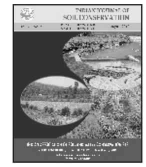
Vol. 47, No. 1, pp 63-73, 2019
Indian Journal of Soil Conservation
Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Developing land use plan through advanced land resource inventory (LRI) technique in Chhotanagpur plateau region of Jharkhand

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ARTICLE INFO

Article history:
Received : September, 2018
Revised : February, 2019
Accepted : March, 2019

Key words:
Conservation measures,
Impact assessment,
Land resource inventory (LRI),
Land use plan (LUP)
Soil quality index (SQI)

ABSTRACT

Land resource inventory (LRI) at 1:10,000 scale, using fine resolution remotely sensed data of IRS P6 LISS IV in Katkamdag block of Hazaribagh district, Jharkhand representing Chhotanagpur plateau region, India revealed 6 landforms, 11 soil series mapped in 13 soil mapping units (as phases of soil series) and 5 land management units (LMUs). Soil quality index (SQI) of LMUs revealed LMU 4 as the best land with percentage of goodness of SQI of 66.0, whereas, LMU 1 as poor land with the same as 27.9%. Priority ranking of land management indicators (LMIs) divulged coarse texture of soils, low soil organic carbon (less than 0.50%), low CEC [less than 5.0 cmol (p^+) kg^{-1}] and Zn deficiency (less than 0.6 mg kg^{-1}) as the major constraints for crop growth in LMU 1, 2 and 3. Impact assessment of LRI based land use plan (LUP) unveiled that LRI based alternate cropping systems with best management practices enhance the average annual net returns and average annual B:C ratio of the farmers by 207% and 94%, respectively over the existing cropping system.

1. INTRODUCTION

Land use planning (LUP) is the systematic assessment of land and water potential, alternatives for land use, economic and social conditions in order to select and adopt the best land-use options (FAO, 1991). An evaluation of the suitability of land for its alternate use requires a survey to define and map the land units together with collecting of descriptive data of land characteristics and resources. The concept of using the land for suitable utilization lies within the LUP process, which aims at optimizing the use of land while sustaining its potential by avoiding resource degradation. Participatory land use planning (PLUP) approach helps greatly in developing site-specific land resource management options to improve the land productivity and to minimize land degradation (Ramamurthy *et al.,* 2018). Knowledge intensive soil resource mapping using advanced geo-spatial techniques is indispensible for identification of constraints and potentials (Srivastava and Saxena, 2004), which is much required for adoption of proper soil management practices towards diversified LUP.

The present endeavour has been focused on developing LUP of Chhotanagpur plateau region of Jharkhand considering its richness in bio-diversity, geological complexity and physiographic versatility (Dunn, 1941). The region is by and large *rainfed* and agriculturally underdeveloped (NRAA, 2012) due to difficult undulating topography and lack of proper land management. Studies conducted earlier by several researchers (Sarkar, 2002; Sarkar *et al.,* 2001) on soil resources of Chhotanagpur plateau region were confined at small scales only and lacks systematic and site specific information. LRI at large scale (1:10,000) provides site specific information required for village level planning, which sets the path for suggesting right land use and right agro-techniques on each parcel of land (Singh *et al.,* 2016). In this backdrop, an attempt has been made to conduct LRI techniques in this region towards developing alternate agricultural LUP for the betterment of livelihood of the farming community. The objectives of the present investigations are i) to conduct advanced LRI techniques in this region towards developing alternate agricultural LUP for the betterment of livelihood of the farming community, ii) to suggest appropriate conservations measures and iii) to study the economic impact.

2. MATERIALS AND METHODS

Study Area

The study has been conducted in Katkamdag block of Hazaribagh district of Jharkhand, representing Hazaribagh plateau sub physiographic section of Chhotanagpur plateau region of India, situated in the geographical extent between 23°52'24''N to 24°01'14''N latitude 85°14'52''E to 85°23'51''E longitude and covering an area of 12834 ha (Fig. 1). The climate is dry-sub humid representing the agro-ecological sub region of 11.0, representing the Eastern plateau (Velayutham *et al.,* 1999) The average daily maximum temperature is 37°C during April-May and the average daily minimum temperature is 10°C during December-January (Statistical Handbook, 2015). The mean annual humidity is 60% and the mean annual rainfall in Hazaribagh is 1340 mm. The soils are under hyperthermic temperature and ustic moisture regimes. The major drainage streams are Konar and Bokaro. The vegetation type is dry-deciduous with predominance of *Sal (Shorea robusta),* Mahua (*Madhuca latifolia)* and Palas *(Bute frondosa)* and the major filed crops grown in the region are paddy, maize, pigeonpea and vegetables in *kharif* and wheat and chickpea in *rabi* season (Statistical Handbook, 2015).

Methodology of LRI

Detailed LRI on 1:10,000 scale has been conducted during 2016-17 in Katkamdag block using Survey of India (SoI) topographical sheets (73 E/5; 73 E/1; 72 H/4 and 72 H/8) in conjunction with Resourcesat-2 Indian Remote Sensing Satellite (IRS) Linear Imaging Self Scanning Sensor (LISS)-IV cloud free full multispectral scenes with swath of 70 km (FMX) (rows-55A and 55C; path-105; data captured dated 17^{th} February, 2016) as base maps (Fig. 3). Land use land covers were visually interpreted using IRS LISS-IV data. Landforms were identified by digital terrain analysis using open source digital elevation data like ASTER-DEM (30 m resolution) with spatial analyst tool in GIS platform (ARC GIS software ver. 10.3.2). Soil profiles were studied in selected transects for establishing soil-landform relationship followed by soil classification (Soil Survey Staff, 2003; 2014) of the region. Representative pedons from each landform were examined for physical and chemical properties of soils following standard protocols (Sparks, 1996). A methodology flow chart of LRI has been briefed in Fig. 2.

Methodology for Establishing LMU

The central concept of LMU (Bandyopadhyay *et al.,* 2015, 2017; Baruah *et al.,* 2014) of the study area by grouping of homogeneous land units using important soil properties affecting the land use and cropping systems of the study area (namely, texture, depth of soil, soil drainage, gravelliness,

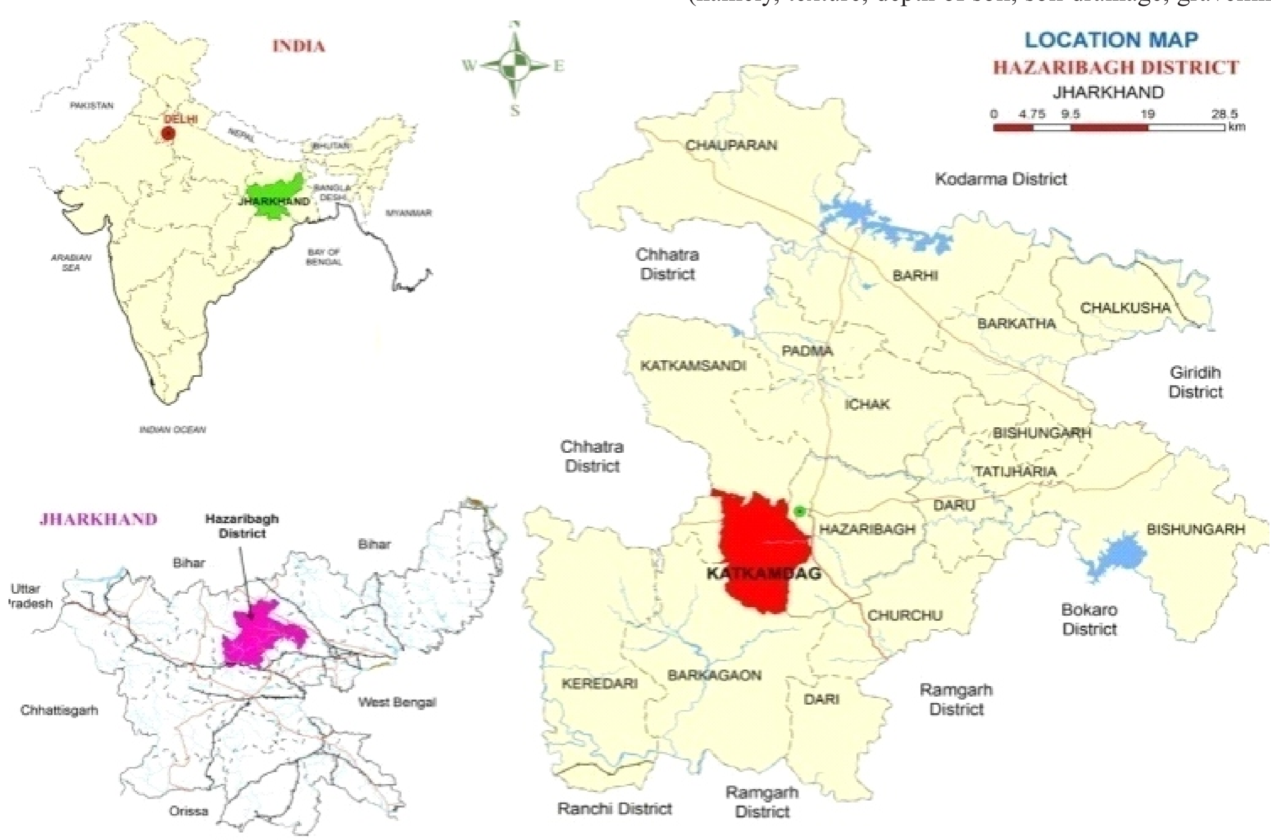

Fig. 1. Location map of the study area

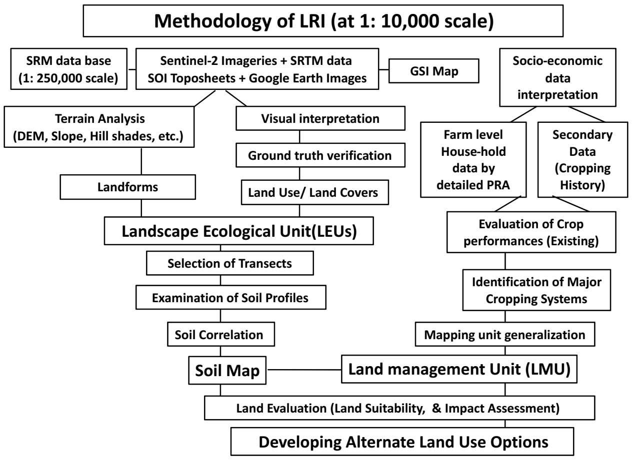

Fig. 2. Methodology flow chart of LRI of the study area

Fig. 3. Base map of the study area

pH, SOC, CEC and soil fertility status) were established as outlined by Bandyopadhyay *et al.* (2018) and Ghosh *et al.* (2018) for different physiographic regions of India.

SQI

SQI has been determined for each LMU by principal component analysis (PCA) of 15 important soil parameters including bulk density, pH (Jackson, 1973), SOC (%) (Walkley and Black, 1934), percentage of sand, silt, clay (Jackson, 1973) and their ratio *viz.,* sand/silt and silt/clay (Schaetzl and Anderson, 2015), CEC [cmol(p^+)kg^{-1}] (Piper, 1966), CEC/clay (Smith, 1986), base saturation (%), available N (kg ha^{-1}) (Subbiah and Asja, 1956), P_2O_5 (kg ha^{-1}) (Brays and Kurtz, 1945), K_2O (kg ha^{-1}) (Sparks, 1996) and available Zn (mg kg^{-1}) (Lindsay and Norvell, 1978) of surface (0-25 cm) as well as sub surface (25-50 cm) soils using SPSS software version 22.0 following the procedure of Doran and Perkin (1994) and modified by Andrews *et al.* (2002).Selected indicators in minimum data set (MDS) were scored into dimension less values ranging from 0 to 1 using linear scoring method (Liebig *et al.,* 2001). Indicators were ranked in ascending or descending order depending on whether a higher value was considered "good" or "bad" in terms of soil function (Andrews *et al.*, 2002). SQI for each LMU has been rated as good, average and poor based on the mean value of the same as standard for setting its upper (good) and lower limits (poor). SQI is also represented in percentage for its better understanding of its goodness considering the fact that LMU with high SQI describes the good soil health conditions with better nutrient bearing capacity towards higher crop production (Spandana *et al.,* 2013).

Methodology of Developing Land Use Plan (LUP), Impact Assessment and Conservation Measures

LUP consists of the two steps, first one is the establishment of LMU followed by soil site suitability of crops as outlined by Sys *et al*. (1993). SQI was interpreted to identify LMIs of each LMU towards assessing the land suitability for crops. The LMIs were prioritized based on ranking on a scale of 1 to 9. Crops were selected for each LMU, considering the weightage of LMI as well as the need of the local conditions. For impact assessment, economic performances of crops have been evaluated in before and after LRI in three distinct components *viz.,* (i) traditional or existing cropping systems, (ii) LRI based alternate cropping systems and (iii) LRI based alternate cropping system with best management practices by adopting the methodology outlined by Sharda *et al.* (2005, 2012); Ghosh *et al*. (2018) and Bandyopadhyay *et al*. (2018). Appropriate soil conservation measures were recommended for each LMU as outlined by Singh *et al.* (2004).

3. RESULTS AND DISCUSSION

LRI

Landform analysis of the study area resulted six distinct landform units in the order of their occurrence *viz.,* gently sloping undulating plains (42.8% of TGA), gently sloping undulating uplands (35.2% of TGA), moderately sloping undulating plateaus (6.1% of TGA), gently sloping undulating plateaus (3.8% of TGA), gullied lands (1.8% of TGA) and isolated hillocks (0.2% of TGA) (Fig. 4). Eleven soil series were identified in the region and mapped in 13 phases (Fig. 5). Dhengura series was found to be the most predominant one occupying 21.4% of TGA, whereas, Banadag series was found as the least occurring soils (0.08% of TGA).

Soils-landform Relationship

Soil-landform relationship of the Chhotanagpur plateau region has been depicted in Table 1. Soils on undulating plains were very deep (more than 150 cm soil depth), somewhat poor (occurrence of redoximorphic mottling at a depth below 50 cm from surface) to poorly drained (redoximorphic mottling occurring at a depth below 25 cm from surface), with Ap-Bw-Bt or Ap-Bt horizons sequence having silt loam to silty clay loam texture and

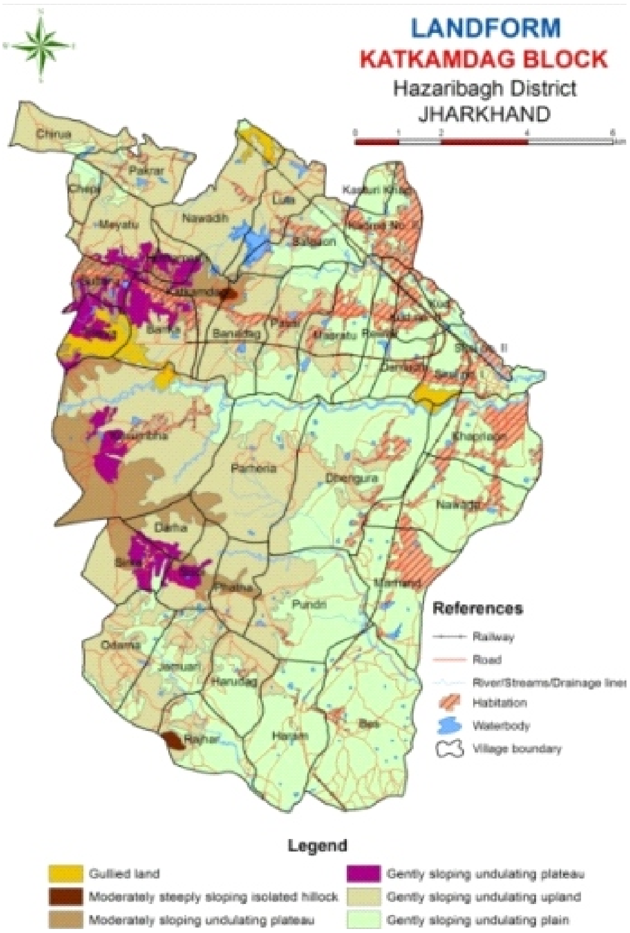

Fig. 4. Landform map of the study area

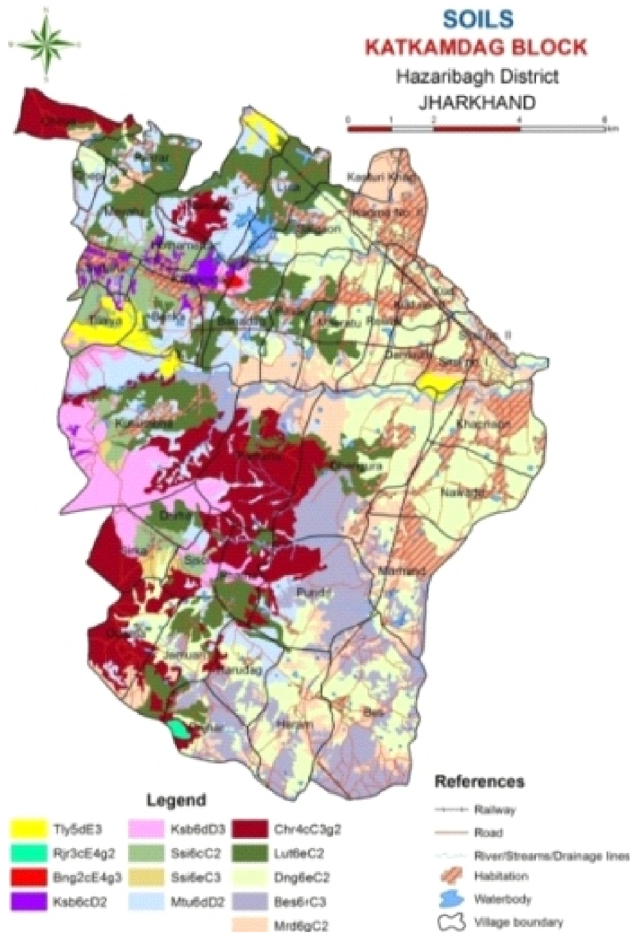

Fig. 5. Soil map of the study area

Table: 1
Soil- landform relationship of the study area

Landforms	Elevation (amsl, m)	Slope (%)	Soil depth	Gravelliness of soils	Soil drainage	Soil horizon	Soil texture	Soil colour (years)	Soil Classifications (Soil Survey Staff, 2014)
Isolated hillocks	670	10-15	Shallow to mod. deep	Moderate to severe	Excessive	A-AB-2Cr/ A-Bt-2Cr	Sandy loam-sandy clay loam	5-7.5	*Lithic Ustorthents* *Typic Haplustalfs*
Gullied lands	620-650	10-15	Deep	Slight	Excessive	A-Bw-Bt-BC	Loam-sandy clay loam	2.5	*Typic Rhodustalfs*
Undulating plateaus	640-650	5-10	Very deep	Slight	Well	A-Bw-Bt	Loam-sandy clay loam	5-7.5	*Typic Haplustalfs*
	630-640	3-5	Very deep	Nil	Well	Ap-Bw-Bt	Loam-clay loam	5-7.5	
Undulating uplands	620-640	3-5	Very deep	Nil	Moderately well	Ap-Bt/ Ap-Bw-Bt	Loam-clay loam	2.5-5	*Rhodic Paleustalfs* *Typic Haplustalfs*
Undulating plains	600-620	3-5	Very deep	Nil	Somewhat poor	Ap-Bw-Bt	Silt loam-silty clay loam	10-7.5	*Oxyaquic Haplustalfs* *Aquic Haplustalfs*

Soil depth: Shallow-25-50 cm; Mod. deep-75-100 cm; Deep-100-150 cm; V. deep-> 150 cm; Gravelliness: Slight-5-10% coarse fragments; moderate 15-35% coarse fragments; Severe-35-50% coarse fragments) were classified in the sub groups of *Oxyaquic Haplustalfs* and *Aquic Haplustalfs.* Soils on undulating uplands were very deep, well drained, with Ap-Bw-Bt horizon sequence having loam to clay loam texture and were classified in the sub groups of *Rhodic Paleustalfs* and *Typic Haplustalfs.* The soils on undulating plateaus were very deep, well drained (absence of any redoximorphic mottles upto 100 cm depth of soil) with A-Bw-Bt or Ap-Bw-Bt horizon sequence having sandy loam to sandy clay loam texture and were classified in the sub groups of *Typic Haplustalfs.* Soils on gullied lands were deep, excessively well drained, with A-Bw-Bt-BC horizon sequence having loam to sandy clay loam texture and were classified in the sub groups of *Typic Rhodustalfs.* Soils on isolated hillocks were moderately deep to shallow, excessively well drained, moderate to severely gravelly in nature with horizon sequence of A-AB-2Cr or A-Bt-BC-Cr having sandy loam to sandy clay loam texture and were classified in the sub groups of *Lithic Ustorthents* and *Typic Haplustalfs* (Table 1). It was note-worthy that, the study area represents a typical catenary sequence of soils of Chhotanagpur plateau with occurrence of well to excessively well drained, shallow (25-50 cm soil depth) to moderately deep (75-100 cm soil depth) and gravelly red-loamy soils at higher slopes (10-15% slope gradient) and elevations (>650 m amsl) to somewhat poorly drained, non gravelly, very deep alluvial soils at lower sites (3-5% slope gradient) (600-610 m amsl). The plains, plateaus and uplands consist of highly matured soil profiles compared to that on gullied lands and hillocks. Formation of deep soils in gullied lands is indicative that the original landscape was very old with matured soil formations. The gully formation might have been has taken place in the recent era (Roychoudhury, 1957). Similar research findings have been reported by Sarkar (2002) and Sarkar *et al.* (2001) in the region.

The results of descriptive statistics (Table 3) showed high standard deviations in sand, silt, clay, sand/silt, silt/clay, CEC, available N and Zn, indicating their variability in different landform situations. In particle size fractions, sand content was maximum (76.7%) in soils on isolated hillocks and minimum (11.6%) in that occurring on undulating plains. Soils on undulating plains comprised weakly acidic to neutral soil reaction (pH 6.7), whereas, the same on undulating uplands consists of strongly acidic soil reaction (pH 5.2). OC was minimum in soils on isolated hillocks under waste lands (0.11%) and maximum in soils on plateaus under forest (0.71%). The soils have variable CEC and base saturation with maximum in undulating plains (18.1 cmol kg^{-1} and 83%, respectively) and minimum in isolated hillocks (3.5 cmol kg^{-1} and 60%, respectively). Soils on gullied lands comprise minimum available N (169 kg ha^{-1}), whereas, soils on undulating uplands consist of maximum available N (299 kg ha^{-1}). Available Zn was maximum in undulating plains (2.12 mg kg^{-1}) and minimum in gullied lands (0.24 mg kg^{-1}).

LMUs

LMU is the product of superimposition of land ecological unit (LEU) (product of land form, slope and land use) with soil resource map (Ramamurthy *et al.,* 2015). In this landscape, 11 soil series were merged into 5 LMUs considering broad landform situations, gravelliness, soil depth, internal drainage and texture of soil control section as salient soil properties and occurrence of soils in major land use/cropping systems (Table 2 and Fig. 6). It was noted that LMU 5 characterized by very deep, somewhat poorly drained, silt loam to silty clay loam soils occurring on gently sloping undulating plains under rice-fallow system was the most predominant one occupying 32.1% of TGA, whereas, LMU 2 characterized by deep, well drained, loam to clay loam soils occurring on gullies under barren/waste lands was found to be the least occurring one (1.8% of TGA).

SQI of Different LMU

It was noted that 82.3% of variance has been explained

Table: 2
Land management units of the study area

LMU	Characteristics	Soil Series	Area (ha)	% TGA
1	Shallow to moderately deep, excessively well drained, sandy loam to sandy clay loam soils with moderate to severe gravelliness on isolated hillocks, gently sloping plateaus and undulating uplands under forest & sparse area under Pigeonpea-Fallow system	Banadag (*Lithic Ustorthents*) Rajhar (*Typic Haplustalfs*) Chirua (*Typic Haplustalfs*)	1571	12.2
2	Deep well drained loam to clay loam soils on moderately steeply sloping gullies under fallow and waste lands	Tilayia (*Typic Rhodustalfs*)	225	1.8
3	Very deep, well drained sandy loam to clay loam soils on moderately to gently sloping plateaus and undulating uplands under Vegetables-Chickpea system	Kusumba (*Typic Haplustalfs*) Meyatu (*Rhodic Paleustalfs*) Sisoi (*Typic Paleustalfs*)	2549	19.9
4	Very deep, moderately well drained, clay loam to silty clay loam soils on gently sloping undulating plains and uplands under Maize/ Rice-Fallow system	Luta (*Typic Haplustalfs*) Bes (*Typic Haplustalfs*)	3050	23.7
5	Very deep, imperfectly drained silt loam to silty clay loam soils on gently sloping undulating plains under Rice-Fallow system	Dhengura (*Oxyaquic Haplustalfs*) Marhand (*Aquic Haplustalfs*)	4123	32.1
	Miscellaneous		1316	10.3
	Total		12834	100.0

by four PCs out of which, PC1 (6.33), PC2 (2.94) and PC3 (2.68) exhibit 74.7% of the cumulative variance. Hence, assessment of SQI was considered based on PC1, PC2 and PC3 only (Table 4). Considering the expert's opinion for selecting important soil quality indicators suited for the local environment (Sarkar, 2002), high standard deviations values and higher weightage of factor loadings, the parameters namely, sand, silt, sand/silt and CEC were selected as MDS for PC1, whereas, silt/clay and CEC/clay ratio for PC 2 and SOC, available N and Zn were considered as MDS for PC3. For each LMU, the weightage of mean value of each MDS was considered for SQI calculation (Table 5). The SQI of LMUs ranged from 14.6 to 34.6 with a mean value of 26.2. LMU 4 and 5, exceeding far behind the mean values of SQI (32.9-34.6) were considered as good category of lands, whereas, LMU 2 and 3 were under average category (SQI of 23.9-25.1) and LMU1 under poor category with much lower value of SQI (14.6) compared to its mean. The percentage of SQI follows the sequence of LMU 4 (66.0%) > LMU 5 (62.8%) > LMU 3 (47.9%) > LMU 2 (45.6%) > LMU 1 (27.9%), considering the mean value of SQI (26.2) representing 50% goodness of the property (Spandana *et al.,* 2013) (Table 6). LMU 1 has poor SQI (27.9% goodness), because, it has majority of the LMIs at their higher priority ranking and needs a lot of attention for soil ameliorative measures, whereas, LMU 4 (66.0% goodness of SQI) comprises most of the LMIs at their lower priority ranking, indicating minimum risk in cropping practices and hence was fit into most good land for opting crop diversification.

Land Management Indicators-Land Suitability for Crops

Coarse soil texture (with high sand, sand/silt, silt by clay and low silt content), low SOC, low CEC and low available Zn content were the major soil based limitations of LMU 1. Moreover, moderate to severe gravelliness, shallow to moderately deep soils and steepness of the slopes are the further deteriorative indicators affecting majority of the crops. Soil site suitability for crops resulted only marginal suitability for groundnut, pigeonpea, chickpea, green gram and cucurbits, restricting all other crops not suitable. In LMU 2, sand, silt/clay, SOC, CEC and available Zn were found to have high priority ranks and needs due attention for soil amendments. Only groundnut, pigeonpea and cucurbits are marginally suitable. In LMU 3, the critical LMIs were

Table: 3
Descriptive statistics of soil characteristics of the study area

Soil Parameters	Mean	Median	Minimum	Maximum	Range	STD Dev.	STD. Error
Bulk density (Mg m^{-3})	1.41	1.42	1.32	1.49	0.17	0.05	0.01
Sand (%)	37.9	36.3	11.6	76.7	65.1	18.4	3.6
Silt (%)	39.4	44.6	10.5	54.9	44.4	13.5	2.6
Clay (%)	22.6	22.9	6.5	41.3	34.8	8.9	1.7
FS/TS	0.46	0.44	0.22	0.85	0.64	0.18	0.04
Sand/ Silt	1.48	0.78	0.25	5.79	5.54	1.68	0.33
Silt/ Clay	1.99	1.92	0.34	6.20	5.86	1.07	0.21
pH	5.9	5.9	5.2	6.7	1.5	0.4	0.1
SOC (%)	0.36	0.31	0.11	0.71	0.60	0.16	0.03
CEC [cmol(p^+)kg^{-1}]	8.67	7.55	3.50	18.10	14.60	3.68	0.72
CEC/Clay	0.40	0.39	0.22	0.75	0.53	0.11	0.02
Base saturation (%)	69	69	60	83	23	5.8	1.1
Available N (kg ha^{-1})	225	203	169	299	130	38	7
Available P_2O_5 (kg ha^{-1})	10.8	11.1	2.7	18.0	15.3	4.9	1.0
Available K_2O (kg ha^{-1})	186	219	55	268	213	69.6	13.6
Available Zn (mg kg^{-1})	0.80	0.63	0.24	2.12	1.88	0.49	0.10

Table: 4
Principal Component Analysis of soil parameters of the study area

Pcs	Total Variance Explained											
	Initial Eigen Values			Selection of minimum data sets for SQI (MDS) based on factor loadings								
	Total	% of Variance	Cumulative %	Sand	Silt	Sand/Silt	Silt/Clay	SOC	CEC	CEC/Clay	Av. N	Av. Zn
1	6.33	39.56	39.56	**-0.98**	**0.85**	**-0.82**	-0.06	0.35	**0.85**	0.06	-0.07	0.39
2	2.94	18.39	57.95	-0.01	0.41	-0.40	**0.95**	0.31	-0.20	**0.80**	-0.19	-0.17
3	2.68	16.77	74.72	0.10	-0.19	0.07	-0.11	**0.63**	0.30	0.37	**0.84**	**0.73**
4	1.22	7.63	82.34	0.02	-0.10	0.04	-0.04	-0.45	0.28	0.32	-0.25	0.01

Bold figures represent the selected MDS from each PC

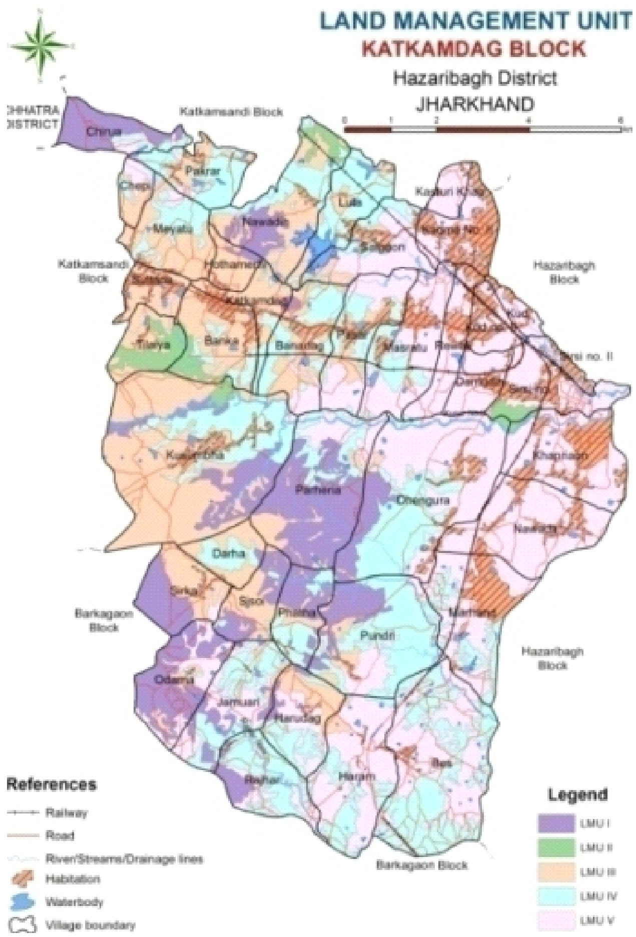

Fig. 6. Land management unit map of the study area

identified as sand, silt/clay, SOC, CEC and available Zn with relatively lesser priority ranking as compared to LMU 1 and 2, indicating its better sustainability to crops. Groundnut, pigeonpea, chickpea, green gram, cucurbits and maize are moderately suitable, whereas, wheat and *rabi*-vegetables were marginally suitable in this land. LMU 4 and 5 with lower level of priority ranking of LMIs appeared to be the promising lands for crop diversification (together with 55.9% of area occupancy) with moderate suitability for wide spectrum of crops *viz.,* paddy, wheat, maize, mustard, *rabi*-vegetables, cucurbits, greengram and blackgram (Table 5).

Impact Assessment of LRI Based Land Use Plan (LUP)

It is evident from the Table 4 that in the existing cropping system, the average annual net returns of all the LMU have been estimated as ₹ 30947/- ha^{-1} with an average annual B:C ratio of 1.39 only. The rice-fallow system in LMU 4 bears lowest net returns (₹ 2920/-) and B:C ratio (0.60), whereas, the rice-*rabi*-vegetables in LMU 5 provided highest net returns (₹ 85650/-) and B:C ratio (2.33). LRI based crop diversification resulted average annual net returns of ₹ 59575/- and B:C ratio of 2.08 with an increase from existing one by 93% and 50%, respectively.

Table: 5
Land suitability of LMU based on ratings of SQI and priority ranking of LMI

LMU	SQI	% of goodness of SQI	SQI rating	Priority Ranking of Land management Indicators (weightage of mean values on a scale of 0 to 1)									Moderately Suitable Crops (S2)	Marginally Suitable Crops (S3)	Major Limitations of LMI
				Sand	Silt	Sand/ Silt	Silt/ Clay	SOC	CEC	CEC/ Clay	Av. N	Av. Zn			
1	14.6	27.9	Poor	1 (0.01)	4 (0.37)	1 (0.01)	6 (0.52)	6 (0.59)	4 (0.41)	8 (0.76)	10 (0.99)	6 (0.59)	Chickpea, Pigeonpea	Groundnut, Cucurbits, Greengram	Coarse texture, gravelliness, low SOC, low CEC, deficient Zn
2	23.9	45.6	Average	5 (0.48)	10 (0.98)	9 (0.83)	1 (0.01)	5 (0.50)	5 (0.49)	8 (0.78)	8 (0.77)	3 (0.23)	Chickpea, Pigeonpea	Groundnut, Cucurbits, Greengram	Coarse texture, gravelliness, low SOC, low CEC, deficient Zn
3	25.1	47.9	Average	4 (0.40)	9 (0.85)	8 (0.77)	1 (0.07)	7 (0.69)	6 (0.59)	10 (0.93)	10 (0.93)	6 (0.54)	Groundnut, Chickpea, Pigeonpea, green gram	Maize, Wheat, Cucurbits, *rabi*-vegetables	Coarse texture, low CEC, deficient Zn
4	34.6	66.0	Good	7 (0.68)	10 (0.99)	9 (0.90)	4 (0.38)	10 (0.99)	10 (0.99)	10 (0.99)	10 (0.96)	10 (0.99)	Maize, Wheat, Rice, Mustard, Black gram, Cucurbits, *rabi*-vegetables	--	–
5	32.9	62.8	Good	7 (0.70)	10 (0.99)	9 (0.90)	4 (0.38)	10 (0.97)	9 (0.89)	8 (0.79)	10 (0.97)	9 (0.83)	Maize, Wheat, Rice, Mustard, Blackgram, Cucurbits, *rabi*-vegetables	--	–

However, best results are obtained when rice-*rabi*-vegetables has been replaced by black gram-*rabi*-vegetables in LMU 5with an annual average net return of ₹ 107610/- and a B:C ratio of 3.00. With best management practices, crop productivity has been increased for all the crops, which resulted a big jump in net returns and B:C ratio. LRI with BMP resulted an annual average net returns of ₹ 95092/- with a B:C ratio of 2.69. Highest net returns were obtained in LMU 5 by adopting black gram-*rabi*-vegetables with net returns of ₹ 193370/- and B:C ratio of 3.57. The net returns and B:C ratio in LRI based cropping systems with BMP were increased by 207% and 94%, respectively compared to existing and 60% and 29%, respectively compared to LRI based cropping systems only (Table 6). Hence, LRI based alternate cropping systems with best management practices appeared to be much superior over existing system of low input management.

Alternate Land Use Options with Conservation Measures

LMU wise alternate land use options have been suggested considering LRI based alternate cropping systems with recommended best management practices by harmonizing the packages of practices (Table 7). Working out of different soil and water conservation for each LMU have boosted the crop productivity as reported earlier by Singh *et al.* (2004) for the region. But they did not work out in LMU concept which is larger scale in our study and will be more beneficial for the planners and farmers (Table 5). LMU 1 has been rated as poor land with low SQI percentage (27.9% goodness). This land may be brought under social forestry with mixed deciduous species, bamboo-based forestry and silvitucure system with plantation of orchards like mango, guava, lemon, lichi, etc. In the adjoining patchy area under cultivation, existing pigeon-pea-fallow system can be replaced by cucurbits-greengram, pigeonpea-chickpea and groundnut-chickpea systems with conservation agriculture by 30% crop residue management, adoption of zero tillage, vegetative strips with grass and fodders (Napier/Niger) intercropping with pulses (pigeonpea in *kharif* and green gram and chickpea in *rabi*) adoption of integrated nutrient management (INM) with lifesaving irrigation (Drip/Sprinkler system) sourced from localized small earthen check dams, ponds and other existing natural water bodies.

LMU 2 has average SQI (45.6% goodness), though the landscape situation is not conducive for crop diversification as it represents gullied lands. Gully control is of utmost important by gully ploughing. Water harvesting units may be constructed besides the gullied lands with vegetative strips on the embankments. Cultivation in adjoining areas of gullied land may be performed by making compartmental bunding (30 cm height of bund with 2-5 m width). Groundnuts and cucurbits may be grown in *kharif* and Chickpea and green gram in *rabi* seasons in the gully adjoining areas using lifesaving irrigations from localized water harvesting units. LMU 2 needs special attention to additional zinc supplementation over its normal dosage because of its high priority rank as well as for available nitrogen. LMU 3 has average SQI (47.9% of goodness) having relatively better land quality compared to LMU 2. The crop combination can be made similar as opted in LMU 1 and 2. Besides these, maize-chickpea and pigeonpea-wheat may also be introduced in this land parcel using 30 cm contour bunds, vegetative strips with Niger/ Napier, 30% crop residue management and using drip or sprinkler-based irrigation systems. Liming is essential in LMU 1, 2 and 3 in order to reduce the negative impact of strongly acidic soil reaction to crops by application of commercial liming materials in furrows for *rabi* crops. Application of zinc will be beneficial for both LMU 1 and 3 at its normal dosage (state recommended) since, it is in medium priority rank. LMU 4 has been rated as most suited for crop diversification with highest observed SQI (66.0% of goodness) in the study area. The best cropping option is blackgram-*rabi*-vegetables at upper terraces (620-640 m amsl) followed by cucurbits-greengram and maize-wheat system. However, in lower terraces (600-620 m amsl), where, soil moisture persists at 65-70% of its field capacity level, rice-mustard, rice-*rabi*-vegetables can be introduced. Similar set of cropping systems can also be applied for LMU 5 (62.8% of goodness of SQI). The soil conservation measures of LMU 4 and 5 should include ridge and furrow cultivation, line sowing with minimum tillage operations (1-rotarvator + 1 cultivator), adoption of INM, intercropping with green gram and black gram, dug-out ponds for macro-irrigations and also adoption of lifting and micro-irrigations for *rabi* crops at lower elevations (< 610 m amsl) using deep tube wells/bore wells/open wells (Table 7).

4. CONCLUSIONS

It is concluded from the study that the standardized methodology of LRI of Chhotanagpur plateau region of Jharkhand at 1:10,000 scale soil mapping and establishment of LMU were a better options of best LUP. The details soil survey data base generated from this study will be helpful in multipurpose modeling more specifically estimating event wise soil loss using WEPP model. The concept of LMU being a large scale for alternate LUP will control land degradation more efficiently. Integrating soil quality rating in formulating crop suitability in each LMU have boosted productivity and thereby net return which will bring down the poverty of the farmers of the region. This study unfolds scaling up of the LRI technology for optimizing agricultural LUP in similar physiographic and climatic situations elsewhere.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Director, ICAR-NBSS&LUP, Nagpur for extending constant institutional support and encouragement to conduct the present piece of

Table: 6
Impact assessment of LRI based LUP of the study area

LMU	*kharif* crop (rainfed)	*rabi* crop (irrigated)	*kharif* yield	*rabi* yield	*kharif* NR	*rabi* NR	*kharif* BCR	*rabi* BCR	Total Ann. NR	Av. Ann. BCR
	Existing/Traditional Cropping System									
1	Pigeonpea	Fallow	0.54	--	13540	--	1.39	--	13540	0.69
2	Fallow	Fallow	--	--	--	--	--	--	--	–
3	Finger millet	Chickpea	0.85	0.63	4700	14000	1.35	1.83	18700	1.59
	Cucurbits	Chickpea	11.0	0.70	67820	14000	2.54	1.83	81820	2.33
	Pigeonpea	Chickpea	0.95	0.70	24180	14000	2.49	1.83	24180	2.16
	Maize	Chickpea	1.51	0.70	9460	14000	1.49	1.83	23460	1.66
4	Maize	Fallow	1.71	--	10720	--	1.67	--	10720	0.84
	Rice	Wheat	1.10	1.50	2920	9230	1.20	1.55	12150	1.38
	Rice	Vegetables	1.10	14.1	2920	82000	1.20	2.82	84920	2.01
	Rice	Fallow	1.10	--	2920	--	1.20	--	2920	0.60
5	Rice	Fallow	1.38	--	3650	--	1.40	--	3650	0.60
	Rice	Vegetables	1.38	14.1	3650	82000	1.40	2.82	85650	2.11
	Maize	Fallow	1.54	--	9650	--	--	--	9650	0.75
	Average								30947	1.39
	LRI based Alternate Cropping Systems with Existing Management									
1	Groundnut	Chickpea	1.03	0.57	24375	11340	2.21	1.49	35715	1.85
	Pigeonpea	Chickpea	0.74	0.57	18800	11340	1.93	1.49	30140	1.71
	Cucurbits	Green gram	9.87	0.69	57400	15040	2.03	1.47	72440	1.75
2	Agri-Horti-Silviculture system/Agro-forestry									
3	Groundnut	Chickpea	1.20	0.70	28270	14000	2.51	1.83	42270	2.17
	Maize	Chickpea	1.51	0.70	9460	14000	1.49	1.83	23460	1.66
	Pigeonpea	Wheat	0.95	1.50	24180	9230	2.49	1.55	33410	2.02
	Vegetables	Green gram	12.7	0.86	73860	17020	2.54	1.84	90880	2.19
	Cucurbits	Green gram	11.2	0.86	67820	17020	2.38	1.84	84840	2.11
4	Maize	Wheat	1.71	1.50	10720	9230	1.67	1.55	19950	1.61
	Black gram	Vegetables	0.75	14.1	14860	82000	2.04	2.82	96860	2.43
	Rice	Vegetables	1.10	14.1	2920	82000	1.20	2.82	84920	2.01
	Rice	Mustard	1.10	0.64	2920	14040	1.20	2.15	16960	1.68
	Cucurbits	Green gram	12.2	0.95	75350	19100	2.64	2.77	94450	2.71
5	Rice	Mustard	1.38	0.75	3650	16520	1.40	2.53	20170	1.97
	Rice	Vegetables	1.38	15.7	3650	91100	1.40	3.13	94750	2.27
	Black gram	Vegetables	0.83	15.7	16510	91100	2.26	3.13	107610	2.70
	Maize	Wheat	1.54	1.67	9650	10260	1.50	1.72	19910	1.61
	Cucurbits	Green gram	13.6	0.99	83720	19900	2.93	3.07	103620	3.00
	Average								59575	2.08
	LRI based Alternate Cropping Systems with Best Management Practice (BMP)									
1	Agri-Horti-Silvicultural system (Mango/Guava/Lichi/Lemon intercropped with Cucurbits/Groundnuts/Pigeonpea with appropriate soil conservation measures)/Agro-forestry									
	Groundnut	Chickpea	1.17	1.54	29670	41460	2.32	2.58	71130	2.45
	Pigeonpea	Chickpea	1.41	1.54	42230	41460	3.39	2.58	83690	2.99
	Cucurbits	Green gram	11.6	0.87	67530	19040	2.39	1.86	86570	2.13
2	Agri-Horti-Silvicultural system (Mango/Guava/Lichi/Lemon intercropped with Cucurbits/Groundnuts/Pigeonpea with appropriate soil conservation measures)/Agro-forestry									
3	Groundnut	Chickpea	1.53	2.01	38780	54200	3.03	3.38	92980	3.21
	Maize	Chickpea	2.35	2.01	14190	54200	1.74	3.38	68390	2.56
	Pigeonpea	Wheat	1.41	1.95	42230	12000	3.39	1.77	54230	2.58
	Vegetables	Green gram	14.9	1.07	86900	22150	2.99	2.26	109050	2.63
	Cucurbits	Green gram	13.9	1.07	79800	22150	2.80	2.26	101950	2.53
4	Maize	Wheat	2.77	2.94	16690	18100	2.05	2.08	34790	2.07
	Black gram	Vegetables	0.95	18.2	18820	105850	2.58	3.64	124670	3.11
	Rice	Vegetables	2.85	18.2	21380	105850	1.94	3.64	127230	2.79
	Rice	Mustard	2.85	0.95	21380	23250	1.84	2.48	44630	2.16
	Cucurbits	Green gram	15.4	1.15	88410	23810	3.10	2.43	112220	2.77

Table: 6
Continued...

LMU	Existing/Traditional Cropping System									
	kharif crop (rainfed)	*rabi* crop (irrigated)	*kharif* yield	*rabi* yield	*kharif* NR	*rabi* NR	*kharif* BCR	*rabi* BCR	Total Ann. NR	Av. Ann. BCR
5	Rice	Mustard	3.62	1.15	27160	28150	2.34	3.00	55310	2.67
	Rice	Vegetables	3.62	20.7	21160	171570	2.34	4.14	192730	3.24
	Black gram	Vegetables	1.10	20.7	21800	171570	2.99	4.14	193370	3.57
	Maize	Wheat	2.56	3.20	15430	19700	1.89	2.26	35130	2.08
	Cucurbits	Green gram	17.2	1.20	98750	24840	3.46	2.53	123590	3.00
	Average								95092	2.69

Impact Assessment (in terms of % of increase)			
Parameters	LRI over Existing	LRI with BMP over Existing	LRI with BMP over LRI
Average Annual Net Returns	93%	207%	60%
Average Annual B:C Ratio	50%	94%	29%

Table: 7
Suggested alternate land use options of the study area

LMU	Option 1	Option 2	Option 3	Option 4	Option 5	Strategic Management (BMP with Soil Conservations Measures)
1	Agro-forestry/ Social forestry	Agri-Horti-Silviculture	Cucurbits (*kharif*)-Green gram (*rabi*)	Pigeonpea (*kharif*)-Chickpea (*rabi*)	Groundnut (*kharif*)-Chickpea (*rabi*)	Conservation agriculture with 30% crop residue and zero tillage/Vegetative strips with grass and fodders (Napier/ mulching/Intercropping/ NM/Life saving irrigation (Drip/ Sprinkler)/ liming/ additional Zn supplementation.
2	Agri-Horti-Silvicultural system (Mango/Guava/Lichi/Lemon intercropped with Cucurbits/Groundnuts/Pigeonpea) in adjoining areas of gullied lands/Agro-forestry					Gully ploughing/ Vegetative strips with grass and fodders (Napier/Niger)/Intercropping/Compartmental bunding/ Vegetative mulching/ Conservation agriculture with zero tillage/ liming/ additional N and Zn supplementation.
3	Tomato/Chili (*kharif*)-Greengram (*rabi*)	Cucurbits (*kharif*)-Green gram (*rabi*)	Groundnut (*kharif*)-Chickpea (*rabi*)	Maize (*kharif*)-Chickpea (*rabi*)	Pigeonpea (*kharif*)-Wheat (*rabi*)	Conservation agriculture with 30% crop residue and zero tillage/Contour bunding (30 cm)/Vegetative strips with grass and fodders (Napier/Niger)/Life saving irrigation/ Small check dams/liming/additional Zn supplementation.
4	Blackgram (*kharif*)-Cabbage/Tomato (*rabi*)	Rice (*kharif*)-Cabbage/ Tomato (*rabi*)	Cucurbits (*kharif*)-Green gram (*rabi*)	Rice (*kharif*)-Mustard (*rabi*)	Maize (*kharif*)-Wheat (*rabi*)	Ridge and furrow/line sowing/Minimum tillage (1 rotarvator + 1 cultivator) Intercropping/ Small check dams/ Dugout ponds for life saving irrigation for vegetables/INM/ Micro-irrigation
5	Black gram (*kharif*)-Cabbage/ Tomato (*rabi*)	Rice (*kharif*)-Cabbage/ Tomato (*rabi*)	Cucurbits (*kharif*)-Green gram (*rabi*)	Rice (*kharif*)-Mustard (*rabi*)	Maize (*kharif*)-Wheat (*rabi*)	Ridge and furrow/line sowing/Minimum tillage (1 rotarvator + 1 cultivator) Intercropping/ Small check dams/ Dugout ponds for life saving irrigation for vegetables/ INM/ Micro-irrigation

research work under the project on LRI of Katkamdag block of Hazaribagh district, Jharkhand on 1:10,000 scale for optimal agricultural LUP using geo-spatial techniques.

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