Agroforestry Site Suitability for Wasteland Greening - A case study of selected districts of various agroclimatic zones

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Abstract: Agroforestry being an agroecological practice has potential benefits of climate adaptation and mitigation while preventing land degradation and increase in agricultural productivity. In the present study, GIS based methodology was followed to identify suitable sites for agroforestry in 17 districts, representing different agroclimatic zones of India. A weighted index approach was adopted to integrate all parameters (land use land cover, wasteland, soil carbon, slope and surface water body) using GIS techniques. Weightages are given to each parameter based on its importance towards objective of the study and subsequently ranks are assigned to each category within the parameters. By multiplying weightage and rank, Agroforestry Suitability Index (ASI) was derived. The ASI has been further classified in 5 categories (High, Moderate, Less, Very Less, and Not Suitable). The model was validated based on ground truth (GT) data collected in selected districts. Comparison of GT points collected in High and Moderate suitable wasteland regions showed good agreement with the model and registered an accuracy of about 86.60%. District-wise agroforestry systems with multipurpose trees species have been recommended in high and moderate suitability classes for 17 districts across India. This approach is efficient and uses simple integration to prioritize the wastelands suitable for various other land use purposes vis-à-vis restoration projects expanding green cover and help to achieve national commitments under UNFCCC and UNCCD focussed on Ecosystem restoration, Paris Agreement, Land Degradation Neutrality and UN-sustainable development goals.

Key words: Agroforestry, Wasteland, GIS, Weighted Index Approach, Suitability

1. Introduction

Agriculture and forestry are the two most important land-use systems and are currently primary drivers of climate change and land degradation because of widespread unsustainable practices, even as they may contribute to short term economic growth. Numerous authoritative reports (IPCC, IPBES etc.) have clearly shown that a transformation of land management, especially agriculture and forestry, towards sustainability is required if we are to avert major crises that threaten ecology, society and economy in catastrophic ways. These reports and others point to the potential of agroforestry and other agroecological approaches of offering a pathway to sustainability. It is apparent that, land is a finite resource and need planning to foster its sustainability and scalability. Fast urbanization, agricultural intensification, deforestation and land degradation are globally attributed reasons to climate change and ecosystem degradation (Shukla et al., 2019). "Agroforestry, the integration of crops, trees and livestock on the same piece of land, mimics the productivity and resilience of complex ecological systems such as forests and offers great opportunities to mitigate the challenges faced, as has been recognised by India in its NDC".

Agroforestry, a set of practices that has a several thousand-year history of innovation in India that continues into the present, is being implemented under purview of National Agroforestry Policy (2014) and subsequent under the sub-mission on Agroforestry (SMAF). Agroforestry could make a remarkable impact in restoration of degraded and wastelands (Planning Commission 2001; FAO, 2017; Maji et al., 2010). It can act as a promising land-based transformation solution because of its aligning co-benefits viz. enhancing farmers income, increasing green cover, conservation of natural resources, production of forest based raw-materials, achieving NDC's, rural development and scalability (Chaturvedi et al., 2014 & 2017; Dagar and Tiwari, 2016; Mishra and Rath, 2013; Handa et.al., 2015; Planning commission, 2001; MoA&FW, 2014; Duguma, 2017). Further, this will help in mitigating the green house emission from Land Use Land-Use Change and Forestry (LULUCF) which is estimated as 2,531.07 million tonne CO_2 (MoEF&CC, 2021). The LULUCF sink (CO_2 removal) is on the rise by 3.4 per cent between 2014 and 2016 and by approximately 40 per cent between 2000 and 2016 (MoEF&CC, 2021). Along with carbon sequestration, greening of wasteland with agroforestry will support in fulfilling commitment made under Bonn challenge i.e. to restore 26 million hectares by 2030 and aligns with the UN Decade of Ecosystem restoration (2021-30). At present, the total wasteland in India is estimated to be 55.76 million hectares i.e. 16.96% of total geographical area of the country (NRSC, 2019). The wasteland has 23 classes which can be cultural and non-cultural. Agroforestry inventions through sustainable plantation models can restore the various classes of wasteland (Planning commission, 2001; Handa et al., 2015). There are several identified agroforestry systems that are suitable for wastelands in different agroclimatic zones of the country (ICAR-CAFRI, 2016). Keeping goods and services provided by agroforestry in view, the Union Budget Announcement of Government of India (FY-2022-23) has underlined the promotion of agroforestry and private forestry and also providing financial support to farmers belonging to Scheduled Castes and Scheduled Tribes practicing agroforestry (https://www.pib.gov.in/PressReleasePage.aspx?PRID=1794165).

Mapping of agroforestry suitable area using spatial information has been a challenging area in agroforestry across the world. Nevertheless, the Indian Council of Agricultural Research and the Forest Survey of India took initiatives to assess the area under agroforestry in the country. As per ICAR's Central Agroforestry Research Institute (2021), 28.427 m ha of area is under agroforestry in the country covering 15 agro-climatic zones. Most researchers used remote sensing and Geographic Information System (GIS) for this purpose. Agroforestry suitability analysis based upon nutrient availability mapping has also been carried out using GIS techniques for part of Jharkhand area (Ahmad et al., 2017). The study was aimed at application of geo-spatial tools for visualizing various parameters in revealing the trends and interrelationships to achieve nutrient availability with agroforestry suitability map.

Agroforestry land suitability analysis was carried out in the Eastern Indian Himalayan region (Nath at el., 2021) to address the problem of soil erosion by evaluating the land suitability for agroforestry through multi-criteria evaluation modelling through GIS.

Suitability assessment is an imperative step for planning agroforestry systems – tree species that are ideal for those regions. Agroforestry suitability will help landowners to adopt agroforestry for growing agroforestry specialty products.
Objective of the study is to identify suitable land area for agroforestry to increase green cover in wasteland region.

2. Data used

In this study, five parameters viz. land use/ land cover, wasteland, Slope, surface water and Soil Organic Carbon (SOC) are selected to determine the agroforestry site suitability. Input data used are existing and readily available from associate institutes as mentioned in the data source. These input parameters play significant role in determining sites suitable for planning forestry and agriculture plantation. However, the selection and number of parameters may vary based on local site and importance towards agroforestry objective. The input parameters and source of the data is mentioned in table 1.

(1) Land use / Land cover: Land utilisation / practices to which land is being put for use define the land use / land cover class types. Land use / land cover data with 24 categories of level-II classes prepared using remote sensing data (IRS L3 of time frame 2015-16) have been used in the present study. Llevel1 classes are further classified in level2, for example Agriculture is further classified in Crop land, Plantation, Fallow land etc. Fallow land, scrub land and scrub forest are important towards facilitating a greening with agroforestry. Waterbody and built-up lands are masked in the study.

(2) Wastelands: Wastelands are "degraded lands which can be brought under vegetative cover with reasonable efforts and which are currently under-utilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes" (*http://dolr.nic.in/wasteland_ division.htm; Planning Commission report 1989*). Based on the topographies and available resources, wasteland can be culturable and non-culturable. Remote sensing data utilised to derive wasteland categories based on visual interpretation techniques. Detailed wasteland classes with 23 categories are identified. Open scrub, jhum cultivation, degraded forest and degraded pasture are significant towards agroforestry

(3) Slope: Slope is described as the measurement of the rate of change of elevation of the land per unit distance. Land with gentle slopes is good for plant growth as water stays there for some period provide adequate moisture to the soil. Thus, the gentle slopes are suitable for agroforestry than steep slopes. Source of Slope is National Resources Data Base (NRDB). It is derived using elevation points /contour as input to generate slope using raster surface tools of 3D analysis in GIS. Slope are classified into 6 categories from very gentle to very steep slope.
(4) Surface water: Surface water body comprising of all rivers / streams, lakes / ponds and reservoirs. These are derived using remotes sensing data (IRS L3) based on visual interpretation techniques. Proximity from the water body is utilised for agroforestry suitability analysis.
(5) Soil Organic Carbon (SOC): Soil organic carbon is a measurable component of soil organic matter that makes up 2-10% of most soil's mass and has an important role in the physical, chemical and biological function of agriculture soil. SOC prepared using Land Degradation Surveillance Framework (LDSF) database and Landsat 8 surface reflectance satellite data (Minasny et al., 2017; Vågen et al., 2018, 2013; Vågen and Winowiecki, 2019; Winowiecki et al., 2021). Areas with higher SOC values were scored as also having a higher the suitability for agroforestry.

3. Study Area

The study area selected based on well distributed districts in different agroclimatic zones of India. Total 17 districts identified across 14 agroclimatic zones (ACZ) of India. There are total 15 agroclimatic zones in the country which are delineated based on type of soil, climate (temperature & rainfall) and captive water resources (*Planning Commission, 1989*). The agroclimatic zone -15 which include island state is not included in the study.

Pilot study was conducted in 3 districts (Bhavnagar, Agra and Sidhi). Subsequently another 14 districts were selected from different agroclimatic zones (in total 17 districts).

Study area is shown in figure 1 and list of agroclimatic zone-wise districts are given in table 2.

Table 1. Input Parameters and source of data.

SN	Parameter	Source
1	Land use / land cover	1:50K (IRS L3 data (2015-16)), National Remote Sensing Centre (NRSC), ISRO, Hyderabad
2	Wastelands	1:50K (IRS L3 data (2015-16)), National Remote Sensing Centre (NRSC), ISRO, Hyderabad
3	Slope	1:50K, National Resources Data Base (NRDB) (2005), Space Applications Centre (SAC), ISRO, Ahmedabad
4	Surface waterbody	1:50K (IRS L3 (2018)), Space Applications Centre (SAC), ISRO, Ahmedabad
5	Soil Organic Carbon (SOC)	250m raster data. International Centre for Research in Agroforestry, Nairobi and New Delhi (ICRAF)

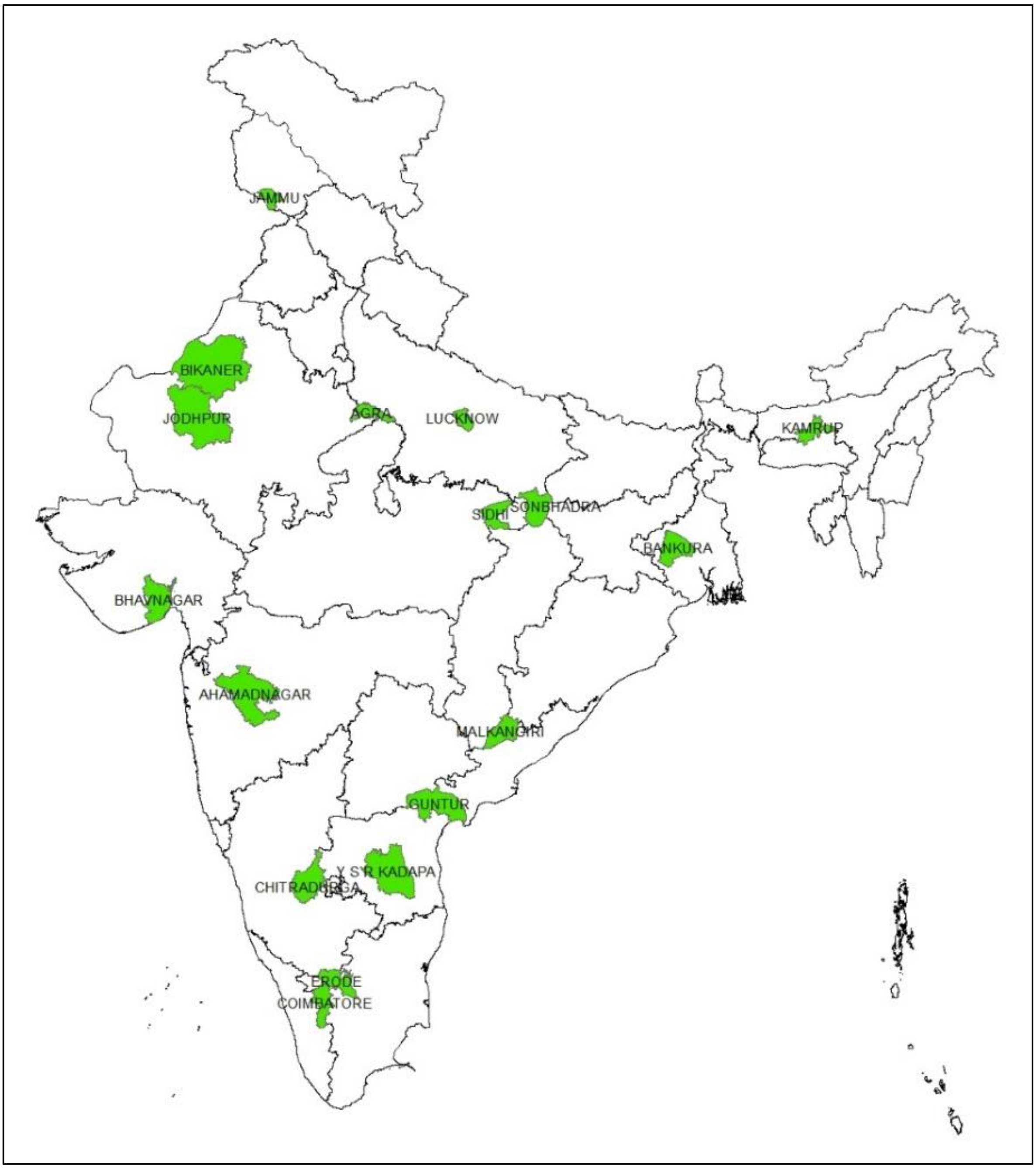

Figure 1. Study area (17 selected districts across different agroclimatic zones of India)

Table-2 List of agro climatic zone-wise districts under study

SN	Agro-climatic zones of India	State /UT represented	District	Area# under Wasteland in ha	Institutions supported in Ground truthing
I	Western Himalayan division	Jammu & Kashmir (J&K), Himachal Pradesh and Uttarakhand	Jammu	13754.88	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu
II	Eastern Himalayan division	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal	Kamrup (Assam)	33317.01	Assam Agricultural University, Jorhat-785013 Assam
III	Lower Gangetic plain region	West Bengal	Bankura (WB)	40109.85	Not available

IV	Middle Gangetic plain region	Uttar Pradesh, Bihar	Sonbhadra (UP)	29021.31	Not available
V	Upper Gangetic plain region	Uttar Pradesh	Lucknow	10130.61	Not available -
			Agra*	39044.95	Krishi Vigyan Kendra, Agra District, Uttar Pradesh
VI	Trans-Gangetic plain region	Chandigarh, Delhi, Haryana, Punjab, Rajasthan	Bikaner (RJ)	699349.56	Swami Keshwanand Rajasthan Agricultural University, Beechwal, Bikaner-334006 Rajasthan
VII	Eastern plateau and hill region	Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, West Bengal	Malkangiri (Odisha)	129389.56	Orissa University of Agriculture & Technology, Siripur Square, Bhubaneswar 751003, Odisha
VIII	Central plateau and hill region	Madhya Pradesh, Rajasthan, Uttar Pradesh	Sidhi* (MP)	61501.53	Krishi Vigyan Kendra, Sidhi district, Madya Pradesh
IX	Western plateau and hill region	Madhya Pradesh, Maharashtra	Ahmednagar (Maharashtra)	222046.02	Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar-413722 Maharashtra -
X	Southern plateau and hill region	Andhra Pradesh, Karnataka, Tamil Nadu	Erode (TN) YSR Kadapa (AP) Chitradurga (Kar)	31162.55 385379.95 131548.82	Tamil Nadu Agricultural University, Coimbatore-641003 Tamil Nadu Dr YSR Horticultural University, Administrative Office, PB No. 7, Venkataramannagudem534101, WG Dist., Andhra Pradesh University of Agricultural Sciences, GKVK Campus, Bangalore-560065 Karnataka
XI	East coast plain and hill region	Andhra Pradesh, Odisha, Puducherry, Tamil Nadu	Guntur	-	-
XII	West coast plain and hill region	Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu	Coimbatore (TN)	28046.61	Tamil Nadu Agricultural University, Coimbatore-641003 Tamil Nadu
XIII	Gujarat plain and hill region	Gujarat, Dadra & Nagar Haveli, Daman & Diu	Bhavnagar*	158508.93	Krishi Vigyan Kendra, Bhavnagar District, Gujarat
XIV	Western plain and hill region	Rajasthan	Jodhpur	389653.47	Not available
XV	Island region	-	-	-	Not considered in the study

** Pilot districts, # Source of Area is from wasteland input parameter*

4. Methodology and Analysis

Agroforestry suitability analysis has been carried out using various physical parameters based on integrated weighted approach using GIS techniques. The GIS facilitates integration of input parameters and allow applying logical criteria to select suitable sites. SOC parameter has been converted to vector format before integration with other parameters in GIS. Individual parameters are weighted based on its importance and priority for suitability (*Satty T L, 1980*). Ranks are assigned to each category within the parameter. Assignment of weightage and ranks are required subject expertise. In the present study, predefined fields (parameters) like Land use, Wasteland, Slope, Ground water prospect, Vegetation type etc. are taken and high weightage is given to wasteland parameter. After integrating all parameters in GIS, Agroforestry Suitability Index (ASI) was derived. Further, ASI was classified in 5 categories (High, Moderate, Less, Very Less and Not Suitable).

To validate the ASI, Ground truthing (GT) was carried out in selected districts. Random points for GT location were generated in High and Moderate categories of Agroforestry Suitability area across districts for ground truth (GT) purpose. Ground truth has been carried out by teams of respective Krishi Vigyan Kendra (KVK) and State Agricultural Universities (SAU) for validation of agroforestry suitability areas. GT data were collected using android mobile based application developed by Visualization of Earth observation Data and Archival System (VEDAS), Space Applications Centre, Indian Space research Organization (*https://vedas.sac.gov.in*). Most of the sample points fall in the wasteland area. Based on the information thereof, promising agroforestry systems have been prescribed for the study districts keeping in view the livelihood and environmental opportunities, and commitments.

4.1 Assigning weights to the parameters

A weighted index model (*Mukund Rao et al., 1991*) was adopted for derivation of agroforestry suitability. Agroforestry Suitability Analysis has been carried out using various physical parameters i.e. Land use / land cover, Wastelands, Slope, Distance from Surface waterbody and Soil Organic Carbon (SOC). GIS database was organized for agroforestry suitability analysis. Weightage of each parameter was decided by the experts based on importance of parameters (Satty TL, 1980) towards agroforestry suitability (Table 3). Importance is decided based on significance of parameters towards objective of the study. Further ranking was done for various classes/categories falling under each parameter (Table 4).

Table 3. Weightage Assignment to Parameters

SN	Parameter	Weightage
1	Land use / land cover	0.2
2	Wasteland	0.4
3	Slope	0.2
4	Distance from Surface Waterbody	0.1
5	Soil Organic Carbon (SOC)	0.1
	Total	1.0

Table 4. Rank assigned to each category within thematic parameter

SN	Suitability	Rank
1	High	4
2	Moderate	3
3	Low	2
4	Very Low	1
5	Not Suitable*	0

* Mask (exclusion of waterbody and built-up)

Ranking was given to each category within the parameters based on its significance towards suitability of agroforestry (Table 5 to 9). Integrated weighted approach adopted for agroforestry suitability analysis using GIS techniques is shown in the figure 2. After integrating all parameters in GIS, Agroforestry Suitability Index (ASI) was derived. Further ASI classified in 5 categories (High, Moderate, Less, Very Less and Not suitable), areas excluded are classified as Not Suitable (Table 10).

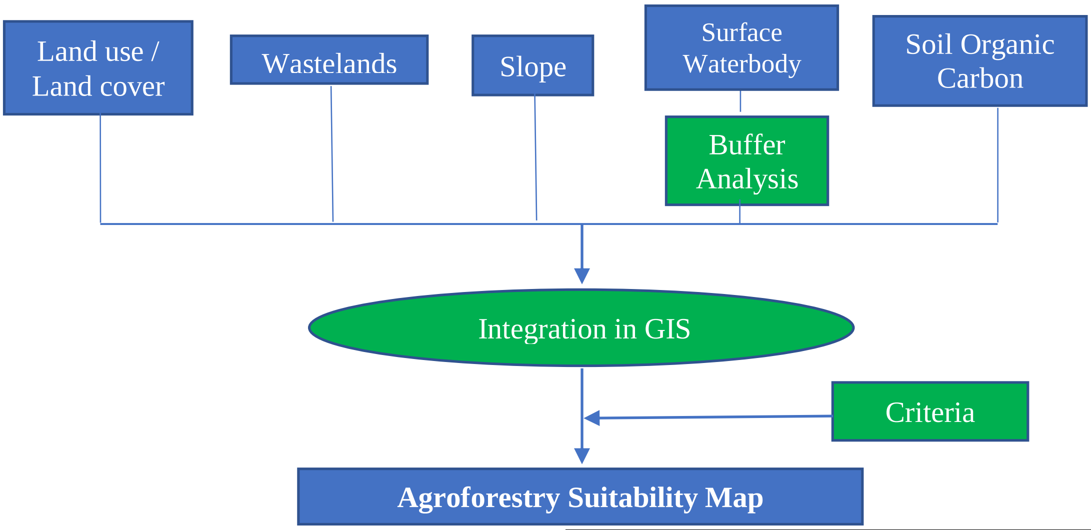

Figure 2. Methodology for agroforestry suitability analysis

Table 5. Rank for land use / land cover

LUCode	Level-1 class	Level-2 class	LU Rank
1	Builtup	Urban	0
2	Builtup	Rural	0
3	Builtup	Mining	0
4	Agriculture	Crop land	3
5	Agriculture	Plantation	1
6	Agriculture	Fallow	4
7	Agriculture	Current Shifting cultivation	4
8	Forest	Evergreen / Semi Evergreen	0
9	Forest	Deciduous	1
10	Forest	Forest Plantation	2
11	Forest	Scrub Forest	4

12	Forest	Swamp / Mangrove	1
13	Grass / Grazing land	Grass / Grazing land	1
14	Barren / Unculturable wastelands	Salt affected land	1
15	Barren / Unculturable wastelands	Gullied / Ravinous	2
16	Barren / Unculturable wastelands	Scrub land	3
17	Barren / Unculturable wastelands	Sandy area	1
18	Barren / Unculturable wastelands	Barren rocky	0
19	Barren / Unculturable wastelands	Rann	1
20	Wetland / Waterbodies	Inland wetland	0
21	Wetland / Waterbodies	Coastal wetland	0
22	Wetland / Waterbodies	River / Stream / Canals	0
23	Wetland / Waterbodies	Waterbodies	0
24	Snow	Snow	0

Table 6. Rank for wasteland

WLCode	Wasteland	WL Rank
1	Gullied and/or ravinous land (Medium)	2
2	Gullied and/or ravinous land (Deep)	1
3	Land with Dense Scrub	3
4	Land with Open Scrub	4
5	Waterlogged and Marshy land (Permenant)	0
6	Waterlogged and Marshy land (Seasonal)	1
7	Land affected by salinity/alkalinity (Medium)	2
8	Land affected by salinity/alkalinity (Strong)	0
9	Shifting Cultivation_Current Jhum	2
10	Shifting Cultivation_Abadoned Jhum	4
11	Under -utilised/degraded forest (Scrub domain)	4
12	Under -utilised/degraded forest (Agriculture)	4
13	Degraded pastures/grazing land	4
14	Degraded land under plantation crop	3
15	Sands_Riverine	1
16	Sands_Coastal	1
17	Sands-Desertic	0
18	Sands-SemiStab_Stab>40m	0
19	Sands-SemiStab_Stab 15- 40m	1
20	Mining Wastelands	1
21	Industrial Wastelands	0
22	Barren Rocky/Stony waste	0
23	Snow covered/Glacial area	0

Table 7. Rank for slope

Slope Code	Slope (%)	Description	Slope Rank
1	0-3	Very Gentle	4
2	3-8	Gentle	4
3	8-15	Moderate	3
4	15-35	Moderately Steep	2
5	35-50	Steep	1
6	>50	Very Steep	0

Table 8. Rank for distance from Surface Water (WB)

WBCode	Waterbody Proximity (meter)	WB Rank
1	0-500	4
2	500-1000	3
3	1000-2000	2
4	>2000	1
5	Waterbody	0

Table 9. Rank for Soil Organic Carbon (SOC)

SOC-Code	Soil Organic Carbon (SOC) (g/kg)	SOC Rank
1	0-10	1
2	10-20	2
3	20-30	3

4	>30	4

Table 10. Agroforestry Suitability Index (ASI) Classification

ASI value range	Class	Suitability
> 3 to <= 4	1	Highly Suitable
> 2 to <= 3	2	Moderately Suitable
> 1 to <= 2	3	Less Suitable
> 0 to <= 1	4	Very Less Suitable
0	5	Not Suitable

4.2 Agroforestry suitability calculation and integration in GIS

4.2.1 Agroforestry Suitability Index (ASI) Calculation

Agroforestry Suitability Index (ASI) for particular parameter is calculated by multiplying weightage of that parameters and ranks of each category within the parameter.

Calculation of Index for parameter1

$Index_{p1} = R_{p1} * W_{p1}$

where R_{p1} : Rank of categories within parameter1
W_{p1} : Weightage of parameter1

Similarly index for other parameters are calculated.

4.2.2 Integration of parameters in GIS and Calculation of Total Index

All parameters are integrated in GIS and Total Index (ASI) is calculated by summing up of individual parameter index (*Mukund Rao et all, 1991*).

Total Index (ASI) = $Index_{p1} + Index_{p2} + Index_{p3} + \text{---} \quad \text{---} + Index_{pn}$

here $Index_{p1}$: Index of parameter1

ASI = [WLRank] * 0.4 + [LURank] * 0.2 + [SlopeRank] * 0.2 + [WBRank] * 0.1 + [SOCRank] * 0.1

For Built-up and waterbody, calculate ASI = 0. Total Index (ASI) is further classified in five classes

4.3 Ground Truth (GT) data collection

The ground truthing creates linkages between the image and ground reality required for planning and execution of research projects/city planning etc. Ground truth data was for selected districts were collected with the help of nominated Scientist/Officials/Researchers from Indian Council of Agricultural Research- Krishi Vigyan Kendra (KVK) and State Agricultural Universities (SAU). The VEDAS android mobile based application developed by Space Applications Centre, Indian Space research Organization was used for data collection at various points (*https://vedas.sac.gov.in*).

Random points for ground truthing were generated for highly and moderately suitable classes. The GT data collected by different team from KVKs/SAUs from each district was updated on the VEDAS mobile application. GT Data was collected from selected districts falling under 10 different Agroclimatic Zone i.e I, II, V, VI, VII, VIII, IX, X, XII and XIII.

GT Visit: GT data collected by Officials of Space Applications Centre, Ahmedabad (SAC), Ahmedabad and Krishi Vigyan Kendra (KVK Bhavnagar) is shown below as example (Table 11, Figure 3). Similarly, expert teams from different State Agricultural Universities (SAU) and Krishi Vigyan Kendra have collected the GT data in same format and later compiled for assessment of suitability validation.

5. Agroforestry systems for classified wastelands

In the present study, recommendations of species to be planted are prescribed by the ICAR-Central Agroforestry Research Institute, Jhansi Uttar Pradesh for the selected districts falling under highly and moderately suitable regime (Table 12). In each case species were selected based on their adaptation to local climate / environment and potential to survive. Such tree and shrub planting, or natural regeneration where the opportunities arise, can be carried out in areas classified as “high” or “moderate” as far as their suitability is concerned.

Given that the potential natural vegetation of India is mostly forest, the availability of sites suitable for agroforestry, to be planted to deliver an appropriate and productive agroforestry system, as an approach to greening of wasteland is not in question. As noted earlier and supported by the literature, agroforestry systems are ideal for delivering synergistic ecological, economic and social welfare outcomes. The challenge is one of optimizing the potential agroforestry systems based on appropriate tree species composition, age of trees, geographic location, local climatic factors and management regimes etc. so as to support the greening of wasteland/degraded land while acting as carbon sinks, sources of fodder, timber etc and supporting livelihoods.

Figure 3. Officials of SAC and KVK during data collection at Bhavnagar

Table 11. GT data collection in Bhavnagar District along with field photo

SN	GT point name	GT point location (long, lat)	Suitability as per Model	Suitability as per GT	Field photo	Remarks
1	Rampur, Umrala	71.81833, 21.85615	Moderate	Moderate		Sparse Babul plantation, Plain land
2	Devaliya (Parvala)	71.69336, 21.78495	High, Moderate	Moderate		Scrub, Undulating
3	Langala	71.71839, 21.78347	Moderate, Less Suitable	Moderate		Scrub, Gentle slope

Table 12. Recommendation of plantation species for agroforestry

SN	Agro-climatic zones	State	District	Potential Multipurpose Trees (MPTs)	Potential Agroforestry System
I	Western Himalayan division	Jammu & Kashmir (J& K), Himachal Pradesh and Uttarakhand	Jammu	*Populus deltoides, Salix alba, Melia azedarach, Toona ciliata, Grewia spp.*	1) Mulberry based silvipastoral system (Napier-Bajra hybrid/*Seteria*), 2) Apple based agroforestry system (fodder and agricultural

					crops like beans and vegetables), 3) Apricot based agroforestry system (Peas, Barley and mustard)
II	Eastern Himalayan division	Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal	Kamrup (Assam)	*Bamboo, Parkia roxburghii, Gmelina arborea, Arecanut, Acacia mangium*	1) Bamboo based agroforestry system (Pineapple, Banana, Papaya and lime)
III	Lower Gangetic plain region	West Bengal	Bankura (WB)	*Anthocephalus cadamba, Eucalyptus tereticornis, Acacia auriculiformis, Gmelina arborea, Tectona grandis, Zizyphus spp., Azadirachta indica, Dalbergia sissoo, Shorea robusta, Swietenia mahogoni, Diospyrus, Melanoxylon, Madhuca indica, Terminalia arjuna, D. latifolia, Pongamia pinnata,*	1) Kadamb based agroforestry system (Mustard, Lentil and Vegetables)
IV	Middle Gangetic plain region	Uttar Pradesh, Bihar	Banda , Sonbhadra (UP)	*Tectona grandis, Dalbergia sissoo, Acacia Senegal, Acacia nilotica, Bamboo, Emblica officinalis, Azadirachta indica, Pongamia pinnata, Anogeissus latifolia, Melia dubia, Leucaena leucocephala,*	1) Teak based agroforestry system (Wheat, Gram, Sesamum or fodder crops) 2) Neem based agroforestry system (fodder crops) 3) Aonla-based agri-horticulture system
V	Upper Gangetic plain region	Uttar Pradesh	Lucknow , Agra (UP)	*Tectona grandis, Dalbergia sissoo, Anthocephalus cadamba, Bamboo, Emblica officinalis, Azadirachta indica, Pongamia pinnata, Terminalia arjuna, Melia dubia, Leucaena leucocephala,*	1) Aonla-based agri-horticulture system, Poplar-based agri-silviculture system, 2) Eucalyptus-based agroforestry system
VI	Trans-Gangetic plain region	Chandigarh, Delhi, Haryana, Punjab, Rajasthan	Bikaner (RJ)	*Tectona grandis, Dalbergia sissoo, Anthocephalus cadamba, Populus spp, Bamboo, Emblica officinalis, Azadirachta indica, Pongamia pinnata, Terminalia arjuna, Melia dubia, Leucaena leucocephala, Casuarina equisetifolia*	1) Silvopastoral with *L. leucocephala* + Napier grass; and *Albizia amara* + grass+ stylo; Popular based agroforestry system (wheat and mustard)
VII	Eastern plateau and hill region	Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, West Bengal	Malkangiri (Odisha)	*Tectona grandis, D. sissoo, A. senegal, A. nilotica, A. cadamba, L. leucocephala, A. excelsa, G. arborea, Emblica officinalis,*	1) Amla based agroforestry system, 2) Boundary plantation of timber species
VIII	Central plateau and hill region	Madhya Pradesh, Rajasthan, Uttar Pradesh	Sidhi* (MP)	*Acacia tortilis, D. sissoo, A. nilotica, P. cineraria, Azadirachta indica, Tecomella undulata, Pithecelobium dulci, Salvadora persica, Zyziphus nummularia*	1) *P. cineraria* + pearl millet/cluster bean/mothbean/medicinal plants/groundnut (Agri-silviculture system) 2) Ber + kharif crops (Agri-horticulture)
IX	Western plateau and hill region	Madhya Pradesh, Maharashtra	Ahmednagar (Maharashtra)	*T. grandis, Terminalia paniculata, T. chebula, Madhuca indica, M. dubia, L. leucocephala, T. arjuna, Eucalyptus, D. sissoo, D. latifolia, P. pinnata, Bamboo spp.*	1) Bamboo based agroforestry system; Pongamia based agroforestry (Chickpea, Onion) 2) Boundary plantation of timber species
X	Southern plateau and hill region	Andhra Pradesh, Karnataka, Tamil Nadu	Erode (TN)-	*Casuarina equisetifolia, Eucalyptus, Anthocephalus cadamba, Melia dubia, Bombax ceiba, Azadirachta indica, Leucaena leucocephala, Albizia lebbeck, Pongamia pinnata,*	1) Bund planting of *Albizia lebbeck, Ailanthus excelsa, Hardwickia binate* 2) Intercropping tapioca, groundnut, sesame with *E. tereticornis*

				Terminalia arjuna, Tamarindus indica	Woodlots of *Ceiba pentandra* Silvipasture consists of *Acacia leucophloea* with fodder sorghum, *Cenchrus* spp. *Melia dubia* based Agroforestry system.
			YSR Kadapa (AP) - -	*Casuarina equisetifolia, Eucalyptus, Melia dubia, Dalbergia sissoo, Azadirachta indica, Albizia procera, Acacia nilotica, Azadirachta indica, Capparis deciduas, D. latifolia, Pongamia pinnata, L. leucocephala*	
			Chitradurga (Kar)-	*Tectona grandis, Melia dubia, Anthocephalus cadamba, Dalbergia latifolia, Casuarina equisetifolia, Acacia mangium, Acacia auriculiformis, Leucaena leucocephala, Sesbania grandiflora, Acacia nilotica, Pongamia pinnata, Terminalia arjuna, Eucalyptus, D. sissoo, P. pinnata*	1) Trees with fruit crops (*Mangifera indica, Manilkara zapota, Psidium guajava, Citrus limon*)
XI	East coast plain and hill region	Andhra Pradesh, Odisha, Puducherry, Tamil Nadu	Guntur (AP)	*A. mangium, T. grandis, Eucalyptus spp., C. equisetifolia, Sesbania grandiflora, G. arborea, D. sissoo, D. latifolia, P. pinnata, T. arjuna*	1) *Acacia mangium* based agroforestry (Maize, Ragi, Seasamum and Vegetables); Homegardens
XII	West coast plain and hill region	Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu	Coimbatore (TN)	*Casuarina equisetifolia, Eucalyptus, Anthocephalus cadamba, Melia dubia, Bombax ceiba, Artocarpus fraxinifolius, Azadirachta indica, Leucaena leucocephala, Albizia lebbeck, Hibiscus tiliaceaous, Calophyllum ionophyllum, Pongamia pinnata, Terminalia arjuna, Tamarindus indica, Prosopis juliflora, Acacia leucophloea*	1) Bund planting of *Albizia lebbeck, Ailanthus excelsa, Hardwickia binate* 2) Intercropping tapioca, groundnut, sesame with *E. tereticornis* Woodlots of *Ceiba pentandra* 3) Silvipasture consists of *Acacia leucophloea* with fodder sorghum, Cenchrus spp. 4) *Melia dubia* based agroforestry system
XIII	Gujarat plain and hill region	Gujarat, Dadra & Nagar Haveli, Daman & Diu	Bhavnagar (GUJ)		
XIV	Western plain and hill region	Rajasthan	Jodhpur	*Prosopis juliflora, Acacia tortilis, D. sissoo, A. leucophloea, A. nilotica, P. cineraria, Azadirachta indica, Tecomella undulata, Pithecelobium dulci, Salvadora persica, Zyziphus nummularia*	1) *P. cineraria* + pearl millet/cumin/chilies/moth/cluster bean (Agri-silviculture system) 2) Ber + kharif crops (Agri-horticulture). 3) *C. ciliaris* dominant silvi-pastoral system
XV	Island region	-	-	-	

Table 13. Suitability Model Validation w.r.t. Ground Truth Data

SN	District	Total GT points	GT points collected in High and Moderate category as per Model	GT points Suitable as per Ground Truth	GT points Suitable as per Ground Truth (%)
1	Bhavnagar	14	13	12	92.31
2	Sidhi	16	5	5	100.00
3	Agra	12	2	2	100.00
4	Kaddapa	7	7	7	100.00

5	Coimbatore	8	8	8	100.00
6	Erode	7	6	6	100.00
7	Ahmednagar	40	39	23	58.97
8	Kamrup	115	75	75	100.00
9	Jammu	42	37	28	75.68
10	Malkangiri	22	17	15	88.24
Total		**283**	**209**	**181**	**86.60**

6. Results

For accuracy assessment, model was validated based on ground truth (GT) data collected in selected districts. GT points collected in high and moderate suitability area as per model are compared with actual suitability as per ground truth. Out of 209 points, 181 points falls in suitable area as per ground truth. Comparison of GT points collected in high and moderate suitable wasteland regions showed good agreement with the model and registered an accuracy of about 86.60% (Table 13).

Output results in the form of map of agroforestry suitability for pilot study are shown in figure below (Figure 4 to 6), similarly agroforestry suitability maps generated for all the 17 districts are shown in (Figure 7). Agroforestry Suitability is classified in 5 categories (High, Moderate, Less, Very Less and Not Suitable). Area statistics for different suitability classes along with map for three districts are shown in table 14 to 16, Same for all 17 districts is shown in the table-17. It is observed from the maps and statistics that suitable areas for agroforestry are well distributed and it varies for each the districts. From statistics of all 17 districts, it is observed that total area under Highly suitable is 5.91%, Moderately suitable 11.01%, Less suitable 69.98%, Very less suitable 6.48% and for Not Suitable it is 6.62%. Area available for agroforestry under highly and moderately suitable class is 2648734.64 ha (16.92%). Graph shows percent distribution of agroforestry suitability areas in 17 districts (Figure 8).

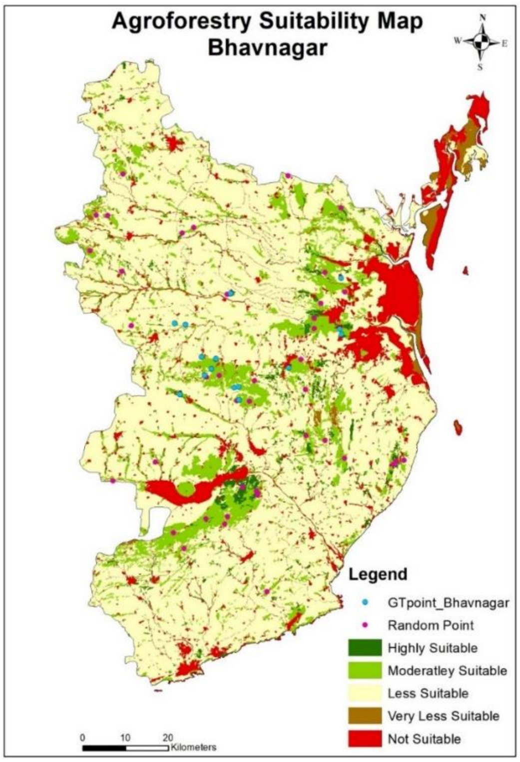

Figure 4. Agroforestry Suitability Map for Bhavnagar

Based on the above result, recommendation of tree species for agroforestry has been prescribed for high and moderate site suitability area across the selected districts

Table 14. Agroforestry suitable areas in Bhavnagar

Class	Suitability	Area(ha)	Area(%)
1	Highly Suitable	17967.89	2.18
2	Moderately Suitable	102528.99	12.44
3	Less Suitable	592490.39	71.92
4	Very Less Suitable	17879.96	2.17
5	Not Suitable	92999.54	11.29
	Total	**823866.77**	**100.00**

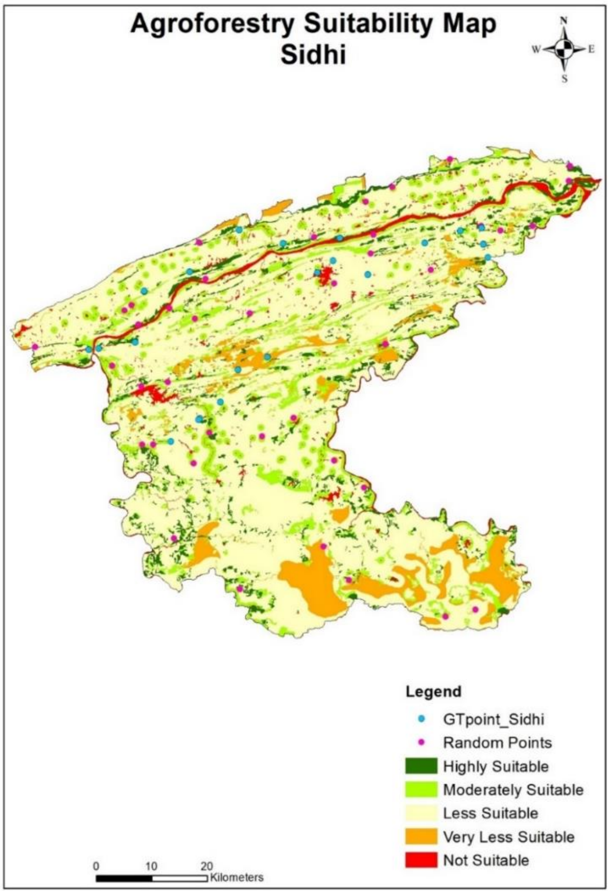

Figure 5. Agroforestry Suitability Map for Sidhi

Table 15. Agroforestry suitable areas in Sidhi

Class	**Suitability**	**Area(ha)**	**Area(%)**
1	Highly Suitable	29511.41	6.43
2	Moderately Suitable	60660.90	13.21
3	Less Suitable	312942.63	68.15
4	Very Less Suitable	38894.16	8.47
5	Not Suitable	17165.47	3.74
	Total	**459174.57**	**100.00**

Table 16. Agroforestry suitable areas in Agra

Class	Suitability	Area(ha)	Area(%)
1	Highly Suitable	6333.28	1.85
2	Moderately Suitable	20345.64	5.93
3	Less Suitable	280192.64	81.70
4	Very Less Suitable	5516.07	1.61
5	Not Suitable	30581.04	8.92
	Total	**342968.67**	**100.00**

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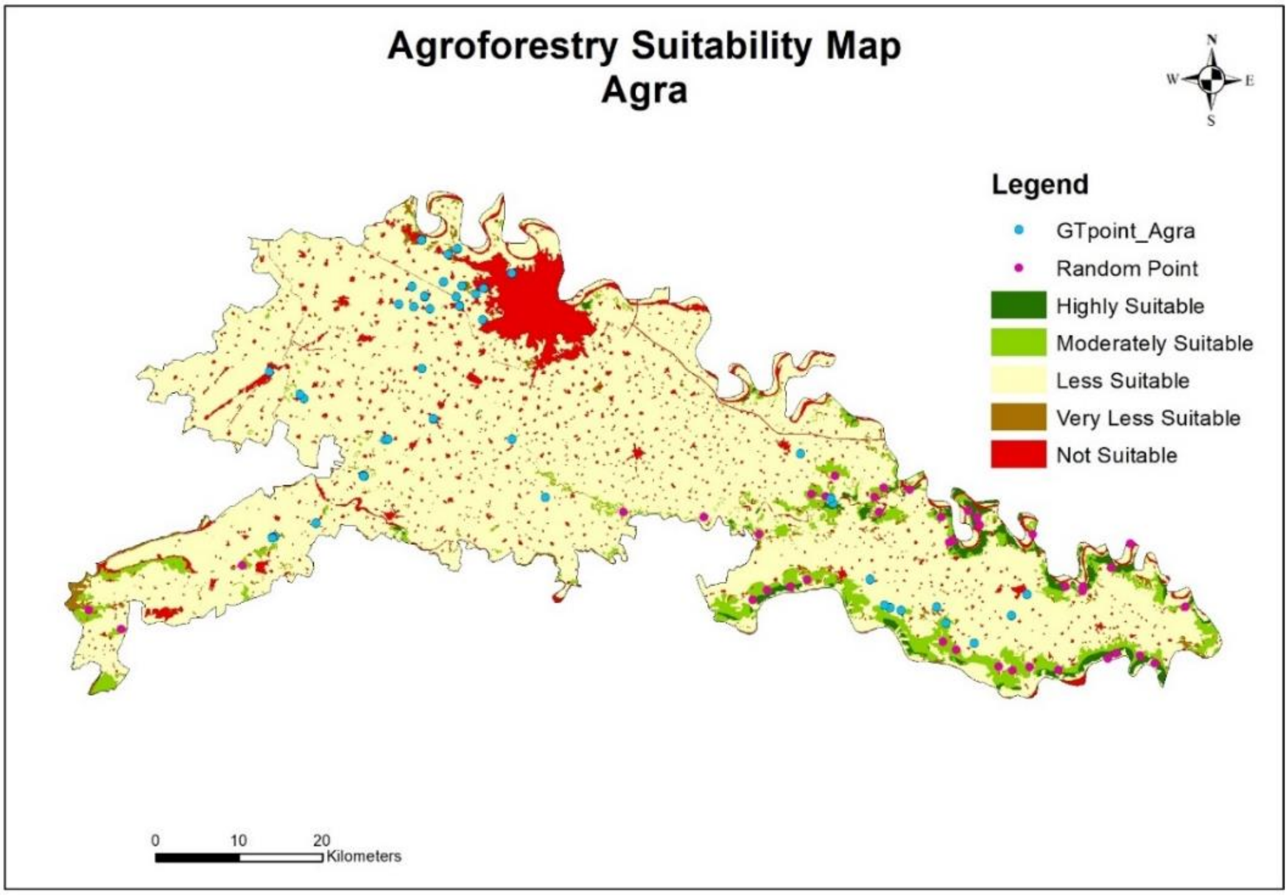

Figure 6. Agroforestry Suitability Map for Agra

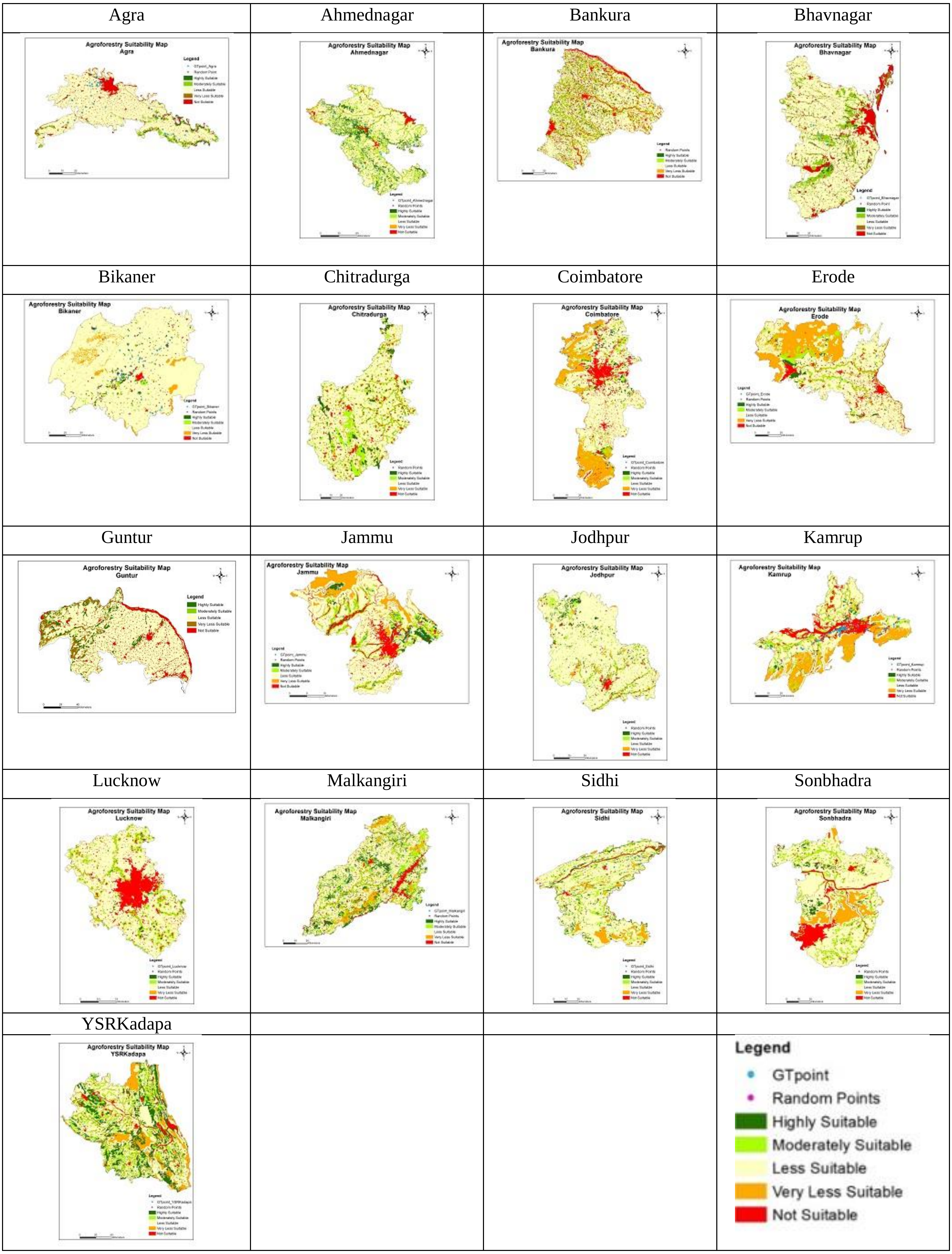

Figure 7. Suitability Maps (17 Districts)

Table 17. Area Statistics (study 17 Districts)

		Agroforestry Suitability Class wise Area (ha)										
		Highly Suitable		Moderately Suitable		Less Suitable		Very Less Suitable		Not Suitable		
SN	**District**	**Area(ha)**	**Area (%)**	**Area(ha)**	**Area (%)**	**Area(ha)**	**Area (%)**	**Area(ha)**	**Area (%)**	**Area(ha)**	**Area (%)**	**Total Area(ha)**
1	Agra	6333.28	1.85	20345.64	5.93	280192.64	81.70	5516.07	1.61	30581.04	8.92	342968.67
2	Ahmednagar	177786.69	10.74	308748.64	18.65	1057191.50	63.88	22772.54	1.38	88582.83	5.35	1655082.21
3	Bankura	35256.60	5.32	123452.65	18.64	393824.40	59.48	1560.18	0.24	108043.14	16.32	662136.96
4	Bhavnagar	17967.89	2.18	102528.99	12.44	592490.39	71.92	17879.96	2.17	92999.54	11.29	823866.77
5	Bikaner	46623.05	1.59	67001.35	2.29	2641272.07	90.31	128041.44	4.38	41792.78	1.43	2924730.69
6	Chitradurga	39913.74	4.78	175792.91	21.06	553460.81	66.31	15046.55	1.80	50479.89	6.05	834693.90
7	Coimbatore	13468.94	2.82	30958.34	6.47	276396.14	57.77	103636.60	21.66	53947.89	11.28	478407.91
8	Erode	11795.26	2.27	51738.62	9.98	292964.02	56.50	124293.54	23.97	37743.46	7.28	518534.91
9	Guntur	56661.48	4.99	23474.80	2.07	855522.68	75.38	74583.04	6.57	124771.40	10.99	1135013.40
10	Jammu	9743.01	4.10	29082.15	12.24	139968.10	58.92	29217.74	12.30	29531.35	12.43	237542.36
11	Jodhpur	102491.12	4.69	175463.09	8.03	1799286.74	82.32	58617.77	2.68	49846.65	2.28	2185705.37
12	Kamrup	7084.15	1.72	53740.10	13.06	200163.41	48.66	96630.35	23.49	53763.78	13.07	411381.79
13	Lucknow	2048.00	0.84	36184.90	14.84	161708.73	66.31	1328.82	0.54	42588.16	17.46	243858.61
14	Malkangiri	73241.94	13.04	100279.94	17.86	302650.59	53.90	46357.21	8.26	39003.21	6.95	561532.90
15	Sidhi	29511.41	6.43	60660.90	13.21	312942.63	68.15	38894.16	8.47	17165.47	3.74	459174.57
16	Sonbhadra	20524.97	3.10	82178.03	12.41	427280.89	64.52	64266.38	9.70	67955.65	10.26	662205.92
17	YSRKadapa	275062.53	18.15	281589.53	18.58	666953.07	44.01	184850.67	12.20	107071.25	7.06	1515527.05
	Total	**925514.07**	**5.91**	**1723220.58**	**11.01**	**10954268.83**	**69.98**	**1013493.01**	**6.48**	**1035867.50**	**6.62**	**15652363.98**

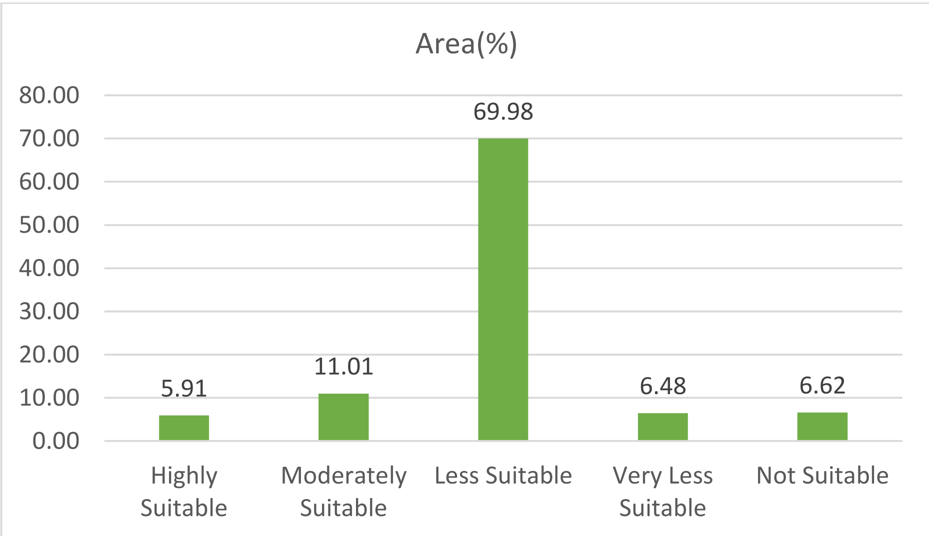

Figure 8. Graph shows percent distribution of agroforestry suitability areas in 17 study districts.

Discussion

The integrated farming by mixing of woody perennials, crops and livestock operations in a land use system will provide resilience and effective resource management. As per FAO report (2017), Agroforestry is a suitable tool for landscape restoration. Agroforestry practices have included with the various programs/ schemes focussed on watershed development, rehabilitation of problem soils, treatment of degraded and other wastelands etc. Many studies have showed that integrated farming systems can be grown on wasteland & degraded land with economically viability factors for farmers, especially extremely rural regions, enhances green cover with environment services. Several studies based on mapping of suitable areas esp. degraded/wasteland was undertaken by scientific fraternity. Several Researchers and scientists have evaluated the land for various agroforestry application using remote sensing and GIS. Studies have been reported national or regional level agroforestry suitability, which used various coarse to medium resolution thematic layers for analysing the suitability. 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) were worked out to provide national level and district level prioritization. Climate, soil, topography, socio-economic criteria along with remote sensing derived parameters used to prioritize area at coarse scale (Nath et al, 2021).

The present study provides priority regimes along with ground truthing of the district data. The data was updated on the universal data collection application – VEDAS (https://vedas.sac.gov.in/data-collection/). Area available for agroforestry under highly and moderately suitable class is 2648734.64 ha (16.92%). The suitability regime provided in the study will facilitate plantation of sustainable agroforestry models across the districts. The multipurpose trees that produce food, fodder, timber, and fuelwood and their integration in agroforestry farming systems provides sustainable solutions to several serious land-management issues such as food security, environmental protection, degradation and climate-change mitigation. Agroforestry techniques involving planting multipurpose trees are tolerant of adverse soil conditions and used of reclamation of these areas (King and Chandler, 1978). In the present study, list of multi-purpose trees and agroforestry systems are provided for moderate and highly suitable areas in the districts across various agroclimatic zone.

8. Conclusion

The present study of land suitability analysis for promotion of agroforestry reveals that the integrated weightage approach used has served its purpose, being a well-established method for identification of suitable sites. The GIS tools and techniques used with remote sensing based thematic inputs have further facilitated integration analysis of various parameters and enabled a logical criterion to prioritize on the suitable sites. However, optimum selection of parameters and logical assignment of weightage and ranks gave the best suited sites. Assignment of weightage and ranks requires subject expertise. The results obtained have been validated by ground-truthing (GT) that gave 86.6% accuracy. It is therefore recommended that the present approach could be utilized further to upscale our efforts in this direction on a pan-India basis. Such approach is also helpful to monitor land restoration and assessment of increasing green areas too. With appropriate parameters, this approach helps in identification and/or recommendation of appropriate tree species and tree-crop combinations befitting the climate and other ecological conditions. This will ensure successful establishment of agroforestry / private plantations in wasteland. The research findings have greater importance as India has adopted agroforestry policy and committed towards achieving the Sustainable Development Goals, national commitments of Land Degradation Neutrality (LDN), restoration of 26 Million ha of degraded land by 2030.

This database generated in the present study will open avenues for researchers, policy maker, government and private players to design the restoration of the prioritized area for various social and commercial ventures.

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