Harnessing the Potentiality of Farm Landscape for Trees Based on Satellite Evaluation: A GIS Modeling Perspective

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Abstract

Increasing agroforestry areas is an important step to adapt to climate change, increase food security, and have many ecological and socio-economical benefits. Proper planning and strategies are required for the assessment of land potential and selection of suitable land for the multifunctional benefits of agroforestry. Remote sensing (RS) and geographical information system (GIS) tools are widely used to identify the priority areas for agroforestry and policy-making. The multi-high resolutions of Google pro mosaicked images were used as a base map for precision, detailed analysis, and valid interpretation. To identify the farm landscape suitability areas in the Belpada block of Belangiri district, Odisha, a GIS modeling approach was used based on satellite data measurement. The post-monsoon multi-date monthly cloud-free Landsat-8 data and products of the Digital Elevation Model were used to understand the farm landscape characteristics of agroforestry. Soil wetness, slope, drainage, and Normalized Difference Vegetation Index (NDVI) were used in the preparation of landscape suitability analysis. Overall 27.8% (134.16 sq. km) of land was highly suitable, 50.0% (241.85 sq. km) of land was moderately suitable and 19.7% (94.98 sq. km) was marginally suitable and the remaining 2.5% (12.01 sq. km) of land was found unsuitable for agroforestry. Out of 116 villages, 14 villages are found with high (greater than 70%) farmland potentiality, the highest is found in the Jalia village. The moderate and highly suitable land/villages should be given preference for tree-based farming in various agroforestry arrangements. The high-resolution farm landscape potential grid maps were produced for the first time which was earlier a research gap in the past that will support micro-level agroforestry planning. There is a need for a robust synergic approach when integrated with native and multifunctional trees in potentially suitable agroforestry farmland with adequate watershed management and conservation practices enriched with indigenous knowledge that will significantly support achieving the many sustainable development goals (SDGs) up to the smallest unit (village) level.

Keywords Agroforestry · Climate Change · Geospatial technology · Odisha · Suitability

1 Introduction

The enormous increasing population increases the demand for farmland, maintaining the area and productivity of the land to provide adequate food (Mazahreh et al. 2018).

According to the UN Food and Agriculture Organization globally, 38% of the land surface is farmland and about a third of this is used as cropland, remaining two-thirds (pasture/meadows) are utilized for grazing livestock (ICRAF 2021). There is a need for a robust synergic approach that

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not only leads to safe habitats for animals, and fertile ground for a range of plant life but also promotes transitions of agriculture/farm landscape towards many of the ecological, nutritional, and social issues associated with prevailing agricultural systems (ICRAF 2019a; HLPE 2019). However, agricultural lands are often transformed for other non-agricultural purposes which pose a greater risk to food security and sustainable development (Zou et al. 2019). Unplanned conversion of land for agriculture also damages ecological spaces leading to low productivity, soil erosion and habitat loss, and fragmentation (Akpoti et al. 2019). Inappropriate use of natural resources during the last decades caused the degradation of water, soil, and biological resources (Ziadat et al. 2017). Sustainable land-use planning can minimize the risk of soil erosion and environmental degradation. Sustainable developmental goals (SDGs) of the FAO report reveal India's rank was 110 in 2017 which has down to 117 in 2020. India's SDG performance gap is more than 20% in more than 10 SDGs in the areas of hunger, health and well-being, inequality, gender equality, sustainable communities, clean water and sanitation, energy, infrastructure, strong partnerships, and institutions for goals (Mourya and Mehta 2021). India also represents 23.8% of the achievement gap on SDG2 (zero hunger) and the reduction of undernourishment for 14.5% of the Indian population can help to achieve to reduce the gap of 27.4% of the world in SDG2 targets (Sachs et al. 2020).

According to Food and Agricultural Organization (FAO 2015), 1.3 billion people on the earth involve in agriculture and most of them are from developing countries. The agriculture sector of India is also very much important in reducing hunger and poverty and thus achieving such SDGs. Despite the increased yield in the agricultural crop, relative income per farmer needs special attention as over 70% of the country's population is dependent on agriculture for their livelihood. As 90% of the small and marginal farmers depends on 55% of the total cultivated lands being rainfed in India and most of the lands in the country are prone to natural disasters (Mourya and Mehta 2021). Thus it is a great challenge for increasing farmers' income, health, and happiness and mitigating poverty among them.

Several studies suggested that cooperatives in agriculture, horticulture, silviculture, and other allied sectors collectively can increase income, reduce poverty, and support the achievement of SDGs (Iyer 2020). Agroforestry practice has been well recognized and utilizes the power of trees to make farming and livelihoods socially, and economically sustainable to facilitate food security, mitigate climate change, increase soil fertility, reduce soil erosion, increase groundwater levels, and conservation of biodiversity at various levels (MEA: Millennium Ecosystem Assessment 2005; Mbow et al. 2014; Albrecht and Kandji 2003; Ramos et al. 2015; Hernandez et al. 2015; Asbjornsen et al. 2014; Sutti

2016; ICRAF 2019b). Executing agroforestry ventures from a landscape perspective has a strong capability for consolidating nature conservation objectives into farming systems (Plieninger et al. 2020; Zinngrebe et al. 2020). An estimation of agroforestry area in the world revealed that presently 10.23 million (M) sq. km area of land are used for different agroforestry purposes. These areas could be increased by the addition of 6.3 M sq. km of currently degraded land, grassland, and unproductive land (Nair and Garrity 2012; Nath et al. 2021). The government of India also has set a goal to increase the land area for agroforestry up to 53,000 sq. km by 2050 from the existing 167,000 sq. km (Nath et al. 2021). The ICRAF has the leading role in agroforestry research with the basic objective to utilize the potential of trees to make farm landscapes sustainable at various levels (ICRAF 2019b). Several projects are running in different parts of India including in the Odisha state to increase agroforestry extent at the local level with appropriate land and water management intervention (Singh et al. 2021, 2022). The project entitled "Enabling smallholders in Odisha to produce and consume more nutritious food through agroforestry systems" was funded by the government of Odisha under the supervision of world agroforestry (ICRAF) to familiarize the agroforestry practice and its successful implementation of the project(ICRAF 2019a). As part of the project, a unique app has been developed by ICRAF to avail the information about suitable crops, trees, available location of seeds, and planting material in Odisha. Dhankher and Foyer (2018) observed that climate-resilient crops and trees are crucial to overcoming climate uncertainty and significantly increasing the nutritional quality of food.

Ahmad et al. (2020) highlighted the potential land for agroforestry in South Asia by using climate, edaphic, topographic, and ecological criteria. However, region-specific characterization of lands for agroforestry is important as national-level classifications are more general while regional/local classifications are more precise and specific (Nath et al. 2021).

Large amounts of both qualitative and quantitative data are necessary when evaluating land suitability (Nguyen et al. 2015). The qualitative approach relies heavily on farmers' experience and intuitive knowledge (Jamil et al. 2018b) while the quantitative approach involves parametric methods and statistical analysis (De la Rosa 2009). The multi-criteria decision-making (MCDA) process helps to choose the best alternatives (Jankowski 1995) and is used extensively in suitability evaluation (Memarbashi et al. 2017; Sharma et al. 2018; Dagıstanlı et al. 2018; Musakwa 2018; Everest et al. 2021). FAO, Food and Agricultural Organization framework MCDA for optimal and sustainable utilization of natural resources by minimizing biases in planning and management of land resources (Baja et al. 2002; Jamil et al. 2018a; Yohannes and Soromessa 2018). Geographical Information

System (GIS) is used to overlay analysis, distribution of maps, and suitability levels' classification (Leisz et al. 2005; Everest 2021) and is considered an excellent tool for proper planning and sustainable utilization of land resources (Lopresti et al. 2015; Ahmad et al. 2020). It has been successfully used for land suitability analysis for specific crops in many different regions of the world (FAO 2007; Joss et al. 2008; Elsheikh et al. 2013; Zolekar and Bhagat 2015; Singha and Swain 2016; Ahmad and Goparaju 2017b; Aldababseh et al. 2018; Herzberg et al. 2019).

Soil wetness, Slopes, NDVI, and drainage are important parameters in agroforestry modeling as these are directly or indirectly related to farmland characteristics. The potentiality of the farm landscape can be manifested by NDVI which quantifies plant health, vigor, stress, and farm greenness (Hult 2019), and can be used for seasonal agriculture activity monitoring (Choudhary et al. 2019). The slope and drainage map are important topographical parameters widely used in sustainable land potentiality modeling (Hoechstetter et al. 2008; Grohmann 2016; Ahmad and Goparaju 2017a; Mazahreh et al. 2018) and are delicately associated with poverty mitigation, livelihood initiation, environmental safeguarding, biodiversity conservation, and transformation to climate change. The slope layer is highly useful for the identification of land potentiality for agroforestry at a local/regional scale because this is linked to the runoff potential (Kolekar et al. 2017) and water availability to crops. There is a significant knowledge gap about the village landscape potentiality assessment for trees up to the level of the farm for planning and management of better agroforestry strategies. With this background, the present study aims to determine the farm landscape potentiality for trees using the GIS modeling concept at local/village levels in the part of rural area of Odisha state of India using post-monsoon multi-date monthly Landsat-8 data, and products of the Digital Elevation Model (DEM). The soil wetness, slopes, NDVI, and drainage products are used to understand the farm landscape characteristics linked to agroforestry.

The study addressed by producing high-resolution farm landscape potential grid maps for trees encouraging the most vulnerable/tribal people for micro-level project planning for agroforestry venture with the following Sustainable Development Goals (SDGs) linked to mitigating poverty (SDG 1), ending hunger (SDG 2), nutritional security (SDG3), gender equality (SDG 5), mitigation and adaptation of climate change (SDG 13) and degraded and wasteland restoration and enhancing the biodiversity (SDG 15).
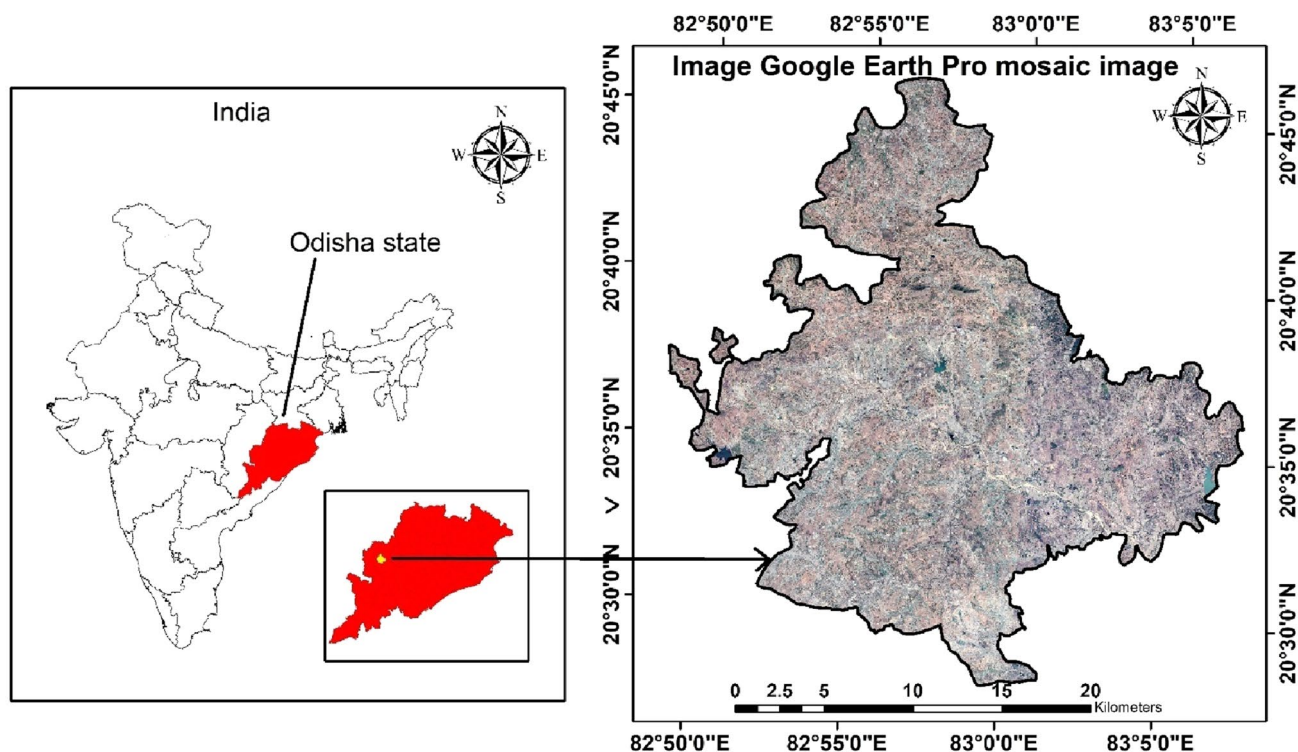

Fig. 1 Map of the study area

2 Materials and Methods

2.1 Study Area

The study area (Fig. 1) is Belpada block administrative unit is a part of the Balingir district of Odisha situated in the eastern state of India, located between 20.46°N and 20.76°N latitudes and between 82.81°E and 83.13°E longitudes covering 483 sq. km of the geographical (Fig. 1).

The state of Odisha shares a boundary with West Bengal in the northeast, Jharkhand in the north, Chhattisgarh in the west, and Andhra Pradesh in the south, and a 482 km-long coastline with the Bay of Bengal in the east. Because of its peculiar geographical location, the physiography of the state varies widely. About three-fourths of the areas of the state are covered by mountains and valleys made by rivers which are the lands for agriculture and human habitation.

National Agricultural Research Project (NARP) classified the state into 10 major agro-climatic zones based on climate, soil, topography, vegetations, etc., whereas Bolangir district falls under the physiographic zones in the central tableland with soils in the plain areas being very fertile due to deposition of silt. The area experiences winter (January and February), pre-monsoon (March–May), southwest monsoon (June–September), and northeast monsoon (October–December). The annual average rainfall is about 1300 mm and most of the rainfall comes from the southwest monsoon between June and September. This rainfall is essential for agriculture in the state as irrigation facilities are still not adequate.

Poverty levels are very high, with over 60 percent of households estimated to fall below the poverty line (Wandschneider and Mishra 2003). The diminishing livelihood opportunities at the village level compel them to migrate to nearby towns for better life and nourishments which needs adequate strategies in agroforestry practices at the local level to improve food, nutrition, and income security for their families to break the migration flow (Baisakh 2010; WAC 2021).

2.2 Data Processing and Analysis

The study utilized four main parameters as Soil wetness, NDVI, Slope, and drainage derived from satellite images for GIS modeling and mapping. Supplementary section Table 1 describes the major data source and resolution. A detailed systematic flow diagram of the methodology for this study is given in Fig. 2. We have downloaded post-monsoon eight Landsat-8 cloud-free data (each continuous month) from October 2017–May 2018 from USGS Earth Explorer. These data are radiometrically and geometrically corrected (Markham et al. 2014; Morfitt et al. 2015; Ihlen 2019). The Landsat data descriptions are given in the Table 1.

The 40 high resolutions of Google pro images (screen-print) were used and later rectified with a vector grid and finally mosaicked for a base map to support the study with more precision, detailed analysis, and valid interpretation (Ahmad et al. 2017).

The multi-date monthly Landsat images were used to determine the soil wetness and to generate the NDVI images. Seasonal soil wetness is an important determinant for harnessing the farm landscape for crops/trees in various agroforestry domains for maintaining soil and agrobiodiversity and interconnecting ecosystems. We have used Baig et al. 2014 formulas which determine various band coefficients (Table 2) to derive the Landsat satellite-based wetness images.

The Landsat image Digital Number (DN) values were first converted to reflectance as per the USGS manual and then into soil wetness utilizing the above-mentioned wetness coefficient given in Table 2 (Baig et al. 2014; Ahmad and Goparaju 2017b).

All Landsat 8 data were used for generating month-wise NDVI images as the proxy indicator of land degradation/farm health (Meneses-Tovar 2011; Hult 2019) and their spatial patterns are widely recognized for GIS modeling and for identifying the land for agroforestry suitability (Ahmad et al. 2020).

The high-resolution ASTER Digital Elevation Model (DEM) (30-m spatial resolution) was downloaded from the

Table 1 Data description

| Downloaded Landsat-8 data	Sensor	Path/row	Dates
LC08_L1TP_141046_20171028_20171108_01_T1.tar	OLI	141/46	28th October 2017
LC08_L1TP_141046_20171129_20171207_01_T1.tar	OLI	141/46	29th November 2017
LC08_L1TP_141046_20171215_20171223_01_T1.tar	OLI	141/46	15th December 2017
LC08_L1TP_141046_20180116_20180120_01_T1.tar	OLI	141/46	16th January 2018
LC08_L1TP_141046_20180217_20180307_01_T1.tar	OLI	141/46	17th February 2018
LC08_L1TP_141046_20180305_20180319_01_T1.tar	OLI	141/46	5th March 2018
LC08_L1TP_141046_20180422_20180502_01_T1.tar	OLI	141/46	22nd April 2018
LC08_L1TP_141046_20170521_20170526_01_T1.tar	OLI	141/46	21st May 2018
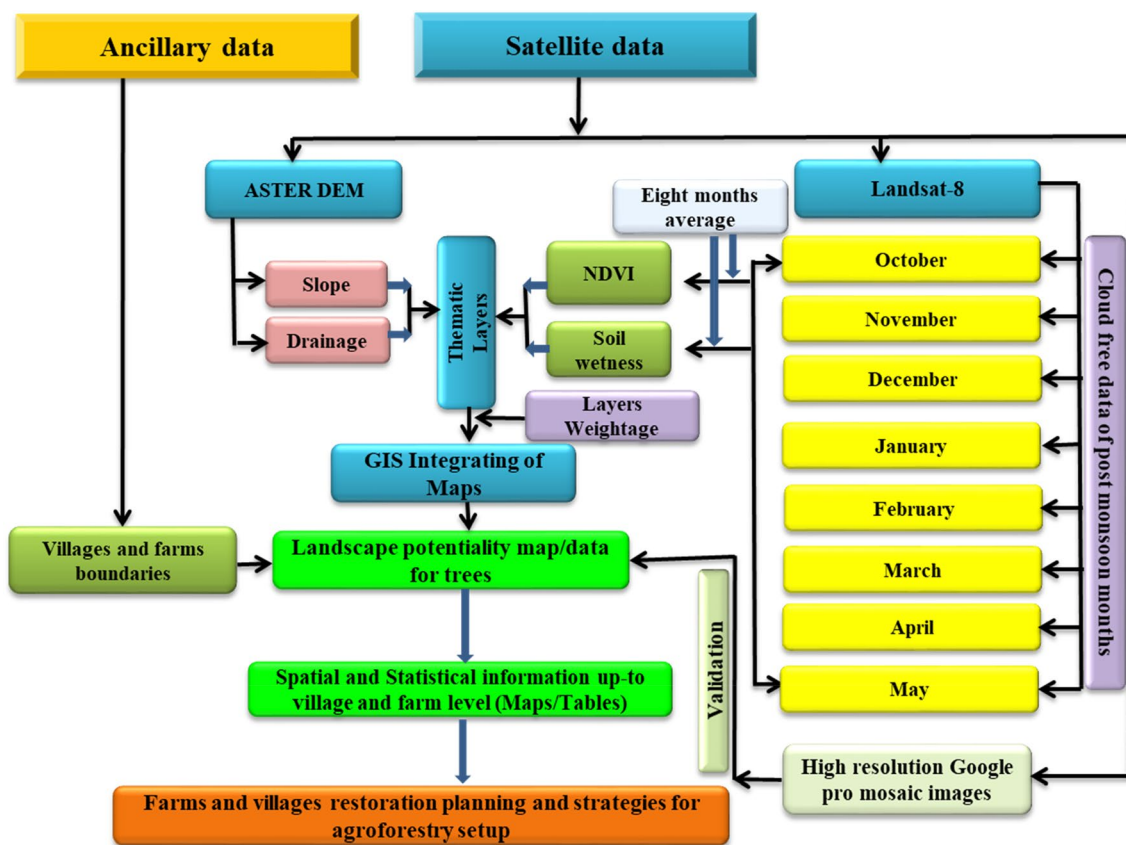
Fig. 2 A detailed schematic methodological framework of the study area

Table 2 The wetness coefficient (Baig et al. 2014) for Landsat 8 operational land imager (OLI)

Bands	Wavelength (micrometers)	Resolution (meters)	Wetness coefficient
Band 2—Blue	0.45–0.51	30	0.1511
Band 3—Green	0.53–0.59	30	0.1973
Band 4—Red	0.64–0.67	30	0.3283
Band 5—Near Infrared (NIR)	0.85–0.88	30	0.3407
Band 6—SWIR 1	1.57–1.65	30	-0.7117
Band 7—SWIR 2	2.11–2.29	30	-0.4559

USGS Earth Explorer. The slope layer was generated using the DEM. The drainage layer with various stream orders was produced from DEM (Fig. 3) with help of the Arc GIS hydrology spatial analyst tool. We have created the Euclidean distance of a raster surface from the drainage vector file. Euclidean distance gives the distance from each cell in the raster to the closest source.

The 100-m vector square grid was created over the study area for GIS modeling and analysis. The soil wetness and NDVI values of each month were brought into a separate column of the vector file with the Arc GIS Zonal Statistics tool. The all month's average soil wetness and average NDVI were calculated and brought into two

different columns. Similarly, the slope layer values and drainage euclidean distance values were brought into a separate column. Each column value has been normalized (scaling the attribute values) with maximum and minimum techniques (Han et al. 2012). The GIS modeling for farm potentiality for agroforestry has been done by integrating four normalized parameters (Soil wetness, Slopes, NDVI, and drainage) by assigning different weights calculated (Fig. 4) using Analytic Hierarchy Process (AHP) (Saaty1980; Qayum et al. 2020) calculator (Goepel 2022) based on professional field knowledge and high-resolution base map review. The land potentiality driving factor
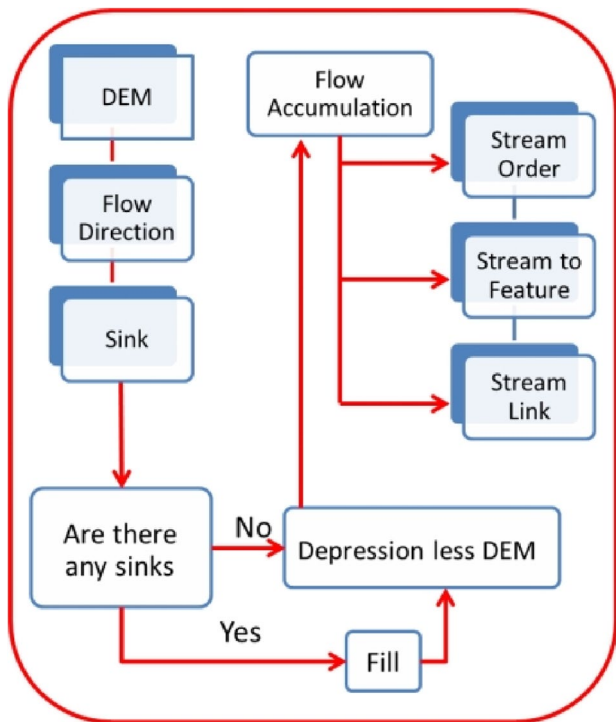
Fig. 3 Methodology for generating drainage showing various stream orders from DEM

(Table 3) and criteria for evaluation for agroforestry uses (Fig. 5) are given below.

All four parameters' weights were calculated by AHP and brought into an approximate fraction (Fig. 5) for integration in GIS modeling was scientifically chosen and calculated using the following equation:

$$
\text{GISintegration} = \sum (0.4 * \text{SWavg}) + (0.3 * \text{SLP}) + (0.2 * \text{NDVIavg}) + (0.1 * \text{DR}), \quad (1)
$$

where SWavg is eight months average value of soil wetness, *SLP* is the slope value, NDVIavg is eight months' average value of NDVI, and *DR* is the drainage raster surface value. Finally, the GIS integrated data are scaled to percent (0 to 100) for producing landscape potentiality percent for trees.

The integrated landscape potentiality percent data was adequately validated using high-resolution google pro mosaic images and in situ field experiences. Our validation result showed the map is highly beneficial for agroforestry ventures in many of the study areas. The scaled land potentiality percent data was analyzed with farm and village boundaries to identify the farm/village land potentiality maps/tables.

3 Results

The plant growth on the farm largely depends on the soil moisture available to them. The soil wetness is significantly high in October and shows a decreasing trend from October onwards (Fig. 6). In May, soil wetness is found slightly higher than in April due to pre-monsoon rain (approximately doubled: comparing it with the preceding month's precipitation). We have verified the findings of soil wetness (October) with part of the high-resolution base map. The soil wetness is significantly high (dark to light green color) at ponds/temporary water structures and in low land flooded fields (Fig. 7). Around, 65% of the landscape area lost more than 40% of soil moisture from October to May. The average eight-month soil wetness was divided into four classes

Fig. 4 AHP calculation for determining the weight of each parameter

Table 3 Landscape potentiality driving factors descriptions for agroforestry

Landscape potentiality driving factors for agro-forestry	Parameter characteristics and references	Relationship
Soil wetness	The soil moisture/wetness is generally high at ponds/temporary water structures and in low land fields and is significantly used for identifying land potentiality for trees and GIS design(Ahmad and Goparaju 2017b)	Directly proportional
NDVI	NDVI seasonality is an indicator of vegetation dynamics such as biomass and vegetation growth (Tian et al. 2016) and is widely used for the GIS Modeling framework for agroforestry suitability mapping (Ahmad et al. 2019)	Directly proportional
Slope	The slope variation is delicately linked to soil properties (physical/chemical/soil depth) and water availability to plants thus affecting the landscape ecology in terms of plant diversity (Hoechstetter et al. 2008; Silva et al. 2014; Mazahreh et al. 2018; Zhang et al. 2018)	Inversely proportional
Drainage	The soil moisture nearer to streams are high which facilitates the agroforestry activity significantly. The raster surface of drainage highlights the proximity of water availability and is used for GIS Modeling(Dosskey et al 2008; Nath et al. 2021)	Inversely proportional

Fig. 5 Criteria for evaluation of farm landscape for agroforestry purposes

based on visual interpretation. They are categorized as high, medium, low, and very low. Approximately,17% of the land has high soil wetness. The soil moisture of the villagesMalpara, Talbhata (gram panchayat: Bagdor), Guhiriapadar (gram panchayat: Sarmuhan), Barbahal (gram panchayat: Kandhenjhula), and Jalia (gram panchayat: Dhumabhata) are found highest. The high soil moisture is found in low land areas, along the river/streams, near ponds, and water harvesting structures. Generally, 47% of the land has medium soil wetness. About, two-thirds of the area showed high to medium soil moisture where agroforestry practices are more or less sporadic and can be exploited for agroforestry magnification practices. About, 26% of the land has low soil wetness where agroforestry practices are more or less very

sparse. The rest 10% of the land has very low soil wetness where the vegetation is absent.

Most of the land in the study areas are plain and gentle slopes (Fig. 8a). About 37.11% of the areas are very gentle, gentle, and undulating hills with a slope of fewer than 8 percent. The rolling, hillock, or moderately steeps (8–25% slopes) are the highest and constitute 59.02% (25.05 sq. km) of the area. Hilly and high steeps (25–40% slopes) are very less covering 3.29% (15.89 sq. km) in the area (3.29%) and the remaining marginal areas are extremely steep and abrupt. The raster drainage map is given in Fig. 8b. In nearby streams and rivers, the soil characteristics are more favorable for plant growth with significantly good soil moisture. Many

Fig. 6 Soil wetness maps showing seasonal drift from October (start of winter) to May (end of summer season)
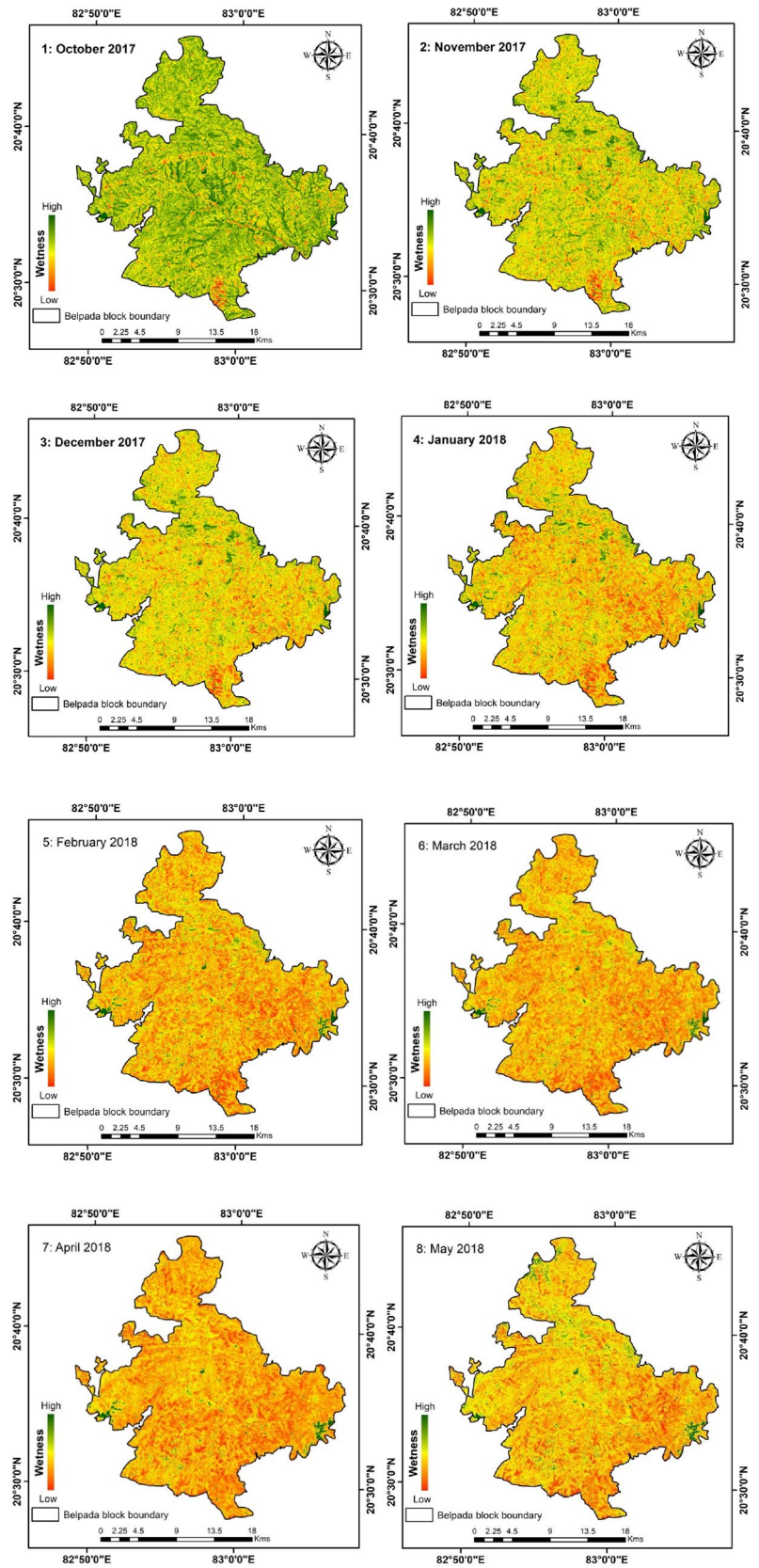
Fig. 7 The top image is a base map and the bottom image is a transparent soil wetness (October) map draped over the base map

Base map (February 2017)

Soil wetness (October) draped over base map

High

Low

Fig. 8 DEM generated product (**a**: Slope map, **b**: Euclidean distance surface from drainage map)

Fig. 9 NDVI maps: **a** Seasonal NDVI greenness drifts from October (start of winter) to May (end of summer season); **b** A base map and the bottom image is transparent farm NDVI mean value (8 months average) draped over the base map
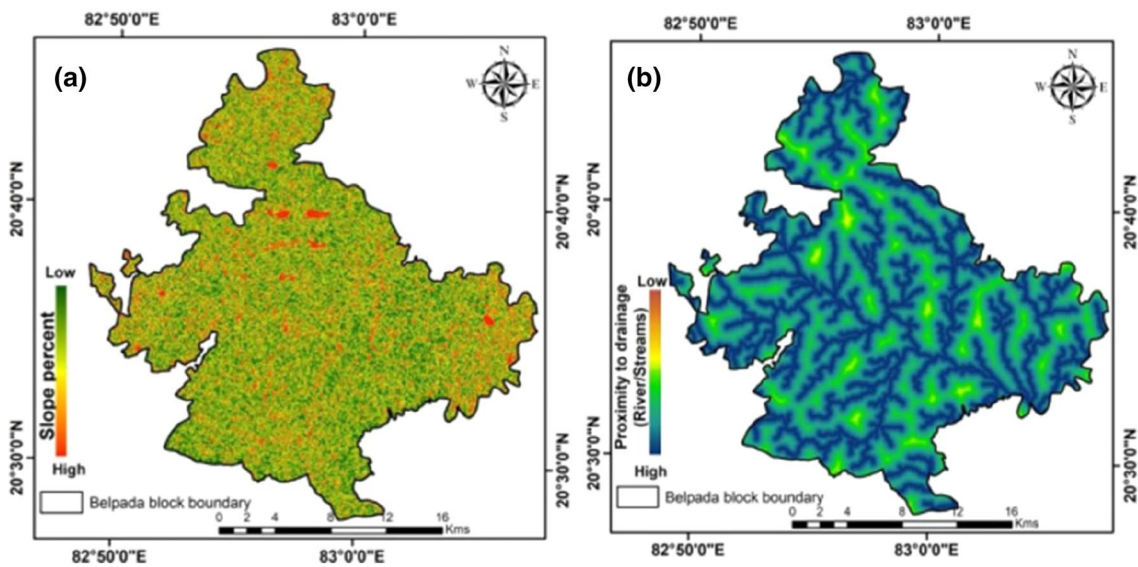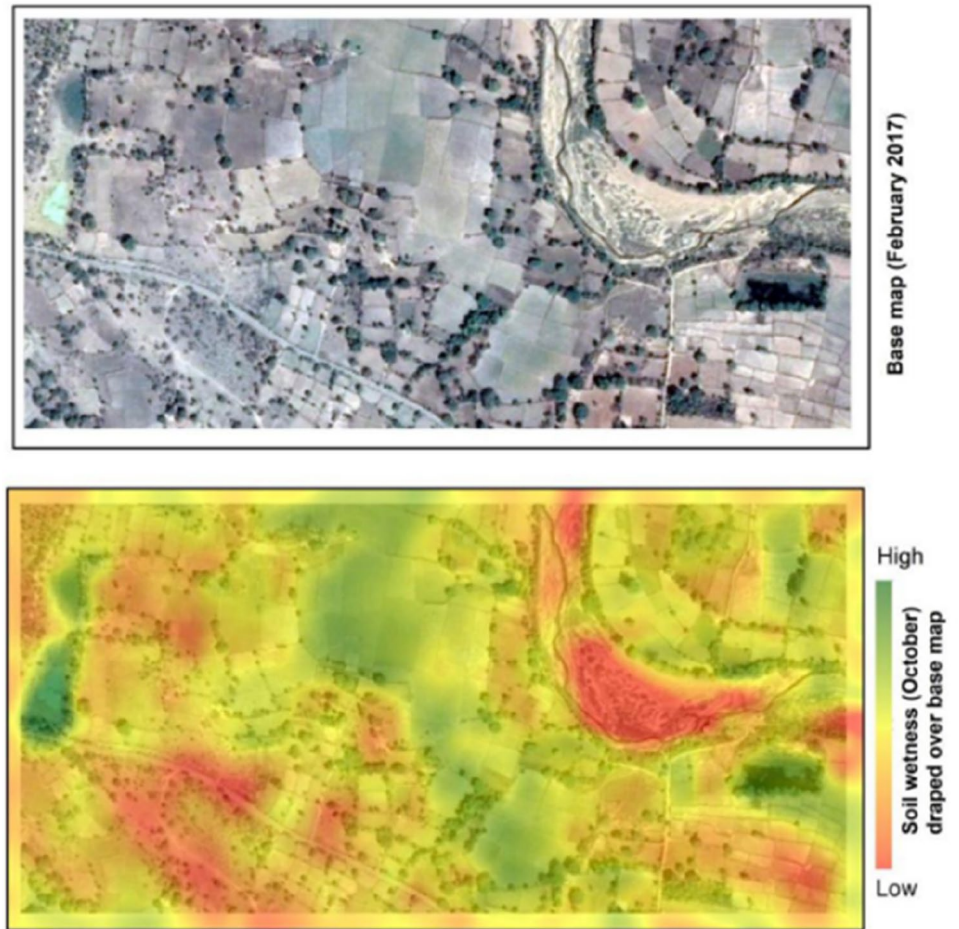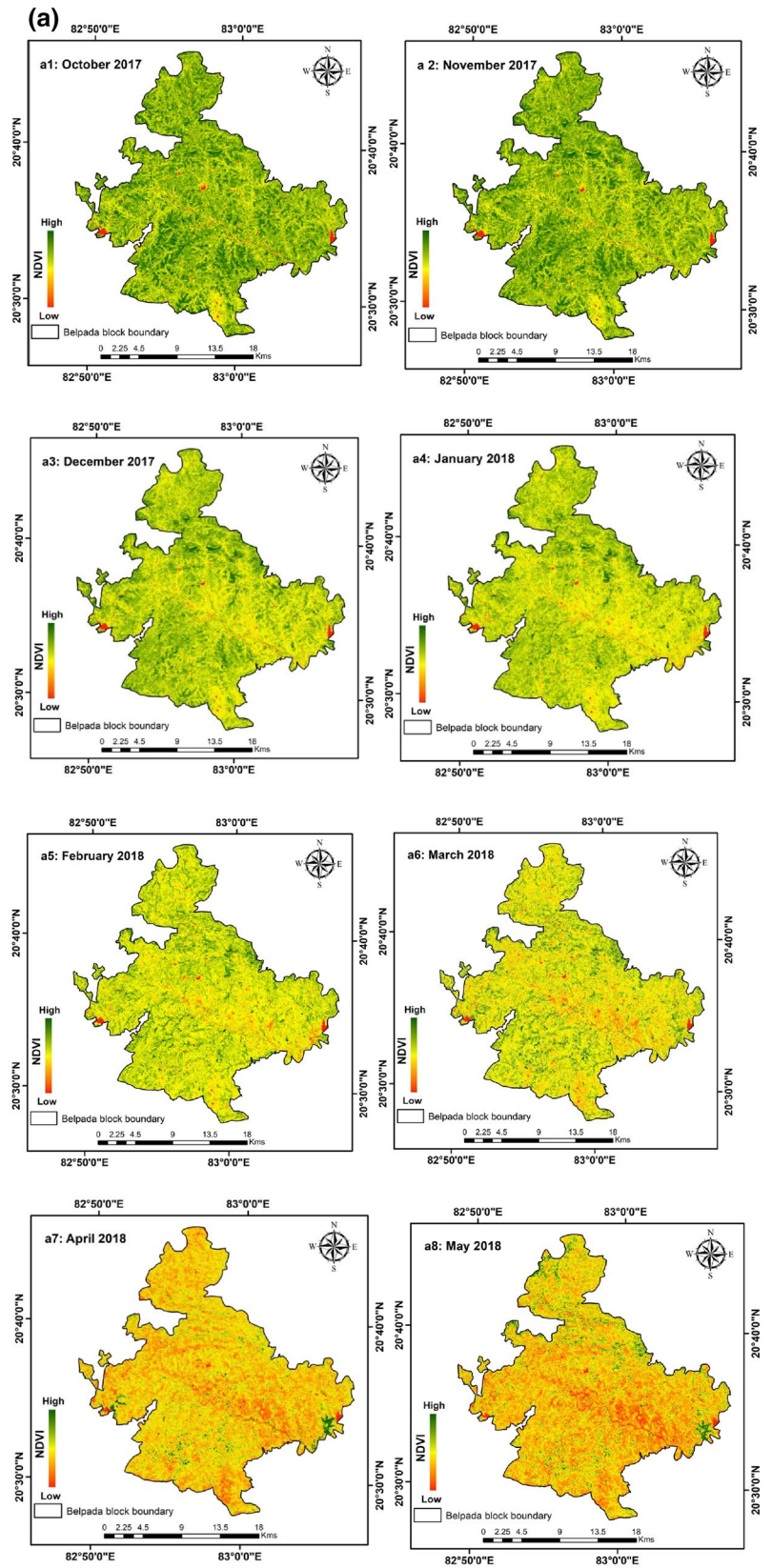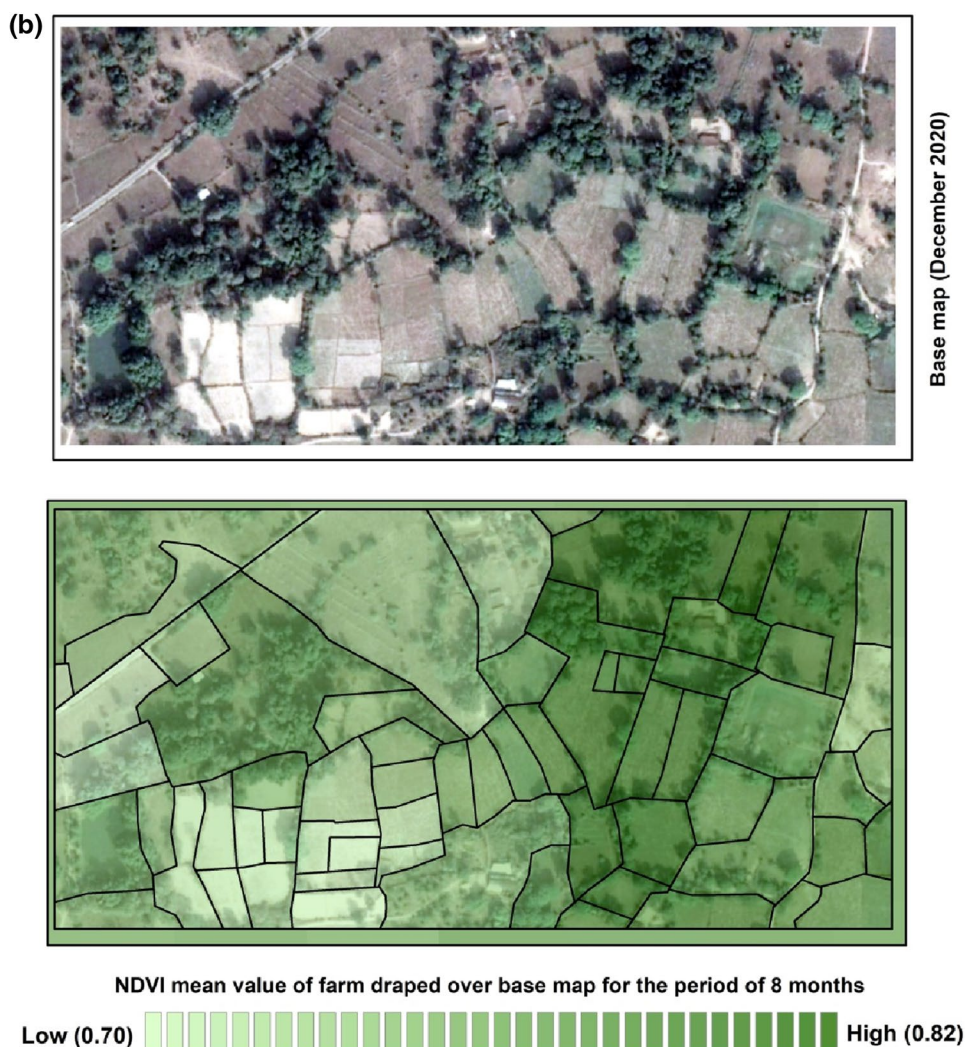
Fig. 9 (continued)

(b)

NDVI mean value of farm draped over base map for the period of 8 months

Low (0.70) ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮ High (0.82)

agroforestry patches are identified in proximity to rivers and streams.

The visual interpretation of monthly NDVI highlights the gradual decrease in greenness from October onwards till May (Fig. 9). About 8.45% of the landscape was found with a very high mean NDVI value (0.7–0.88) over 8 months because of tree cover adequately mixing with agricultural activity throughout the year. The majority of the areas (90.3%) exhibit medium to high values of NDVI (0.5–0.7) because of poor agroforestry practices linked to the weak socio-economic activity of inhabitants(majority of them are tribal) and seasonal decrease in soil moisture. The areas with lower vegetation with seasonal grass intermixed with low to nil in farmland activity constituted only 1% of the areas which had lower NDVI (0.3–0.5). The remaining 0.3% of the areas had the lowest NDVI (0.12–0.3) where vegetation was missing due to constraints of plant growth mostly in river sands/rocky/stony areas/ human settlements.

The overall farm landscape potentiality of the study area map for trees is given in Fig. 10. The data were further segregated into four categories (high, moderate, marginal, and unsuitable) based on adequate verification. The highly potential, moderate potential, and marginal potential areas for agroforestry purposes were 27.8% (134.16 sq. km), 50.0% (241.85 sq. km), and 19.7% (94.98 sq. km) respectively. The unsuitable areas include the high slopes, less vegetation, and poor soil moisture retention land constitutes only 2.5% (12.01 sq. km).

We have utilized the latest (2021) village data (Github 2022) for the study area. There are 116 villages in the study area. The farmland potentiality % (mean, minimum, maximum, range, and standard deviation) up to the local administrative (village) level for all are given in supplementary Table 2. Out of 116 villages, 14 villages were found to have high (greater than 70%) farmland potentiality.The village Jalia (gram panchayat: Dhumabhata) had the highest (74.1%) mean farmland potentiality followed by Malpara
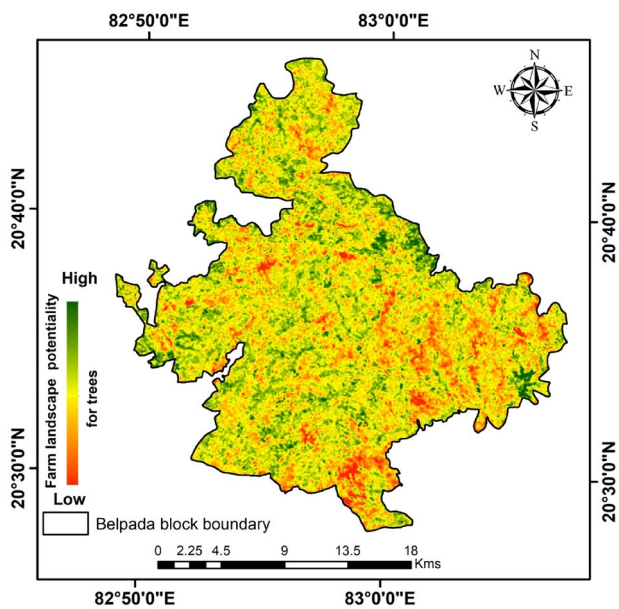
Fig. 10 The farm landscape potentiality map for trees of the study area

(gram panchayat: Bagdor) (73.4%), Malpara (gram panchayat: Kandhenjhula) (73.1%),Budamunda(gram panchayat: Kapani) (72.2%), Banmal (gram panchayat: Bagdor) (71.6%), Dudukamal (gram panchayat: Bagdor) (71.4%), Chhuinara (gram panchayat: Kapani) (71.3%), and Semelpali (gram panchayat: Sihini) (70.5%).

4 Discussion

The results of the study reveal that the majority of the landscape of the Belpada block is moderate to a high level suitable (yellow–dark green) for agroforestry considering the soil moisture, NDVI, slope, and drainage (Fig. 10). These are the most important variables delicately associated with regional landscape characteristics linked with the ecological, edaphic, topographic, and climatic components. The farm landscape potentiality was found high and characterized by adequate soil wetness and greater NDVI (low erosion degree) throughout the year mostly in the lowland plain area (low slope) having proximity to streams/rivers. Similar findings during restoration of the landscape for sustainable farming were also reported by various scientists around the globe (Hillbrand et al. 2017; Ahmad et al. 2019; Nath et al. 2021; Kumar et al. 2020; World Bank 2020). In contrast, the barren exposed rocky area manifested low landscape potentiality for tree harvesting (supplementary Fig. 1). Approximately 50% of the study areas were found to have greater than 66% landscape potentiality for growing trees in various existing land-use domains which come under the proximity of several

tribal-dominated villages suffering from acute poverty and diminishing livelihood opportunities. There is a need for adequate strategies in agroforestry practices at the local level to halt the migration flow to a nearby town. The high-resolution farm landscape potential maps (Fig. 11) which were generated first time at the local level with such high precision will support various stages of micro-level project planning. Farm landscape potential areas need to be harnessed for reconstructing local value chains, especially for smallholders linked to livelihood/employment/income/nutrition (ICRAF, 2019a) which are significantly reduced over due course of time due to forest cover degradation (Reddy et al. 2014; Mishra 2019). Furthermore, several farm landscapes of the study area are found very high suitable for trees which can be harnessed for growing two or three crops in a sequence (Waha et al. 2020) using intensive multi-cropping systems applying locally improved cultivars to optimize efficiency and success for nutrient cycling and efficient soil and water use, as well as pest protection approach for biodiverse agroecosystems (Francis and Porter 2017). Such a potential landscape can be restored and may be a key pathway for achieving many of the SDG goals for some of the most vulnerable people (tribal dominated) living in the rural area of the state of Orissa (ICRAF 2019a).

Soil wetness is one of the least understood elements of meteorologic setup (Dirmeyer, 1995) which nowadays is reliably measured due to the technological advancement in satellite imaging (Baig et al. 2014). Soil wetness is generally adequate during the monsoon season (approximately more than 200 mm each month from June to September: BR 2022). The lowland fields are widely used for paddy cultivation during the monsoon season and the majority of them remain uncultivated for the rest of the season because of inadequate irrigation/soil and water conservation facility. The areas where soil wetness was found to decrease swiftly (Fig. 6) need to be given preference for watershed-based conservation (FAO 2017). The seasonal greenness of the agricultural landscape is mostly highlighted by farmland in use in terms of various existing agroforestry setups. The farmland with the appropriate practice of Agri-silvi agroforestry system with adequate tree dominance also exhibits significantly high mean NDVI values (Fig. 9b). The selection of appropriate trees and intensification of trees along the field boundary in the lowland paddy field can provide high returns along with other benefits of agroforestry. The water availability on farmland by any source (irrigation by river, stream, canal, etc.) is better than those that rely on seasonal rains which impact the agroforestry venture. However, seasonal rainwater can be retained for a longer period with appropriate soil and water conservation measures to boost farm production (Dey 2016; Ahmad and Goparaju 2017b). The vast swaths (60% of agricultural land) of farmlands in India rely on rainwater and the majority of them are poor

(a) Part of a base map showing farm boundaries
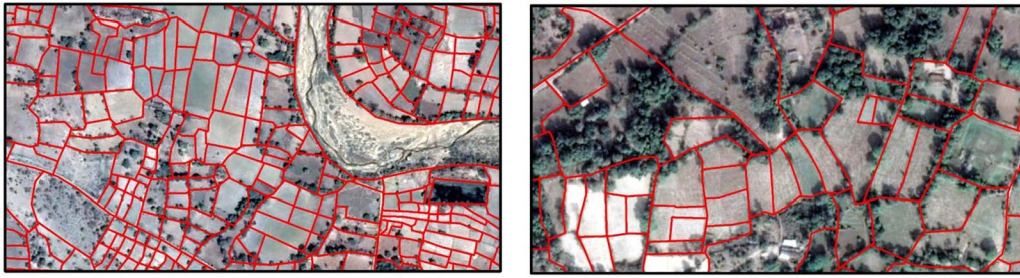
(b) Draped transparent farmlands potentiality map over base map

Low (61%)   Farmlands potentiality   High (79%)

Low (64%)   Farmlands potentiality   High (80%)
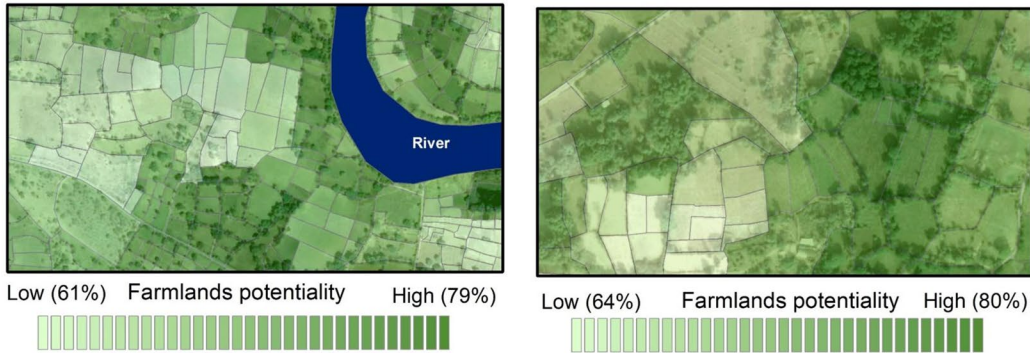
(c) Farm Landscape potentiality Atlas of Belpada, Balangir, Odisha, India
(Draped over the high resolution google earth pro images)

Legend
Agroforestry uses
Farm landscape potentiality (%)

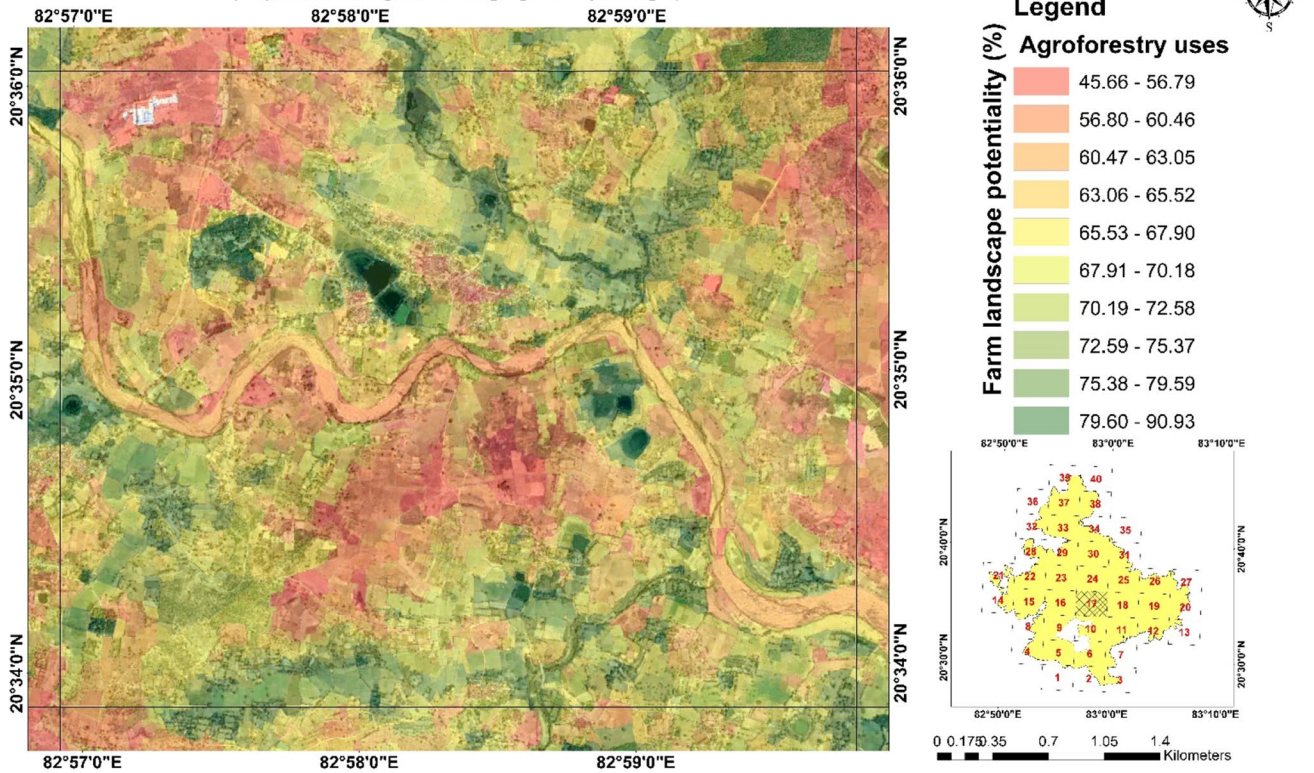|	
	45.66 - 56.79
	56.80 - 60.46
	60.47 - 63.05
	63.06 - 65.52
	65.53 - 67.90
	67.91 - 70.18
	70.19 - 72.58
	72.59 - 75.37
	75.38 - 79.59
	79.60 - 90.93

Fig. 11 The landscape potentiality map for trees on the farms

farmer's lands (Rajshekhar 2011). The inadequate financial support integrated with seasonal rainfall variation and poor soil and water conservation measures on farmland of poverty-stricken farmers hinder the farm activity, output, and income.

The landscape potentiality data for trees in the study area were further analyzed with farm boundaries to know the farm capacity for harnessing future agroforestry ventures. The farm landscape potentiality for trees in part of the study area is given in Fig. 11. The analysis revealed that the farm landscape in this area has adequate potential for agroforestry. The tree-dominant farm landscapes have high values in terms of their potentiality because multifunction agroforestry practices (shown by the dark green color) offer huge ecological benefits such as carbon sequestration, magnifying soil fertility, water efficiency, shelterbelt/ windbreaks, and finally help in enhancing the farmland output/income with a broader spectrum of conservation of biodiversity and transforming land to climate change (Sahoo and Wani 2019; Neha 2021). Furthermore, low-land rice fields/farms have enough soil moisture during the monsoon season showing approximately greater than 60% suitability for trees. Trees in such rice-production landscapes can be grown as per the ICRAF manual which will provide food and non-food products to regulate hydrologically and nutrient cycles, protect the soil and improve nutrition and income, and play an important role in mitigating and adapting to the multiple stressors that agricultural systems are currently facing and, consequently, in increasing food and nutrition security of rice-based farming communities (Wangpakapattanawong et al. 2017).

The farmland potentiality up to the village level (the smallest administrative units) and high-resolution farm landscape potential grid maps for trees will help in micro-level community-based planning when adequately supported by funds for agroforestry magnification/venture will serve many sustainable development goals (SDGs) to the rural people of Odisha suffering from acute poverty, hunger, enormous malnourishment (ICRAF 2019a; Baisakh 2010).

5 Conclusions

Farming agroforestry is vital for climate adaptation, poverty reduction, proper utilization, and restoration of the land. It is an ancient practice in different regions of the world which needs proper land use planning and practices to replicate in the region of interest based on specific climatic, edaphic, ecological, and socioeconomic variables. The landscape potentiality modeling primarily focuses to improve the decision-making up to the level of the farm for harnessing various agroforestry models which suit the specific site/location as per farmers' needs based on indigenous knowledge. Such a framework can be executed using GIS software which

needs high-resolution data, GIS analysis skill, and modeling concept.

Our study found that the Belpada block is moderately to highly suitable for agroforestry. Furthermore, the farmland potentiality evaluation using GIS for trees up to the village level (the smallest administrative units)and high-resolution farm landscape potential grid maps were one of the potential research gaps in the past that were the for first time addressed which will significantly support the execution of local/micro level community-based planning using agroforestry for eradication of poverty, increasing livelihood opportunities and social safety to the tribal-dominated community.

The farm landscape potentiality was found to be high and characterized by adequate soil wetness and greater NDVI (low erosion degree) throughout the year mostly in the lowland plain area (low slope) close to streams/rivers/wetlands which can be scientifically used for the conservation and management of watersheds for enhancing soil moisture for an extended stretch and thus magnify the future agroforestry opportunities.

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