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RESEARCH ARTICLE

Impact Assessment of GIS Based Land Resource Inventory Towards Optimizing Agricultural Land Use Plan in Dandakaranya and Easternghats Physiographic Confluence of India

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Abstract
GIS based land resource inventory (LRI) with fine resolution imagery is considered as most authentic tool for soil resource mapping. Soil resource mapping using the concept of soil series in a smaller scale limits its wide application and also its impact assessment for crop suitability is controversial. In this study, we attempted to develop LRI at large scale (1:10,000 scale) at block level land use planning (LUP) in Dandakaranya and Easternghats physiographic confluence of India. The concept of land management unit was introduced in this endeavour. The impact assessment of LRI based LUP was exercised to develop efficient crop planning with best possible management practices. The study area comprised six landforms with slope gradient ranging from very gentle (1–3%) to steep slopes (15–25%). The very gently sloping young alluvial plains occupied maximum areas (19.95% of TGA). The single cropped (paddy) land appears to dominate the land use systems (40.0% of TGA). Thirty three landscape ecological units were resulted by GIS-overlay. Eighteen soils mapping units were generated. The area was broadly under two soil orders (Inceptisols and Alfisols); three great group (*Haplaquepts*, *Rhodustalfs* and *Endoaquepts*) and ten soil series. Crop suitability based impact assessment of LRI based LUP revealed that average yield of different crops increased by 39.2 and 14.5% in *Kharif* (rainy season) and *Rabi* (winter) seasons respectively and annual net returns by 83.4% for the cropping system, compared to traditional practices. Productivity and net returns can be increased several folds if customized recommended practices are adopted by the farmers. Informations generated from the study emphasized the potentiality of LRI towards optimizing LUP and exhibited an ample scope to use the methodology as a tool to assess in other physiographic regions in India and abroad.

Keywords Dandakaranya and Easternghats physiography · Land management unit · Land resource inventory · Land use plan · Impact assessment

Introduction

Reliable and timely information on the available natural resources is very much essential to formulate a comprehensive land use plan for sustainable development which empowers people to make decisions about how to allocate those resources (Saxena and Prasad 2008). To meet the challenges of increasing population and stagnating agricultural production, an inventory of the land resources base is a prerequisite not only to understand their potential and constrains, but also plan towards sustained agricultural production. The soil resource maps serve as a base for monitoring changes in soil quality with respect to erosion and deposition, inundation and natural calamity. Soil maps have become valuable tools for natural resource management. Adequate knowledge about the distribution and properties of soils is a key issue to support sustainable land management, which, among others, includes erosion control, fertility management, crop choice, and possibilities for irrigation (Van de Wauw et al. 2008; Seid et al. 2013).

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Detailed soil information (spatial) in 1:10,000 scale is required for many environmental modeling and land management applications (Nagarajua et al. 2015). Remote sensing has become an indispensable scientific tool for mapping and monitoring of natural resources (Kasturirangan et al. 1996) and frequently used in the characterization of the soil resources (Srivastava and Saxena 2004) for planning. GIS has emerged as a powerful tool for spatial analysis of natural resources and data base management, efficient and versatile l to automate the transformation of soil data in soil information. Failure to understand these complexities has resulted shortcoming in crop production and management techniques; hence low agricultural production trend (Ololade 2010). Earlier, the concept of establishment of soil series, a procedure for scientific classification of pedogenic soil formation under diverse soil forming factors have generated useful information on soil and input management but limits its extent of application on smaller scale soil survey database and similarity of properties (Sehgal 1995). Though, soil resource mapping at series level have improved its accuracy significantly in last two decades with the introduction of high resolution satellite imaginary but require integration of similar properties (Manchanda et al. 2002). The concept of land management unit is a recent endeavour of its own kind describing the unique characteristics of a land parcel under similar bio-physical (climate, physiography, soil, land use and eco-system) and socio-economic environments (Baruah et al. 2014; Bandyopadhyay et al. 2015). The concept may efficiently be used for optimizing land use plan at village/watershed/block/district level in a site specific mode. Successful agricultural technology implementation depends upon crop planning based on soil resource inventory *vis-a-vis* establishment of land management unit which can respond similar soil and input management practices (Saxena and Prasad 2008). Land use plan of Mysore district of Karnataka (Ramamurthy et al. 2015) and Jorhat district of Assam (Bandyopadhyay et al. 2017) were developed using LMU approach. Such models are highly accepted by the state agricultural and allied line departments for implementation of land use planning at regional and local levels. Land resource inventory (LRI) based land use planning (LUP) for field crops could augment crop productivity many folds, sustain soil health and provide higher use efficiency of applied inputs as evidence by several studies (Nagarajua et al. 2015; Walia et al. 2010). Other studies (Kudrat and Saha 1993) have emphasized the importance of controlling land degradation if land use planning is based upon LRI. LRI based land suitability of crops (FAO system) has been considered beneficial (Sys et al. 1991, 1993). It is important to ascertain the economic evaluation of LRI towards efficient crop planning for a given area and has not been worked out so far. However, impact assessment of the same has not either been studied elsewhere or sporadically exercised. The innovative idea of the present investigation is to evaluate the profitability in terms of net returns and benefit to cost ratios for the farmers thriving in the physiographic confluence of the Dandakaranya and Easternghats Regions towards developing improved and efficient crop planning. We hypothesized that LMU based land use planning will be more rational and viable management options. Contemporarily, we have delineated land resources (including landforms, land use/land covers, landscape ecological units, soils and land management units) of Titlagarh block, Bolangir district, Odisha on 1:10,000 scale using fine resolution temporal satellite data. The objectives of the present study were to develop LRI based land use plan using the central concept of land management units (LMUs) followed by its impact assessment on the economics of crop performances with respect to traditional/existing cropping systems.

Materials and Methods

Study Area

The study has been conducted in Titlagarh block of Bolangir District, Odisha state (geographic extent of 20°10′02″N to 21°0′38″N Latitude & 82°40′52″E to 83°40′33″E Longitude) covering an area of 47,200 ha, comprising 133 villages (Fig. 1). The study area is placed in the physiographic confluence of Dandakaranya and Easternghats under the agro-ecological sub region (AESR) of 12.1 (dry sub-humid) (Velayutham et al. 1999; Velayutham 2000). Parent materials were granite gneiss and alluvium in plains. The area receives an average annual rainfall 1289 mm with *Isohyperthermic* temperature regime with temperature ranging from minimum of 13–15 °C and maximum of 40–42 °C (CGWB 2013) and the difference between mean summer and mean winter soil temperature is less than 6 °C (Velayutham 2000). Source of irrigation were mostly rain-fed with canal, tank, shallow tube well, dug-well etc. as sources in some areas and major crops were cereals (paddy, maize, finger millets and jowar), oil seeds (groundnut, sesamum, mustard, sunflower), pulses (red gram, black gram and green gram), vegetables and fiber crops etc.

Methodology of Land Resource Inventory (LRI) Based Land Use Plan (LUP)

At the outset, the detailed land resource inventory (Soil Survey Staff 2003) on 1:10,000 scale of the block was conducted using Resourcesat-2 Indian Remote Sensing Satellite (IRS) Linear Imaging Self Scanning Sensor

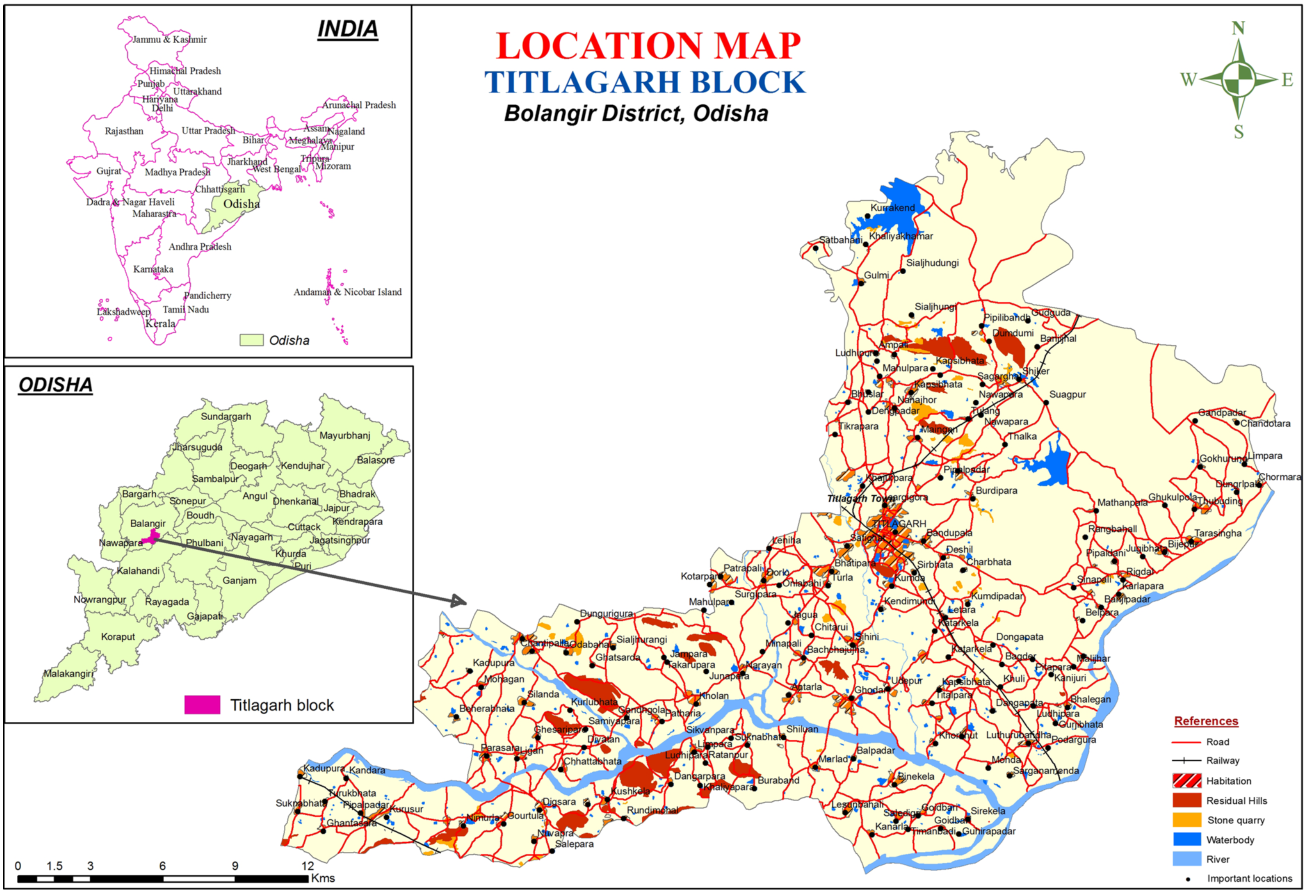

Fig. 1 Location map of the study area

(LISS)-IV (Rows-57, 58; Paths-107, 108; data captured on November–January, 2014) full multispectral scenes with swath of 70 km (FMX) as base maps (Fig. 2) (Srivastava and Saxena 2004). Land use/land covers were identified and delineated through visual interpretation technique followed by ground truth verification in the field. The fine spatial resolution (5.8 m at nadir) of multi-spectral images of LISS-IV with wide swath coverage (70 km) helped in identifying the land use/land covers at length (on 1:10,000 scale). The spectral signatures were sharply identified in 4-3-2 (RGB) band combinations using the variability in tone, texture, pattern, shape, size and association of land features. The Survey of India (SOI) Topographical sheets (at 1:50,000 scale) are used to demarcate permanent land features like roads, railway tracks, important locations, etc. in the base map, which helped in navigation during the progress of field level survey. Since, the topography of the terrain is undulating; Digital Terrain Model (DTM) has been developed from open source Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) (30 m resolution). Counter, drainage, hill shades and slope were derived from DTM. These are considered as the input layers for developing very precise and quantified information on landforms. IRS LISS-IV image in conjunction with SRTM-DEM and SOI appears to be very effective to comprehend drainage, contours, slope, etc. which helps in precise judgment of local topographic variability and hence, accurate delineation of landforms of the study area (Singh et al. 2016). Land resource inventory is dependent on soil-landform relationship. LRI is basically meant for developing sustainable agricultural land use plan, which is dynamic and dependent on present climatic conditions and the prevailing soil forming process. Therefore landscape ecological unit (LEU), which represents agro-ecosystem as a whole, is preferred over landform as the basis of mapping. LEU is the assemblage of landform, slope and land use. Landform is the testimony of climatic events, whereas slope and land use represent the influence of present climatic conditions on the soil formation. It has been regarded as the base for conducting land resource inventory (Singh et al. 2016). In this study, the landforms and land use/land covers were superimposed by using *Union-Overlay* operation to develop LEU. The GIS-overlay resulted landscape ecological units (LEUs). Transects were selected based on intensive traversing of the study area in such a way that in each transect strip maximum

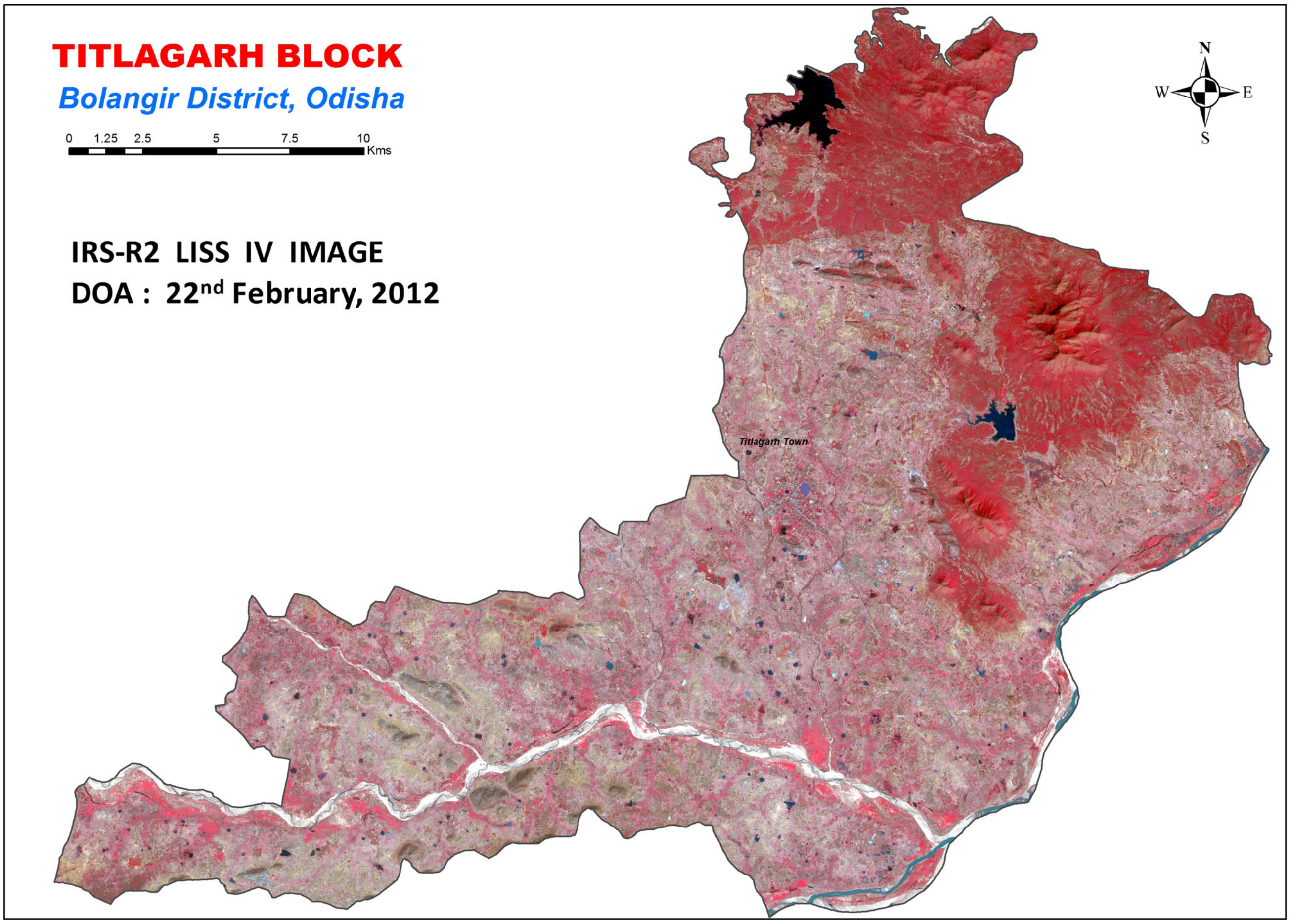

Fig. 2 Base map of the study area

number of LEUs can be placed. Subsequently, soil profiles were examined for morphological properties at selected transects. The variability in texture and slope was regarded as phases of soil series as soil mapping units. The soil map was established by field level soil correlation followed by laboratory estimations of physico-chemical characteristics of soils following USDA procedure (Soil Survey Staff 2003). The soil mapping units were delineated at phase level considering changes in surface texture, slope and erosion status (Velmurugan and Carlos 2009).

The central concept of land management unit (LMU) lies in GIS-overlay of climate, soil, land use/land covers and cropping/production systems of a given area so as to obtain a manageable number of mapping units for land use planning interventions (Ramamurthy et al. 2015). In doing so, generalization of mapping units are made by merging small and insignificant sliver polygons (having an area of less than one hectare) with the larger polygons of most similar characteristics in GIS platform. In Titlagarh block, it was hypothesized that internal soil drainage, soil depth, texture of soil control section (0–100 cm), soil reaction (acidity/alkalinity) and soil erosion status were the major limiting characteristics of soils that affect greatly the changes in land use systems. As a consequence, these characteristics were regarded as the critical indicators for obtaining LMUs. We have grouped the soil series comprising similar properties of critical indicators into one land management unit. Henceforth, from 18 soil mapping units (phases of soil series) effectively, 7 LMUs have map generalization technique under GIS environment. Each LMU was thoroughly evaluated for soil site suitability for crops following standard procedures (Sys et al. 1991, 1993). The LMU wise land suitability evaluation of crops further helped in alternate land use options through improved crop planning for the block. This may be regarded as the LRI based land use planning without management strategies. The next step is the introduction of customized management interventions using effective soil conservation measures (tillage, mulching, etc.), recommended dosages of soil nutrients by fertilizers/amendments, etc. The farmer's practice of that area is considered as traditional land use. The economics of crop performances were evaluated in all the three systems viz., (1) existing/traditional cropping system, (2) LRI based improved and alternate cropping system and (3) LRI based alternate cropping systems with customized recommended management as per the need of local environments.

Broadly, three-step approaches were followed to accomplish the objectives. In the first step, the detailed land resource inventory (Soil Survey Staff 2003) on 1:10,000 scale (i.e., at block level) in each AESR was done using latest fine resolution imageries as base maps (Srivastava and Saxena 2004) and subsequently established the soil map with series and or phases as mapping units. In the second step, the concept of land management unit (LMU) has been improvised to bring out the mapping units to a meaning and manageable quantities so as to undertake management interventions (Annual Report 2012–13, 2013–14) which consider the narrow ranges in soil characteristics clubbing by selecting only those inherent soil properties that are affecting land use systems for long terms (similar soils under broad ranges in characteristic under similar production/cropping system are considered as unique land management units (Baruah et al. 2014; Bandyopadhyay et al. 2015). Soil site suitability of the crops was evaluated for each LMU following FAO guidelines (Sys et al. 1991, 1993). Alternate and bio-physically viable and economically acceptable land use options are identified for each LMU (Ramamurthy et al. 2015).

The impact of land use plan can be assessed in different indices of natural resource management; but LRI based LMU which response to similar management was more scientific and rational (Ramamurthy et al. 2015; Bandyopadhyay et al. 2017). Economic analysis of LRI projects was carried out separately for all established LMU following benefit–cost–ratio and net return of the cropping system as indicator following the procedure for assessing the bio-physical as well as socio-economic impacts (Sharda et al. 2005, 2012). In the third step, we attempted using the crop productivity (single and sequence) and net return component (meaningful impact for farmer's point of view) as impact indicator. To exercise, crop productivity data were collected primarily from farm level house-holds (average crop yield of five farmers plot) through participatory rural appraisal (PRA) exercise before and after soil survey in different land management units in three distinct established land use system such as, (1) traditional cropping systems, (2) LRI based cropping system; and (3) LRI based cropping system with customized management practices considering respective land limitations and physiographic unit (bio-physical suitability of land and as well as the socio-economic viability of the region). To order to avoid the large error of estimation in PRA procedure, these dataset were also crossed verified through District Contingency Plan (2012) (http://www.crida.in/cp-2012/index.html). To work out the net return of the crops and cropping system, each component parameters were work out for cost and benefit for each land management categories based on dataset finalized through PRA and District Contingency Plan (Joshi et al. 2005, 2008). The minimum support prices of Government of India (GOI) in respective years were considered as sale price of the produce for estimation of benefit. The net return was find out as benefit minus cost of cultivation and cost–benefit (B–C) ratio by division of benefit with cost of cultivation for each crop and as well as for the cropping system. The schematic diagram of the impact assessment of LRI in different land use systems has been depicted in Fig. 3.

Results and Discussion

Land Resource Inventory

A wide range of landform and land use-land covers were identified. Six broad landform units were identified under different elevations varying from > 720 to 170 m viz, Hills, Pediment, Upland, Valley fill, Old Alluvial Plain and Young Alluvial Plain varying from very gentle to steep slopes. The very gentle sloping young alluvial plain covers maximum (20.0% of TGA) whereas gentle sloping pediment covers minimum (1.2% of TGA) area of the block. The land use of the block varies from forest, barren land, cultivated (single/double cropping), fallow land, wastelands and open scrublands. Maximum area is under single crop coverage (40.0% of TGA) and minimum by plantation crops coverage (0.2% of TGA). Miscellaneous area (including habitation, stone quarries, water bodies and rivers) occupied 12.7% of TGA of the block. It was noted that very gently sloping young alluvial plain under single crop had maximum area occupancy (15.7%v of TGA. It was observed that soils were shallow (< 50 cm) in 6.7% of TGA, moderately shallow (50–75 cm) in 11.5% of TGA, moderately deep (75–100 cm) in 18.2% of TGA and deep (100–125 cm) in 51.3% of TGA of the block. While the soil texture ranges widely from sandy loam to clayey. Soils with imperfect drainage conditions occur in about 24.1% of TGA, whereas, 35.5 and 28.1% of TGA comprise soils with well and moderately well drained situation. Strongly acidic soils (pH < 5.5) occur in 22% of TGA. Soils having low ($< 0.5\%$) organic carbon content covers 50% of TGA. Soils with low available water capacity (AWC) (< 50 mm m^{-1}) cover 6.7% of TGA while that with medium AWC (50–150 mm m^{-1}) occur in 76% area. About 36% of TGA comprises soils with moderate to severe erosion constraints. Severity of soil erosion may be attributed to moderate to steep slope of the lands, gravelliness and shallow depth of soils and light texture of soils (Sarkar et al. 1998).

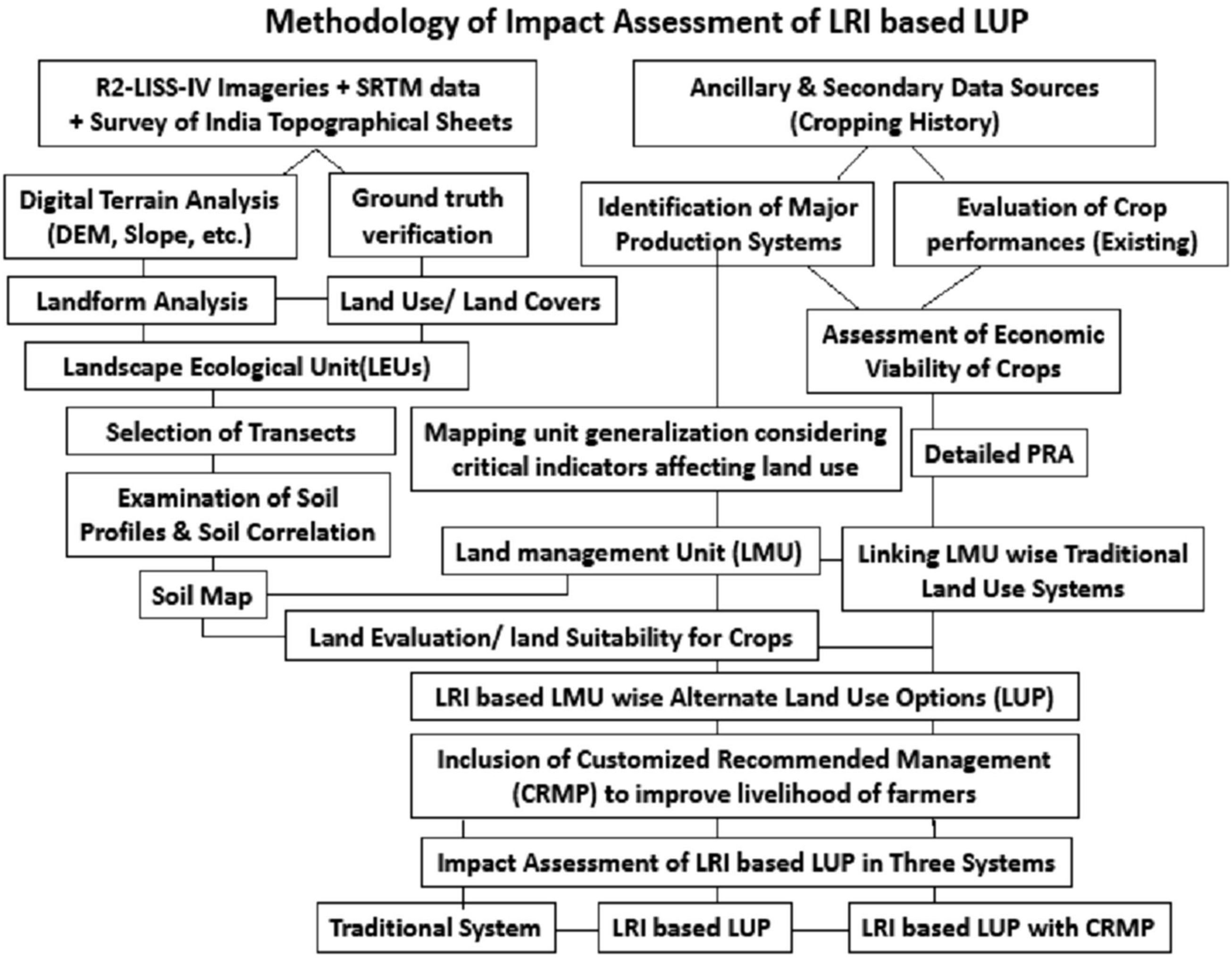

Fig. 3 Methodology for impact assessment of LRI based land use plan of the study area

Landscape Ecological Unit (LEU)

After the preparation of landform and land use/land cover map separately, superimposition of these two map were completed. Superimposition of landform and land use/land cover map produced a total of 13 landscape ecological unit (LEU) which is the building block of soil characterization (Fig. 4). The LEUs were considered as base map for soil survey because of inclusion of all the components of soil forming processes (Singh et al. 2016).

Soil Resources

Details Soil Resource Studies Revealed

10 soil series in the block with 18 mapping units as phases of series (Fig. 5; Table 1). Soils of Banjihal, Katarkera, Dorla and Sihini, Kholan were formed on gently to very sloping valleys and alluvial plains. The soils are moderately deep to very deep, excessive to well drained, neutral to slightly alkaline, fine loamy soils, moderate to severe erosion. The soils were classified as *Fine loamy Typic Haplustepts*. The soils of Digsara and Pipaldada series were very deep, moderately drained, moderately acidic, silt loam to silty clay loam in texture with slight erosion. The soils were classified as *Loamy Typic Haplustepts*. Dumduni, Khumbhipada, Mahulpada and Laitar series are developed on hills and pediments. The soils are moderately shallow, well drained, strongly acidic, gravelly coarse loamy textured with severe erosion and were classified as *Loamy-skeletal Typic Haplustepts.* Strong soil acidity of soils is due to acidic parent materials of Eastern Ghats. Soil acidity, shallow depth and gravelliness are the major limitations of the soils for crop growth. Chandutara-II series are derived on gently sloping pediments and are very deep, well drained, well drained slightly acidic, fine loamy textured with slight erosion and classified as *Fine loamy Typic Rhodustalfs.* Strong red colour

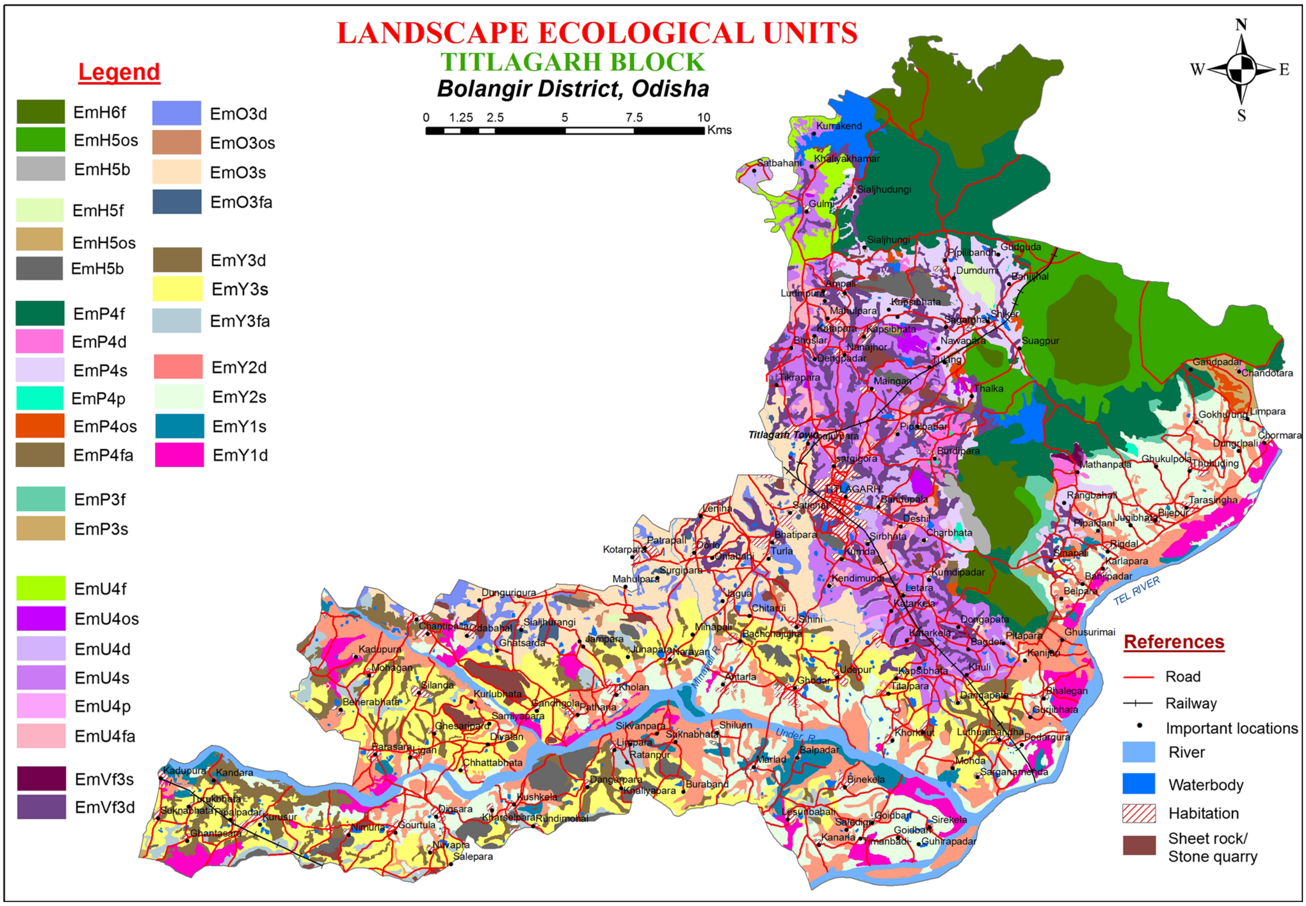

Fig. 4 Landscape ecological unit (LEU) map of the study area

was imparted in these soils indicates their formation from high degree of weathering of ferruginous parent materials dominant in hematite. The soils of Jampada and Ichgaon series are derived on older alluvial plains with *vertic* intergrades of Inceptisols due to dominance of smectitic minerals in clay fractions. They are very deep, moderately well drained, neutral to slightly alkaline in reaction, silty clay loam in texture with moderate erosion and classified as *Fine*, *Vertic Haplustepts*. The soils of Spikelet and Pasara series are derived on younger alluvial plains. They are very deep, imperfectly drained, slightly alkaline to neutral in reactions, fine textured and gleyed below 50 cm with reduced matrix showing the dominant characteristics of endo-saturation and classified as *Fine Aeric Endoaquepts.* Our findings showed similarity while studying Orissa soils in smaller scale (1:2.5 m) up to order and great group levels (Sarkar et al. 2005) but differences in series level might be attributed to higher scale (1:10,000) in our study and intense weathering with time elapsed under such tropical climate situation.

Land Management Units (LMU)

Land management unite studies which is basically the superimposition of LEU and soil resource map resulted 7 LMUs in the block. The LMUs were mapped considering soil mapping unit after careful merging of soil mapping units in similar broad ranges in characteristics based on the critical parameters namely soil depth, soil reaction, soil texture, internal soil drainage conditions and status of erosion (Table 2; Fig. 5). Soil of Banjihal, Katarkera, Dorla, Sihini and Kholan series were grouped as LMU 2; Digsara and Pipaldada as LMU 3; Dumduni, Khumbhipada, Mahulpa and Laitar as LMU 4; Jampada and Ichgaon as LMU 6 and Srikela and Pasara as LMU 7. Soil of Chandutara-I and II were considered as LMU 5. Soils of Kumlipada series was considered as LMU 1. Since, LMU-1 was under forest cover; its impact on agricultural land use planning has not been considered. Details map studies showed that LMU-3, 4 and 5 suffer with slight to moderate soil acidity, whereas, LMU-2, 6 and 7 suffer with slight to

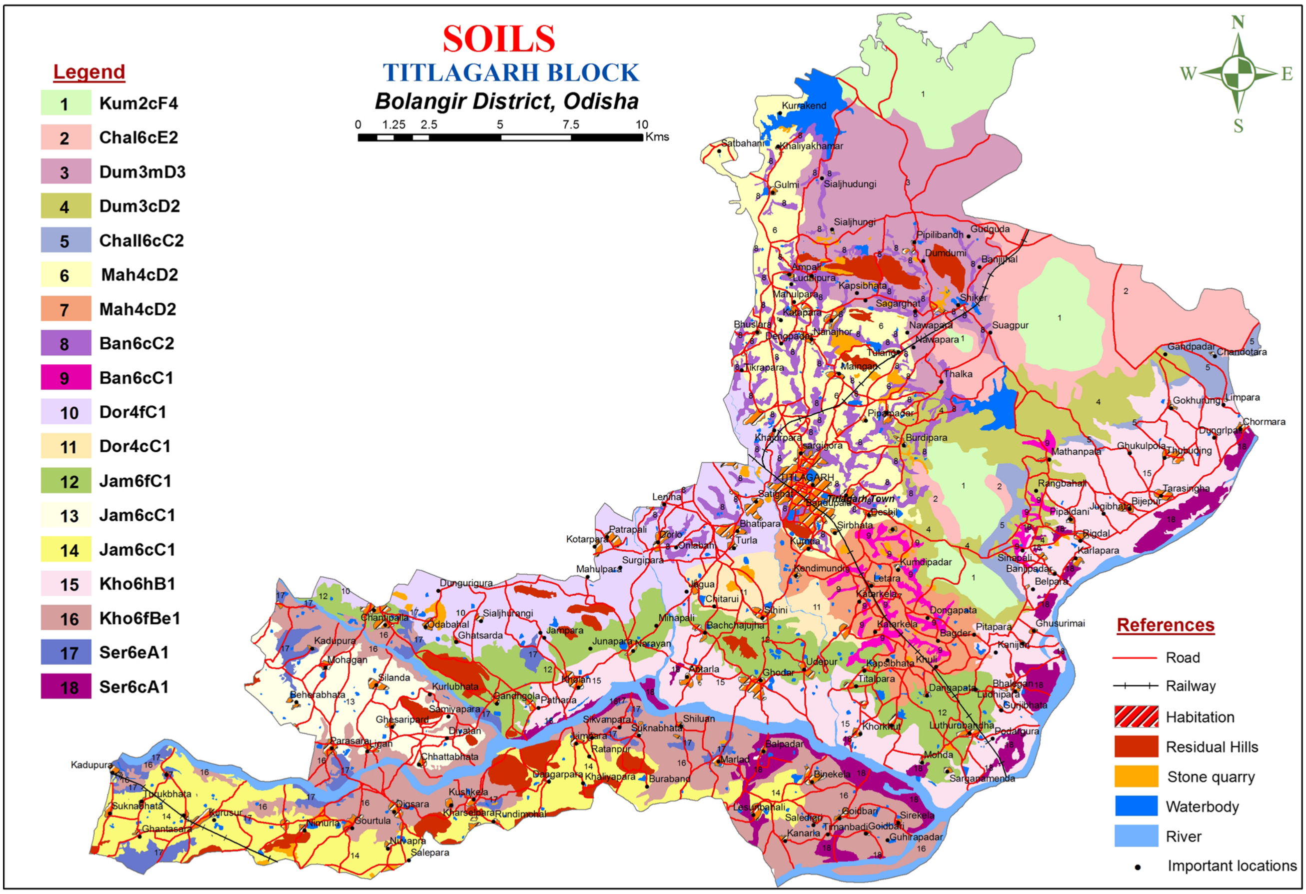

Fig. 5 Soil map of the study area

moderate alkalinity. LMU-4 comprises gravelliness and soil depth (moderately shallow) constraints, whereas, LMU-7 consists of imperfect drainage constraint. Strong soil acidity, shallow depth and gravelliness are the major limitations for crops in gently to very gently sloping pediments, whereas, slight to moderate alkalinity and internal drainage problems are the major constraints for crops on older and younger flood plains. Similar results were also reported by other researchers while conducting soil resource mapping of Orissa (Sarkar et al. 1998, 2005) (Fig. 6).

Land Management Unit (LMU) Based Land Suitability Evaluation

LMU-1 was under forest and has been excluded from any kind of agricultural management and its impact assessment studies. The land use of the unit has been suggested for forest plantation only. Soil site suitability for crops was evaluated for LMU-2 to LMU-7. It was revealed that LMU-2, 5 and 6 were moderately suitable for majority of the crops grown in the region namely, finger millet, groundnut, mustard, maize, sunflower, black gram and green gram with moderate limitations of soil depth (moderately deep) and alkalinity (slight). LMU-4 was found to be least suitable for most of the crops due to moderately shallow depth, skeletal and gravelly soils and strongly acidic reaction. However, with appropriate soil management and conservations, crops like maize, wheat, finger millet and sunflower can be grown. Imperfect drainage coupled with alkalinity problem restricts LMU-7 for growing of most of the crops except rice and wheat.

Impact Assessment (Productivity and Economics)

LMU wise land suitability of crops appears to be highly useful in developing appropriate crop calendar for the farmers of the block. Such crop calendar may be treated as highly rational, alternate and superior crop planning option as compared to the traditional/existing cropping systems adopted by the farmers of the block. Secondly, LRI based alternate land use/cropping system approach opens a new vista for enhanced income generation for the farmers by many-folds. In order to answer the question of whether LMUs based LUP is more remunerative compared to traditional system followed by farmers, an exercise on the

Table 1 Soil-LEU relationship of Titlagarh block, Bolangir district, Odisha

LEU	Description of soils series
EmH6f (steeply sloping denudational hills under forest)	Soils of Kumlipada series are shallow, excessively well drained, brown to strong brown gravelly (40–60%) sandy clay loam soils with sandy loam surface and very severe erosion (*Loamy-skeletal*, *mixed*, *isohyperthermic*, *Lithic Ustorthents*)
EmH5os (moderately steeply sloping denudational hills under open scrub)	Soils of Chandutara-I are very deep, well drained, dark reddish brown to red, loam to sandy clay loam soils with gravelly sandy loam surface and moderate erosion (*Fine loamy*, *mixed isohyperthermic*, *Typic Rhodustalfs*)
EmP4s (moderately sloping pediment under single crop)	Soils of Dumdumi series are moderately shallow, well drained, dark yellowish brown to yellowish brown gravelly (40–60%) sandy loam soils with loam surface and severe erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Rhodustalfs*)
EmP4f (moderately sloping pediment under forest vegetation)	Soils of Dumdumi series are moderately shallow, well drained, dark yellowish brown to yellowish brown gravelly (60–70%) sandy loam soils in the surface and sub surface and severe erosion (*Loamy-skeletal*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmP3s (gently sloping pediment under single crop)	Soils of Chandutara-II series are very deep, well drained, dark reddish brown to red loam to sandy clay loam soils with sandy loam surface and moderate erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Rhodustalfs*)
EmU4fs (moderately sloping upland under single crop)	Soils of Mahulpada series are moderately deep, well drained, yellowish red to red gravelly (50–60%) sandy loam soils with sandy loam to gravelly sandy loam surface and moderate erosion (*Loamy-skeletal*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmUv3d (gently sloping valley fill under double crop)	Soils of Banjihal series are very deep, moderately well drained, dark yellowish brown sandy clay loam soils with sandy loam surface and slight to moderate erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmO3s (gently sloping old alluvial plain under single crop)	Soils of Dorla series are moderately deep, moderately well drained, dark brown to dark yellowish brown sandy clay loam soils with sandy loam to clay loam surface and slight erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmY3s (gently sloping young alluvial plain under single crop)	Soils of Jampara series are very deep, moderately well drained, very dark grayish brown to dark brown clay loam to clayey cracking soil with sandy loam to gravelly sandy loam to clay loam surface and slight erosion (*Fine*, *mixed*, *isohyperthermic*, *Vertic Haplustepts*)
EmY2s (very gently sloping young alluvial plains under single crop)	Soils of Kholan series are very deep, imperfectly drained, yellowish brown to dark yellowish sandy clay loam to sandy clay soils with sandy clay loam surface and slight erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmY2d (very gently sloping young alluvial plains under double crop)	Soils of Kholan series are very deep, imperfectly drained, yellowish brown to dark yellowish sandy clay loam to sandy clay soils with clay loam surface and slight erosion (*Fine loamy*, *mixed*, *isohyperthermic*, *Typic Haplustepts*)
EmY1d (nearly level young alluvial plains under double crop)	Soils of Sirekala series are very deep, imperfectly drained, dark grayish brown to very dark grayish brown clay loam to clayey soils with silt loam surface and slight erosion (*Fine*, *mixed*, *isohyperthermic*, *Aeric Endoaquepts*)
EmY1s (nearly level young alluvial plains under single crop)	Soils of Sirekala series are very deep, imperfectly drained, dark grayish brown to very dark grayish brown soils clay loam to clayey soils on nearly level young alluvial plain with sandy loam surface and slight erosion (*Fine*, *mixed*, *isohyperthermic*, *Aeric Endoaquepts*)

economics of crop performances of LRI based alternate land use plan as impact assessment has been worked out. In the traditional land use system (farmers practice), average productivity of rainy season crops (*kharif*) ranges from 0.34 to 1.72 t ha^{-1} whereas in winter crops (*rabi*) 0.85–1.48 t ha^{-1} in different crops. Irrespective of rainy season crops, average productivity was 0.81 t ha^{-1} whereas winter crops 1.07 t ha^{-1}, respectively (Table 3). In the LRI based land use system, average productivity of rainy season crops (*kharif*) ranges from 0.28 to 2.45 t ha^{-1} whereas in winter crops (*rabi*) 0.96–1.74 t ha^{-1} in different crops. Irrespective of rainy season crops, average productivity was 1.12 t ha^{-1} whereas winter crops 1.08 t ha^{-1}, respectively. It was observed that LRI based LUP, all the crops yield were higher (Table 3) indicating the importance of soil resource mapping and LMUs categorization of areas nullifying the idea of soil series as basic unit (Singh et al. 2016). On advancement of these ideas, it is well established that crop productivity can be enhanced if customized recommendation of technologies were adopted in each LMUs. In the LRI based land use system with customized recommended management practices (CRMP), average productivity of rainy season crops (*kharif*) ranges from 0.34 to 3.04 t ha^{-1} whereas winter crops (*rabi*) 1.02 to 2.58 t ha^{-1} in different crops. Irrespective of rainy season crops, average productivity was 1.38 t ha^{-1}

Table 2 Parameters of LRI of Titlagarh block in 1:10,000 scale for land use planning

LMU	Series	Description	Crop suitability
1	Kaumlipada	Shallow to moderately deep, excessively well drained, moderately acidic, gravelly loamy soils, low to medium AWC with very severe erosion occurring in denudational hills	Not suitable for crops (under forest cover)
2	Banjihal, Katarkera, Dorla, Sihini, Kholan, (*Fine loamy Typic Haplustepts*)	Moderately to very deep, excessive to well drained, neutral to slightly alkaline, fine loamy soils, moderate to severe erosion	Fingermillet-S2tf, Groundnut-S2st, Mustard-S2f, Sesamum-S3ts, Maize-S2f, Wheat-S3tsf, Sunflower-S2tf, Blackgram-S2tsf, Greengram-S2tf
3	Digsara, Pipaldada (*Loamy-loamy Typic Haplustepts*)	Very deep, moderately drained, moderately acidic, gravelly Silty to silty clay loam, slight erosion	Rice-2s, Wheat-S2w
4	Dumduni, Khumbhipada, Mahulpada, Laitar (*Loamy-skeletal Typic Haplustepts*)	Moderately shallow, well drained, strongly acidic, gravelly coarse loamy soils, severe erosion	Maize-S2f, Wheat-S2s, Fingermillet-S2t, Sunflower-S2f, Blackgram-S3ts, Greengram-S3ts
5	Chandutara-I & II (*Fine loamy Typic Rhodustalfs*)	Very deep, well drained, well drained slightly acidic, fine loamy soils, slight erosion	Maize-S2f, Wheat-S2s, Fingermillet-S2t, Sunflower-S2f, Blackgram-S3ts, Greengram-S3ts
6	Jampada, Ichgaon (*Fine*, *vertic Haplustepts*)	Very deep, moderately well drained, neutral to slightly alkaline, silty clay loam, moderate erosion	Fingermillet-S2tf, Groundnut-S2st, Mustard-S2f, Sesamum-S3ts, Maize-S2f, Wheat-S3tsf, Sunflower-S2tf, Blackgram-S2tsf, Greengram-S2tf
7	Srikela, Pasara (*Fine*, *Aeric Endoaquepts*)	Very deep, imperfectly drained, slightly alkaline to neutral, fine soils, very slight erosion	Rice-S2s, Wheat-S2w

whereas winter crops 1.53 t ha^{-1}, respectively. These data indicate slightly higher yield than LRI base. Actually, in the earlier concept of LUP, only crop suitability and management practices were mostly reflected for higher yield increase ignoring LRI. Here our studies laid more emphasis on LRI based LUP impact. In general, yield data indicated that average productivity of rainy season crops were less in traditional and CRMP based LRI whereas in LRI based LUP is slightly higher compared to winter season crops. It has also been found that LRI and LRI plus CRMP based LUP increased rainy season crop yield by 39.2 and 70.1% whereas winter season crops increased by 14.5 and 61.3%, respectively. Productivity enhancement has been reflected into increase in net rerun and benefit–cost–ratio for all the crops and cropping system. The net returns of the crops were the difference of cost of cultivation and benefit, i.e., sale price of produce (grain + -straw/by-product). It is considered as most significant indicator of profitable agriculture for the land use system. The net return increase was observed to be Rs. 1595–13,322, 2779–32,205 and 5159–29,616 with average values of Rs. 7670, 14,067 and 21,813 in traditional, LRI and LRI plus CRMP land use system, respectively. The range of values involved because of different crops/cropping system present in the differen nt LMUs. The average net return increase was found to be 83.4 and 171.0% higher in LRI and LRI plus CRMP, respectively compared to traditional land use system. The average percentage increase in net return indicates a significant impact of LRI based LUP which further increases if CRMP were adopted. It is pertinent to mention that benefit–cost–ratio was also increased to the tune of 26.5 and 42.9% in LRI and LRI with CRMP, respectively compared to traditional land use system (Table 3). Yield enhancement and net return clearly indicated importance of LRI based LUP.

In general the productivity levels of different rainy as well as winter season are low in traditional land use system because of undulating land form, moderately soil erosion, light texture soil and low level of input management. Of the two different seasonal filed crops, winter season crops average productivity level was slight higher because of better input management, less soil erosion and nutrient loss. Farmers of the region use to adopt better management practices in winter crops owing to stability and assured productivity level. It has been found that irrespective of rainy season crops, in the LRI based LUP average productivity was 1.12 t ha^{-1} whereas in winter crops 1.08 t ha^{-1}. The higher productivity level in rainy season crops might be ascribed to crop suitability coupled with good seasonal rainfall distribution for the study period compared to winter season which mostly rain or supplemental irrigation base. The importance of soil conservation measures for the region has been reported by several workers (Madhu et al. 2016). Most studies (Adhikary et al. 2015; Jakhar et al. 2010) have reported increase in productivity in land capability based LUP compared to

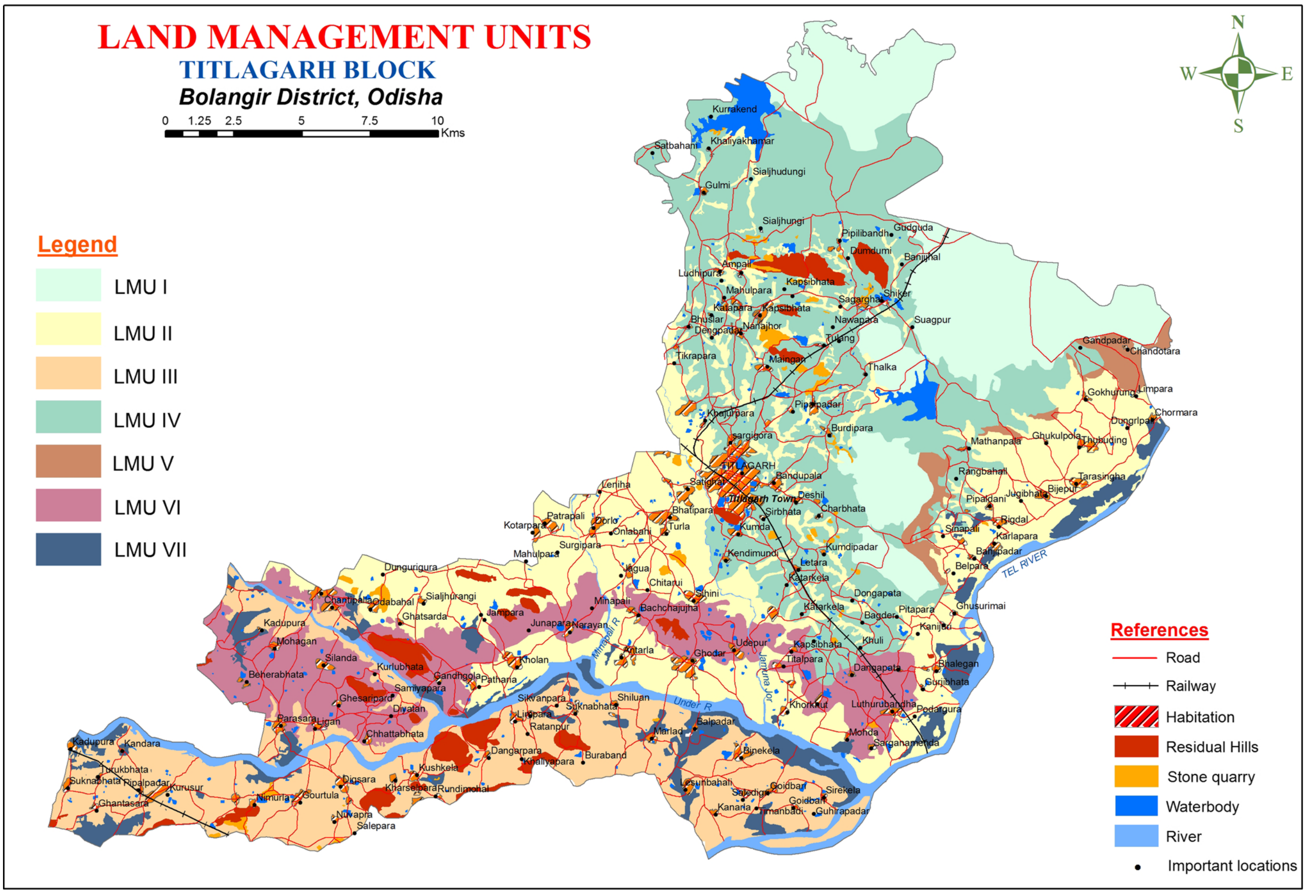

Fig. 6 Land management unit (LMU) map of the study area

traditional practice for both the cropping season as it has been observed in our study with LRI based LUP. Other researchers (Madhu et al. 2016) have reported increase in productivity without segregating the impact of LRI based LUP with customized recommended management practices (CRMP) or best management practices. Our results showed increase rainy season crop yield by 39.2 and 70.1% whereas winter season crops yield increased by 14.5 and 61.3%, respectively in the LRI and LRI plus CRMP based LUP (Table 3). This has been ascribed to the improved scientific management of soil resources coupled with nutrient and water synchrony during the crop growth period for the physiographic region of the country (Sarkar et al. 2005). Monetary benefit of scientific management of soil resources is totally depending upon productivity level of crops, cost of input and sale price of produce. Our estimation could find out average annual net return increase by Rs. 6406 and 14,143 in LRI and LRI plus CRMP land use system compared to traditional system which corresponding to 83.4 and 171.0% higher (Table 3). Compilation reports (Joshi et al. 2005) in different crops and land use system were also reported similar results. Moderately higher values by our study might be attributed to soil and water resource allocation to different crops in an improved land management unit.

Conclusion

For soil resource mapping, pedologists still use classical concept of soil–landscape models which call for development of knowledge-based classification system of land management unit (LMU). It is concluded from this study that Remote Sensing and Geographic Information System (GIS) technology which was earlier used mapping scale of 1:50,000 or smaller can be utilized for detailed soil mapping (1:10,000 scale). However, digital remote sensing and use of GIS are yet to gain momentum in addressing the various issues in soil survey like quantitative aspects of soil fertility; soil mineralogy and hydrological aspects. Moreover, uses of thermal remote sensing of soils are yet to be explored. The present study clearly reestablished that satellite imaginary data and GIS can be used as a valuable tool in physiographic analysis and soil resource mapping. Satellite imaginary data of LISS IV can be utilized satisfactory for land resource inventory in large scale (1:10,000) for block level planer.

Table 3 Land resource inventory based LUP and its impact on yield and profitability

LMU	Traditional land use						Management practice
	Land use (cropping system, CS)		Av. yield (t ha^{-1})		Net return of CS (Rs. ha^{-1} year^{-1})	B:C ratio	
	Kharif	Rabi	Kharif	Rabi			
LMU2, 3, 4, 5, 6 & LMU7	Rice (RF)	Wheat	1.42	0.984	3491	1.21	Local variety, conventional tillage, broadcasting, without SWC, rain-fed, limited irrigation, no liming, available organic sources of nutrient (2–6 t/FYM), without/very less chemical fertilizer (only N or NP), less plant protection measures
	Rice (IR)	Wheat	1.72	1.45	7785	1.37	
	Rice (RF)	Mustard	1.278	0.85	9903	1.49	
	Finger millet	Fallow	0.785	Nil	1595	1.24	
	Maize	Wheat	1.84	1.48	7040	1.31	
	Black gram	Mustard	0.255	0.867	10,555	1.79	
	Green gram	Mustard	0.34	0.884	13,322	1.89	
Average			0.81	0.96	7670	1.47	
LMU	LRI based LUP						Management strategies (soil and crop)
	Land use (cropping system, CS)		Yield (t ha^{-1})		Net return of CS (Rs. ha^{-1} year^{-1})	B:C ratio	
	Kharif	Rabi	Kharif	Rabi			
LMU7 and LMU3	Rice (RF)	Wheat	1.562	1.0824	6889	1.42	Local variety, conventional tillage, broadcasting, without soil conservation measures, rainfed, limited irrigation, no liming, available organic sources of nutrient (5–10 t/FYM), without/very less chemical fertilizer (only N or NP), less or no plant protection measures
	Rice (IR)	Wheat	1.892	1.74	12,927	1.63	
LMU6 and LMU2	Finger millet	Fallow	0.89	Nil	2779	1.42	
	Ground nut	Mustard	1.70	0.935	31,205	2.18	
	Sesamum	Mustard	0.49	0.982	21,046	2.50	
LMU2, LMU5 and LMU4	Maize	Wheat	2.45	1.10	12,556	1.59	
	Finger millet	Fallow	0.940	Nil	3245	1.49	
	Sunflower	Mustard	0.71	0.910	16,854	1.88	
	Black gram	Mustard	0.286	0.96	15,495	2.19	
	Green gram	Mustard	0.381	0.97	17,684	2.31	
Average			1.12	1.10	14,067	1.86	
Av. % increase over traditional			39.2	14.5	83.4	26.5	

Table 3 continued

LMU and description	LRI LUP with CRMP						Management strategies (soil, crop and best management input)
	Land use (cropping system, CS)		Yield (t ha^{-1})		Net return of CS (Rs. ha^{-1} $year^{-1}$)	B:C ratio	
	Kharif	Rabi	Kharif	Rabi			
LMU7 and LMU3	Rice (RF)	Wheat	1.87	1.55	13,137	1.73	HYV, ridge and furrow tillage, Conservation tillage, line sowing, with appropriate SWC (leveling, mulching, bounding, R&F, vegetative barriers, water harvesting structure etc.), appropriate liming (dose and source), INM (recom. NPK + 5–10 t FYM/2–4 t ha^{-1} VC), micronutrient, SPNM and with appropriate plant protection measures
	Rice (IR)	Wheat	2.37	2.26	22,865	2.16	
LMU6 and LMU2	Finger millet	Fallow	1.06	Nil	5159	1.87	
	Ground nut	Mustard	2.08	1.05	43,626	2.37	
	Sesamum	Mustard	0.572	1.18	26,158	2.37	
LMU2, LMU5 and LMU4	Maize	Wheat	3.04	2.58	24,387	1.73	
	Finger millet	Fallow	1.13	Nil	5225	1.79	
	Sunflower	Mustard	0.888	1.02	23,933	1.00	
	Black gram	Mustard	0.343	1.24	24,061	2.60	
	Green gram	Mustard	0.457	1.38	29,616	2.92	
Average			1.38	1.53	21,813	2.10	
% increase over traditional			70.1	61.3	171.1	42.9	

Methodologies outlined for identification of LMU which responds to similar kind of soil and input management practices will help for scientific land use planning for field crops. Impact assessment of LRI based LUP with respect to productivity and economics showed immense scope of LRI based land use plan for increasing productivity, profitability and controlling degradation. Crop productivity can be increased many folds if customized recommended management practices were followed in a LMU for food security.

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