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Geospatial application for agroforestry suitability mapping based on FAO guideline: case study of Lohardaga, Jharkhand State of India

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Abstract In view of climate change scenario, the increasing population, higher food demand and deteriorating land productivity are the key issues which need to be addressed in present time frame because it will be more critical in the future. The scientific evaluation of land for agroforestry is a step towards sustainability for achieving the socio-economic and environmental goal of the community. The objective of the present study was to investigate the suitability of land use/land cover of Lohardaga district of state of Jharkhand, India for agroforestry use based on FAO land suitability criteria utilizing Landsat-8 images (NDVI/wetness), ASTER DEM (elevation/slope/drainage and watershed), ancillary data source (rainfall/organic carbon/pH and nutrient status). The analysis of our study for agroforestry suitability reveals that 50.5% area as highly suitable (S1), 28.2% area as moderately suitable (S2), 20% area as marginally suitable (S3) and 1.3% area as not suitable (NS). Only 2.9% of the total land area is dominated by two season crop which is a matter of serious concern. The statistical analysis of the results reveals that the lands have huge potentiality for harnessing agroforestry crops if utilized scientifically. Such results will greatly help to the state level policymakers for achieving the national agroforestry policy goal for extending it to the new areas in the districts of Jharkhand.

Keywords Agroforestry · Nutrient status · FAO · LULC · Remote sensing · GIS · Land suitability

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1 Introduction

Agroforestry is defined as "a collective name for land-use systems and technologies, where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately applied to the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components" [1]. Agriculture is most vulnerable to climate change especially for smallholder farmers [2].

Agroforestry is an integrated land use system applicable in both farm and forest [3], and has tremendous capacity in food security [4], poverty mitigation [5], livelihood resilience [6] in rural area by providing several tangible and nontangible services [7], improve the soil fertility [8], enhance the farm household resilience [9], ameliorate the existing eco-system [10], safeguard the biodiversity [11], and reduce the climate change impact [2].

Scientific evaluation and decisions on land use/land cover practices and its future management have always been part of planning for the benefit of human society in both developing and developed countries with the assessment of land performance when used for specified purposes.[1]

[1] http://www.fao.org/docrep/x5310e/x5310e02.htm#1.1general.

Land evaluation is described as "the investigation of land performance that involve anatomization based surveys of the existing land forms, soils, vegetation, climate and other characteristics of land in order to identify and make a comparison of promising kinds of land use in terms of suitability to the objectives of the evaluation" [12]. A number of scientific progresses in geospatial technology, computer science including various user-friendly software have facilitated the implementation of its principles and attracted the scientists/researchers globally. One of the most significant developments has been the advent of computer based geographic information systems (GIS) [13].

GIS facilitates the user to capture, manipulate, gather/pool, manage, store (large data sets in form of raster and vector files) and analyze of a wide range of spatial data and simultaneously can perform GIS modeling [14, 15] which is highly useful for land evaluation for specific purpose based on the well-defined objectives. Such analysis, result and statistics are highly beneficial for land managers, planner and policy makers.

Geospatial technology and various image processing tools/methods are widely used in diversified discipline [16–18] including for determining the spatial relationship [19]. Free accessibility to the satellite based resources and ancillary datasets [20] these days are a bonanza for the researchers across the globe. The GIS analysis when combined with statistics/expert knowledge significantly support studies in various discipline including land suitability assessment [21]. Spatial layers of bio- physical environment can be used for land investigation which can logically delineate agroforestry suitable sites [22].

The research in agroforestry suitability mapping using remote sensing and GIS is significantly low. Ritung et al. [23] have analyzed the land for few agroforestry suitable crops using remote sensing and GIS. Resiner et al. [24] examined the land for agroforestry in Europe using geospatial technology and suggested the Silvoarable agroforestry which will be highly suitable for the area. Yedage et al. [25] have analyzed the land and delineated the area suitable for fruit tree. Recently, FAO guideline and GIS modeling concept have been successfully utilized for evaluation of land suitability for agroforestry [26, 27].

The objective of the present study is to use geospatial technology in existing Landuse/landcover (LULC) for visualizing the diversified spatial layers and to manifest the trends, interrelationships and finally to identify the land suitable for agroforestry. The agroforestry suitability map was further compared with LULC of the same area to understand its correlation.

2 The study area

The present research was executed in seven blocks of Lohardaga district of the state of Jharkhand, India. The blocks are Kisko, Kuru, Lohardaga, Bhandra, Senha, Kairo and Peshrar. It retains the latitudes 23°17′16.66″N–23°40′26.24″N and longitudes 84°23′15.77″E–84°56′29.35″E (Fig. 1) with geographical area 1502 sq. km dominated by tribes. The altitude varies in this district from 399 to 1122 m. The climate is quite healthy as compared to other districts of the state. The annual rainfall (mm) varies from 1000 to 1150. Around 80% of the rainfall received during the *monsoon* periods from June to September. The rainfall in this area is heaviest during the month of July and August.

Temperature drops to the lowest level (below 20 °C) during December, January and February whereas it is high (above 30 °C) during April and May.[2] The areas have occupied by tropical deciduous forest. *Shorea robusta tree species* is widely found in large numbers whereas other few predominant species are *Terminalia tomentosa*, *Gmelina arborea, Anogeissus latifolia*, *Boswellia serrate*, *Syzygium cumini* etc. *Madhuca latifolia* trees are also widely found in this district spread largely in the hill areas [28]. Bauxite is the main mineral (largest in Asia) found here confined to the hills. The area has witnessed deforestation and is gradually brought under cultivation. The study area dominated by tribal people whose population is 56.9% of the total population [29]. The cultivable land of the district is divided into the two classes, viz., Don and Tanr. The *Don* lands are the terrace low lands area have abundant water during monsoon season mainly used for rice crop and the *Tanr* are the uplands which produce a course form of rice, millets, pulses and oil seeds crops. Rice is the main crop whereas wheat on the other hand, covers a very small proportion of the total gross area sown. Soil wetness/moisture is abundant during monsoon season whereas it is major problem during off monsoon season due to poor irrigation facility and lack of soil and water conservation practices.

3 Materials and methods

The satellite data (Landsat-8) which retain the Operational Land Imager (OLI) sensor were downloaded from the USGS website. The two data sets (Path/Row: 141/44; Dates: 25/10/2016 & 28/12/2016; Projection: WGS84 UTM zone 45) which were having eleven different band were layer stacked. They were subset with the study area polygon. These images were used extensively for various

[2] https://www.yr.no/place/india/Bihar/Lohardaga/statistics.html.

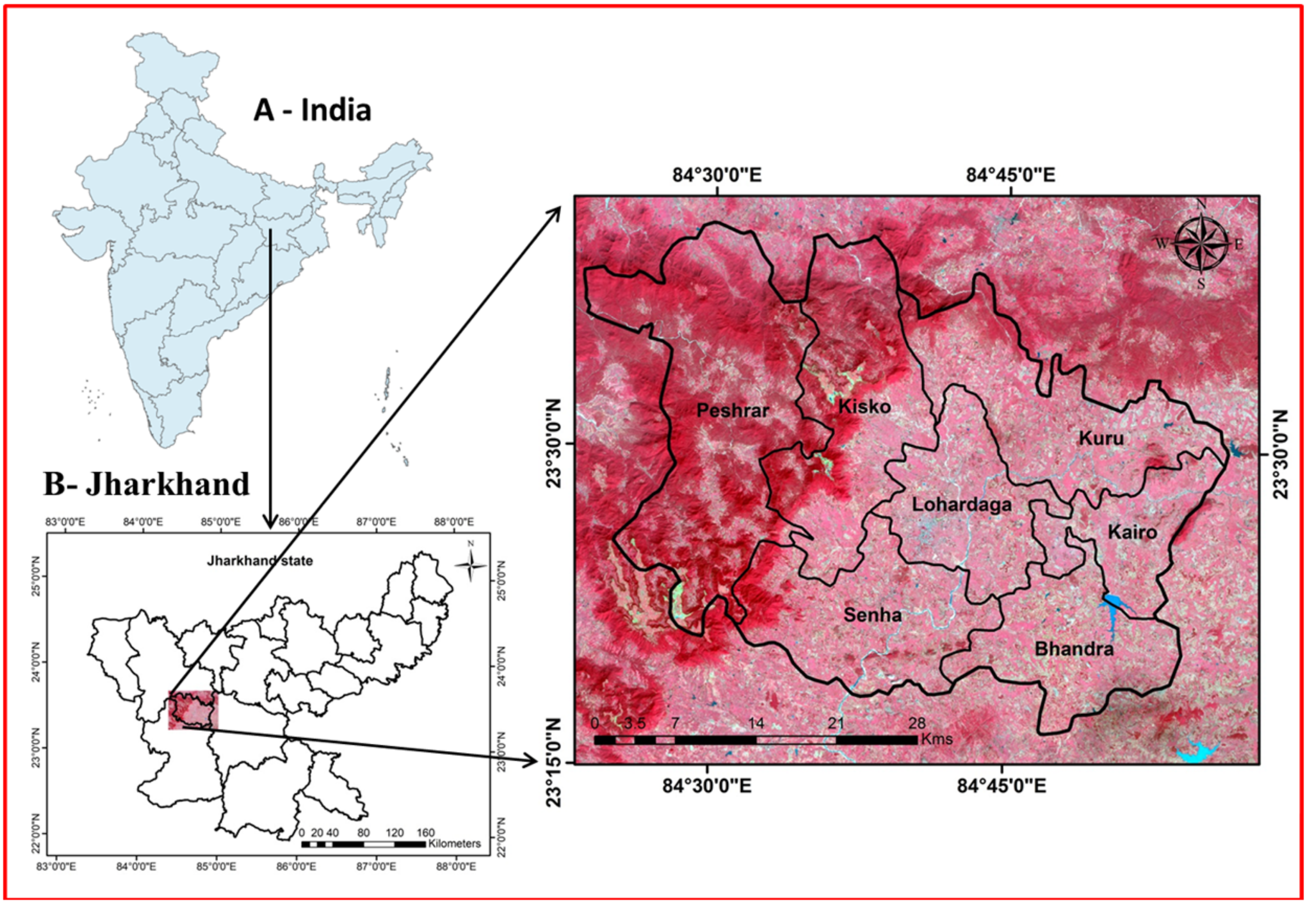

Fig. 1 The study area

analyses including classification. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model was obtained from USGS website for the production of various maps. The ancillary data such as rainfall and soil map are also utilized in the process of mapping procured from different source. We have used the Erdas Imagine (version 9.1) and ArcGIS (version 10.1) software and its various modules significantly to achieve the overall objectives. A clear overview of the GIS used mapping process is shown with flow diagram (Fig. 2).

In this classification we have utilized the procedure of Ahmad et al. [27] to delineate various LULC classes using the Erdas imagine software. The kharif and rabi crops land were delineated digitally using the October (kharif season) and December (rabi season) satellite data respectively [30]. Forest mask was generated to segregate the agriculture land from the forest from the false colour composite (FCC). The final LULC classes were forest, agriculture (only kharif crop, kharif and rabi crop, only rabi crop), settlement, mines, water and open land (Fig. 3). Quality assessment support the standard of the classified LULC image produced from satellite data [31]. The analysis of accuracy was executed by producing the uniformly distributed points over satellite image. The desired accuracy related statistics are produced for LULC map.

The Normalized Difference Vegetation Index (NDVI) is a widely used formula (Eq. 1) for knowing the vegetation health from remote sensing data [32, 33].

$$\mathrm{NDVI} = (\mathrm{Band5} - \mathrm{Band4})/(\mathrm{Band5} + \mathrm{Band4}) \quad (1)$$

A significant correlation was found between NDVI numerical values and vegetation density. The increase in the numerical value of NDVI reflects low erosion [34] (Supplementary Figure 1).

We have utilized the formula given by Baig et al. [35] for determining wetness from Landsat-8 data which is widely used for research studies [26, 27]. Wetness of soil is important to tree/crop growth. It promotes the nutrient uptake to the plants. The wetness map produced using the coefficients provided by Baig et al. [35] are given in supplementary figure 2.

Aster DEM was analyzed in ARC/GIS software with existing module such as Spatial Analyst toolbar for producing maps like elevation (Supplementary Figure 3), slope (Supplementary Figure 4) and drainage with watershed (Supplementary Figure 5).

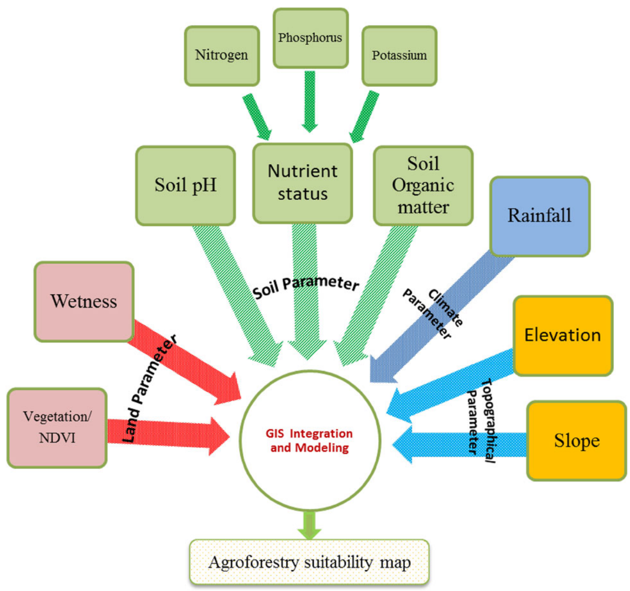

Fig. 2 Flow diagram for agroforestry suitability mapping

Decadal rainfall data from the year 1993 to 2002 was procured from the website.[3] The data was brought into point vector file with separate column with an annual average rainfall values. These values were used to build raster rainfall surface (Supplementary Figure 6) by kriging interpolation technique [36]. All soil maps such as Nitrogen, Phosphorus, Potassium, Organic Carbon and soil pH layers were downloaded.[4] Furthermore, they brought into GIS domain(Organic Carbon as Supplementary Figure 7 and soil pH as Supplementary Figure 8).

The produced N, P and K thematic layers were ranked separately based on Table 1. These maps were further utilized to develop nutrient map (Supplementary Figure 9) based on the methodology (modeling and GIS integration) of Ahmad et al. [27].

In present study we have followed the FAO guidelines [12] to evaluate the land potentiality to comprehend its productivity for agroforestry suitability. Agroforestry suitability layer was produced based on "raster weighted overlay" modeling function by integrating all necessary thematic layers based on weight factors (%) as per their importance (Table 2). In this analysis we have given equal importance to all four land qualifier parameter (Table 2) such as "Sufficiency of energy" (25%), "Sufficiency of water" (25%), "Sufficiency of nutrients" (25%) and "Erosion degree/Ease of water control" (25%). The final integrated surface was reclassified based on "Suitability classification as per FAO guidelines" Table 3 as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (NS). Similar analyses have been done by Ahmad et al., Ahmad and Goparaju [22, 26, 27, 37] for agroforestry suitability mapping.

[3] http://www.indiawaterportal.org/met_data/.

[4] http://sameti.org/Soil_Inventory/Lohardaga_Soil_Map.pdf.

4 Results and discussion

4.1 Agroforestry suitability mapping

The overall classification accuracy for the LULC classified image was 92% and kappa statistics was 0.89. Similar finding was observed by Ahmad et al. [27]. Our LULC classified image was further validated with LULC image of Lohardaga district generated by National Remote Sensing Centre, Hyderabad, India (provided by Bhuvan website) and found agreement at large extent.

The analysis of land suitable for Agroforestry showed that 50.5% of area as highly suitable (SI), 28.2% of area as moderately suitable (S2), 20% of area as marginally suitable (S3) and 1.3% of area as Not suitable (NS) (Table 4; Fig. 4). Similar finding have been observed by Ahmad et al. [27]. These analysis and result have very high significance because it has been evaluated utilizing the FAO manual and applied the geospatial technology adequately for achieving the objectives. Such study has also addressed the scientific/research lacuna and crucially communicated the strategy of National Agroforestry Policy 2014.

The highly suitable (SI) and moderately suitable (S2) areas are significantly fertile land. Agriculture crop specially paddy crops in low land areas can be harvested due to sufficient availability of water and moisture during the rainy season. The adequate soil and water conservation practice with suitable rainwater harvesting system will provide significant amount of water and moisture after monsoon season in soil to make the use of such land for next crop. The best suitable agroforestry practice will be agri-silvi-horticulture system (Agriculture + Forestry + Orchards), Agri-silvi-pastoral system (Agriculture + Forestry + Pasture + Livestock) and Horti-pastoral system (Orchards + Pasture + Livestock). The tree species Sisam (*Dalbergia sissoo*), Gum arabic (*Acacia nilotica*), Neem (*Azadirachta indica*), Asan (*Terminalia tomentosa*), Arjun (*Terminalia arjuna*) trees and Ber (*Zizyphus mauritiana*) tree, Palas (*Butea monosperma*), Siris (*Albizia lebbeck) and* Kusum (*Schleichera oleosa*) can be grown. Shelterbelt plantation along the agriculture land will protect the land from high wind and conserve the soil moisture during the hot weather. The horticultural crops such as Mango (*Mangifera indica*), Guava (*Psidium guajava*), Litchi (*Litchi chinensis*), Lemon, Banana, Papaya and Jackfruit etc. whereas vegetables such as potato, cauliflower, brinjal, tomato, cabbage, pea, okra, chilly and cucurbits etc. can be suitable cultivated [27].

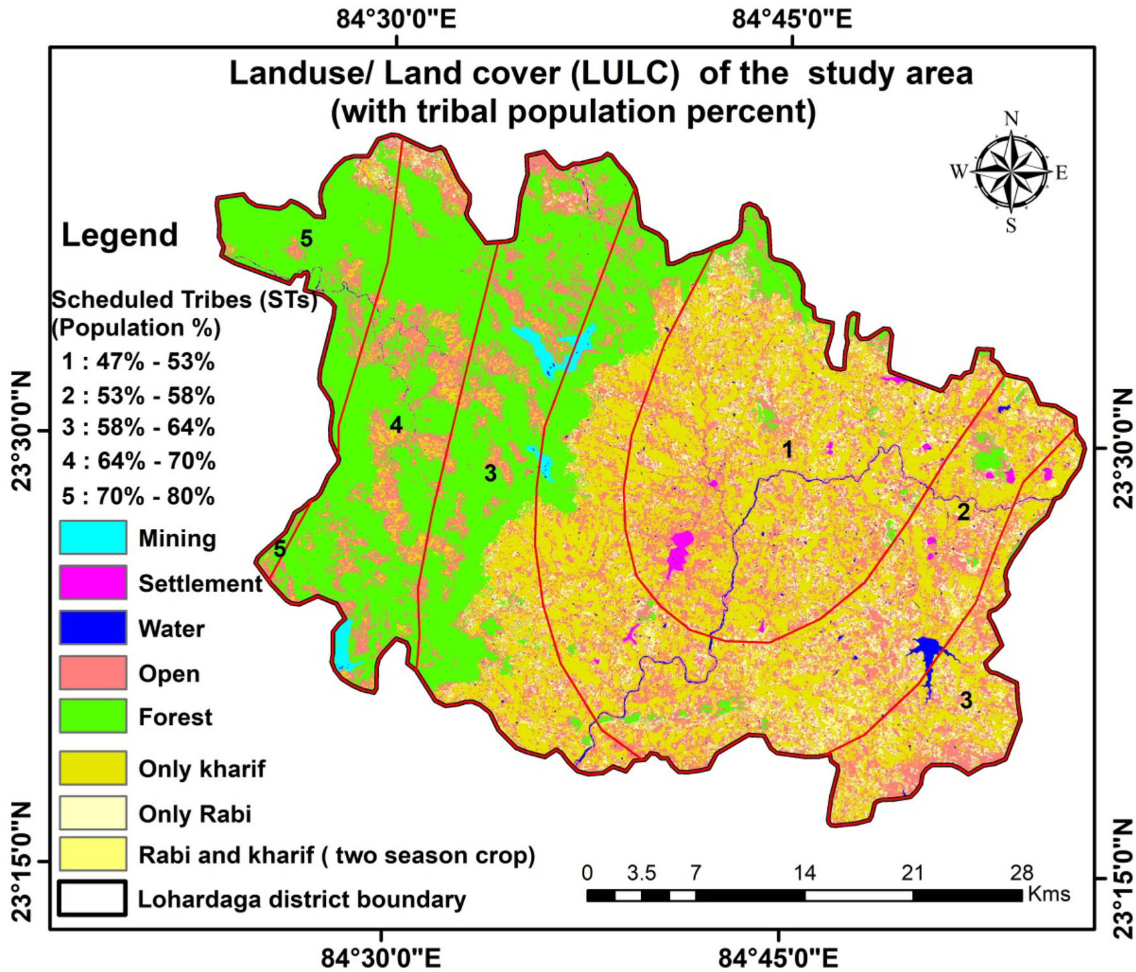

Fig. 3 LULC map

Table 1 Weight for N, P, K layers and its ranking for nutrient status mapping

Nutrient layers	Weights (%)	Value/description (kg/ha)	Ranks	Suitability
Nitrogen	33.3	> 560	3	High
		560–280	2	Medium
		≤ 280	1	Low
Phosphorus	33.3	> 25	3	High
		25–10	2	Medium
		≤ 10	1	Low
Potassium	33.3	> 280	3	High
		280–108	2	Medium
		≤ 108	1	Low

4.2 Agroforestry suitability versus LULC

In this analysis we have compared the agroforestry suitability map generated by FAO guideline with the LULC map of the same area to manifest their interlink relationship (Table 5). Such cross comparison provides better understanding and knowledge of existing LULC resources and its present status and future utilization. Similar comparison has also been done by Ahmad et al. [27]. The study area reflects high dominance of tribal

Table 2 Land prerequisite for agroforestry purposes

Land qualifies	Land characteristics	Weight factor (%)	S1	S2	S3	N
Sufficiency of energy	Elevation[a] (m)	25	< 700	700–900	> 900	
Sufficiency of water	Rainfall (mm)	12.5	> 1075	1050–1075	< 1050	–
	Wetness	12.5	High	Medium	Low	–
Sufficiency of nutrients	Nutrient status	8.33	High	Medium	Low	–
	Organic carbon (%)	8.33	> 0.75%	0.75–0.50%	< 0.50%	
	Soil pH	8.33	6.5–5.6	5.5–5.1	5–4.5	
Erosion degree/ease of water control	NDVI (vegetation vigorous)	12.5	High (> 0.3)	Medium (0.3–0.2)	low (< 0.2)	–
	Slope angle (%)	12.5	< 5	5–15	15–35	> 35
Ease of cultivation	Stones/rock/dams/ice and snow		–	–	–	Rock/dams/river/sands/mines/ settlement

[a]Elevation is used to assess sufficiency of energy where temperature data are not available

Table 3 Suitability classification as per FAO guidelines

Order	Class	Description
Suitability categories	Highly suitable (S1)	Land having no limitations towards application of a given use, or only minor limitations that will not significantly reduce productivity and benefits and will not raise inputs above an acceptable level
	Moderately suitable (S2)	Land having limitations which in aggregate are moderately severe for sustained application of a given use, the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use
	Marginally suitable (S3)	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity and benefits, or increase required inputs, that this expenditure will be only marginally justified
Not suitable-NS	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs	

population in western side of the district of forest and hills (Fig. 3). There is adequate opportunity of agroforestry in LULC class such as agriculture (only kharif crops area, only rabi crops area and both kharif & rabi crops area) and open area land. It is evident that roughly 31% of land is cultivated for only Kharif crops, 6.6% of land is cultivated for only rabi crops, 2.9% of land is cultivated for both Kharif and rabi crops and 28.6% of land is open land not being used for any types of cultivation. Furthermore, 68.8% of total land of the study area are either occupied by agriculture crop or kept open (without any crop) whereas out of these land 46.0 and 29.5% of the area falls in the category highly suitable (S1) and marginal suitable (S2) respectively for agroforestry. This statistical analysis reveals that there is huge potentiality for harnessing the agroforestry practices if utilized scientifically. The major problem in the study area is to retain soil moisture in off monsoon season which was evident from our LULC class statistics (only rabi 6.6%; kharif and rabi 2.9%). Roughly 2.9% of the land is two season crops is a serious concern for the district management authority and the state policy makers. The irrigation facility in these areas is very poor and restricted to roughly 10% of the cultivable land. The majority of land owners are poor farmers (largely tribal ethnic groups) who don't have adequate money to irrigate their fields to make it cultivable. The adequate manpower, technical support and funding are needed to enhance the soil moisture at watershed level by adopting in situ soil moisture conservation practices to conserve seasonal rain-water which is being lost through runoff. Integrated watershed management[5] practices is one of the viable solution as suggested by the President, Soil Conservation

[5] http://www.fao.org/tempref/docrep/fao/009/a0644e/a0644e10.pdf.

Table 4 Agro forestry suitability with area statistics

Agro forestry suitability	Area in hectares	Percentage
Highly suitable (S1)	76,755	50.5
Moderately suitable (S2)	42,823	28.2
Marginally suitable (S3)	30,405	20.0
Not suitable (NS)	2017	1.3

Society of India which have the capacity of doubling the agricultural outputs, enhance the soil water and moisture, fixing of ecological balance in the degraded ecosystems by greening the areas and diversification of crop farming pattern system [38]. The constructions of small check dams over non-perennial river and streams at watershed level during off monsoon season can not only supplies the water for irrigation to the crops along the streams after rainy season but also recharge and enhance the soil moisture in downstream. Such work has been well demonstrated by Shri Simon Oraon an environmentalist and Late Shri P.R. Mishra (soil conservationist) in the adjacent district of Ranchi and Palamu respectively which changed the land cropping pattern [37]. Simon Oraon utilized the tradition knowledge for soil and water conservation practices in 51 villages of Bero block in Ranchi district of Jharkhand, India [39]. The waste lands turned green and now those areas retain adequate soil moisture and can grow more than one crop per year became the agro horticultural hub. Their work has brought prosperity among villagers/farmers, reduced poverty by enhancing livelihood at local level. We need to replicate such agroforestry practices in conjunction with the intensive soil and water conservation measure in our study area will certainly change the land cropping pattern scenario. Finally we can conclude the delineation of watershed, drainage, the existing Land use/Land cover (LULC) and agroforestry suitability mapping are an important aspect which provides adequate knowledge/

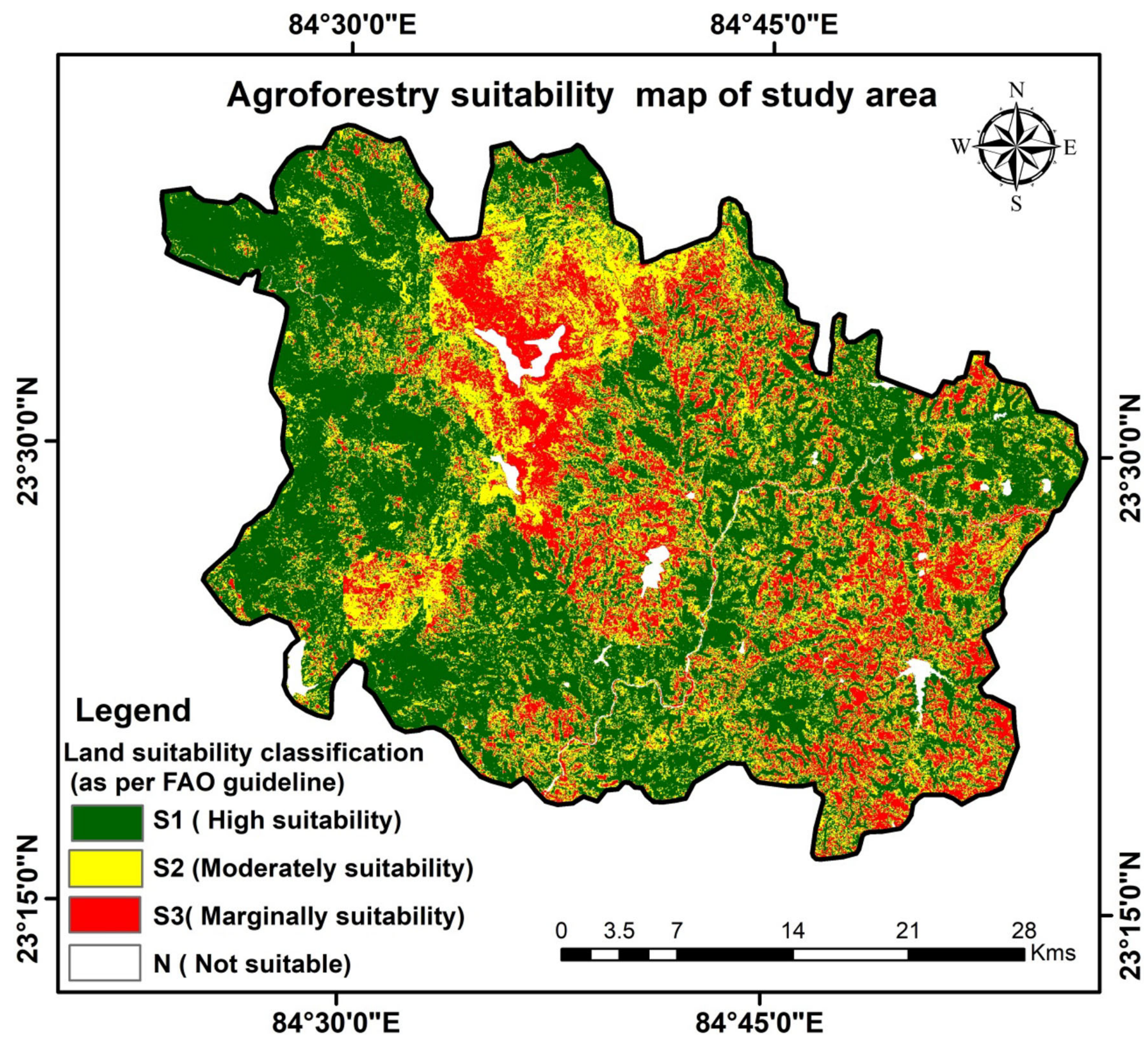

Fig. 4 Integrated agroforestry suitability map

Table 5 Agroforestry suitability area versus LULC Class

LULC classes	Agroforestry suitability types				
	S1	S2	S3	N	Total ha (%)
Forest	28,539	11,951	4839	4	45,333 (29.8%)
Only Kharif	32,417	10,167	4095	15	46,694 (30.7%)
Only rabi	2047	3661	4306	3	10,017 (6.6%)
Kharif and rabi	1861	1509	1021	1	4392 (2.9%)
Open	11,846	15,484	16,109	67	43,506 (28.6%)
Mining	1	3	8	781	793 (0.5%)
Settlement	2	3	1	391	397 (0.3%)
Water	42	45	26	755	868 (0.6%)
Grand total in ha (%)	76,755 (50.5%)	42,823 (28.2%)	30,405 (20.0%)	2017 (1.3%)	152,000 (100.0%)

understanding of the area and will significantly support to utilize seasonal rain water by adopting appropriate water conservation management practice and by utilizing the land scientifically with its optimum potential for achieving sustainability [27].

5 Conclusion

In this study we have achieved our objective and successfully delineated the land for agroforestry suitability (S1, S2, S3 and NS) based on FAO documented procedure. Furthermore, our comparisons with existing LULC cover map manifested some hidden relationship. From the present study it was found that around two-third of the entire land either occupied by agriculture crop or kept open (without any crop) whereas out of these land 46.0% area falls in the category highly suitable (S1) for agroforestry. Furthermore, only 2.9% of the total land areas are muti-season crop. The result indicates the soil moisture is the major constrain for cultivation of crop in off monsoon season. Majority of farmers in this district are small land-holders especially the tribal people who rely on rains for the cultivation. The rest of period (off monsoon) land is not adequately utilized for cultivation due to lack of irrigation facility and poor socioeconomic status of the tribal people. The rainwater harvesting structure when integrated with intensive soil and water conservation practices at watershed approach [40] will facilitate soil moisture to the land in off monsoon period. Such work needs sufficient funding, proper technical guidance and adequate people participation to revive the livelihood in tribal dominated district. The government has initiated many projects and programme such as Mahatma Gandhi National Rural Employment Guarantee Programme (MGNREGA), National Rural Livelihood Mission (NRLM) and Integrated Watershed Management Programme (IWMP) etc. for the poor and tribal people/farmers in rural area. There is a need to incorporate such analysis/findings/result/maps by policy makers for harnessing agroforestry in current ongoing and future land based management program/projects.

Furthermore, such analysis will greatly help Government of India to increase the forest cover from present level of 23% of land area to 33%. This will also help to increase the farmer's income because of the diversified farm output. The objective of national agroforestry policy 2014 also clearly says to increase the forest/tree cover outside the natural forest boundary. Various nodal agencies in India such as Indian Council of Agricultural Research (ICAR), Indian Council of Forestry Research and Education (ICFRE) and Forest Survey of India (FSI) etc. are working in agroforestry research. There is a need to replicate such study at block level (1:5000 scale), district level (1:10,000 scale), state level (1:50,000 scale) and country level (1:250,000 scale).

This research highlights the aptness of remote sensing and GIS with spatial relationship of various themes/layers (land, soil, climate and topography) which can be scientifically and logically integrated in GIS platform, they have huge capacity to analyze the land productivity for certain purpose.

5.1 Limitation

The result will be more significant if socio-economic aspect of the people will be integrated in this study.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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