19.5). Soils are dominantly silt loam (58.99% TGA) followed by silty clay loam (13.50% TGA) and silty clay (5.19% TGA).

19.4.5.2 Drainage

Soil texture, landscape position and ground water depth directly influence the internal drainage of the soils (Reza et al. 2014a). Interpretation of data showed that three soil drainage classes were dominant in the study area (Fig. 19.5). Well drained soils occupied 40.15% of TGA followed by moderately well drained (31.34% TGA) and poorly drained (6.18% TGA), respectively.

19.4.5.3 Soil Reaction (pH)

The intensity of soil acidity or alkalinity is a measured soil reaction (pH). It acts as an indicator to assess the availability of different plant nutrients and also the percentage base saturation (Black 1968). The pH value also helps to determine the amount of various amendments to be added to the soils for acidity or alkalinity. Soils of the study area were grouped into eight soil reaction classes (Fig. 19.5). It is observed that very strongly acid to moderately acid soils occupy 50.58% of TGA, neutral soils

8.22% of TGA and soils in alkaline range occupy only 4.88% of TGA. The large extents of acid soils in the block is due to Mahananda river originated near Chimli, east of Kurseong in Darjeeling district from the Himalaya range at an elevation of 2100 m and sediments carrying by the rivers and their tributaries are acidic in nature and deposited in the study area (Kumari 2014; Reza et al. 2017a) as well as application of high dose of N fertilizer in rice–wheat cropping system (Yadav et al. 1998; Reza et al. 2017a).

19.4.5.4 Organic Carbon (OC)

Organic matter serves as a reservoir of soil nutrients that are essential for plant growth and is therefore, considered as the vital and essential soil attribute controlling productivity (Reza et al. 2019a, 2020a). OC in the study area were grouped into three organic carbon classes (Fig. 19.6). OC status in soils of study area was low to high. Data indicated that high to medium level of OC occupied 64.10% of TGA and only 13.57% of TGA was low (<0.5%). Maximum area in the S-E quadrant of the study area was high in OC due to balanced application of NPK and NP in rice–wheat cropping sequence can increase production of root biomass and stubbles (Subramaniam and Kumarswamy 1989), which may have increased OC.

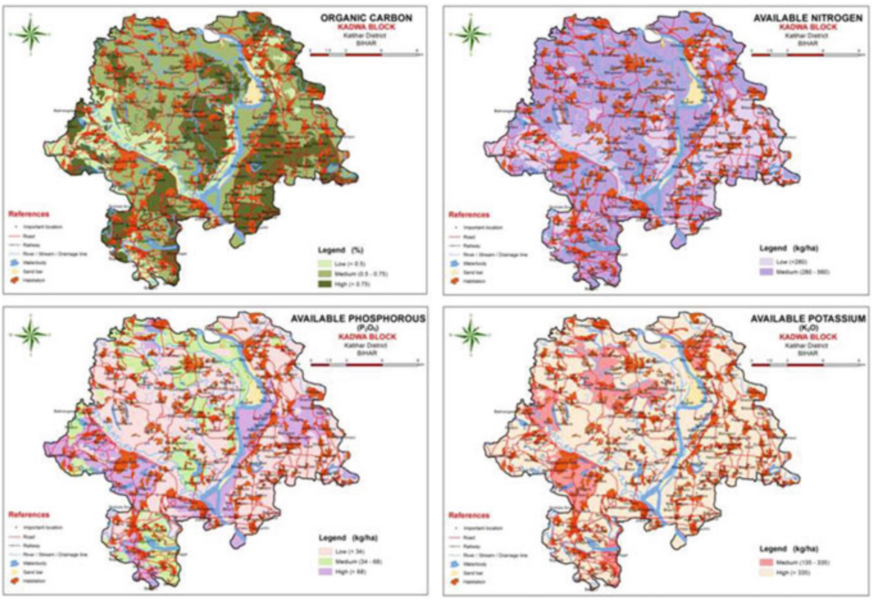

Fig. 19.6 Organic carbon, available nitrogen, phosphorus and potassium maps of Kadwa block

19.4.5.5 Available Nitrogen (N)

Soil nitrogen (N) is important macronutrients and play important role for crop growth and development. The presence of N in soil also governed the yield of crop and their yield attributes. However, it's adverse affects in crop production and productivity may also observe due to imbalance use in soil (Reza et al. 2019b, c). In the study area soils were grouped into two classes (Fig. 19.6). It was observed that 51.90% of TGA were medium in N, whereas 25.77% of TGA was low in category.

19.4.5.6 Available Phosphorous (P)

Among three major nutrients, phosphorus (P) plays an important role to complete the life cycle of a plant. Its functions start right from the stimulation of root growth to proper seed filling and seed setting, in addition to it is an indispensable constituent of genetic material (Khasawneh et al. 1986). It also plays a vital role in photosynthesis, carbohydrate breakdown and transfer of energy in the form of ATP and ADP compounds in various metabolic processes. P content of surface soils of the study area were grouped into three classes (Fig. 19.6) viz. low, medium and high. It was observed that 45.82% of TGA were low in P, whereas 15.87% of TGA and 15.98% of TGA comes under medium and high categories, respectively.

19.4.5.7 Available Potassium (K)

The importance potassium (K) is well recognized in agriculture (Krauss and Johnson 2002) and it is an essential nutrient for plant growth. Exchangeable K i.e. available K is widely used to evaluate the soil K status and to predict the crop K requirements (Askegaard and Jørgen 2002; Reza et al. 2014b, c). K content of soils was grouped into medium and high and is depicted in Fig. 19.6. It was observed that about 67.35 of TGA of the study area were high in K, whereas 10.32% of TGA comes under medium category. Subba Rao et al. (2011) were also reported similar observation for alluvial soils of India.

19.4.6 Land Capability Classification

Land capability classification is an interpretative grouping made primarily for broad agricultural and non-agricultural uses. The United States Department of Agriculture (USDA) was placed the arable lands into I-IV classes according to their limitations, grazing and forestry into class V-VII and class VIII lands for recreation having maximum limitations, wild life and quarrying. The capability classes were further sub-divided into sub-classes based on dominant limiting factors, such as erosion (e), soil (s), climate (c) and wetness (w). It was observed that the soils of the study area

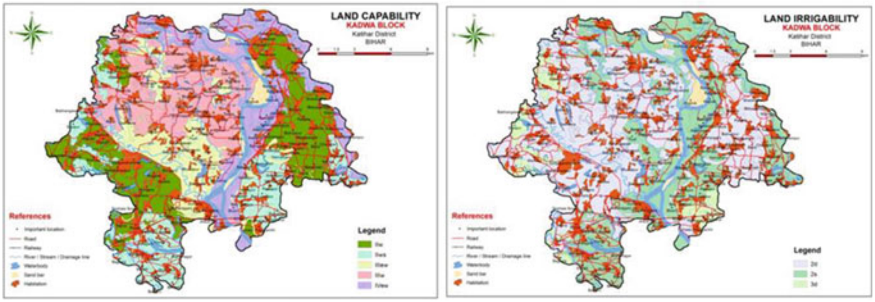

Fig. 19.7 Land capability and land irrigability maps of Kadwa block

divided into three land capability classes viz. II, III and IV. The major limiting factors are erosion and drainage. Five land capability sub-classes were recognized viz. IIw (19.46% TGA), IIws (13.74% TGA), IIIw (17.85% TGA), IIIew (12.76% TGA) and IVew (13.87% TGA) (Fig. 19.7).

19.4.7 Land Irrigability Classification

The study showed that soils were grouped into two irrigability classes which further sub-divided into three sub-classes based on the limitation of soils and site characteristics. The data revealed that about 44.82% of TGA was under 2d sub-classes followed by 2 s (27.67% TGA) and 3d (5.19% TGA) (Fig. 19.7).

19.4.8 Soil Suitability for Crops

Soil and climatic conditions play a vital role for optimal crop growth. The physico-chemical characteristics and micro-environments of soils were largely influenced by water and plant nutrients availability. As such, soil depth, subsoil texture, fertility and drainage conditions etc. are taken into account for soil site evaluation, so that soil maps can be interpreted in terms of suitability for agricultural crops for better socio-economic upliftment. The results showed that soils of the study area was moderately suitable for paddy (53.6% TGA), jute (54.8% TGA), maize (69.9% TGA), wheat (55.0% TGA), mustard (69.9% TGA) and potato (68.8% TGA) due to coarse texture, fertility and wetness (flooding) limitations whereas, 24.1, 22.9, 7.8, 22.7, 7.8 and 8.9% area of TGA were marginally suitable for paddy, jute, maize, wheat, mustard and potato, respectively due to coarse texture and wetness limitations (poor drainage and reduced matrix colour) (Fig. 19.8).

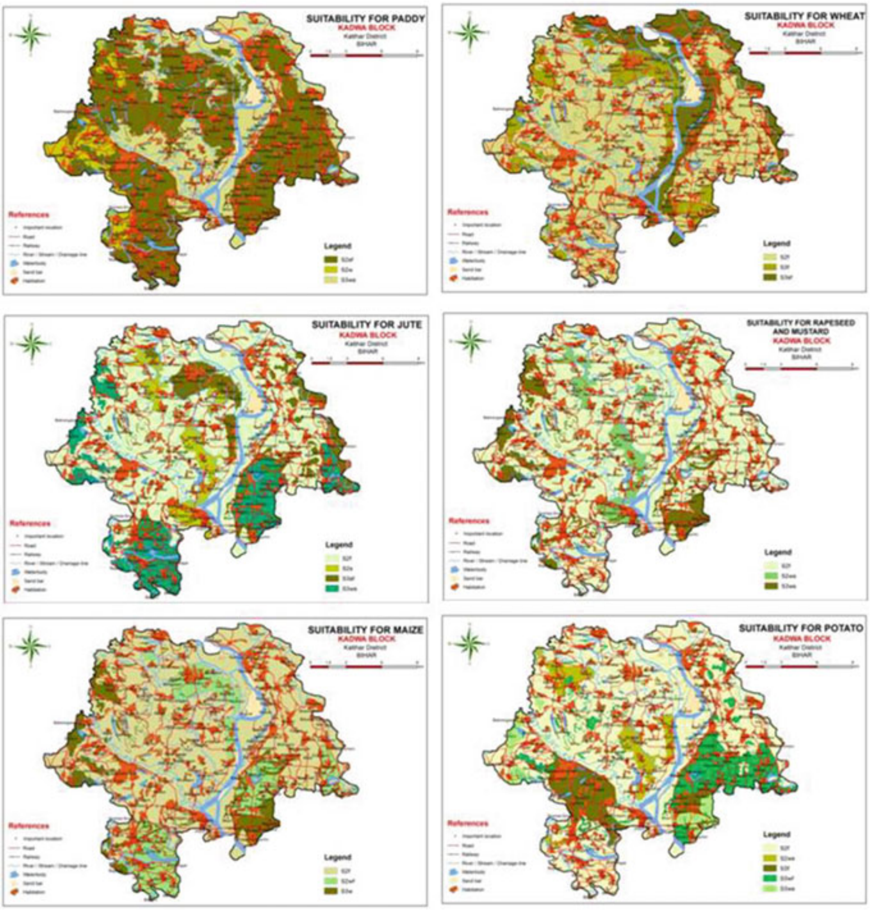

Fig. 19.8 Crop suitability (paddy, jute, maize, wheat, rapeseed and mustard, and potato) maps of Kadwa block

19.4.9 Identification of Alternate Land Use Options Based on Problems and Potentials of Soils

In the study area the low productivity of cultivated agricultural crops is due to the combined effect of the soil and water (Reza et al. 2017b). Erosion, soil acidity, light texture, low fertility status (Reza et al. 2016, 2017a) is the major dominant soil problems. Based on above mentioned characteristics four land management units (LMUs) were identified and mapped after merging 8 soil series (Fig. 19.9) in the study area. Hence, after carefully merging of soil series with similar range of soil characteristics like soil texture, soil pH, internal soil drainage conditions and status of fertility and erosion the LMUs were mapped (Ghosh et al. 2018; Reza et al. 2020b). In each LMU the present and alternate land use option was proposed in Table 19.5

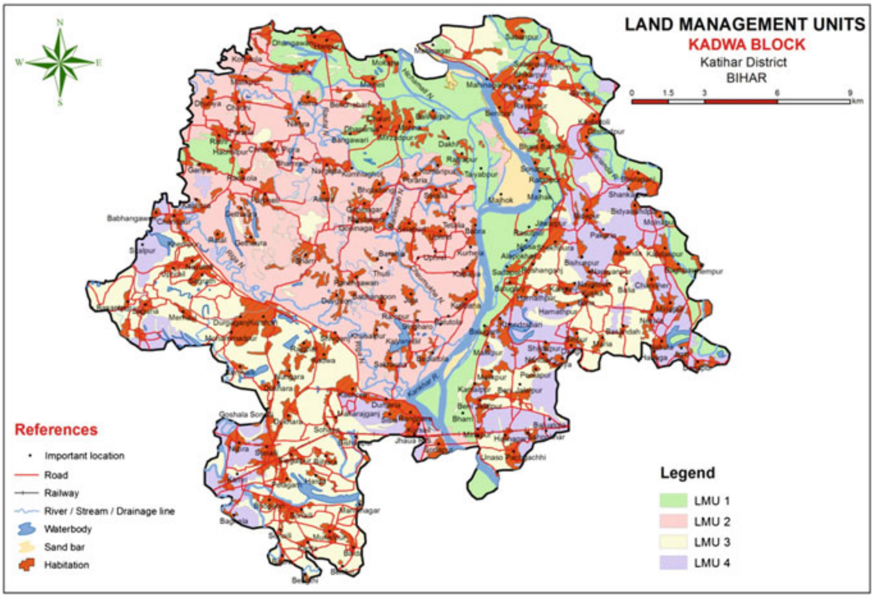

Fig. 19.9 Land management units (LMUs) map of Kadwa block

for the study area. The adaptation of LRI based land use plan will help the farmers to increase the productivity and profitability as compared to traditional based land use system.

19.5 Conclusions

In this study a detailed land resource inventory was carried out at 1:10,000 scales. Geomorphologically, the study area represents 1–3% slope means flat topography with regional slope decreased from north to south. The entire study area is underlain by thick unconsolidated sediment of Quaternary period and belongs to agroecological sub-region (AESR) 13.1, North Bihar and Avadh plains, hot dry to moist subhumid transitional ecological sub-region. Three types of land use/land cover were observed viz. (i) single crop paddy (*kharif*), (ii) double crop (paddy followed by *rabi* crops) and fallow. Visual interpretation of LISS-IV data indicated that the block was characterized into flood plain, meander plain young alluvial plain and old alluvial plain. In ArcGIS landform, slope and land use/land cover maps were integrated and LEU map was prepared with 15 LEU units. At 1:10,000 scale, eight soil series were identified and mapped into 14 soil mapping units (phases of series). Fertility status of the soils indicate that soils of the study area was wide range in soil reaction (very strongly acidic to strongly alkaline), low to high in organic carbon, low to medium in available nitrogen and available phosphorus. Soil survey interpretation showed that

Table 19.5 Present and suggested land-use of Kadwa block

LMUs	Present land use	Suggested land use options
1	Only potato/vegetable/maize cultivation in *rabi* season	• After short duration maize, summer vegetables like bottle guard, snake guard, cucumber and watermelon can be grown Management: It is recommended that some preventive measures are necessary in this unit to maintain the pH of the surface soils in near neutral range which will help to increase the efficiency of phosphatic fertilizers
2	Kharif paddy/fallow—mustard/maize—boro paddy/fallow	• If no flooding then kharif paddy—lathyrus/bengal gram as paira crop—maize—boro paddy • If heavy flooding occurs then early vegetable/mustard/potato—wheat/maize—boro paddy Management: early rice varieties like Prabhat, Dhanlaxmi, Richharia and Turanta; Wheat varieties like HD-2733, PBW-343 and PBW-502
3	Kharif paddy—maize/wheat/potato	• kharif paddy—lathyrus/bengal gram as paira crop—maize/wheat—boro paddy Management: early rice varieties like Prabhat, Dhanlaxmi, Richharia and Turanta; Wheat varieties like HD-2733, PBW-343 and PBW-502
4	Kharif paddy—maize/wheat/potato	• kharif paddy—lathyrus/bengal gram as paira crop—maize / wheat—boro paddy Management: It is recommended that some preventive measures are necessary in this unit to maintain the pH of the surface soils in near neutral range which will helped the phosphatic fertilizers to increase its efficiency; reduced the use of nitrogenous fertilizer; the drainage may be improved by installing surface and sub-surface drainage channels

the study area was divided into three land capability classes viz. II, III and IV and two irrigability classes which further sub-divided into three sub-classes based on the limitation of soils and site characteristics. The suitability for different crops grown in the study area showed marginally suitable due to coarse texture, fertility and wetness (flooding) limitations. Finally, based on major problems and potential the study area were divided into four soil management units and suggested the alternative land-use options LMU wise for the study area.

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